Planning A General-Purpose CIM System

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1. Introduction

The main objective of this paper is to establish a planning structure for the design, purchase / manufacture and modular implementation of a general-purpose Computer Integrated Manufacturing (CIM) system. The resulting CIM system will be able not only to cover effectively specific needs of a company, but also to serve educational purposes, and as a vehicle for research.

In the course of this work, a number of key areas are addressed, such as:

- Formulation of a general definition of Computer Integrated Manufacturing in order to establish the constituents of the general-purpose CIM system.
- Investigation into each of the identified constituent technologies, hence enabling both their implementation and integration to be planned.
- Preparation of an outline design model for the general-purpose CIM system.
- Investigation into Project Planning and Management techniques, in order to recommend a suitable planning structure for the general-purpose CIM system.

The start point of the paper is research into the exact meaning of Computer Integrated Manufacturing and its physical format, in order to provide an outline specification of the general-purpose CIM system. Then the background of Project Management and Project Planning is investigated, in order to allow a planning structure to be devised and recommendations for the management of the project and completed system to be made. After that, analysis of each constituent area of the proposed CIM system is made, in order to produce a planning structure for the general-purpose CIM system. Finally, recommendations are included about the overall strategy to be adopted from specifications to operation.

2. General Definition of CIM

After analysing various definitions of CIM [8][9][15] [14][17], a CIM system can be viewed as a strategy in which:

- Functional systems within a company are clearly identified and defined.
- Systems are computerised to some degree where benefit will be accrued using 'enabling' technologies.
- The systems are integrated via a common communications medium which provides the benefits of company wide data availability and distribution.

- More effective management of engineering and administrative data is facilitated. Providing opportunities for increased efficiency, flexibility, quality and cost reduction thus enabling a company to gain commercial advantage over its competitors.

CIM facilitates the effective control and implementation of change, essential for the optimum operation of a company in the commercial environment of the 1990's.

3. Project Management

A project is an endeavour towards achieving specified end results within time, cost and organisational constraints. The characteristics of projects are that they are usually unique, involve many disciplines, have life cycles with identifiable start and finish points and a number of phases or stages. The character of a project changes at each phase, with the finish point of one phase becoming the start point for the next and a major review of the project as a whole at each phase end point.

The project planning element of project management enables the objectives to be achieved as efficiently as possible by:

- Developing a 'model' of the project prior to the start of work.
- Identifying key events or milestones.
- Facilitating consideration and selection of alternatives.
- Preparing task descriptions.
- Scheduling tasks and activities.
- Identifying resource requirements.
- Allowing 'cheap' mistakes to be made at the planning stage rather than 'expensive' mistakes at the implementation stage.
- Providing a basis for comparing actual achievement with desired results.

A simple 'generic' project planning procedure consists of the following steps:

- Define objectives.
- Establish start and completion criteria.
- Determine and list tasks to be performed.
- Determine the logical sequence for all tasks taking into account all technical constraints.
- Sketch the sequence as a network and number the activities / events.
- Identify discrete project phases.
- Determine task duration and resource requirements.
- Calculate the earliest and latest start and finish times for all tasks and the complete project.
- Determine the critical path for each phase and identify float for all other activities.
- Reappraise the above steps in order to smooth the plan or aid critical path.
- Produce milestone charts, bar charts, overview networks, detail networks and task sheets to enable project management and implementation.

For the project planning process various tools and techniques such as Critical Path Analysis Techniques, Critical Path Method (CPM), and Program Evaluation and Review Technique (PERT), can be employed.

4. The General-Purpose CIM System

4.1. Introduction

From the establishment of a general-purpose CIM system a company expects the following benefits:

- Effective coverage of some specific needs of the company.
- Provision of teaching support to the employees of the company, and to the employees of other branches of the company, who will use CIM systems in the future.

- Provision of a vehicle for research, especially applicable to a Manufacturing system or a Robotics research group.
- Establishment of a system would positively encourage funding from the headquarters of the company.
- Provision of the opportunity to demonstrate the system to other companies on a consultative basis. Industrialists would be given the opportunity to examine a working system with possibly wide range of configurations, aiding them in assessing the benefit of new technologies to their companies.

4.2. General -Purpose CIM System Planning Strategy

In general, successful adoption of CIM requires a top-down planning approach. The executive management of the manufacturing organisation should be deeply involved in the first key stages of defining both the project objectives and the scope of the work to be performed. Their involvement is essential as they have an overview of the requirements of different individuals, groups, and problems solved.

The implementation of a general-purpose CIM system can differ from company to company. More specifically, CIM can be purchased in virtually 'off the shelf' form if the capital investment is available. For those with more limited resources a system can easily be built up gradually using one supplier whose entire product range is fully compatible and designed for integration. However, in most existing companies the task involves applying new technology to existing plant and systems; linking the islands of automation. These are the results of the computerisation of company sub-systems such as design and manufacturing.

In such a case CIM is a long term strategy and a plan for several years, not a project to be completed in months. There is much to be said for this step by step approach to CIM, providing it takes place and supports the overall business plan or strategy [17]. Introduction of CIM must be done in a piecemeal fashion by means of modular components of the total solution that must be capable of further evolution to suit changing requirements [4].

Thus, by adopting a modular approach the company would be able to expand the system gradually as funding or resources become available. By setting up a number of discrete sub-projects (that deal with the implementation of sub-systems of the general-purpose CIM system) that are capable of 'stand alone' operation, the following advantages would be accrued:

- Provision of 'working' systems at an early stage by concentrating on one area within the system at a time instead of 'nibbling' at all problems at once.
- Discrete working systems will satisfy the company's needs much better than a total system that is only partially finished and not operational.
- Bugs on one sub-system can be rectified before starting the next sub-system, thus making successful integration between the two easier.
- Modular implementation facilitates the review of progress and enables the revision of specification to accommodate new technology and opportunities.
- By establishing operational sub-systems sooner, the educational and research benefits of the system will be experienced at an earlier stage.
- Motivation of those involved in the project would be increased by tangible results at an earlier stage.

Some crucial decisions about the general-purpose CIM system are:

- What functions must it encompass?
- Should it be dedicated to a family of products or is the utopia of total flexibility required?
- What business systems does the company wish to incorporate into the system?

These decisions must come from the executive management, possibly after the analysis of feasibility studies and consideration of benefits and resource constraints.

In most industrial situations the operations of the company are usually modelled, using one of a number of structured modelling techniques, in order to represent the operations that occur in a complex manufacturing system.

Three types of models can be distinguished: The 'as-is', 'should-be' and 'to-be' [2]. 'As-is' describes the company's current situation, 'to-be' models describe the system modified by simplification and rationalisation processes (in many cases the expense of CIM is not required in order to provide substantial benefits). The 'should-be' models are then developed to identify functional requirements of CIM introduction to meet the company's objectives. Finally, the 'to-be' models are developed to show the manufacturing system following the implementation of CIM.

In general, the use of modelling techniques to model the desired system, highlighting all interaction and control mechanisms, is essential. The costs of correcting errors in CIM grow approximately logarithmically the later in the development life cycle they are detected.

Some of the formal methodologies available for developing a system specification are [6]:

- IDEF (Integrated computer-aided manufacturing DEFinition) methodology.
- SSADM (Structured Systems Analysis and Design Methodology).
- GRAI (Groupe de Recherche en Automatisation Integrée) approach.
- Checkland method.
- SADT (Structured Analysis and Design Technique).
- Data flow diagram.

Of all these IDEF and SADT are most commonly utilised by system designers [14]. IDEF 0, whilst initially for some a difficult concept to grasp, is both a powerful and simple method for breaking down a system, project or enterprise into its constituent sub-systems. It is the choice of the modeller as to what degree of detail he breaks the system down to (how many layers are examined).

Following modelling of both the system and the project, detailed design of hardware and software can begin, involving analysis of different options available. This stage is important as CIM is a 'state-of-the-art' technology and new technology is being made available constantly. The detailed design of the system should be matched to the model of the system.

Initially the most important factor will be that of standardisation. In order to facilitate modular implementation of sub-systems and their integration, common communications and computing links along with compatible production hardware must be designed into each sub-system at the onset. This will allow the system to be integrated as it is built and not as a final exercise of linking computerised sub-systems that have only limited compatibility.

In parallel with the detailed design of the system the detailed planning of its implementation can begin. Once again with the key objective of allowing integrated functionality of each sub-system at the earliest possible time within the resource constraints imposed. It is suggested that only the logic of planning networks should be finalised at this stage until detailed design is completed and the physical constraints of the final design configuration can be assessed.

The planning structure detailed above is summarised in Figure 1.

4.3. Physical Elements of a General-Purpose CIM System

To constitute a general-purpose CIM system the proposed minimum performance requirements are the following:

- Design components / sub-assemblies using Computer Aided Design (CAD).
- Produce part programs for machine-tools using Computer Aided Manufacturing (CAM).
- Transfer part programs to Direct Numerical Control (DNC).
- Use the DNC to send part programs to machine-tools.
- Manufacture parts.
- Assemble parts.
- Inspect parts/assembly.

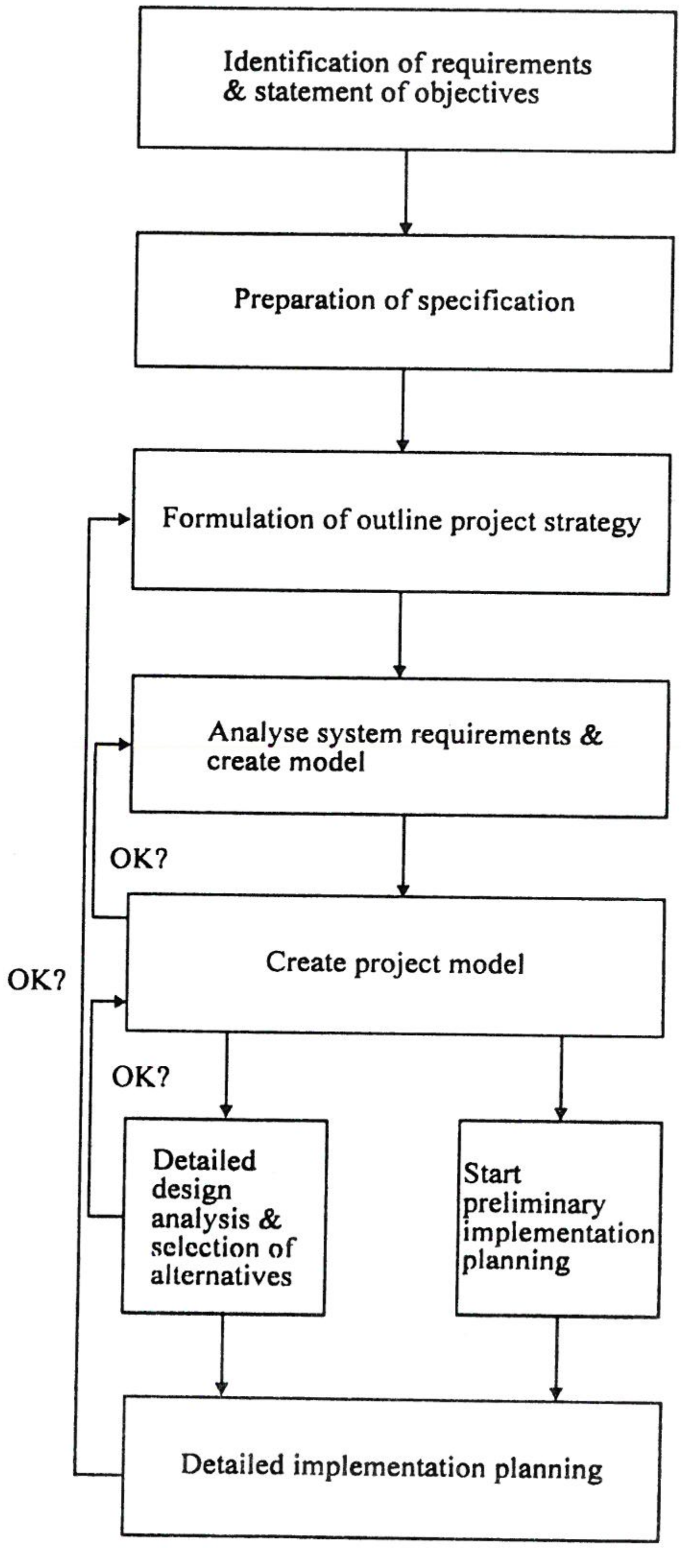

Figure 1. General-Purpose CIM System Planning Strategy

A general-purpose CIM system should also include an automated storage and retrieval facility, production planning / scheduling control and should make available shopfloor data for analysis by other business functions.

In proposing the physical elements of the general-purpose CIM system, the following main areas should be addressed:

1) Flexible Manufacturing System (FMS)

An FMS is a computer controlled configuration of semi-independent workstations and a material handling system designed to efficiently manufacture more than one part number at low to medium volumes [2].

The three essential physical components of an FMS are:

- NC or CNC machine-tools or work cells.
- Conveyance network to move parts and tools between machines, cells and fixturing / tool setting stations.
- Control system that co-ordinates machine-tools, cells, parts moving elements and workpieces.

An outline design model incorporating features of the general-purpose CIM system can be seen in Figure 2. Its constituent elements are discussed briefly below.

Machining Cell

The machining cell is that part of the FMS that performs all milling, turning, boring, etc. The main objectives of machining centres are the following [5]:

- Flexibility: Stand alone or FMS.
- Unmanned machining features.
- Mechanical / Control interfaces for easy upgrade and integration.

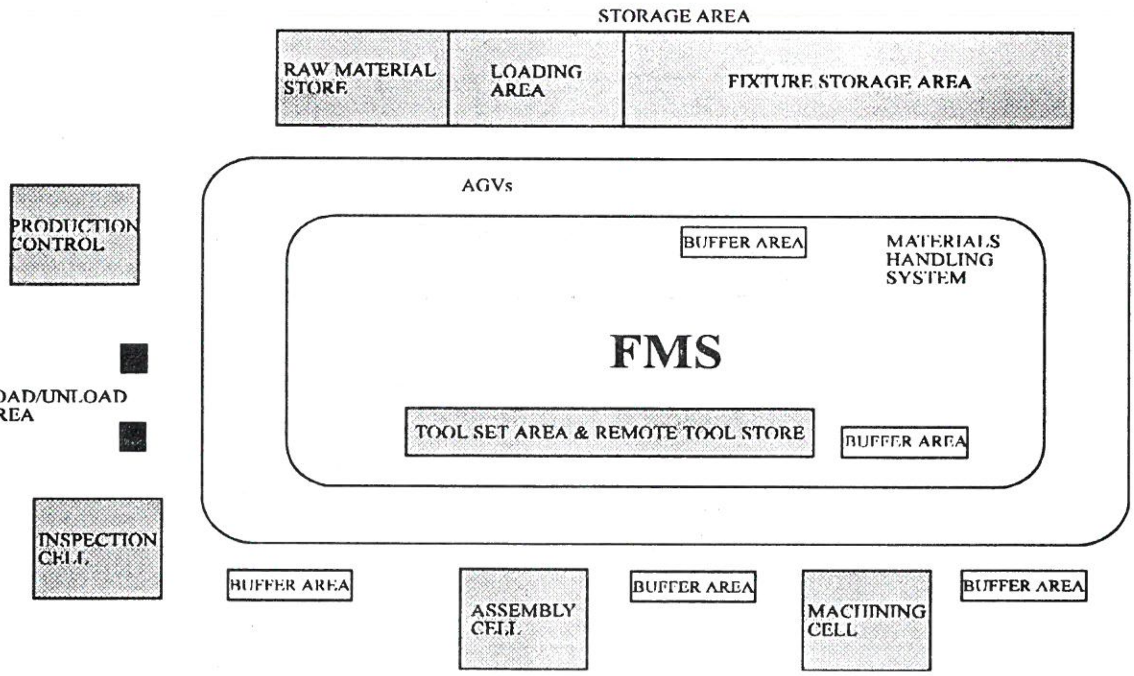

Figure 2. Outline Model of an FMS System

- Standard pallet interface for rail cars or Automated Guided Vehicles (AGVs).
- Tool management.
- High performance and specification.

The basic set up is of a machine-tool that is linked to a material handling system and incorporates its own computer controller, tool store and tool management system.

Assembly Cell

The assembly cell is concerned with performing automated assembly operations. An assembly process is made up of handling, composing and checking operations, plus special processes.

A suitable configuration for the general- purpose CIM system would be a simple one robot design, capable of picking components from a number of pallets and assembling them on another pallet. Integrating a tool store carrying a number of gripper configurations would increase the flexibility of the cell. A cell controller would control operations liaising with the materials handling system that would provide / remove parts and fixtures.

Inspection Cell

This inspection cell element of the FMS could be responsible for dimensional checking of components and sub-assemblies as verification of the material properties of raw -material coming into the FMS environment.

The latter purpose could be achieved using eddy current or ultrasonic non-destructive test techniques in an automated system. However perhaps of more relevance is the dimensional inspection function. This can be achieved automatically in three ways. Co-ordinate measuring machines (CMM) use a probe configuration to gauge the dimensions of components and assemblies.

The second option is the use of computer vision which can be approached in three ways [1]:

- An interactive approach where the user selects and shows the required feature to be examined, for example a dimensional measurement between two specified points.
- A teaching approach which assumes that the system has previous knowledge of the features to be inspected. Full information on the inspection procedure must be incorporated into the system, for example dimensions of drilled holes and their relative positions.
- A fully automated approach. Here the system has no prior information about the object or its position and should be capable of determining the nature of the object and the most appropriate inspection procedure to employ.

The third option involves the use of laser tracking technology. A system can use multiple robots, each with touch sensitive probes, laser tracking facilities and off- line programming, to check for dimensional integrity of an object compared with some sort of pre-defined data (e.g. from CAD), thus allowing 100% inspection.

The inspection cell would be fed by the materials handling system with its controller linking it to the other parts of the FMS.

Automated Storage and Retrieval

The storage area for raw -materials would take the form of a bin system. The fixture, component and sub-assembly storage would have a pallet stack arrangement. The pallet is the basis for work-holding / fixturing all raw -materials, components and sub-assemblies, and for their movement around the FMS. Its standardised design must be acceptable to every element of the FMS that it encounters.

The pallet stacking system delivers required pallets onto some form of transporter. The three principal pallet movements categories are carts, roller conveyers and robots [10]. Guidance and control of carts can take many distinct forms. Carts can move along tracks, activated and externally controlled by a central computer. Sensors (optical, proximity or limit switch) located at appropriate points along the track identify the cart's precise location. Positioning of carts to the required tolerance, typically 1.5 mm to transfer pallets to a machine or unload station, can also be used via sensors. Battery powered carts or AGVs are guided by an antenna that detects an underfloor wire, laser techniques or computer vision systems.

A third cart design uses a tow chain in a trough under the floor. The chain moves continuously and cart movement is controlled by extending a drive pin from the cart down into the chain.

A system recommended for the general- purpose CIM system would be a rail system with carts and pallets being identified by barcodes or in-built chips, thus providing a mechanism for control of materials handling.

Tooling Management

The tooling management element is one of the most essential aspects of effective FMS. A tooling management strategy contains the following elements [7]:

- A Machine Control Unit (MCU) that provides for tool breakage detection. tool wear detection and compensation, redundant tooling and adaptive control.
- A tool identification system that is machine readable, normally a barcode designation or embedded computer chip.
- A tool preset area with tool assembly components, an automatic tool pre-setter and a tool identification reader.
- Computer control software for tooling management under the FMS operating system.

Supervisory Computers

In this model a system host computer would supervise the entire FMS operation. Each cell has its own controller that is linked to the system host which is also linked to the programmable controllers for the AGV system, tool setter, fixture store and materials storage area. The system host minicomputer provides both on-line control of the system and off-line capacity planning. The off-line planning function allows trial orders to be put into the system and the results to be looked at in terms of machine utilisation, necessary fixtures and tooling requirements.

On-line control from the system host monitors the status of each machine and issues transport orders to the AGV control system. From this point the operation of the AGV system is delegated to the AGV central process controller which monitors all transport orders on a priority basis, and identifies vacant vehicles, buffer stations and stores. It also optimises all travel routes. Other on-line functions of the host include updating the tool master file, recording components manufactured, recording production status of workpieces and position pallets in the system, downloading NC programs, organising work in the FMS, issuing instructions to the load/ unload stations and organising the storage areas.

As the host computer downloads tasks to individual cells for execution, the tasks are queued within the cell controller and maintained as a mini schedule. Its progress is reported to the host computer and to cells / functions 'upstream' that supply materials and 'downstream' that receive the cell's output. The cell controller is responsible for ensuring everything is at hand to perform the task, the task being performed and finally for collecting information on its execution.

2) Computer- Aided Design (CAD)

The design office is one of the first areas of the manufacturing organisation to receive the benefits of computerisation. CAD systems give the designer an array of powerful tools. Instant call up of drawings, 2D and 3D drafting and modelling facilities and a large number of other features have revolutionised this field.

3) Computer -Aided Manufacturing (CAM)

The use of computers in manufacturing planning and CNC programming has developed apace with CAD. CAD drawings are used as the basis for providing 2D and 3D toolpath geometries. NC programs are such prepared that they can be downloaded to the appropriate work centre or cell. Recently CAM has been made available on low cost PCs with some packages operating in the Windows 3.1 environment. Data can be transferred from the CAD to CAM via a suitable file transfer system.

4) Business Systems

Systems encompassed in general by this area are:

- Company level production planning and management (MPS, MRP, MRP II, OPT, etc.).
- Resource scheduling and control.
- Inventory control.
- Purchase order control.
- Financial Management.

5) Communications Media

Data interchange is the key concept in the pursuit of CIM and in order for information transfer to take place a common mechanism must be established between the communicating parties. A common physical link such as RS 232 cable or Ethernet and a common set of protocols, such as MAP (Manufacturing Automation Protocols), TOP (Technical and Office Protocol) or TCP/IP (Transmission Control Protocol / Internet Protocol), are required.

The simplest solution to the communication problem in a general-purpose CIM system would be to use computers supplied by one supplier which would lead to the provision of a proprietary communications system which is cost- effective and well- established. However, in this case, this scenario is not particularly feasible as it is highly likely that most of the manufacturing systems will come from different sources. It is important that the communication system should conform to a common standard that supports most or all existing systems and does not restrict choices in expansion. Evidence indicates that using a Local-Area Network (LAN) would provide flexibility and expansion capability by providing a communications backbone to the manufacturing area and allowing connections to other systems via other LANs.

In general the requirements for communications in an integrated manufacturing environment are [16]:

- Standard protocols enabling communication with diverse computers and digital devices.
- Reliability and timely responses.
- Potential growth in size and capacity.
- Flexibility.
- Ability to cover the geographical layout of all manufacturing systems and be reconfigur- able.
- Robustness to withstand the shopfloor environment.

At the physical level, the selection of cable is a very important consideration. Some cables while suitable for office use, perform badly in environments where electromagnetic interference (EMI) is a significant factor. For this reason, it is proposed the use of a broadband cable type , which, although relatively expensive, provides all voice data and video transmission facilities for a system.

6) Supervisory Computer System and Database

Automation in CIM is achieved at discrete levels. The lowest level encompasses the drives, motors and limit switches of production plant. Level two includes those microcomputers, programmable large controllers and computerised numerical controllers that enable machines to run without support of controllers at other levels of the hierarchy.

At level three PCs or minicomputers act as production cell host computers organising stand - alone machines in a cell. Level four is the workshop host or in the case of a general - purpose CIM system the FMS host computer. At level five minicomputers and mainframes serve to automate the production system including material requirements planning, CAD, CAM and CAP.

This configuration provides a distributed processing system as opposed to traditional hierarchical architectures (known as time sharing systems). Improving the speed and efficiency of data interchange and processing.

In order that up-to-date information can be accessed by all areas of the company with ease a database system is required. Use of a distributed database system to make available throughout the organisation the information in each of the discrete databases, is preferable than centralising the data storage, a strategy which divorces data from their point of origin and update.

A relational database is recommended to be used as it would be relatively easy to design and modify its data structure. The simple table form and the high level database query language SQL make it possible to issue a single command in order to retrieve records stored in different tables.

5. Conclusions and Recommendations

The planning structure for the general-purpose CIM system should primarily enable modular implementation of the system 'components'. This strategy provides optimum use of the elements of the CIM environment whilst others are being resourced, planned or installed.

Having adopted this approach, the general-purpose CIM system, should be designed so that integration is made as simple as possible. Detailed design and installation of the network communications media must be the first stage, this provides the rest of the system with a framework in which to fit. Adoption of standard communications protocols should also be a prerequisite in order to allow simple interconnection of all nodes in the system.

The FMS is probably the most difficult area of the CIM model to implement due to the number of sub-systems operating within it. Nevertheless manufacturing is the key function and FMS the 'sharp-end', a computer integrated manufacturing system is meaningless if no manufacture is performed, therefore FMS should be treated as a key element.

The use of Project Management software will be of considerable value in co-ordinating the project and motivating the participants. However it must be stressed that such a software package is a tool only and cannot correct poor initial planning. Therefore it is recommended that the objectives and a specification are published at the inception of the project. Well-defined specification, coupled with organisational support, is also required.

If individual projects are to be linked in order to achieve a number of linked objectives contributing to one larger project, a flexible assembly system, and a co-ordinator / project manager will be required.

The main conclusions are summarised below:

- Modular implementation of the general-purpose CIM system is required to gain maximum use from available technology at any particular time.
- Such a project requires detailed initial planning in order to correctly specify tasks. The best way of achieving this is by modelling the proposed system.
- Project management software provides a powerful tool for project management. However such software packages require a familiarisation period, a factor that should be taken into account.
- Improved 'local' co-ordination and management of 'grouped' projects are required to gain satisfactory results.

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