Design of A Shop Floor Information System

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Abstract: This paper examines the influence of Telematics on the shop floor environment of a modern factory. It proposes a shop floor information system with terminals at every work centre able to provide real-time communication inside the factory. After an analysis of workshop procedures, an overview of the proposed information system is taken. Its external connections and the main elements of the related software architecture are described. The design guidelines of the user interface are then discussed, together with the proposed presentation system in the framework of a relational database.

1. Introduction

Manufacturing industry is heading towards a higher degree of computerisation. The reasons for this are well- known and include above all the increasing availability of telecommunication and information technology (Telematics), together with the real improvements in efficiency it can offer.

For some companies the aim is total automation [11]. However, it is widely accepted that total automation is not and should not be the goal of all companies. (EC Esprit project 1217 (1199) entitled "Human Centred Computer Integrated Manufacturing (CIM) Systems", a joint venture between the UK, Germany and Denmark, is based on the premise that CIM is more efficient, more economical, more robust and more flexible if a person is in charge in contrast to a completely unmanned system). In other words, true CIM does not have to mean full automation; high levels of efficiency can be reached with a manually supported shop floor. In fact it seems that 'manual CIM' is more practical and applicable to more companies than 'fully automated CIM'. For these 'manual' companies the crucial CIM elements are the links between the shop floor and their computer based information systems. The fact that companies achieve greatest efficiency when these links are real-time is widely reported [3], [8],[13]. For this reason, the priority is to "informate" rather than to "automate".

2. The Proposed System

The proposed shop floor information system provides:

- A single point for accessing and entering information.
- Real-time communication to factory production control systems.

The proposal is to have an information terminal at every work centre (machine), the same way as it is increasingly common to have a personal computer on every desk in an office.

The information system is aimed at the manufacturing companies which have already been using (or are planning to use) computer based systems such as MRP (Manufacturing Resources Planning) and CAD (Computer Aided Design), but which at present lack an efficient method of making these systems communicate with their predominantly manual shop floor. This may be because:

- They are using printed schedules in combination with printed route cards and printed drawings to accompany the batch of parts.
- They are using some direct computer communication, such as Direct Numerical Control (DNC) and Shop Floor Data Collection, but have a different information terminal for each type of information.

The prerequisite for the proposed information system is that all work centres and all sources of information are connected by a suitable Local- Area Network (LAN).

No computer based system should be introduced without consideration of the environment in which it will operate. In this paper, a human-machine interface is proposed, which will radically change the working practice of each machine operator.

All information to dictate 'when?' and 'how?' to do a job will come from the terminal. It is necessary to consider the human implications of such a system. The corollary is that the system enables new and more efficient working practices to be adopted.

Information and communication is provided directly between the machine operators and the production control staff; there is no need for supervisors to act as 'link men'.

The most important characteristics of the proposed information system are:

- A terminal at each work centre provides all required information.
- Information is filtered (to keep the system simple) rather than restricted.
- A user-friendly interface is used.
- Shop floor working practices are adopted in conjunction with the information system. So the way the system is used will be similar for all companies.

3. Workshop Procedures

The computer-based factory information systems are powerful tools that aid the manufacturing process; they are not in themselves the key to an efficient factory. This means that no system should be introduced without consideration of both the factory working practices and the human interface.

It is suggested that a company is only truly successful if it creates a dynamic working atmosphere in which the full potential of each employee can be realised. Team building is a particular priority in manufacturing industry where, traditionally, a management hierarchy has operated, with the contribution of those at the bottom being frequently undervalued. The first stage in achieving this aim is to reduce the number of management levels. The immediate result is greater responsibility for those 'at the bottom' and improved communication.

An important role of middle and junior management is in conveying information. Consider for example a machine operator who on finding a defective part contacts the supervisor to decide what should be done. The reason why the supervisor is contacted is not because he or she is any better at deciding on what should be done to rectify the defect, but because the supervisor is both aware of the broader picture of job priorities and must be kept informed that a defect has occurred. In other words the provision of an information system to transmit information to the factory floor as well as means of feedback must happen in tandem with the reduction in levels of management.

By entrusting machine operators (and assembly fitters, etc.) with information and responsibility traditionally in the domain of supervisory staff, there will be a greater interest in and hence commitment to the work. The Japanese, for example [2], found that in striving for reducing batch sizes (a prerequisite of 'Just In Time' manufacturing) defects or faults presented themselves much quicker, and an operator would return a defective part to a previous operation for rectification. The result was groups of workers ('Quality Circles') getting together of their own free will to sort out repetitive problems.

In the same way, entrusting responsibility means that decision can be made by those in the best position to make them, resulting in an improved flow of work through the factory. Information is provided to assist in decision-making and to feedback what decisions have been taken. This means that the level of 'responsibility' is that which enables work to proceed without unnecessary delays in seeking for management approval, and the 'information' is that which is required to perform the manufacturing operations.

The different types of information required to manufacture a component are:

- **Schedule**. This defines when a job must be performed.
- **Clocking on and off**. This tells the scheduling system (and the Accounts Department) that an operation is being or has been performed.
- **Route Card**. This lists all the operations necessary to manufacture the component.
- **Part program**. This controls the CNC machine which makes the component.
- **Instructions**. These advise the machine operator on how to set-up the machine and the material in order to manufacture the component.
- **Drawing**. This shows the finished component together with tolerances, surface treatments, etc.
- **Machine tooling file**. This shows which tools are in the machine tool magazine.

- **Video/sound/photographs**. These media are becoming increasingly important in both teaching how an operation is to be performed, and recording how an operation has been performed.

4. Overview of the Information System

4.1 General Introduction

Each information terminal at every work centre of the shop floor is linked to the company's information system and provides a single point of reference for all information required to perform an operation. Moreover, as each work centre has its own terminal the information presented at the terminal can be dedicated to it. This is an important point, because the terminal has the ability to swamp a machine operator with irrelevant information, but if it does so the system will become time-consuming to use and so it will not be used. It must also be noted that as customising the information to the user there is also a need for customising it to the factory.

The essence of the system is for the information terminal at each work centre to search the schedule database for jobs scheduled to be manufactured at the work centre (and which are available or soon to be available) and then search the information databases for the information required to perform these jobs. Accessing (and feeding back) information involves starting application programs; for example starting the DNC software for transferring part program files or starting the Shop Floor Data Collection system to advise when a job is being worked on.

There are therefore three elements of the information system, namely:

- The user interface.
- The links to the company information databases.
- The links to the company application programs.

4.2 External Connections and Internal Software

In a generic company network from the viewpoint of the shop floor information system, each terminal has connections to both the CNC machine controller (for DNC part program transactions and access to the tooling library) and the main company network (for access to company information systems).

To physically connect the terminal to the network, as well as to the machine controller, hardware adaptors are required. For a typical network these are:

- RS232 adaptor to plug the terminal into the machine controller.
- Network adaptor to make the physical connection to the network.
- Audio and video adaptors for sound, still video and video information.

In addition software interfaces are required.

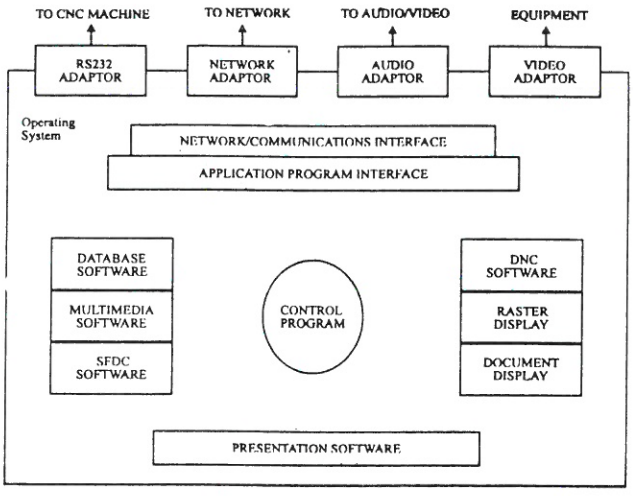

Figure 1. The Software and Hardware Components of the Shop Floor Information Terminal

These are:

- Networking software to handle the communications with the main network.
- Communications software to communicate with a particular machine controller.
- Communications software to perform translation tasks between different operating systems and protocols.
- Application program interfaces to enable the company application software (such as DNC and Shop Floor Data Collection) to be controlled via the presentation system used at the information terminal.

The generic hardware and software links to the company systems are shown in Figure 1. The Figure also shows the internal software required for each terminal which is:

- Presentation software to provide an easy-to- use and appealing operator interface.
- Database software to enable remote databases (storing company information files and index directories for those files) to be accessed as well as to enable local database files to be created.
- Application software for DNC, Shop Floor Data Collection, displaying raster format part drawings, displaying text files (set-up instructions) and displaying and recording video and audio information.
- Control software which links the presentation software with the databases and the application programs, and also controls the logic of the presentation system.

4.3 Control Software Structure

As the intention is to access and present existing information rather than to create new information sources, the system must be individually designed to suit each company. In order to do it efficiently a modular design of the software is required in which the presentation and control logic remains standard but subroutines for calling databases and applications are customised.

In operation, schedule information specific to each terminal is read into a local schedule directory and the available information for each part specified in the schedule is then read into a local information directory. These two local directories are together presented to the user on the screen as a menu. The operator selects a job number in the schedule window for which he requires information. This associates different types of information presented in the information window (in icon form) with the part number related to that job number. Selecting an information type brings up the next presentation window. At the same time this calls the application program for that information type and associates the specific part program number, drawing number, etc. belonging to that part.

A simplified control logic is illustrated in Figure 2. This Figure also shows which parts of the program are standard and which parts must be tailored to the individual company; thus it demonstrates the modular nature of the software.

4.4 Implementing the Information System

The proposal is to select a standard user interface with a standard control structure, but customise the system to suit company specific data and application programs. The stages in implementing the system are therefore:

- To study the overall information requirements of the company.
- To study existing company information systems to establish communication requirements.
- To discuss future information requirements and planned future information systems which will have to be interfaced.
- To write the required application program interfaces and communication protocol translators.
- To customise the shop floor information system to suit company requirements.

5. The User Interface

5.1 General Interface Design Guidelines

In order to keep the user interface as simple and quick as possible it is proposed to avoid the use of a keyboard. This gives three options for providing signals to the computer, namely:

- A mouse
- A joy-stick
- A touch screen

All of these are practical alternatives, although the mouse could have problems with the ingress of dirt in the shop floor environment.

It is suggested that the most intuitively appealing option be the touch screen in which an object on the screen is directly touched in order to perform an action on it. There are two considerations:

- Touching the screen with a greasy finger will soon make it dirty and difficult to see through.
- To select an area of the screen a signal is required, i.e. 'single clicking' to select an object and 'double clicking' to open a window.

For these reasons the best option is to have a touch screen with a pointer. The pointer has a button (similar to the mouse button) and so it can be used to both select and 'click on' an object.

There has been a lot of research on the best way to design a computer user interface [7]. For this purpose [5] there are two underlying design principles:

- Users should be able to develop a 'conceptual model' of the interface. In simple terms this means to provide the users with the outcome they are expecting for.
- Users should be in control of the dialogue. Sequential operations do not support this principle because there is only one way of performing the actions and after each action the user must wait for the computer prompt. To control the dialogue users should be able to perform any action in any sequence they desire.

On developing a conceptual model the following guidelines should be observed:

- Use metaphors. For example icons of files and folders are clear metaphors in the office environment for storing document information.
- Make the model mirror current manual procedures of the user. In this way it is possible to build on a user's existing knowledge.
- Always be consistent. In software terms, the appearance and position of pull- down menus, buttons, etc., must be consistent and the results of performing an action must always be the same.

The normal sequence for dialogue is OBJECT-ACTION. This means that the user selects an object and then performs an action on it. For example, in word-processing a word is highlighted and then deleted. This 'object-oriented' approach is what we feel most comfortable with.

In designing a user interface for the shop floor information system it makes a lot of sense to use a standard presentation package. Such a package allows a programmer to make customised windows, pull-down menus, dialogue boxes, etc.; there is no need to create these elements, only to combine them in the desired manner.

The special considerations of the shop floor information system are:

1) It is designed for people who, mainly, are not computer users.

2) It must be quick and simple to use or it will not be used at all.

3) It is desirable to avoid the use of keyboard, partly because of the two reasons above, and partly because of the shop floor environment.

It is suggested that the presentation system which best meets all the combined requirements (conceptual model, object-oriented, simple to use) is a system with a window based Graphics User Interface (GUI). Such systems have been proved very popular, particularly with 'non-computer users' in the office environment. In such a system, extensive use is made of the mouse to select objects and directly perform actions on them. For example, dragging the icon of a folder onto the icon of a floppy disc copies all the documents in the folder onto the disc, or dragging a document to a waste-bin deletes the document.

The same approach can be used on the shop floor, but here the icon metaphors must be those that reflect the 'factory world'. In the office there is only one traditional medium that the icons must mimic, namely paper in the form of typed documents, drawings and spreadsheets. In the factory there is a number of different media:

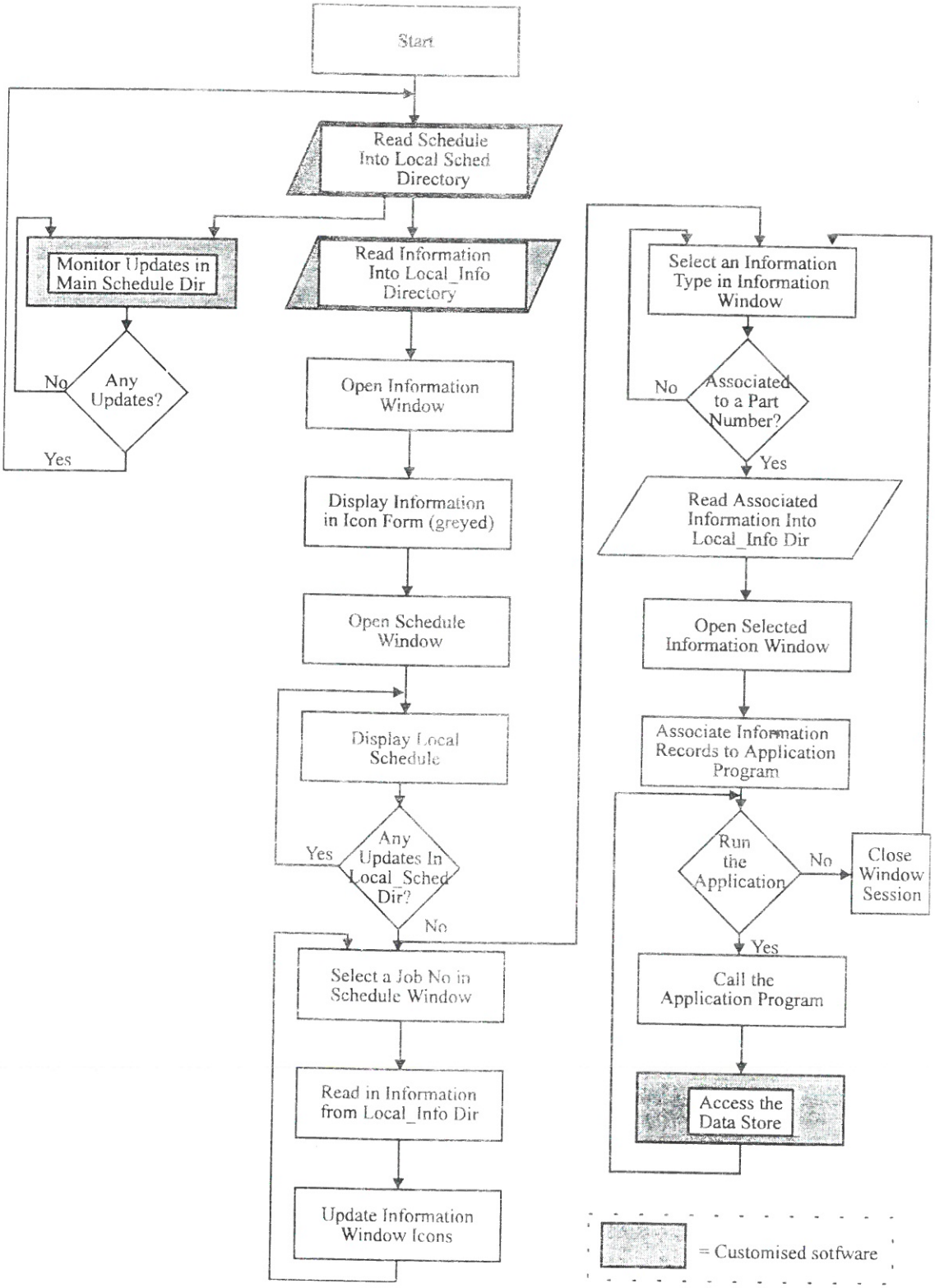

Figure 2. The Control Logic of the Shop Floor Information System

- Material, i.e. raw- material, semi-finished parts, and finished parts.
- Paper, i.e. drawings, instructions, schedules, route cards.
- Machine readable cards, either magnetic cards, bar codes, or punched cards.

- Tools used in the production process.
- Multimedia, i.e. video, audio and still-video.

Each medium requires its own metaphor icon to mimic the traditional objects known to the machine operators who will use the system.

5.2 Description of the Proposed Presentation System

Under the proposed window based presentation system the first screen contains two windows sized to appear side by side (see Figure 3). These are entitled 'Information' and 'Schedule'. In fact the schedule window is called up by double clicking on the 'Schedule' icon in the information window, and to make this clear, this icon appears grey (unavailable) on the screen. The two windows appear together on one screen because they are jointly used to call up the required information. (Windows re-appear in the same form (position and size) as they were left when the window was last closed, and child-windows, left open when the parent window was closed, re-appear open).

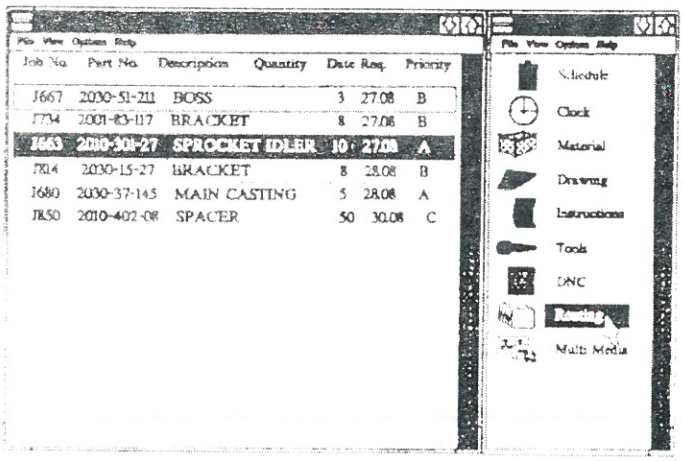

Figure 3. The Menu Screen Containing the Schedule Window and the Information Icon Window

It is the intention to keep the system as simple as possible by only giving access to information relevant to the parts to be manufactured. The parts to be manufactured are listed in the schedule and the types of information required to manufacture those parts are listed in the information window. Clicking on a job number in the schedule causes that job be highlighted (as shown for the third job on the list). At the same time it causes that part number (note that a 'job' is the particular instance of manufacturing a 'part') be associated with the information. All types of information may not be available for every part and so the first visual clue to this association is that some information icons will appear black (available) whilst others may appear grey (unavailable). (Under a multitasking operating system this happens as soon as the job number is selected. Under a single tasking operating system icons will not be updated until the information window is made active by clicking on it).

When no jobs are selected all the icons will appear grey but for DNC and tooling which are the only information types not associated with part numbers. The information types are accessed by double clicking on the relevant icon in the information window. This brings up the next selected window. The available windows are:

Information window

This window contains a list of the information types in icon form. This is the menu window. Single clicking on an icon highlights it, double clicking selects it and causes the relevant information window be opened.

Schedule window

In this window there is displayed a list of jobs relevant to the work centre:

- Jobs currently being worked on at a previous work centre.
- Jobs finished at a previous work centre but not yet transported to the current work centre.These jobs are ready but not yet 'available'.
- Jobs available but not yet started. 'Available' means physically located at the work centre.
- Jobs in progress. These are jobs that are currently executed.
- Jobs completed at the work centre but not yet transported to the next work centre. It is the responsibility of the operator to ensure that finished parts are transported to their next destination (as shown on the route card). This is a reminder to the operator that this task has not been done yet.

Material window

The function of this window is to give a visual display of the physical location of each job

and to allow the location to be updated by the operator. This window contains five icons. These are for the previous, current, and next work centre, and for the 'rework bin' and 'scrap bin'. Double clicking on each machine icon reveals child windows, which show the number of parts at each location in icon form.

In a paper-based factory every part is accompanied by a route card, which gives the list of operations to be performed, and a drawing to show the locations of holes to be drilled, etc. Often there is also a clock card to inform the Shop Floor Data Collection System when the part is worked on, and a punched paper tape (or diskette) containing the machine part program, together with set-up instructions. As this information must stay with parts, a batch must be completed before being passed on to the next operation.

In the proposed system, information is simultaneously available to the previous, current, and next work centre. All that physically accompanies the parts is a label giving the job number. It is therefore possible to split the batch. This flexibility has the potential of increasing the flow of work through the factory or of allowing an urgent part to be manufactured quickly.

Routing window

This window displays the route card on a scrollable screen. The route card gives details of every operation in the manufacturing of the part.

Drawing window

This window displays the part drawing. The relevant application program will include functionality to allow the drawing to be enlarged and reduced and to 'zoom in' on different areas of the drawing.

Clock window

Most factories have a means of collecting machine readable shop floor data (i.e. bar codes, punched cards, or magnetic cards) in order to record when an operation is performed and how long it takes. This window presents the equivalent of the classic 'clocking-on' procedure in an icon form.

The window contains an icon of a clocking machine and icons of clock cards. The number of clock cards will be dependent on company policy. As an example, it might be desirable to record machine set-up and process times separately. In addition it is desirable to have a visual display showing the number of parts which have been processed.

DNC window

Direct Numerical Control is a software (and hardware) which allows CNC part programs to be transferred from the computer where the programs are prepared to the CNC machine controller (DNC download), or from the CNC machine controller to the computer used for the preparation (DNC upload). The two main advantages of the system are:

- It eliminates the need for diskettes, tapes, etc.
- Program transfer can be performed whilst the machine is performing another task. Thus, transfer can take place at any time.

This window presents DNC transfer in an iconised form, which dispenses with both the need for knowing the program number for the DNC download (normally different from the part number as more than one program may be needed for each part), and the need for typing at a keyboard.

Instruction window

Every CNC program must be accompanied by the appropriate set-up instructions. These instructions contain essential information, such as the tools which are required, the positions to place the tools, and the way that the part should be set-up on a fixture. Whilst the CNC part program can be transferred automatically via DNC, these instructions are usually given on paper. Set-up instructions are displayed in a scrollable window.

Tooling window

This is a scrollable window giving a directory of the available tools. In a multitasking operating system this could be displayed simultaneously with the instructions window to make a comparison between existing tools and required tools.

Multimedia window

The purpose of this window is to enable multimedia information (sound, photographs, video) to be displayed and recorded by providing the entry point to a multimedia application program. For simplicity all the media are accessed from one screen.

6. Company Databases

A prerequisite of the information system is that each item of stored information (CAD drawing, CNC program, photographs, etc.) is cross-referenced to a part number. In general, each information type will have two directories; one containing the actual information in the form of computer files and the other indexes of all these files. Each index will contain two fields; one field for the part number and the next for the CNC program number, or the drawing number, or the photograph number, etc. The best way to support such a structure is with the use of a Relational Database Management System (RDBMS).

When an operator starts up his information terminal all schedule records which are related to the work centre are read from the main schedule file (containing records for all the work centres in the plant) into a local schedule directory. The local schedule directory is updated each time a relevant record in the main file is changed. The provision of a local directory minimises network traffic and maximises response time.

It should be noted that the database query statements must be tailored to the individual company's information system. Database query statements (for example written in SQL) can be embedded into a control program (for example written in C, Pascal, etc.); these statements must be altered to suit the individual company.

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