TOOL MANAGEMENT SYSTEM FOR AN FMS

Manuel Romano dos Santos Pinto Barbosa

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To my mother, and in fond
memory of my father and grandfather

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ABSTRACT

The purpose of this project is to analyse tool management issues within Flexible Manufacturing Systems (FMS) and its implementation on a database system, as part of the work at Warwick University involving the implementation of Computer Integrated Manufacturing (CIM) principles using its manufacturing related facilities.

After analyzing the manufacturing aspects of tool management, including the characteristics of general CIM and FMS manufacturing environments, tool management systems within these environments, and the particular CIM/FMS system at Warwick University, the study focuses on database design and the methodology chosen to approach this problem.

The methodology consists of two distinct phases: one concerned with building a conceptual data model based on a previous analysis of the tooling system and which is independent of the database and computers used to implement it, and another basically consisting in restructuring that conceptual model according to the characteristics of the particular database and its physical implementation. The data analysis techniques used to derive the conceptual model are entity modelling, relational model and normalization.

As part of this methodology it is then presented a more detailed analysis of a general tool management system which defines what are its main components, its functions and users requirements, and the interaction with other systems.

From that analysis it was concluded that the design of a general tool management system and its tool database is limited by the large diversity of components of the tooling system and the complexity of its functions, being the methodology exemplified by applying data analysis techniques to a limited set of tools (turning tools). Basically it is defined the entities, attributes and relationships for that particular case. The approach can be used for other sets of tools to increase the capabilities of the tool management system.

LIST OF ABBREVIATIONS

AGV	Automated Guided Vehicle
APT	Automatically Programmed Tools
ASRS	Automated Storage and Retrieval System, usually a computer-controlled warehouse
ATC	Automatic Tool Changer
BOM	Bill Of Materials
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CIM	Computer Integrated Manufacturing
CIE	Computer Integrated Enterprise
CNC	Computer Numerical Control
DNC	Direct Numerical Control
DBA	Database Administrator
DBMS	Database Management System
DDL	Data Definition Language
DML	Data Manipulation Language
FMS	Flexible Manufacturing Systems
ISO	International Standard Organization
I/O	Input/Output
JIT	Just In Time
LAN	Local Area Network
MAP	Manufacturing Automation Protocol
MRP	Material Requirements Planning
MRPII	Manufacturing Resources Planning

MPS	Master Production Schedule
NC	Numerical Control
NF	Normal Form
1NF	First Normal Form
2NF	Second Normal Form
3NF	Third Normal Form
OPT	Optimized Production Technology
OSA	Open Systems Architecture
OSI	Open Systems Interconnection
PLC	Programmable Logic Controller
SPC	Statistical Process Control
SQL	Structured Query Language
TMS	Tool Management System
TQC	Total Quality Control
TOP	Technical Office Protocol
WAN	Wide Area Network

1 INTRODUCTION

The work presented involves the consideration of two main aspects in the development of a computerized Tool Management System. One related with the understanding of the manufacturing systems in which the tool management would be integrated, and the other related with the computer systems involved in the implementation of the Tool Management System as a computerized system.

The tool management is naturally related with an existing tooling system in a manufacturing environment. Its main function would be to provide an effective control and information system relative to tools, to ensure that tools will be available when required. This is important to ensure that the production capacity and the respective plans are not constrained by an inefficient tool support system of the manufacturing operations. This is even more critical when considering the Flexible Manufacturing Systems approach in the control and organization of the manufacturing facilities at the shop floor level, because the required flexibility in terms of manufacturing operations requires a more sophisticated tooling system support. These systems involve expensive equipment and machinery whose utilization cannot be dependent on the availability and preparation of tools. A more sophisticated tooling system is then necessary and requiring a more accurate and effective approaches to its management and control.

This is an overview of the manufacturing systems at the shop floor level. But when considering other subsystems and levels of control, and considering the high level of automation and computerized systems which support these functions, such as the design with its Computer Aided Design / Computer Aided Manufacturing (CAD/CAM), and the planning and scheduling functions using an MRP package for example, the interaction between these systems becomes more evident and their integration a desirable and necessary goal or objective to be achieved. Ultimately this

would consist in the achievement of Computer Integrated Manufacturing (CIM) approach. In this type of manufacturing environment there is a need to share accurate and up-to-date information between the different systems, including the tooling information also. For example the CAD system normally producing the NC part programs for the machine tools, will require information about the tools existing in the tooling system at the shop floor. Also the capacity planning and scheduling must consider the tool capacity and requirements as they consider other materials and capacity requirements, to produce more realistic and accurate plans.

The successful implementation of the tool management system is then dependent on a more detailed analysis and understanding of these systems (FMS, CIM, TMS).

In terms of computerized systems the main emphasis is on database systems and its design, due to the large amounts of data and the need to satisfy the requirements of different systems or users (sharing data).

It is then necessary to analyze the characteristics (eg. data structures) of the different database and the methodology and techniques that best help in the design of the system. As in this particular case it is used a relational database system (ORACLE), the emphasis will be in relational systems.

Based on this analysis it is possible to specify the tool management system by identifying its functions and the interaction with other systems, and then propose the design and components of a particular system.

2 OBJECTIVES

At the existing CIM and FMS environment in Warwick University there is a need to complement the different systems with a computerized Tool Management System that will provide information relative to the tooling system required mainly at three distinct levels:

- at the **FMS cell** for a more effective control of the operations involving the tooling system, such as tool transport, assembly and presetting, stock control and monitoring,
- at the **CAD/CAM system**, where the NC part programs are produced, to provide information related to the tools existing on the tooling system at the FMS level,
- at the **MRPII system**, for a more accurate planning of the capacity available who should include tool capacity.

The **main objective** of this project is to provide the basis or framework for the development of a general Tool Management System (TMS) for a Flexible Manufacturing System (FMS) and which could be used to satisfy the particular needs of the CIM/FMS existing at Warwick University.

To achieve this main objective it is important to define and present:

- the **functions and interaction** with other systems of a TMS,

- the **identification of the information** relative to the tooling system required by its users,

- a **tool database structure**, to be implemented using a relational database system (ORACLE). The tool database structure must provide possibility for further development of the Tool Management System in terms of application programs and expansion of the tool database to satisfy future requirements of the Tool Management System.

3 MANUFACTURING SYSTEMS

In this chapter the primary objective is to present the main issues of Computer Integrated Manufacturing and Flexible Manufacturing Systems and the importance of tool management systems in these particular manufacturing environments.

Computer Integrated Manufacturing will be discussed first because it involves a more general analysis including all subsystems in the manufacturing system. Then Flexible Manufacturing Systems as one of the elements normally considered in CIM, and concerned with the functions directly related to the manufacturing process.

The issue of tool management in these particular manufacturing environments (CIM/FMS) will then be analyzed as one of the fundamental parts as it provides information and control over part of the resources or means (tools) required and indispensable in the manufacturing process.

3.1 Computer Integrated Manufacturing - CIM

Computer Integrated Manufacturing is a fairly recent concept which has no clear (or commonly agreed) definition in terms of what it really means as a concept or philosophy and in terms of the capabilities of the technology to support its implementation.

Some authors [1] refer to CIM as an acronym which follows the sequence of other acronyms such as CAD/CAM and FMS and that will be followed by others (eg. CIE- Computer Integrated Enterprise), as a consequence of the increased usage of computers in the manufacturing environment. Others, eg. [2] and [3], see it as the combination of the different computer systems or techniques already existent, such as MRP/MRPII, CAD, JIT, TQC, OPT, for the integration of business

systems with manufacturing or engineering systems. Others [4] still emphasize the people rather then technical issues as the key for successful implementation.

However, there seems to be general agreement that the benefits of CIM include:

- improved product **quality,**
- lower overall manufacturing **costs,**
- shorter **lead-times,**
- greater responsiveness to changes in **market demand,**
- enhanced **flexibility,**

which are the key to increase **competitiveness** and CIM as a philosophy that can be used to catalyse the means and indicate a direction for development always required in the business or manufacturing environment. In this case we will consider CIM concepts as underlined on the CIM-OSA (Open Systems Architecture) - European Standard approach for the implementation of CIM systems, which emphasizes CIM as a business strategy, and technology issues as to serve the business objectives (ref.[5]). The goal of CIM is the appropriate integration of the "islands of automation".

As a philosophy CIM principles rely on **integration** of all related elements or ones which interact with a manufacturing system to increase the overall performance of the business. As the actions at a particular level will condition other`s performance, integration is necessary for an effective and efficient combination of efforts. Integration should not be concerned with just technology and functions, but also with people, as they are the ones that use the system and that will ultimately make it work.

Integration requires efficient and effective communications and that`s where computer **technology** and automation become important as a

means of providing fast and accurate communications systems. The actual level of integration possible of these systems or the data they provide can determine the level of integration of the whole system. The principles of CIM or integration can be applied in a wider context than just manufacturing systems (eg. supermarkets, hospitals, ...), but, in the context of this project, the main interest is manufacturing systems and particularly those involving metal cutting processes.

As such we are considering CIM as the integration of the different systems and functions in a company which start with the customers orders or demand and finish with the delivery of the products. Typically this would include marketing and purchase functions, integration with the suppliers for the control of the raw materials required, design and manufacturing, despatch and sales. These different functions can be considered as part of two types of systems:

- the **business systems**, concerned with defining the business or product strategy and including finance, marketing, sales, purchase, inventory control, production planning and control functions to support this activity. The most common software used at the business level include MRP systems which are concerned with ensuring the availability of materials (MRP I) and other manufacturing functions (MRP II) such as capacity planning, scheduling, purchasing, finance, despatch, etc.

- the **engineering systems** concerned with the development and design functions of the product and the functions directly related to manufacturing such as process planning, quality control and manufacturing control. In terms of computer based systems to support these functions, different systems are available and are normally referred as CAD/CAM, SPC (statistical process control) and CAPP (computer aided process planning) systems. CAD includes

design and engineering analysis, CAM includes the control and monitoring of the production processes. CAPP as a process planning tool is normally considered as part of the CAM system and as a link between CAD and CAM (eg. direct production and loading of NC part programs to machine tools from CAD systems.

All of these functions contributing with complementary services for a common objective will interact with each other and the decisions or operations of one system will affect the performance of others. Typical examples are the influence of the design on the ease of manufacturing or assembly and the influence of purchase in the quality of the materials. Also, information available in some departments would be useful and necessary for other functions as in the case of sales which requires documentation (specifications, manuals,...)from design, or the need for accurate information relative to available capacity required for planning functions. The characteristics (speed, accuracy, quantity) of the communication between these systems will affect the efficiency of the overall system. Fig 1. represents some of the functions within a company and their interaction, which in a CIM environment requires a communication system.

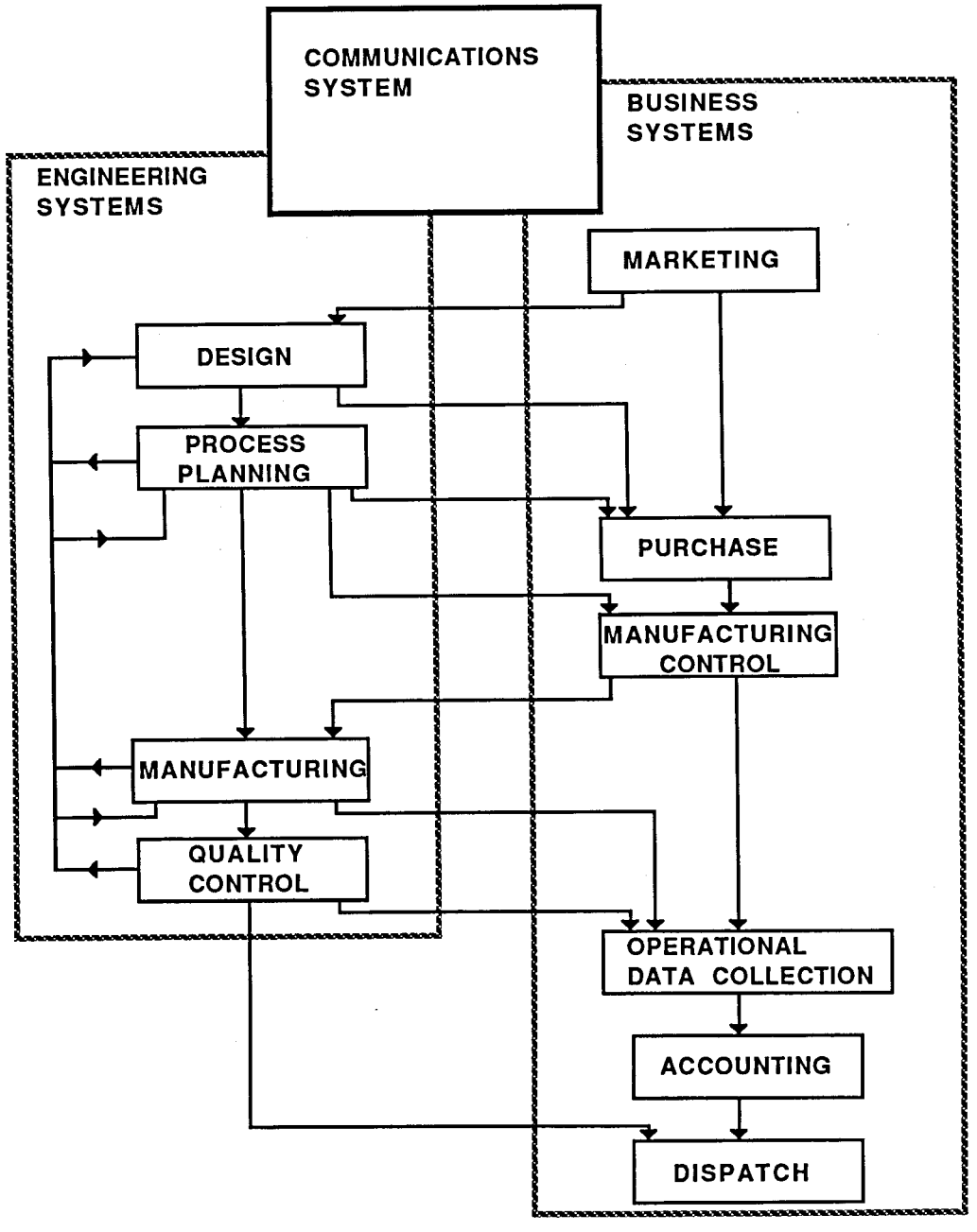

Fig.1 Main systems in a CIM environment (based on ref.[6]).

Integration must then be considered at different levels and as Russell [5] suggests they can be:

- **basic level**, including the physical and logical connections of processes by means of data communications technology operating at specified standards. At this level we can consider the different

devices and computer systems (or "islands of automation") whether at the shop floor and process control systems (CAM or FMS), design system (CAD) or business level (eg. MRPII). When considering FMS they normally include CNC machine-tools, PLC`s, AGV`s, cell controllers, robots, ASRS, or other automatic equipment depending on the processes. At the design system (CAD) and business level for production planning and control, finance and other functions, which normally use mini or mainframe computers. Network systems (LAN/WAN) are used to link these individual elements. As they are normally from different vendors, standards play a key role in providing the necessary protocols and interface communications. Particularly relevant, are the standards based on the OSI model such as MAP/TOP 3.0 version. Figure 2 illustrates a typical hierarchical model of the computer architecture of a CIM system.

- **higher levels**, involve the integration of functions, activities and people within an enterprise. Integration of functions, as they all contribute and are required to achieve a common objective, activities, as they should be subject to the business objectives and capable of react rapidly when they change, and people, as they are behind the functions and activities. This integration normally requires a common data storage in the form of databases accessed concurrently by a number of processes.

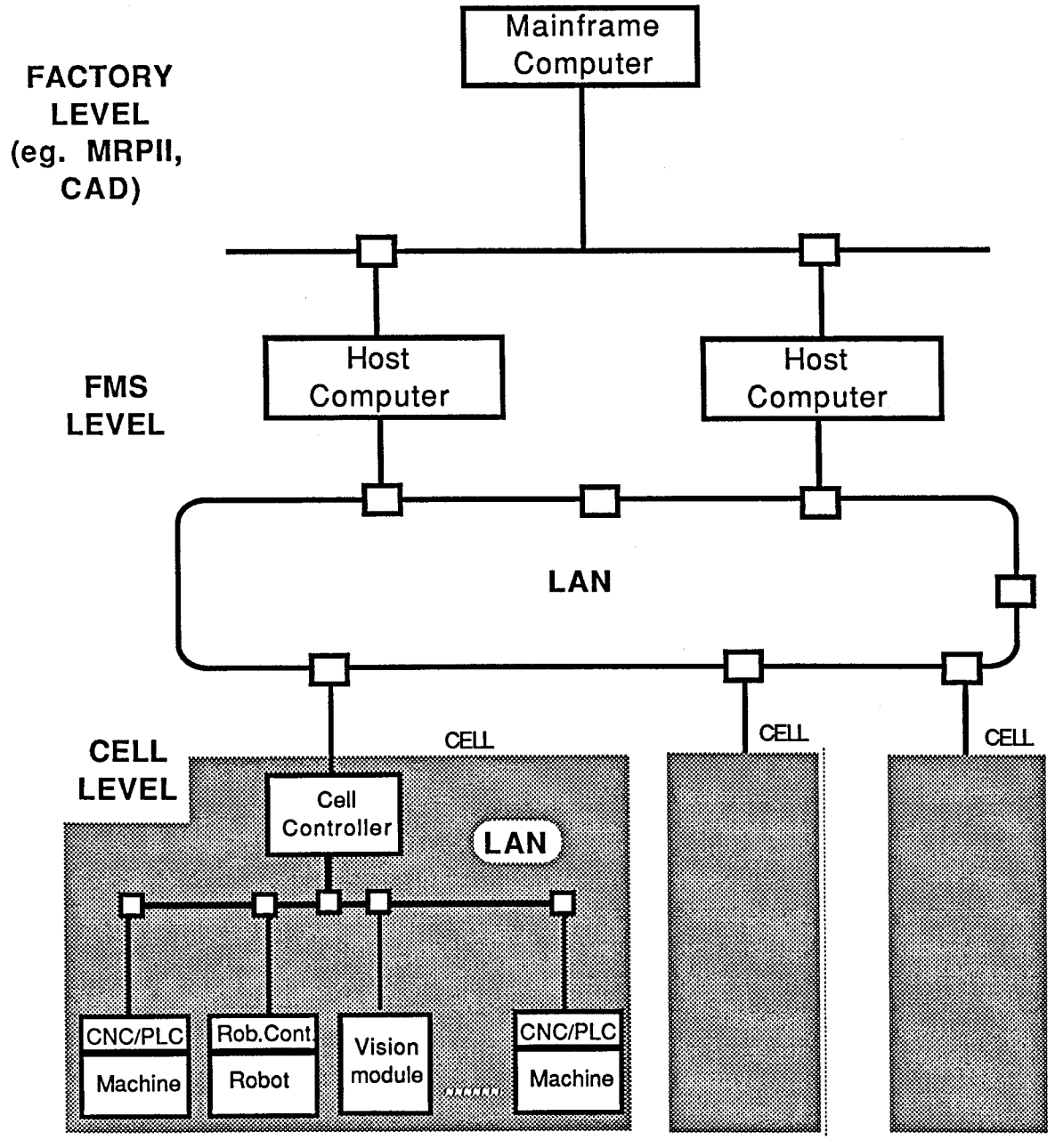

Fig.2 Representation of CIM basic components and communications (based on ref.[7])

3.2 Flexible Manufacturing Systems - FMS

Flexible Manufacturing Systems can be considered as a concept or philosophy in manufacturing systems. Since they have evolved, the main objective has been to bring the economics of scale of mass production to small batch production. This would be achieved by implementing in the manufacturing system the flexibility required to enable it to change its operating environment quickly and in a cost-effective manner. The technology that enables this flexibility to be implemented is based on highly automated systems including process equipment (eg. machine-tools, assembly stations), material handling equipment (eg. robots, AGVs, automatic storage and retrieval systems-ASRS) and communication systems, all under computer control.

When considering in a CIM architecture, FMS represents the use of computers in the control at the manufacturing level (see fig.2).

This concept of FMS is mainly concerned with small batch production (normally batch size less than 50), but the principles and technology behind FMS can be more widely applied, independently of the manufacturing process. Fig.1 from ref [8] represents diagrammatically, possible areas of application of FMS concepts.

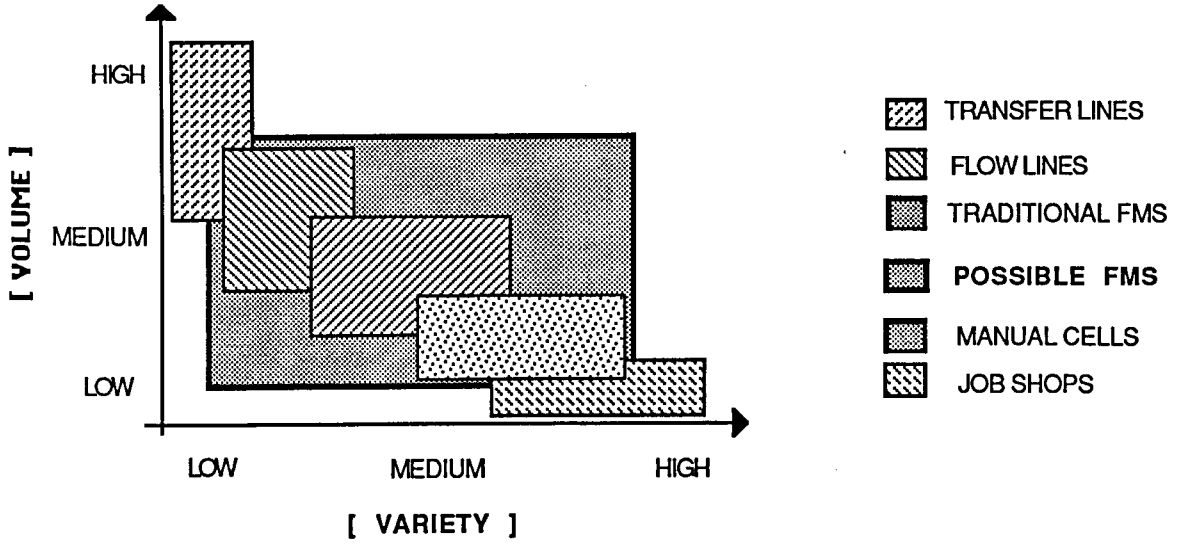

Fig. 3 Application of FMS , ref. [8]

This widespread of FMS concepts to other than small batch manufacturing systems, and even to other than manufacturing itself, is directly related to the characteristics of the market which demands a high variety of products with an increase, or maintenance, of quality levels. To remain competitive in costs, and satisfying these requirements, FMS characteristics seems to be the right approach for a great variety of systems.

When FMS principles are applied they normally result in a more efficient utilization of the manufacturing facilities. This improvement results in the reduction of inventory by reducing work in progress, throughput and lead times, smaller batches, and in the increase of equipment utilization, improved response capability of the manufacturing system to changes in design, volumes of production and variety of products. All in all, there is more efficient control and quicker response of the manufacturing facilities.

The approach to FMS consists not only of the implementation of high level of automation but also on a different approach starting at the design level, production planning and control techniques, and in the implementation and layout of the facilities. Mainly based on Group Technology or Cellular Manufacturing concepts, in an FMS the main objective is not to subdivide the job in many simple operations as possible, as in a traditional batch manufacturing, but into as few as possible, overlap operations on batches wherever possible rather than complete operations on batches sequentially, complete operations consistently quickly, and automate the entire operations sequence rather than individual automate the different operations.

The implementation of group technology principles which mainly consist in associating or classifying the products, using a code and classification scheme, according to their manufacturing requirements,

shape, dimensions, tolerances, surface finish, etc , is of main importance in FMS systems. It gives the basis to decide on the type and characteristics of the flexible manufacturing cells, as units of a FMS, capable of manufacturing families of products. Also it leads to the easy of implementation and functionality of the particular workstations by implementing standard or reducing the number of jigs and fixtures, or automatic changing mechanisms necessary for the different products within a family.

One of the main components that make FMS possible is the use of CNC (computer numerical control) controllers, which are being incorporated in an increasing variety of machines, and with increasing capabilities of control and monitoring functions of the processes.

A major characteristic of FMS is it`s ability to run unmanned or with reduced intervention of the operators in a significant part of the process. This is possible due to the utilization of automatic loading and unloading of materials and tools, increasing level of intelligence at the workstation and cell levels (CNC controllers, PLC or other computer based systems) facilitating tool monitoring and feedback control of information relative to the process (products, tools, machines).

In order to run unmanned, reliability becomes a major concern of FMS systems.

The fact that FMS can be used in a variety of manufacturing processes or others, make it difficult to define in more detail the key characteristic of FMS systems: its flexibility.
Clearly an FMS is not intended to implement in a manufacturing system the capability of producing completely different and dissimilar products, but most certainly capable of producing different products

within a family or range for which it has been designed. Some attempts have been made to define flexibility normally including (see ref.[6]:

- flexibility within a defined family parts, meaning the ease or the loss of time for setups when producing these different components

- the flexibility which characterizes the ability of the system to incorporate in the process new parts added to the family of parts

- the flexibility related to the response of the system to the need of changing the route of the parts, meaning moving the parts to the individual workstations in different sequences, or moving an individual part through different routes depending on machine availability

- flexibility as the ease of accommodating design changes to parts already being manufactured

- flexibility in terms of accommodating changes in the volume of production determined by the Master Production Schedule, without compromising the workpiece cost, productivity, or equipment utilization

- flexibility of the all manufacturing system (hardware, software, communications system), to accommodate future changes in the facilities hardware or information systems

One approach that seems most appropriate in implementing FMS is in a modular form, to allow expansion of the system if necessary and a progressive understanding of the technology and principles behind FMS. Particularly relevant due to the high cost and investment of

these systems.

FMS systems can than be considered in a more wide view rather than manufacturing or small batch manufacturing. But in the context of the present work, the tool management is aimed to be used in a FMS involving metal cutting machine-tools. Mainly CNC, machining and turning centers. Both these types of machine-tools are particularly well suited for FMS systems, as they themselves have evolved from mainly one type of operation machines to a more complex and with a wider range of operations possible. Furthermore they also include automatic tool change mechanisms and normally automatic load and unload facilities for materials.

In general the control of the FMS system can be represented as in the block diagram of fig.2. At the FMS level a DNC (Direct/Distributed Numerical Control) system is often included.

3.3 Tool Management Systems - TMS

A tooling system together with other hardware elements (such as fixtures) which support the manufacturing operations is a crucial part that can constraint the production objectives as determined in the production plans by limiting the available production capacity.

A tool management system main objective is to ensure that tools are available when required and in the appropriate conditions to support the manufacturing operations. A tool management system depends on the type of manufacturing system which obviously determine the type of tools or tooling system used. In the particular case of manufacturing systems involving metal cutting operations, different functions can be associated with a tooling system, and in general

should include:

- the selection of tools for a particular product design
- the tool requirements planning
- tool transportation or supply
- tool monitoring
- tool preparation
- tool inventory

In the traditional manufacturing systems the different functions of a tool management system were considered independently and not as an integrated approach to rationalize and control the different activities related with the tooling system. All these do not correspond to the present definition of tool management system defined as a software implemented system. Normally tools were given consideration when at the planning of a new product, but often the control of the tool status afterwords was of less concern. The tooling system was supposed, or assumed to be capable of satisfying the production planning and control requirements. Such a system, characterized by large batch sizes, long cycle times and mainly manual supervision and control, would work based on large inventories with consequently poor operational efficiency.

The requirements of CIM/FMS manufacturing environments in terms of high flexibility, reliability, maximizing utilization and high levels of automation demand a more efficient approach to tool management as the influence of the tooling system becomes more evident.

A tool management system, considering the different activities or functions related to the tooling system, in an CIM/FMS environment is the system which will provide accurate and updated information related to tooling, needed by its different users or systems in the

manufacturing system. And implemented as a computer based system. In its full implementation the FMS should provide information at the different levels: **production planning, design, process planning, manufacturing operations control.**

PRODUCTION PLANNING

At the planning stage in order to evaluate the viability of the production objectives as defined by the Master Production Schedule (MPS) and to produce a more detailed production planning with the respective scheduling, information relative to the tool requirements and tool availability should also be considered. Otherwise the production plans specified at this stage can be compromised by the absence of tools later at the production stage. The times and standards considered to scheduling at this stage do not take into account the unexpected need for tools that weren`t available when required and consequently affecting the overall planned objectives. The scheduling at this level, when using for example an MRPII package, isn`t normally used directly to specify the particular jobs in the shop floor operations due to changes in the system that normally occur within the respective period of time. However it is important at this stage to check the tool requirements against the tools available and issue the correspondent actions to ensure tools will be available, in the same way it is done for other parts or materials requirements.

Tool requirements can be included as part of the information contained in the Bill of Materials (B.O.M.). Information concerning tool availability involves the consideration of closely related functions such as inventory control, real-time control functions and tool planning strategy.

Tool inventory control is important as most tools, particularly the ones used in metal cutting processes, consist of a set or assembly of

parts which involve cutting parts with a limited life, and support elements which may be used to build different tools. Being then necessary to keep records on the status of the different elements, such as assembled, awaiting refurbishment, etc. Also the control of the remaining life of tools being used is necessary to provide information of the total capacity available involving real-time control functions.

The tool planning strategy can also affect capacity availability by defining for a particular set of operations how the tool capacity would be provided, eg. [9] replacement of a complete set of tools if fewer operations are common, or replace only of a few tools otherwise. This will require an accurate and in real-time control of the remaining life for each tool and its location. Also the characteristics of the tooling system whether [10] machine, cell or manufacturing oriented is important in evaluating the tool capacity.
In a manufacturing oriented type tools are to be shared by different cells, in a cell oriented only by the machines within a particular cell, and in a machine oriented type they are used only by a particular machine.

There is, consequently, a need to integrate the real-time control functions, inventory control and tool planning strategy to have a complete and effective control of the tool capacity which can be used for plans and scheduling of the production system.

At the current state of tool management and according to Carrie [9], there are software packages which can be used satisfactorily for inventory control (eg. Sandvick system -TOMAS), and functions for control in real-time of the location and tool parameters status (eg. tool life) also required for planning functions are also available. The problem being in the lack of integration of both systems.

DESIGN and PROCESS PLANNING

The CAD system requires information relative to what tools exist on the tooling system and its characteristics in order to select the type of tools that should be used for each component. This information is required at the planning stage previously discussed and also when considering the use of a DNC (Direct or Distributed Numerical Control) system to program the machine-tools.

The integration of CAD with tool management is important as the design will condition the type of tools used. Being important that the design specifies, or is made considering the existing tooling system at the shop floor. The consideration of DNC systems, involving the production of NC part programs in a CAD system, can be considered as a link between CAD and CAM, and involves process planning functions. The particular characteristics or parameters of each tool necessary in the NC part programs are required, together with maximum dimensions and tool conditions or status, in order to select the tools that best satisfy the manufacturing requirements. Being possible then, to take in consideration the actual conditions and capacity of the manufacturing system more close to the actual manufacturing operations, and consequently defining a more realistic and efficient scheduling.

MANUFACTURING OPERATIONS AND CONTROL - FMS LEVEL

At this level we are considering the information required from the TMS to perform all the activities and functions of the tooling system at the manufacturing level, or in this case at the FMS level. This functions include **tool preparation, tool supply methods** or **tool flow control, tool storage, tooling maintenance, tooling data preparation** and **transmission, tool monitoring, tool condition control, spare tool control,** etc.

The distribution of this functions within the FMS computer control architecture depends on its particular configuration and computer capabilities of its different elements. The trend being [11] to adopt a distributed system, in which the computer systems at the cell or machine level (eg. cell controllers, PLC`s or CNC controllers) would be responsible for the tool management at the cell or machine level. The increasing computing capabilities of CNC and PLC controllers make this solution a possible alternative to a centralized control at the FMS host computers. Tool monitoring and tool condition control are functions that modern CNC controllers can support (eg. [12] and [13]).

• tool preparation

The equipment used in FMS is very expensive and to justify the high investments it is required maximization of its utilization. The set up of tools on the machine, even if possible is not adequated as the machine would be idle. It is then necessary to present the tools to the machine ready for use, together with the respective information to the CNC controller (eg. offsets, life, maximum torques or forces,...).

The off-line preparation would include [14] servicing and inspection of cutting parts (edges) and tool assemblies, pre-measurement of tools and instructions to ensure correct placement of the tools in the machine.

This operations are done manually and the TMS should provide for every tool procedures for building, servicing, inspecting and measuring required for a correct assembly and set up (eg. components of the tool and assembly sequence, appropriate torque for screwed parts,...) and been able to transfer the parameters of the assembled tool to the CNC controllers (eg. offsets, maximum force or torques of the tool,...). Two possible methods of transferring this information

with good security [9] are using chip memories or bar codes in the tools.

• **tool supply methods**

With the separation of tool preparation and storage from the machines there is a need to provide and control the movement or flow of tools through the workshop. The means used for handling tools can be manual or by automatic systems.

In a manufacturing oriented system in which tools are to be shared between different machines or cells, manual handling is not cost effective, particularly when multiple machines are linked [12]. Automatic systems using AGV`s and robots can be used for tool handling or in combination with materials handling also. But this will require more sophisticated methods to ensure tools are located in the appropriate position of each machine.

• **tool monitoring**

Modern CNC controllers with their inherent and enhanced capacity of automatic control over the all process including diagnosis, tool monitoring and gauging require more precise and specific data concerning tool characteristics and parameters.

In general we can consider a Tool Management System as a system capable of providing information relative to the **availabilities, geometric** and **engineering** characteristics of each tool. This information involves real-time control of data such as actual conditions and location, which must be updated at the different levels to be completely useful and efficiently used by the different systems.

3.4 CIM at Warwick University

As part of its strategy to analyze and being involved in the latest developments in manufacturing systems, Warwick University is applying and implementing CIM principles using its manufacturing related facilities. Its main objective is to integrate the different functions of a manufacturing system including design, production planning and control, and manufacturing operations.

These systems at Warwick University can be represented diagrammatically as in the fig.4. They consist mainly of a CAD system, connected through a fiber optic link to a host computer which runs an MRPII package (IMPCON), and an FMS cell, whose cell controller is linked through an ETHERNET network to the host computer.

The CAD system consists of Computervision systems (CV 4000) running UNIX operating system.

The host computer is a VAX 11/750 minicomputer running VMS operating system.

The FMS manufacturing cell consists of :

- a cell controller
- a Cincinatti Milacron T3 robot arm
- a CNC lathe machine controlled by an Acramatic A900 controller, and is able to machine 250 mm maximum diameter, and has a 14 tool turret.
- a CNC milling machine controlled by an Acramatic A900 controller, and is able to work 500 mm maximum square components, and has a 24 tool carousel.

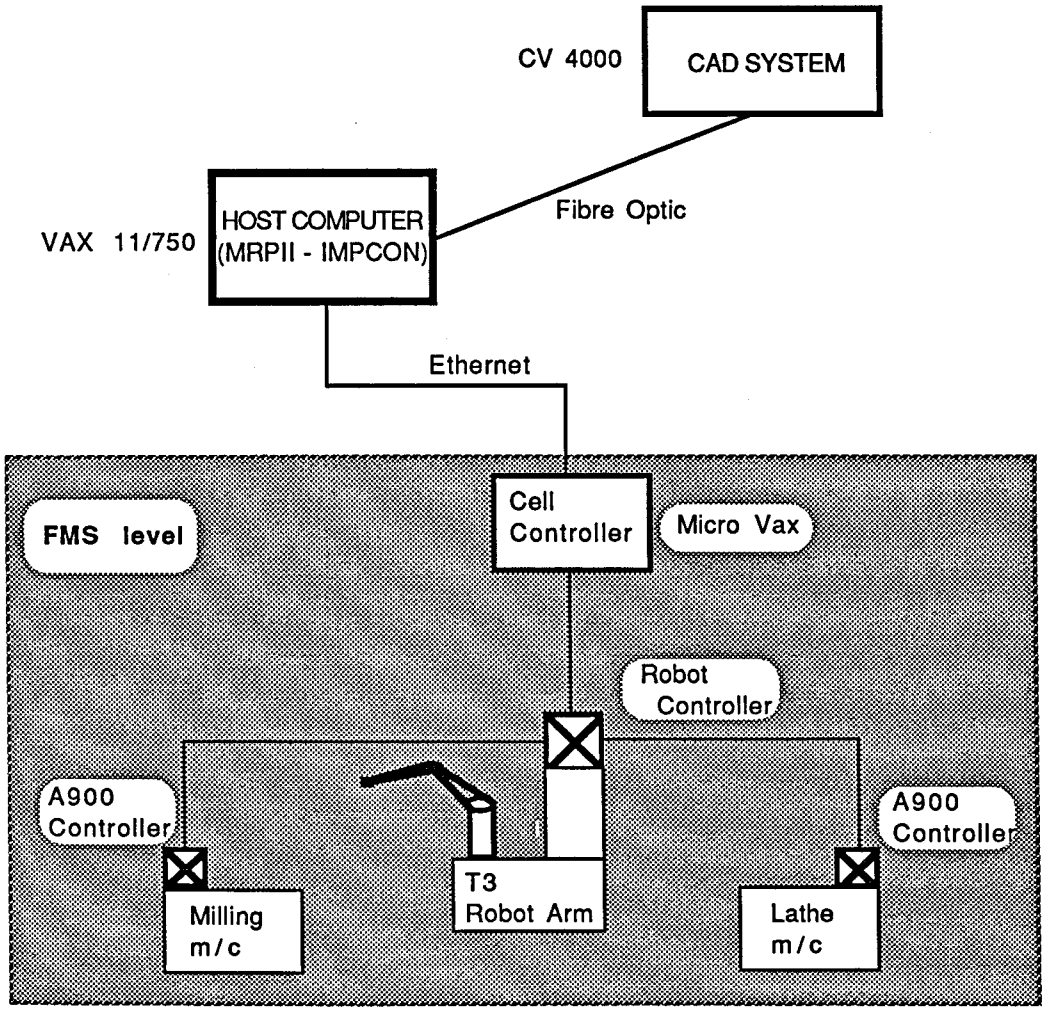

Fig.4 CIM at warwick University

The work presented in this report, in terms of tool management systems, was developed due to a need of improving the existing control of the tooling system of the FMS cell. The main objective was to satisfy the requirements of the users of the tooling system at the FMS cell level, and including the following functions:

- inventory control
- assembly and presetting
- control and monitoring

Also it should be considered the future integration with the CAD and MRPII systems.

4 DATABASE DESIGN

The use of computerized systems in companies or enterprises involves the storage and manipulation of large amounts of data. Databases are systems designed to cope with the characteristics of that data.

In essence a database can be considered, accordingly to Date [15], as a computerized record-keeping system, whose main purpose is to maintain data or information and make it available on demand. But when considering manufacturing systems, and particularly in CIM/FMS environments, database systems and its design assume greater importance. It is the data defined in the database which will be the bases of the computer model that represents the enterprise. Databases are also considered the key to integration on CIM systems, as integration involves sharing data by different systems.

Database design is the process of defining and implementing a database such that the data, its organization and structure best represents the operational data of the enterprise and best satisfies the requirements of its users. This process will necessarily involve the consideration and understanding of the system to be modelled, the database systems that support the data, and a methodology and techniques which will define and support the different phases of this process starting from the analysis of the real system to the physical implementation of the model in the database.

In this case the system to be modelled is a tooling system of an FMS in a CIM environment, and implemented as a Tool Management System using a relational database system (ORACLE). Consequently database systems, the methodology and techniques presented were analysed with emphasis on a relational model. Nevertheless the methodology and techniques chosen (data analysis, entity modelling and normalization) are not limited to relation databases.

4.1 Methodology and Techniques

The complexity of the problem involved in modeling the tooling system in a computerized system through a database requires the use of a methodology which will indicate the main steps and procedures of this process and also the techniques and tool which can be used at each stage.The selection of a methodology should take into account the need to understand first the characteristics of the system to be modelled (in this case the tooling system, its functions and the interaction with other systems) to be possible then a more efficient and effective design and implementation of a model based on data which characterizes the real system.

The case in study can be considered under the theme of (computerized) information systems, and as such the several methodologies [16] developed to design these systems could be considered, and the system in analysis being the tooling system. But when choosing a particular methodology it must be taken into account the characteristics and objectives of the particular system and that the principles underlined in the several methodologies are not necessarily exclusive, being in most cases possible to combine and complement different techniques in the approach to our problem.

The approach proposed in Avison [17], and also referred in Pangalos [18], seems to be appropriate for this case, as it includes an analysis of the system independent of its implementation and its main focus is on the creation of a data model (particularly suited for relational databases design). This approach is represented in fig.5 and it is the basis of the methodology chosen, which includes the following stages:

- business analysis
- data analysis
- database model
- physical model

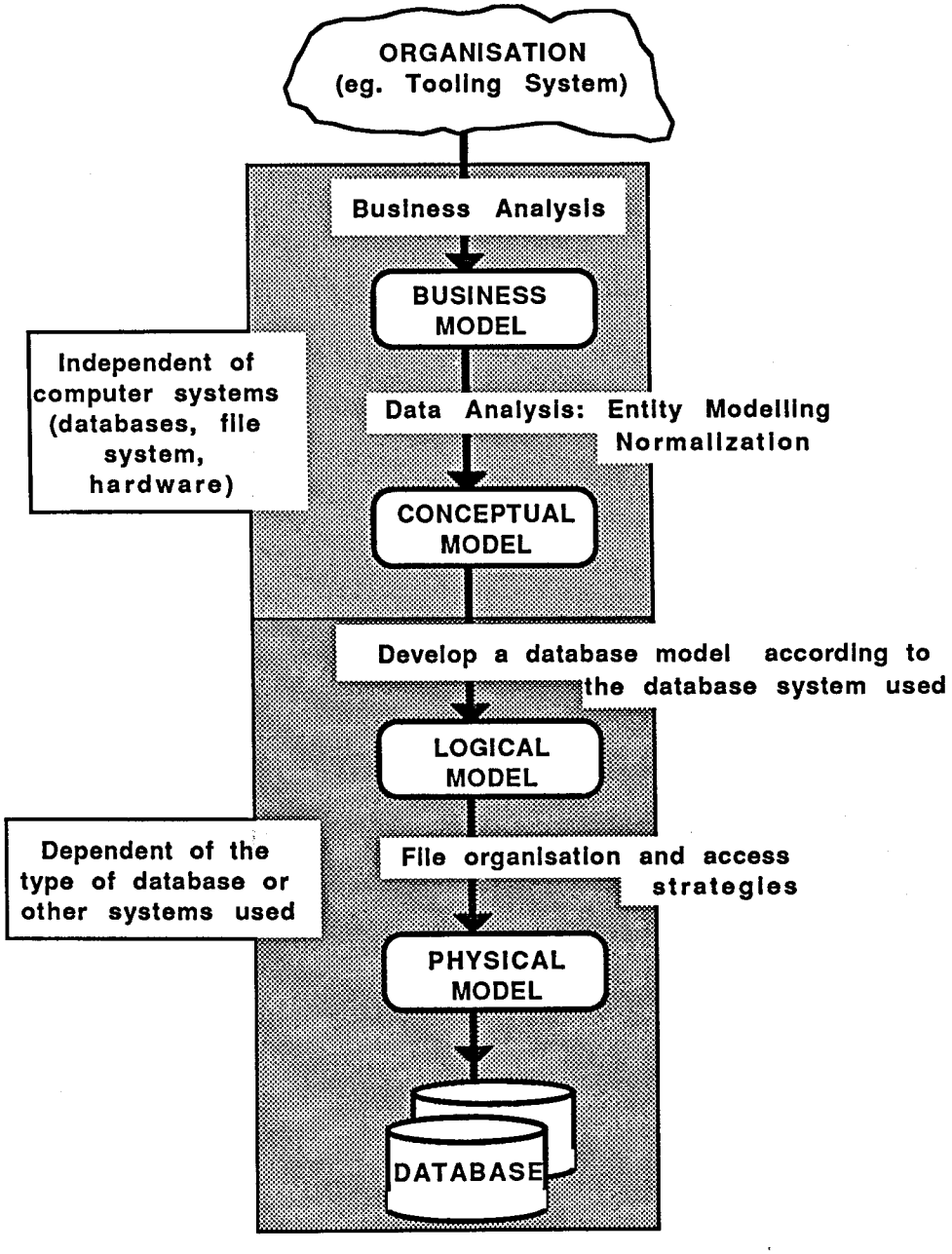

Fig.5 Database design approach, based on ref [17]

• **business analysis,** in general when considering an enterprise, this first stage consist in understanding the system's organization and structures, and its objectives. It would involve necessarily the human aspects.

In the particular case of the tooling system, it should be important to

identify at this stage what a tooling system is, its components, why is it needed, who controls and uses the system, what is expected from it.etc.

• **data analysis,** the objective at this stage is to build a data model of the system based on the representation of its facts by data and its structure. The approach at this stage consist mainly in combining three techniques (entity modeling, normalization, relational model), which are interrelated and the resulting model can be easily mapped into a database.

Entity modelling is a technique that consists basically in representing the facts or anything of interest or importance in the system as entities, data about these entities (attributes), and analyse its association or relationships. Entity-relationship diagrams can be used to help in this process.

Relational model, consists basically in representing these entities and attributes in the form of flat tables (or relations).

Normalization , consists in applying defined rules to simplify and optimize the design of these tables.

These three concepts will be further explained in subsequent sections.

The final result is a data model in a conceptual form, which can then be mapped directly into a relational database system or with an appropriate modification if other systems are used.

• **database model,** at this stage we have defined a global data model as a relational model, which must now be converted according to the specific structure and requirements of the database system used. It is possible to derive from the existing model the most common data structures in database systems: relational, hierarchical and network. Obviously it is straightforward in the case of relational systems.

• **physical model,** at this stage it is necessary to convert the

database model defined and structured in a logical and global level in the structure as physical stored in the database (internal view as defined in section 4.5).

The methodology presented can be considered in two main independent phases:

• the **first** (business and data analysis), is concerned mainly with building a data model of the system in analysis based on the previous understanding of its characteristics and on its representation in terms of data elements and its structure. This data model represents a conceptual view of the system and it can be used and designed independently of the particular computer systems which will support it (eg. type of database system, or other file handling system, hardware-mainframe, minicomputer, etc.). This type of analysis of the system, based on the characteristics of its associated data, provides an understanding of the real system which by its own can justify the application of this methodology.

• the **second** (develop a database model and its physical implementation) is more directly concerned with the requirements of the particular computer based system (database, hardware). It consists on structuring the data accordingly to the database system, defining the structure and access strategy, file organization, etc.

4.2 Entity Modelling

Entity modelling is a data analysis technique which allow us to create a data model as perceived by an understanding of the real system and its data. The analysis is concentrated on the data elements which can be identified on the real system, but should also take into account the processes involved as the final data model have to be able to support these facts or events.

The analysis of the system consist mainly on interviewing whoever might be involved in the system, and/or analysis of the existing documentation of the operations involved in the system.

The data model derived from entity modelling, is represented and defined by three main elements, **entities** (entity types, entity occurrences), **attributes** (attributes, key attributes), and **relationships** (relationships, degree of the relationship).

• ENTITIES, or entity types, are used to represent everything of interest or importance for the real system. They can represent objects as well as concepts, and since they are used to create a data model they should be quantifiable. It is a most important concept as it will define how data will be kept about each element, by defining the elements that characterize the system. It will also define how the different data can be related by defining the association (or relationships) between the different entities.

• ENTITY OCCURRENCES, represent a particular instance of an entity type.

• ATTRIBUTES, are the definition and characterization of the properties of an entity. The processes or events will be supported in the data model by operations on the attribute values.

• KEY ATTRIBUTES, are the attributes which uniquely identify an entity. The values of the key attributes will differentiate within an entity the various entity occurrences.

• RELATIONSHIPS, characterize the type of association between the different entities, and they should represent meaningful and relevant operations (or events) in the real system.

• DEGREE OF RELATIONSHIP, represents the association between two entities, in terms of the number of entity occurrences of the other entity type, a particular entity occurrence can be related with. Its

degree would be:

- one-to-one (1:1), if each entity occurrence of an entity is only associated with one entity occurrence of the other entity type,
- one-to-many (1:m), if each entity occurrence of an entity can be associated with more than one entity occurrence in the other entity type, and
- many-to-many (m:n), if each entity occurrence of an entity can be associated with several entity occurrences in the other entity type, and each of these in turn can be associated with several other entity occurrences in the previous entity type.

Entity modelling is an iterative process which consists basically [16] in for the defined area in analysis, determine:
- the entity types and its relationships,
- complete each entity with all the attributes
- verify if the model can support the events that occur in the enterprise.

The process is illustrated diagrammatically using one of the proposed conventions (see [16]) to represent entities and relationships. Avison [16] uses soft boxes to represent entity types and lines linking the different entities to represent relationships, indicating also its degree and what kind of relationship.

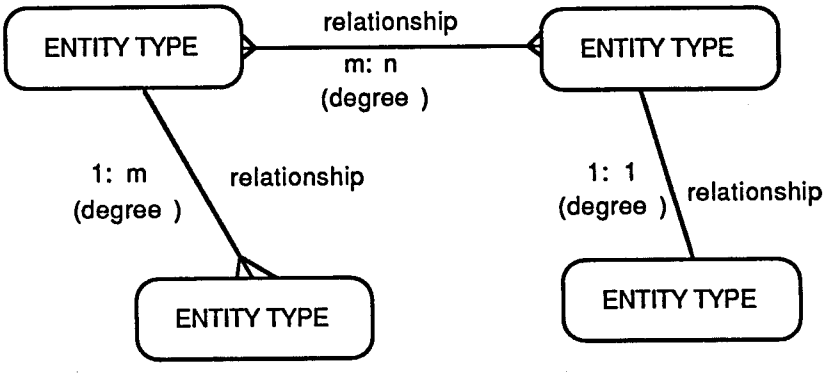

Fig.6 Entity / Relationship diagrams

4.3 Relational Model and Normalization

The relational model is directly linked to the development of the theory of relational databases. But in this section we are interested in presenting the relational model as a data analysis technique, which can use and complement the results of entity modelling, and for which normalization techniques were first developed.

RELATIONAL MODEL

The **relational model**, basically uses entities and attributes in the same or similar concept as they are considered in entity modelling. But its main difference and its basic concept is the term **relations**, which consists of two-dimensional tables representation of the data (entities and attributes). In these tables, each row is called a **tuple**, and each column an **attribute** of that relation. The number of attributes is the **degree of the relation**, and the number of tuples its **cardinality. Key attributes** are used to differentiate each tuple within a table. One of the characteristics of the relational model is that the data represented in the tables, can be used and combined through logical operations to select the particular segments in each table according to the request. These tables have four properties [15]:

- there are no duplicate tuples
- tuples are unordered (top to bottom)
- attributes are unordered (left to right)
- all attribute values are atomic.

Relations are thus a different concept from relationship. In the relational model, relationships as representing the association between entities are implemented as association between tables (or relations) by adding an attribute (foreign key) to a table which correspond to the primary key in the other table.

A relational model can be analysed in three major aspects [19],

- **data structure**: data organised in tables (tuples and attributes), with atomic values (there is only one value for each domain and not a set of values)
- **data integrity**: which specifies basic constraints or rules that must be followed to avoid defining incorrect states of the data. The two rules used are related with primary and foreign keys,

- entity integrity - primary key values must not be null
- referential integrity - foreign key values must match primary key values (or be null)

- **data manipulation**: which provides relational algebraic operators (union, intersection, difference, product, select, project, join, divide) to manipulate the data of the tables.

This relational model will be referred when analyzing relational databases in section 4.6.

NORMALIZATION

Normalization was first developed to simplify and optimize the grouping or definition of tables in the relational model, but can be applied in other techniques irrespective of the relational model.

As an analysis technique for the structuring of data, normalization consists of a set of rules which are applied to data represented in terms of relations (tables). It will help to decide what relations are needed and what their attributes should be. The application of these rules will simplify and verify possible anomalies in the tables, and consequent on the organization of data.

The rules of normalization are referred as normal forms, which specify a number of constraints a relation have to satisfy. Several normal forms have been proposed and the more often used are the three normal forms originally developed by Codd [15]:

- first normal form (1NF), a relation is in the 1NF if and only if all underlying domains (attributes) contain atomic values only (there is only one value for each domain and not a set of values). As referred earlier in this section all relations are in the 1NF.
- second normal form (2NF), a relation is in 2NF if and only if it is in 1NF and every non-key attribute is fully dependent on the primary key.
- third normal form (3NF), a relation is in 3NF if and only if it is in 2NF and every non-key attribute is nontransitive dependent on the primary key (all non-key attributes are functionally independent of each other).

Normalization is basically a mechanical process of analyzing the data and its structure but requires the understanding of the meaning of the relations and its characteristics to be effective and successful. That is why it is helpful to use it after entity modelling.

4.4 Advantages of Database Systems

The advantages of computerized record-keeping systems instead of "paper-based" methods are fairly obvious if considering the fast and

easier access to the information, and consequently more accurate and up-to-date information, the elimination of voluminous paper files and the correspondent tedious work of maintaining files by hand.

When considering computerized record-keeping systems, the advantages of database systems over the individual file handling systems are a consequence of the particular characteristics of data (**integrated** and **shared**) and the possibility of having a **centralized control** over the whole data in database systems. Integrated data means that the different information or data stored on a database can be used and seen as a whole, and by shared data, that different users can have access to the same piece of data.

The most important advantage or objective of database systems is to provide **data independence.** In file handling systems independent programs must use independent files which increases data redundancy, reduces flexibility of the system and creates difficulties to the overall objective of integration of the different applications as it doesn`t allow integrated processing. The objective of data independence in database systems is to separate the application programs from the data storage system in a way that changes in one system would not affect the other. Or more specifically, [15], change in the storage structure and access strategy will not affect application programs.

Other advantages of database systems are:

- **reduction of data duplication** and **controlled redundancy** – as a consequence of integrated data
- **inconsistency can be avoided** – as a consequence of reduced and controlled redundancy
- **provide data compatibility**
- **increase data integrity** – ensuring data accuracy

- **improve standards** – a centralized control of the database can more easily ensure that applicable standards are observed
- **increase speed of implementing systems** – easier access to data and possible use of existing data, allow more time for development of application programs
- provide effective **system support and utilities** for controlling transactions and for user **privacy** and **security** of data

However according to Ranky [11], database systems are more expensive as they require another software package and qualified staff to make full use of it. And also recovery and data backup is more difficult.

4.5 Database Elements and Architecture

Being a computerized record-keeping system a database system will involve other than the data itself and the respective users, hardware and software. Hardware as the physical means for storage and communication of the data or information. And software to implement the database and its functions.

There can be considered three main types of **end-users** of a database system:

- **application programmer**, using high level languages (eg. Cobol, PL/1, C)
- **on-line terminal** user, using a built-in application (eg. SQL)
- **database administrator** (DBA), who is the responsible for overall control of the total system (eg. decide the information content of the database, decide the storage structure and access strategy, define security and integrity checks, define a strategy for backup and recovery, monitoring performance and respond to changing requirements.

The **hardware** elements are common to other systems and normally include secondary storage volumes (eg. moving-head disks), I/O devices, I/O channels, etc. Systems are available for micro, mini or mainframes computers, with obviously different characteristics.

In terms of **software** the main element is the Database Management System (DBMS), whose main purpose is to provide an interface between the end-users and the database, and involving the control of basic functions such as storing, accessing, manipulation, presenting, using and controlling information. Other support facilities or systems interrelated with the DBMS, normally include:

- data communications
- data dictionary
- data access
- data presentation
- application generation
- or others such as word processing, statistical packages, spreadsheet programs, expert systems, etc.

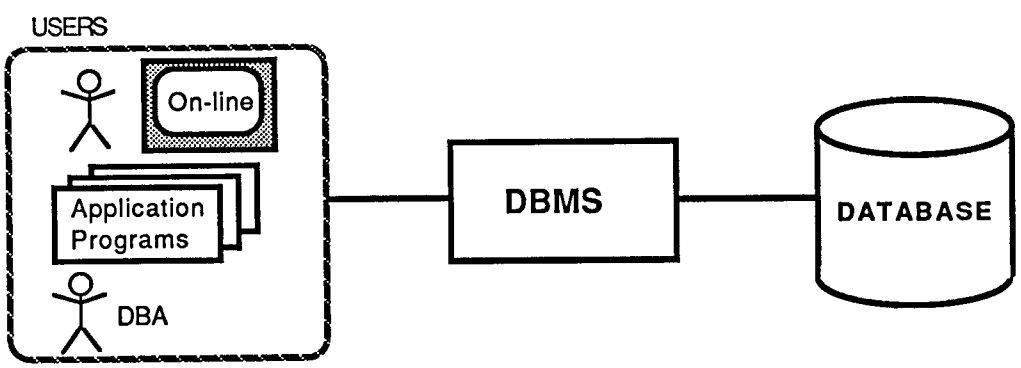

Fig.7 Users access to the database

The definition of a database architecture, even if not satisfying all existing database systems, is useful to analyse the implementation and functioning of a database system (eg. operations necessary to present

the data as physical stored and as required by each different user), and to understand the structure and operators which characterize database systems.

A possible architecture [15], defines three different levels in a database: internal, external and conceptual levels. These levels are concerned respectively with the representation of the data as physically stored or machine-oriented (internal), with presenting different views of the data as required specifically by each user, and as an abstract or logic representation of the whole database (conceptual), and as an intermediate level between the external and internal views. In this representation the conceptual view and external views correspond to the logical model stage of the methodology defined in section 4.1.

This architecture, and considering the representation of data in the form of records, consist in defining the different representations of data at each level as a set of records (external, conceptual, internal) which constitute the respective schemes (external, conceptual, internal), and in defining the correspondence between each level (external/conceptual and conceptual/internal mappings). In fig.8 it is represented this type of architecture, with the three levels and the correspondent mapping and schemes, the Data Base Management System (DBMS) and the Data Communications (DC) software which controls all access to the database, the different users, and the Data Base Administrator (DBA) which is responsible for defining and maintaining this architecture.

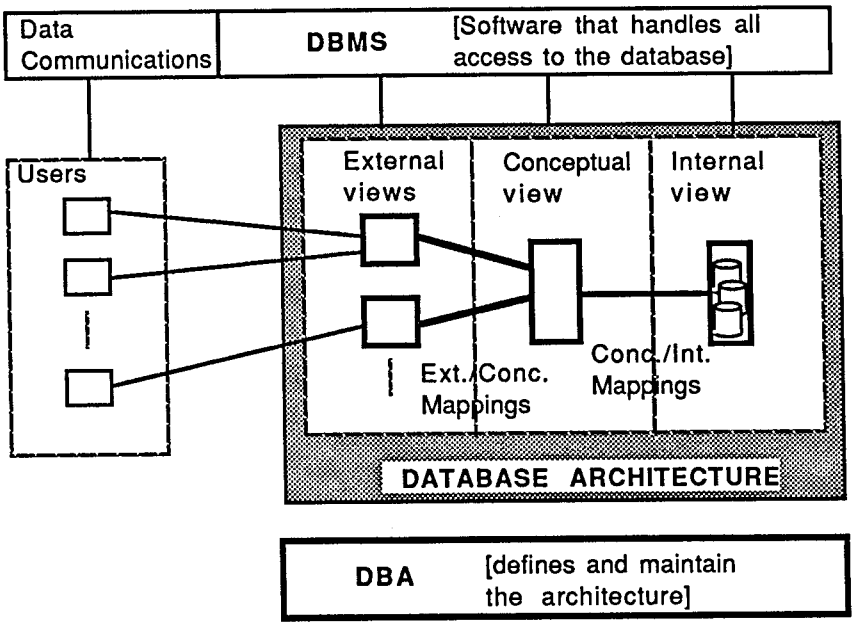

Fig.8 Database architecture and interaction with major components.

The definition of this elements (eg.schemes and mappings) is exclusively the responsibility of the DBA at the conceptual and internal levels and is done using a specific language (DDL-Data Definition Language) for defining or describing database objects. An external DDL and a Data Manipulation Language-DML, can also be used by common users (eg. embedded in other languages, or as a built in application, eg. SQL for on-line users) to define the external schema and to support the manipulation or processing of those elements (DML).

In order to achieve data independence the conceptual schema should include definitions of information content only, and not storage structure or access strategy. Other features such as security and integrity checks should also be included.

The internal schema doesn`t only define the various internal records, but also other elements such as specifying what indexes exist, how stored fields are represented, what physical sequence the stored

records are in, etc.

4.6 Relational Databases

One important aspect of database systems is the data structure or data relationships at the different levels of its architecture. They will determine the view or level of abstraction of the user from the physical storage of data, and also the definition of the schemes and mappings between the different levels of the architecture.

The three major systems or structure models are , **hierarchic, network** and **relational** models.

The hierarchical model represents the data structures by using the so called 'parent-child' relationship in a tree structure. A 'child' can only have one parent, and for every occurrence of the 'parent' there can be any number of occurrences of the 'child' (one-to-many type of relationship). This model can be represented as in Fig.9.

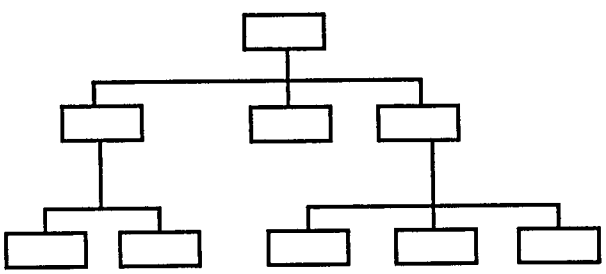

Fig.9 Hierarchic structure.

The structure in a network model can be seen as an hierarchical model in which a 'child' record can have any number of parents (many-to-many relationships). And can be represented as in Fig.10.

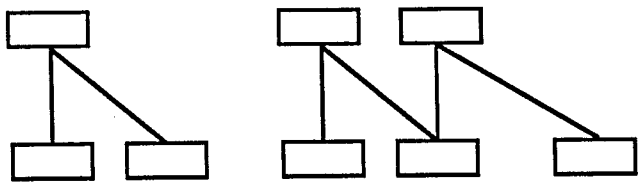

Fig.10 Network structure.

In terms of data structure the relational model can be simply defined as representing in two dimension tables or relations. The relational model was already presented in section 4.3, where it was referred two other important aspects of this model : data integrity and data manipulation.

According to Date[15], the existing databases implement the relational model in different degrees, with the highest consisting on the implementation of the data structure (data perceived as tables) and data manipulation (relational operators) aspects of the relational model, but not supporting data integrity. And his definition of (minimally) relational system is the one that supports:

- 'Relational databases (i.e. databases that can be perceived by the user as tables, and nothing but tables), and
- At least the operations select, project, and (natural) joint, without requiring any predefinition of physical access paths to support those operations.'

According to his definition ORACLE is a **relationally complete** system because it supports all the operators of the relational algebra (select, project, product, union, intersect, difference, join, divide) and not only the three above referred. A **fully relational** system would include also the support of data integrity aspects.

In a relational database the relational structure of the data only has to exist at the external and conceptual levels, and not necessarily at the internal or physical level. The system will be responsible for the correspondent operations, and each association of records is not defined in the structure (as it in the case of hierarchic or network systems) but established each time it is used. This is the basis for the main advantages of relational systems over non-relational.

Some advantages of relational databases are:

- provides a model with a high level of abstraction of the user from the internal structure, and tables are easy to understand
- provides data independence at both the physical and the logical levels (eg.application programs not dependent of the database internal structure)
- ease to access
- easier to restructure
- less procedural
- ability to use high-level languages to manipulate data (eg.SQL)

5 SPECIFICATION OF THE SYSTEM

In this chapter the objective is to define the specifications for a general Tool Management System of an FMS. This should include the definition of what the system does, what are its functions and how it interacts with other systems in the manufacturing environment.

These problems were already presented when considering Tool Management Systems issues. But it is required a more detailed analysis of the components/equipment related to a tooling system and its users requirements to understand and specify in more detail the information a tool database should include, the functions and interaction of the TMS with other systems.

This chapter will include first a presentation of the equipment and components related with the tooling system such as the tools itself, handling system, machines, tool presetting and assembly, etc. Then it will analyse the activities and information about the tooling system required at this physical level and the interaction with other systems (eg. business planning, CAD, CAM, FMS). Based on this analysis would be easier to specify what type of information a tool database should contain to support these functions.
The analysis presented in this chapter can be considered as part of the business analysis necessary to define a conceptual model according to the methodology presented in section 4.1.

5.1 Components of the Tooling System

As previously referred (section 3.2) the principles of FMS can be implemented in a wide variety of manufacturing systems, involving different process equipment. Consequently a tooling system being directly related to the processes can include a wide variety of tools and associated equipment.

Even if we consider only tools associated or used by machine tools, according to the definition of a machine tool by the National Machine Tool Builders Association, these would include tools used in machines to shape or form metal by cutting, impact, pressure, electrical techniques or the combination of these processes. A generic tooling system can thus be very diverse and we are going to consider only the tools associated with metal cutting machine tools, and the ones that are more likely to be used in FMS systems.

A tooling system in an FMS involves many components and equipment, other than tools and its different parts, such as tool transport systems (eg. AGV`s, shuttle carts, ...), tool storage (eg. ASRS, magazines), loading and unloading (eg. robots, manipulators), tool presetting (presetter) and assembly, tool maintenance and refurbishment, the machine tools and respective Automatic Tool Changer (ATC), control unit (CNC, NC), sensing and monitoring devices, data collection system, coding and identification system, or others.

These elements are interrelated and can be analyzed by its association with a main system or location area within the FMS, as for example the one referred in [19]:

- tool transfer system
- tool storage, loading and unloading
- tool room support

In this section we will analyse the main components as within these systems, but first we will analyse the tools itself. How they can be classified, its association with machining operations and machine tools, and general characteristics.

5.1.1Tools (types, general characteristics)

A classification of metal cutting tools depends on many factors or characteristics, and might be considered the:

- type of machining operations they perform

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- characteristics of the machining operations
- machine tools on which they are normally used
- tooling system characteristics (eg. mounting devices)
- tool characteristics

• Machining operations (type and characteristics)

The classification according to the machining operations represents a first and more general division, which traditionally also direct associates the tools with particular machines.

Machining operations which are more likely to be used in a FMS system and the correspondent tools can include: turning (turning tools), boring (boring tools), drilling (drills), reaming (reamers), milling (milling cutters), threading (dedicated tools or single-point tools), sawing (eg. blades) and grinding (grindstone). The characteristics of these operations and tools is as follows [20]:

- turning (turning tools), is a machining process in which a workpiece is held and rotated about is longitudinal axis on a machine tool called lathe. Turning operations consist on the removal of material from external surfaces on rotating workpieces. Related operations on external surfaces, also performed on lathes, include facing, chamfering, grooving or necking, knurling, skinning, threading, and cut off (parting). Operations that can be performed on internal surfaces with a lathe include drilling, reaming, boring, threading, and recessing. In terms of cutting tools for turning, most metal removal in turning operations is done with single-point tools. One exception is the use of form tools ground to specific shapes. A single-point cutting tool has one cutting point (tool point) and a shank by which the tool is held. The cutting part consists of edges, face, flank. Single point tools are available

as solid tools produced from bars of tool steel or from carbide blanks with tips brazed to a tool holder. They are also available as indexable inserts made from various cutting tool materials and clamped to holders.

- boring (boring tools), precision machining process for generating internal cylindrical forms by removing metal with single-point tools or tools with multiple cutting edges. This process is most commonly performed with the workpiece held stationary and the cutting tool both rotating and advancing into the work. Boring is also done, however, with the cutting tool stationary and the workpiece rotating. Boring operations are usually harder on cutting tools than turning operations because the confined machining area, which can cause chip removal problems, especially from deeper and smaller diameter bores. As a result, the size, strength, and stiffness of boring tools are often limited by hole size and length of cut. Owing to the special nature of boring operations, however, some design considerations tend to be more critical.

- drilling (drills), basically the production or enlarging of holes by the relative motion of a cutting tool and the workpiece, which produce chips, the cutting tool, the workpiece, or both may rotate, with the tool generally being fed. Drills, cutting tools for drilling, are rotary end-cutting tools having one or more cutting lips, and one or more helical or straight flutes for the passage of chips and the admission of a cutting fluid. Wide variety of types and geometries. The machines used include a variety of drilling machines, lathes and boring machines, machining centers, milling machines, etc.

- reaming (reamers), is a machining process for enlarging,

smoothing, and/or accurately sizing existing holes by means of multiedge fluted cutting tools (reamers). As the reamer and/or workpiece are rotated and advanced relative to each other, chips are produced to remove relatively small amounts of material from the hole wall. May be performed on the same type of machines used for drilling. A reamer is a rotary cutting tool with one or more cutting elements used for enlarging to size and contour a previously formed hole. Its principal support during the cutting action is obtained from the workpiece.

- milling (milling cutters), is a machining process for removing material by relative motion between a workpiece and a rotary cutter having multiple cutting edges. In some applications, the workpiece is held stationary while the rotating cutter is moved past it at a given feed rate (traversal). In other applications, both the workpiece and cutter are moved in relation to each other and in relation to the milling machine. A milling cutter is a rotary tool provided with one or more cutting edges which intermittently engage the workpiece and remove material by relative movement of the workpiece and cutter.They can be classified by styles or uses, construction characteristics, and methods of mounting.

- threading (dedicated tools or single-point tools), threading is a machining process which can be performed in dedicated machines with special tools for high volumes of production, or also using single-point tools as in a turning center (or lathe) for example.

- sawing (blades), is a machining process mainly used to cut off metal. The machines can be of different types, normally according to the type of the tools or blades (eg. straight, band

or circular).

- grinding (grinstones) is a high precision machining process normally done in different types of grinding machines, which the latest models incorporate also a CNC type controller. The tools used are baically different from those of the previous operations.

For most of these operations, tools were developed that best satisfy particular objectives of the machining operations in terms of, surface finish, accuracy, material removal rate, etc. Normally the characteristics are interrelated (eg. surface finish and material removal rate). This variety of tools within each type is sometimes broadly referred in classes or groups such as extreme finishing, light finishing, finishing, roughing, heavy roughing.

• Machine tools (type, automatic tool changers)

Originally, machine tools were designed to best perform a particular machining operation, such as lathes for turning, milling machines for milling, etc. This is not necessarily the case in modern machine tools as the tendency, particularly in FMS environments, is to increase the flexibility of the individual machines, by implementing additional features that make it able to perform more than one type of machining operations. Modern turning centers and machining centers are good examples.

The main features of machine tools which particularly suit the requirements of an FMS system include:

- CNC controller (even if an FMS does not necessarily have to include only CNC type machines as suggested in [7])
- tool change system (including tool magazines)

- component or workpiece change system.

These elements are very important in an FMS as they are directly related to **integration** with other systems, and the level of **automation and unmanned** functioning. The implementation of the tool management system will also depend on the characteristics of these elements.

The capabilities of the CNC (or control unit) will determine the possibility of tool management functions at the machine level which might include tool monitoring, checking tool positioning in the machine tool storage, coordination with automatic tool change mechanisms and data collection.

The tool change mechanisms whether by general purpose robots or dedicated manipulators will also affect the characteristics of the tooling system by defining the possible tool magazine and tools which can be used at each machine. A tool change mechanism normally would involve some kind of tool storage device in the machine and the mechanism to move the tools from that area (spindle in the case of machining centers). Its function is to provide the machine with a set of preselected tools capable of performing a variety of jobs without tool replacement. This set of tools may include, different tools or sister (fresh) tools to replace worn ones. The capacity and expandability of tool storage areas in the machines depend greatly on the basic configuration of the magazine. It must be considered that automatic tool changing involves not only tool storage and tool change mechanisms, but also tool wear sensing, and positioning. One important aspect which must be considered for tool management, is that even if the different types of machines can perform common machining operations, the interchangeability of the respective tools must take in consideration the solution each tool manufacturer, and machine

tool manufacturer, have chosen for its tooling system (eg. mounting types, automatic change mechanisms, etc.) as there are not a unique standard to be followed.

Among the different types of metal cutting machine tools, turning centers and machining centers, deserve special reference and can be considered basic building blocks of an FMS system, as they have developed in themselves the concepts of flexibility and automated, unattended machining typical of FMS systems. These two types of machines, or the machines that were at their origin, could be considered the more important machines in a machine shop in terms of the variety of parts or jobs that can be done using both machines. Lathes, capable of performing a variety of machining operations, but mainly for rotary parts, milling machines also capable of different machining operations, but mainly for prismatic parts, and drilling machines together can perform most of the jobs normally required in an machine shop. Because of their importance in FMS systems we will be concentrated in these two types of machine tools.

A machining center can be considered as a combination of a milling machine and a drilling machine, and by definition, must also include an automatic tool change (ATC) mechanism. The characteristics of its tool change mechanism is most important as it determines the number and type of tools that can be used at the same time in the machine. Different tool changing mechanisms have been developed, the most popular of which is the two-hand arm. Common storage systems include the disk shape carousel type and a chain type.

A turning center, can be considered as the evolution of the lathe

machine, whose flexibility in terms of machining operations has been complemented with some milling operations. This is achieved normally by using rotary tool spindles and/or multiple chucks. Together with automatic workpiece, chucks and tool changing mechanisms its flexibility approaches the one of the machining centers. A wide range of work is possible without having to move the workpiece to other machines, which simplifies scheduling and planning and reduces lead times. The more common organization of tools in a turning center is using the typical turret solution of traditional lathes. But the capacity of typical turret (eg. [3], [16]) is not enough for the flexibility and unattended machining required. To improve this capacity tool storage systems, normally of the drum or chain type, are also provided. For turning centers there are two main approaches on the tooling system:

- change only the tool heads held on tool storage to the turret (eg. Sandvik Block Tooling system), or
- changing the whole unit (tool holder and tool head).

• Tool characteristics (geometry, parts, tool material)

When considering each individual tool as prepared for use in a machine, the number of parts or elements which constitute that tool can vary from just one piece to a complex assembly of subassemblies or elements, but we can distinguish in general two distinct functional parts:

- **cutting part(s)**, which will be in contact with the workpiece material, and
- **holding or support part(s)**, whose function is to interface or fix the tool to the machine.

In terms of cutting parts, important characteristics are the material, the geometry and the number of cutting elements.

The material is important and can be used to differentiate that tool, as it will affect its performance and the characteristics of the machining operations. Tools for the same type of machining operations, similar geometry but made of different material will perform differently and produce different machined surfaces.

The geometry of the cutting part (eg. cutting angles) will also affect its performance and type of operations.

The number of cutting elements normally depends on the type of machining operations. In turning tools is normally one (single-point tools) and milling cutters use several (eg.multiedges).

In terms of the tool as a whole (cutting part and holding part), its overall dimension is important, as it will determine its ability and performance according to the characteristics of the workpiece.

5.1.2Tool Transfer System

A tool transfer system should be designed to move tools within the FMS with access to the different workstations, and to/from the main storage and tool room preparation, presetting or maintenance areas. The characteristics of the flow of tools depends on the tool distribution and allocation strategies of the system , but will certainly involve large number of moves between large number of destinations, as tools are of short life time (eg. inserts) and must return to the presetting room.

Different transport systems can be used, and one solution could be using the workpiece or materials transfer system. This will reduce the number of transport units required, but it is not advisable (eg. [19]) due to the differences between tools and workpieces regarding size, holding, loading and unloading, frequency of motion and nature of flow. Also a dedicated system will be prepared to react more effectively in case of tool

breakage, or other uncertainties. In a shared transport system the planning will be more complex, and could introduce delays as both tool and workpiece must be ready.

The technology used can vary from complete automated systems, or including manual functions, as for loading and unloading.

Manual systems are more subject to errors and mistakes and should be checked by alternative methods. As for example the possibility of the CNC machine controller verify if the tool is in the correct pocket of the machine tool magazine. Automatic manipulation can be done by robots or dedicated manipulators.

The mode of transportation differs from system to system, and may include:

- the use of AGV`s, which provide high degree of route flexibility [9]
- an overhead transporter (eg. rail guided) controlled by a computer, see [19],[12].
- shuttle carts, which consists of a cart moving on a straight line rigid track serving all workstations (arranged on a straight line)
- a cart moved manually from workstation to workstation.

5.1.3Tool Storage, Loading and Unloading

A machine with an ATC mechanism normally has a storage area in the machine which consists of some type of tool magazines (eg. drum, disk). The replacement of the tools can be done by two main handling techniques [19]:

- using interchangeable magazines
- change tools individually on the magazines

In the first case it is necessary to have a large number of identical and special means to deliver and install them on the machines. The number of duplicate tools, tool setting and

handling costs are increased.

In the second case the transfer system provides the tools to the workstations and a robot or manipulator loads them individually in the magazines. It is necessary to coordinate these actions with the machine operations to avoid interrupting the machining process. A storage buffer can be used at each workstation to limit the size of the tool magazine needed and to supplement its capacity.

Automatic storage equipment at the storage room is also possible by the use of Automatic Storage and Retrieval Units (ASRS).

The major advantage of using automated transport/handling and storage systems is the control they provide over the location of each tool at all time. This requires an identification or coding system in the tools. The more common systems are based on bar coding or memory chips attached to the tool holders. Memory chips can store more than just a code number (eg. name, length, diameter, life, accumulated tool usage, thrust, horsepower, tool offsets, as referred in [12]). This can be extremely useful in terms of data collection and communication for the tool management system.

5.1.4Tool Room Support

The control of the previous systems (transport, storage, loading and unloading) and the activities involved in preparing the tools to satisfy the production schedule is a complex task which justifies the use of a dedicated system for that purpose.

This system can be concentrated at a central tool room support whose main function would be to deal with the activities related with preparing tools, to satisfy:

- tool requirements, for different machines, jobs or batches

- the schedule production
- unexpected tool request (eg. due to tool breakage)

It should also record relevant tool characteristics and tool usage data, and replenish tool stocks in an orderly and timely manner. Different levels of automation can also be implemented to support these functions. But some of the equipment used might include:

- reader/writer system for the memory chip or bar code system
- computer system to communicate or store tooling data
- tool presetter, precisely measure (±0.5 μm) tool diameter and tool lengths. In some cases is linked directly to the host computer, so that the necessary data can be sent to the machine automatically, or through bar codes printed at the presetter.

The building of tools is currently a manual operation, although technically it is possible to automate.

5.2 TMS functions, interaction with other systems and users requirements

Before designing the TMS and tool database it is necessary to analyse, as suggested in [21], who is going to use the data, when and for what purpose. This involves the analysis of the functions of the TMS, how these interrelate the TMS with other systems in the manufacturing environment, and who are the users involved in the processes and what information they require.

The main functions of a TMS include:

- tool requirements planning
- process control
- tool preparation
- tool allocation strategies
- tool distribution
- fault detection
- tool data flow

- tool inventory control.

These functions can be considered as involving activities or operations at the physical implementation and control of the tooling system (as part of the FMS system), and at other systems of the manufacturing environment such as CAD, CAM, Business Planning. At the different levels the users can be systems or human beings.

5.2.1Business Planning - TMS

The business planning represents the highest level of control over the manufacturing system, and one of its functions is to plan and schedule the production system. This includes taking in consideration the actual production capacity available in the manufacturing system and the estimated required volume of production, to determine what is necessary in terms of manufacturing resources to satisfy its objectives.

The tooling system being necessary to support the production processes is affected by these plans and should be taken in consideration at this stage. Production planning will then be interrelated with the TMS, as it requires:

- information concerning current tool capacity
- information concerning tool requirements for components, in the same form as it needs information concerning tool materials requirements and provided in the B.O.M.,

and it will consequently determine the tool requirements planning (eg. purchase orders for new tools). This consists on the tool requirements function performed at the highest level.

These functions involve communication between computerized systems: one used for production planning functions (eg. MRPII) and the other the tooling system. Tool requirements may be included in the BOM. Tool availability should be

included in the capacity module, but this normally do not take in consideration the tooling system.

5.2.2CAD/CAM - TMS

CAD and CAM systems involve different but closely related functions, such as component design (CAD), and manufacturing operations control, NC part programming and process planning (CAM).

This relation is enhanced in FMS or highly automated systems, with the possibility of using the CAD component definition to generate NC part programs and process plans, and the direct link to the CNC controllers through Direct Numerical Control (DNC) systems. The interaction with the tooling system will then be analyzed basically with reference to component design, process planning and NC programming.

Component design, interacts with the tooling system as it will determine the tool requirements in the manufacturing of each component. The objective of linking CAD and TMS is to facilitate design for manufacture (or good design practice), by taking in consideration the tooling system and their capabilities.Ultimately the objective would be to have information at the design stage concerning the possibilities of machining each surface element, if new tools must be acquired, if permanent setups can be used, how the surface should be changed in order to be easily and economically machined.

Process planning, is an engineering function, whose main purpose in general, is to define what must be produced, how it will be manufactured and by what means [22]. This include a wide variety of tasks with direct relation to the tooling system,

such as:

- generation of production plans
- processing of BOM
- NC programming
- planning costs

NC programming, can be done using general NC programming languages (eg. APT) and the geometric component definition at the CAD system, to generate a cutter location file, which will then be post-processed to take in consideration the individual details of each machine and CNC (or NC) controller. This system will require geometric information and tool codes relative to each tool for use on NC programming, and also if possible, for collision simulation.

Generation of production plans involves the selection of machining sequences and respective production equipment planning, and hence must take into account tools also. The determination of operation times for cost and scheduling purposes requires information relative to tool cutting data and costs of tool materials.
As referred previously the BOM may also contain information concerning tool requirements, for planning purposes.

5.2.3 Flexible Manufacturing System - TMS

The tooling system in terms of its physical implementation and control of the activities and strategies that make the system operational and satisfying the required objectives, can be considered as a subsystem of the FMS system control.

We can distinguish two different types of activities within the tooling system: ones related with the execution of physical

activities (eg. tool preparation, tool monitoring, tool handling), and the others related with the control of that activities (eg. tool assembly orders, tool data preparation, purchase and stock control) and the definition of the necessary strategies to satisfy tool requirements at the FMS and machine level (eg. tool allocation, fault detection, tool distribution) and control of tool data flow.

In the first case the activities are performed at the equipment level of the essential elements of the tooling system: tool distribution system, tool storage, loading and unloading, tool preparation room and machines.

- At the tool room preparation, some of these operations can be automated, but are normally done manually, and involve using necessary equipment (eg. presetter). The tasks involve assembling of tools and presetting according to an assembling order, and the users should also be provided with information concerning the correct procedures to inspect and adjust tools, the assembling order tool parts and other necessary information (eg. torques or force in the positioning of indexable inserts)

Feedback information to the system is also necessary and should include notification of tool ready, and its conditions. Important information is the presetting measurements which can be directly sent to a host computer or CNC controller, being then associated with the identification number of the tool (bar code system or memory chips). The tendency is to use memory chips with increased memory capacity to store more information as referred in section (5.1.3).

These information can be sent to a host computer (or machine controller) if it is direct linked with the presetter controller, which can then be associated with the identification code of the tool (eg. using bar code or memory chip systems). Some

memory chips have enough capacity to store all the necessary information.

- At the machine level important activities are tool monitoring, tool condition support, spare tool control and maintenance control. This requires continuous control over the machining operation parameters, execution of necessary operations in case of alarm (eg. due to tool breakage, tool wear), and communication to the host computer of the current status. These are normally automated operations, being not necessary the human supervision.

- Tool loading/unloading, may involve manual or automatic handling systems (robots, or dedicated manipulators), and again operation order and specification must be provided to the users and respective feedback to update information in the tooling files system (eg. tool location and status).

- In the tool distribution system the activities involve manipulation and transport of the tools in pallets or magazines and are done automatically.

The second type are more complex and consist of the basic operations of a tool management system. They include the control of the tooling system at the FMS level and involve various types of tasks:
- defining the strategy to be adopted in case of tool breakage
- decide based on the part process plan, workpiece mix and production volumes, an allocation strategy to assign tools to machines
- receiving tool requirements for different machines, jobs or batches

- replenish tool stocks
- control tool distribution system.

To have control over these elements it is necessary to have control of the tool data flow as the information changes with the movement of tools in the system.

Tool allocation involving the consideration of many parameters, such as tool inventory control, tool magazine capacities and tool setup time, is a difficult problem, being some support decision systems proposed to help in this process (eg.[19]).

As we have seen in both type of activities at the FMS and tooling system operate as dynamic system involving control and update of data in real-time

5.3 Information held on the system

From the previous analysis a database for a general tool management system, in order to satisfy all users requirements and perform all its functions, should include different types of data, such as:

- geometric tool data
- tool description (elements of tool and its characteristics)
- engineering tool characteristics (eg. tool material, cutting data, range of application)
- availability (eg. location, status or conditions, quantity)
- costs
- suppliers

6 DESIGN

In this chapter the objective is to illustrate the entity modelling technique used to determine the entities and their characteristics or attributes as part of the conceptual model referred in the methodology chosen in section 4.1, and applied to a particular set of tools (turning tools) of a tooling system.

The development of a general tool database which can be applied without having to create and define new fields and records, not included at the design stage is constrained by the almost infinite variety of types of tools possible.

The design for a specific and well defined tooling system seems to be the more practical solution. And the approach taken in this particular case can be used as a guide for other systems.

The design of the system was based on the previous understanding of the tooling system as presented in chapter 5, in terms of its components, functions and user requirements.

In the first section it will be presented the entities considered and their characterization in terms of attributes. The second section illustrates the relationships between these entities in a entity/relationship diagram and a description of its characteristics, such as type and degree of the relationship.

6.1 Entities

The system in analysis is the set of turning tools as presented in the catalogue of a particular tool manufacturer (Sandvik-Coromant).

Considering the characteristics of the tooling system we can identify entities to characterize the data related with auxiliary equipment of the tooling system, entities which held information necessary to perform

the functions of the tool management system, and entities to characterize the tools itself.

6.1.1Entities related with tools

The entities direct related with tool must consider the description of the tool structure in terms of its different parts, and the two main characteristics of the tool data:

- data which changes as the tool is being used (dynamic) in real-time operations, such as tool accumulated life and tool location, and
- static or constant data, such as overall dimensions, and structure

A generic tool description method consisting of a four level structure to store the different information relative to tools is presented in [11]. One level holds information relative to each tool as a whole, and being used on the tooling system (dynamic data). Other level holds information relative to each tool which can be assembled on the tooling system and static information. The other two levels define the main parts of the tool as subassemblies (parts that must be handled together) and elements (information for inventory and stock control).

This description method was taken in consideration when selecting the following set of entities:

Tools, Existing Tools, General Tooltype, Boring Tooltype, Block Tooltype, Cartridge Tooltype, Brazed Tooltype, Bits/Toolholder Type, Inserts, Holders, Cutting Heads, Clamping Units. Which identify basically the tool static and dynamic data, the different types of turning tools, and the components of the tools.

ENTITY NAME: **Tools.**

Objective: defined to represent the static information (or data) about each tool that can be assembled with the elements existing in the tooling system. It is of particular interest for systems which need information about the geometric characteristics of the tool as a whole such as in the CAD/CAM system for tool selection during component design and NC programming.

Attributes: the characterization should then include,

- tool identifier
- alphanumeric name of the tool
- type of tool
- nominal tool length
- maximum working length
- maximum useful cutting depth of tool tip
- major cutting edge angle as measured on the assembled and adjusted tool

ENTITY NAME: **Existing Tools**

Objective:

The objective of defining this entity is to separate characteristics of tools which are changing as they are being used such as tool life, location, tool status, from the characteristics which are static or constant for a particular type of tool and which are defined in the previous entity (TOOLS).

Attributes:

Tool usage (wear) (numeric values)

Life expectancy (numeric values)

Tool length compensation (numeric values)

Tool diameter compensation (numeric values)

Tip radius correction (numeric values)

Correction X (numeric values).

Correction Y (numeric values)

Correction Z (numeric values)

ENTITY NAME: **General Tooltype**

Objective: characterize a particular type of turning tools, which basically can be described by the similar components which include tool holder, insert, shank, clamping insert parts. General external turning tools with indexable inserts, and threading, grooving and parting tools can be described by this main elements.

Attributes: the characterization of this tools should include,

- type of tool holder
- type of insert
- clamping insert parts

ENTITY NAME: **Boring Tooltype**

Objective: characterize three possible type of boring tools (solid bars, boring bars with adjustable and interchangeable cutting heads, and anti-vibration boring bars with exchangeable cutting heads.

Attributes: the characterization of this tools should include,

- type of tool holder
- type of insert
- cutting heads

ENTITY NAME: **Block Tooltype**

Objective: characterize a particular type of turning tools system which might include tool for different operations. The tools consist of a holding part and a cutting part which are interchangeable being possible to build tools for different operations by just changing the cutting part. It provides a quick and easier method of changing tools.

Attributes: the characterization of this tools should include,

- cutting units (internal or external)
- block tool
- insert
- spare parts
- adaptors

ENTITY NAME: **Cartridge Tooltype**

Objective: characterize a particular type of turning tools for built in.

Attributes: the characterization of these tools can be defined by an ISO code key , which basically defines

- clamping system
- insert shape
- cartridge style
- insert clearance angle
- hand of tool
- cutting edge height
- type of tool
- type of design
- tool length
- cutting edge

ENTITY NAME: **Brazed Tooltype**

Objective: characterize a particular type of turning tools, whose main characteristic is the use of brazed instead of indexable inserts in a rod, which are also define in ISO standards.

Attributes: the characterization of this tools should include,

- type of rod
- type of tips

ENTITY NAME: **Bits Toolholder Tooltype**

Objective: characterize a particular type of turning tools which

consist of a solid bar cutting unit (tool bits) and an appropriate toolholder.

Attributes: the characterization of this tools should include,

- type of tool holder
- type of tool bit

ENTITY NAME: **Inserts**

Objective: it is important to define "inserts" (tips or edges) as an entity because most of the modern tools, particularly in an FMS environment, uses inserts as a cutting element. So the information relative to these elements is vital both in the selection of the cutting parameters and in the selection of a particular type of "insert" to obtain the desired results from the machining operations. Either the edge or the tool holder are used to select the tool for an operation.

Attributes: its fully description is also defined in ISO codes.,

- insert identifier (eg. ISO code)
- manufacturer
- shape
- clearance angle
- tolerances
- size
- thickness
- radius
- cutting edge condition
- edges per insert
- feed direction

ENTITY NAME: **Holders**

Objective: characterize the holding part of tools which use toolholders and inserts, which also determines the type of machining operations and conditions. A ISO code includes the

important characteristics of this element.

Attributes: the characterization of this elements should include,

- holder identifier
- holder style
- insert clearance angle
- hand of tool
- shank height
- length

ENTITY NAME: **Cutting Heads**

Objective: characterize the type of cutting part of tools of the block tool system type.

Attributes: the characterization of this parts should include,

- type cutting part
- block tool size
- type of insert
- spare parts

ENTITY NAME: **Clamping Units**

Objective: characterize the type of clamping unit of the block tool system.

Attributes: the characterization of this parts should include,

- block tool size
- type of operation (manually, automatically operated)
- type of clamping unit

6.1.2 Entities related with auxiliary equipment

These entities are important to characterize part of the equipment of the tooling system other then the tools itself, and whose characteristics are associated with tools. We have consider Machines, Magazines as they are direct related to tool characteristics.

ENTITY NAME: **Machines**

Objective: it is important to identify MACHINES as an entity, as they will determine the type of tools that can be used in a particular machine, the storage and clamping mechanisms or devices to install the tool on the machine. Also the type, power, dynamic characteristics of the machine will constraint the conditions and cutting parameters of the machining operations (eg. speed, feed, metal removal rate, ...).

Attributes: its characterization should include type of tool change mechanism, type of operations, and description of its main characteristics,

-machine description

- tool change mechanism
- tool storage magazine
- machine power (numeric values)
- number of axis (numeric values)

ENTITY NAME: **Magazines**

Objective: these entity was defined because in a TMS, it is necessary to keep information or data relative to the type and number of tools possible in a tool magazine, and the machines which can directly use the tool magazines.

Attributes: its characterization should include,

- magazine description
- maximum number of tools
- type of tools

6.1.3 Entities related with functions of the TMS

These entities are important to identify data required by the systems that interact with the TMS in operations such as tool selection, time of operation, tool costs of the machining

process, tool inventory control. Some of the entities that can be selected are suppliers, cutting parameters, servicing operations.

ENTITY NAME: **Suppliers**

Objective: to represent and characterize all the information relative to manufacturers or suppliers of each component or element of the tooling system (auxiliary equipment, edges or tips, spares, holders, ...).

Attributes: its characterization might include,

- supplier name
- address

ENTITY NAME: **Servicing operations**

Objective: is to identify and characterize the instructions and information required when servicing, inspecting and assembling tools.

Attributes: its characterization include

- type of assembling operations
- inspection rules
- sequence of operations

ENTITY NAME: **Cutting parameters**

Objective: these entity is required to include all the information necessary to define the conditions and cutting parameters for each tool in particular machining operations.

Attributes: the characterization of this entity is associated with each tool and should include

material (eg. non-alloy carbon steel, high-alloy steel,...)

material condition (eg. annealed, hardened and tempered, hardened,...)

hardness (eg. HB-Brinell values: 125, 150, 200,..)

insert

cutting force

toughness (numeric value or scale)

6.2 Relationships

Relationships between some of the entities defined in the previous section are represented in the following entity /diagram relationship. Entities are represented in soft boxes, the type of the relationship is indicated on the line, and its degree represented by the type of line connection to the boxes as indicated on the key.

Most of the relations indicated are many to many type, which can be described if chosen MAGAZINES and TOOLS, as one magazine can store different tools, and one particular tool can be stored in more than one particular magazine.

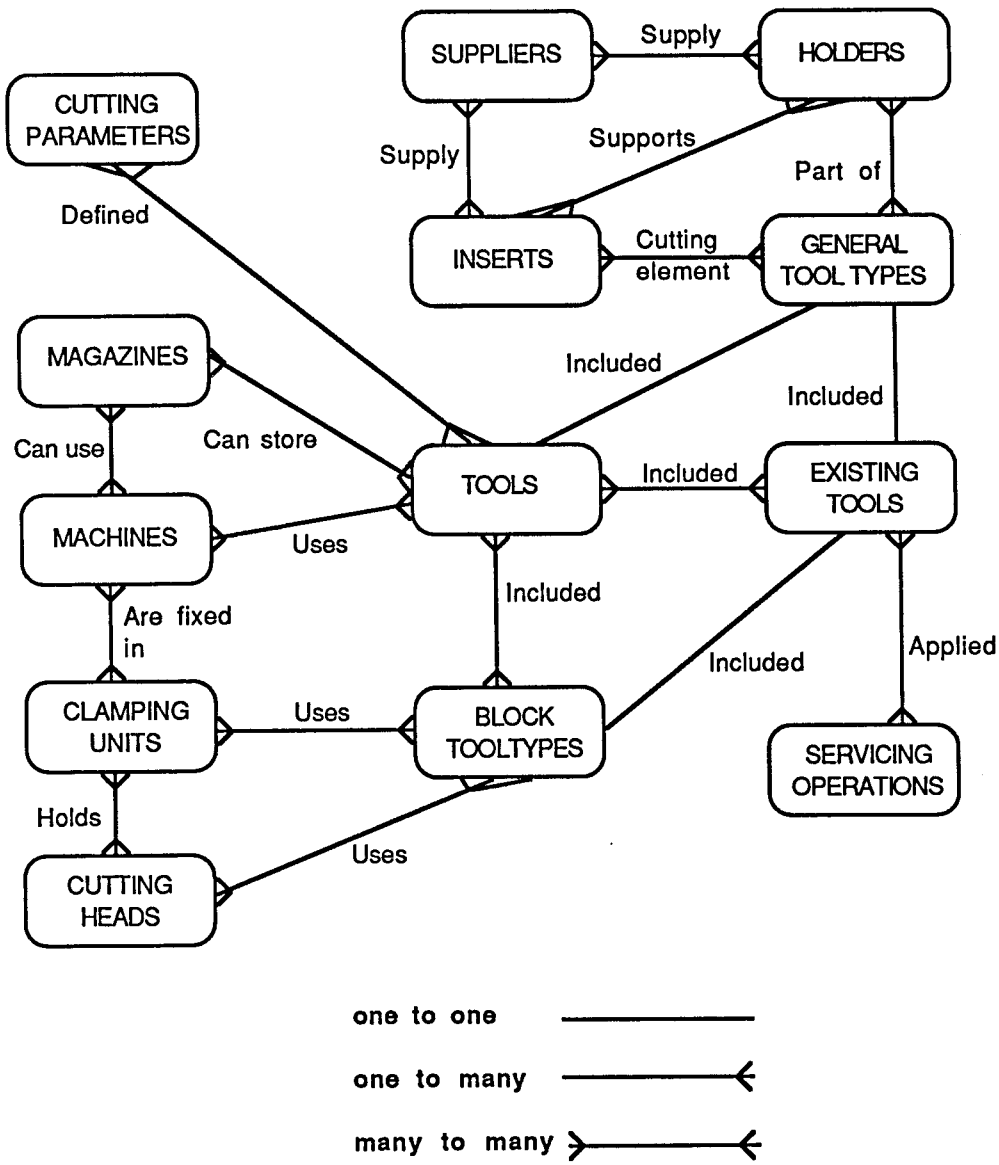

Fig.11 Entity/Relationship diagram

7 CONCLUSION

At the end of the project the work done can be considered as having achieved its objectives of understanding and analyzing related aspects of a tool management system and its main issues in terms of:
- its functions and interaction with other systems,
- and information it should provide to its main users

In terms of the design of a general tool management system, able of performing all its functions and capable of supporting all types of tools and its elements of the tooling system in any possible Flexible Manufacturing System, it was concluded that the implementation of such a system is limited by the almost infinite diversity of tools, and the technology which supports the integration of different systems and functions in the manufacturing environment. It can then be concluded that the project has failed to meet that objective. However the report presents a methodology which can be used in the analysis and implementation of each system, with some of its stages illustrated with a particular set of tools.

What needs to be done next in this project is the development of the stages of the proposed methodology which are concerned with the implementation of the conceptual model in a database model and its physical implementation. This must take in consideration the characteristics of the particular system used. Also the specification and design of programs that can access the data defined on the tool database for the different functions involved in tool management (eg. tool allocation strategies, tool selection)

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