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REALISING THE MAXIMUM BENEFITS OF AUTOMATION/INFORMATION TECHNOLOGY "Part 1 - New-Age Technologies"

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ABSTRACT

Automation/Information Technology is responsible for engendering a more productive and competitive enterprise, by creating a highly flexible operation that quickly responds to changing market demands. Without state-of-the-art technologies, companies will not only fall behind competitors around the world but may even find their mere survival severely threatened. Over the past decade, regional organisations like many industrial companies in developing countries, have not been able to acquire/adopt "new-age" technologies feasibly, due to the problems of high cost, ease of access and upgrades and re-skilling of the labour force to effectively manage and operate such technology. However, technology itself has evolved to the point where these barriers are no longer obstacles they once were, including to small operations and its benefits are available to all.

Part 1 of this paper traces the development of manufacturing and the application of technologies to automate disparate fragments of its process. However, to optimise the benefits, these diverse technologies must be integrated which is essential to informating the organisation. This paper illustrates some of the technological changes that should be harnessed by organisations within the region in order to facilitate more viable approaches to providing a flexible and cost-effective integrated solution. Part 2 of this paper investigates comparatively emerging methodologies and approaches that can improve the feasibility of "new- age" technologies.

1.0 INTRODUCTION

The adoption of appropriate modern automation technologies and their optimised deployment have allowed some manufacturing/process industries to realise tangible and intangible benefits, normally perceived as being impossible to achieve. Contributing to this, is the development of improved software and the availability of low cost computer hardware, which allowed hard and soft automation to be combined in ways that provide powerful and complex discrete/continuous manufacturing systems. Some of the paybacks that have been realised include :

- Increased production, throughput, yield and utilisation of raw materials.;
- Decreased inventories, maintenance cost and energy consumption;
- Consistent product quality; and
- Informed decision-making.

However a number of leading American manufacturing/process industries have not been successful in realising these benefits. In addition, they have found themselves saddled with dedicated manufacturing systems with over capacity, under-utilised capital, and the prospect of obsolescence and thus major reinvestment for future model changes. Our close affiliation with North America, has influenced

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our decision-making process, and as a result, our engineers, are experiencing much frustration in convincing the rest of management about the adoption/adaptation of such technology.

Automation technology is evolving from the single vendor proprietary "black box" product to an *"approach"* that facilitates the implementation of standard, open, modular and flexible systems, comprising of components sourced from a myriad of vendors. This will allow process industries to move away from the traditional costly approach involving the adoption of a closed, limited and proprietary system. Instead, it facilitates a phased implementation of automation providing a more affordable and cost effective approach. The challenge presented is to ensure that what is currently purchased can be integrated with existing systems and those planned for future installations.

2.0 THE EVOLUTION OF MANUFACTURING

During its first era, *manufacturing* began as a monolithic function and was the province of a master craftsman, such as, a gunsmith, shoemaker or a cabinet maker. The master craftsman *conceived* his product, *procured* his materials, *made* his tools and *fashioned* his product. Specialisation of labour was introduced when extra workers were deployed by the master craftsman to perform routine labour functions. As market sizes increased, the marketing of mass-produced products was contracted out to merchants. During the latter part of the 19th century, product development was placed in a separate unit with its own staff which was subsequently followed by a further subdivision into research and development during the early 1900's.

As the volume of production grew, plants grew and the number of echelons in the managerial hierarchy also grew and multiplant companies evolved. The result of the last two centuries of evolution and expansion in manufacturing is a structure of great complexity. This structure was fractionated with each division seeking its own goals and objectives, protecting its own turf and thus optimising its own performance. The final result was a suboptimisation of the whole. A number of communication barriers engendered between units at every level, both horizontally and vertically.

Today manufacturing can be viewed not as a single continuum, but as an aggregation of non-cooperative fractions. The human element within each of these compartments differ in terms of training education and even cultural backgrounds. Basically these changes ensued as the original one-man craftsman structure was subdivided. As the scope of the enterprise grew, skills were specialised and divided and hence authorities were specialised and divided.

2.1 The Second Era of Manufacturing

During the course of the 20th century, manual labour was gradually replaced by machines with the introduction of power into the manufacturing process. As a result, manufacturing evolved into a process utilising costly machines and their engines. Today, manufacturing is viewed as a **capital intensive** process. During the 80's, the data processing mode entered the manufacturing process. This mode can be characterised as the representation of every entity within the structure as data, which can be generated, transformed and transmitted. In the ultimate analysis, all of manufacturing may be seen as a continuum of data processing. It provides the one base to which all parts of the process may be related, the one thread which ties all the parts together.

The concept of the continuum of data processing has become apparent concurrently with the evolution of powerful data processing mechanisms as tremendous strides have been made in the past two decades in *Information Technology (IT)*. This emphasis on data has caused the reintegration of manufacturing. Following the fractionation and compartmentation of manufacturing which occurred during the capital intensive mode, the new *data intensive mode* is going to witness this reintegration striving to make manufacturing a ***monolithic indivisible continuum.***

3.0 AUTOMATION TECHNOLOGY AND ADVANCE MANUFACTURING TECHNOLOGY (AMT)

A number of state-of-the-art technologies have evolved to automate the different fragments of the manufacturing process. This set of technologies collectively known as Advance Manufacturing Technology (AMT), are microprocessor-based technological innovations in some cases and have the potential to revolutionise manufacturing. Some of these technologies include Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Computer Aided Engineering (CAE), Manufacturing Resource Planning (MRP), Group Technology (GT) and Computer Integrated Manufacturing (CIM). Although these technologies originated in discrete manufacturing, they have been applied in continuous process industries in addition to Distributed Control Systems (DCS), Supervisory Control and Data Acquisition (SCADA) and Advance Control Strategies (ACS), which collectively are commonly referred to as Automation Technology (AT).

CAM is the most hardware-intensive of the advanced technologies and has the most direct contact with the fabrication and assembly of products. It is flexible due to its ability to be *reprogrammed* to perform a variety of operations, and hence increases performance and reliability and operates at a lower cost than the direct labour it replaces. In discrete industries, CAM involves the utilisation of robotics, CNCs, NC, dynamically controlled machines and Flexible Manufacturing Systems (FMS). In continuous manufacturing, a number of process industries, over the past fifteen (15) years, have implemented CAM or its equivalent using Distributed Control Systems (DCSs), which, typically, automate regulatory control and sequential control logic. Sitting above this level of control, is cell control (discrete manufacturing) and supervisory control (continuous process control) which are responsible for implementing Advance Control Strategies (ACSs). They present the data gathered from the lower level of control graphically to operators in real-time for alarming, may archive data and provide a variety of tools for recalling and analysing it, and download new parameters to control systems in conjunction with the ACS and changes to the product being produced. The differences between cell control and supervisory control are matters of emphasis [TOMP92]. Cell control systems usually interface primarily to PLCs, while supervisory process control systems are frequently linked to DCSs. The former tends to focus on operator interface functions because PLCs lack this capability and the latter on archiving and analysis, since they provided excellent first-line operator interfaces.

Supervisory Control and Data Acquisition (SCADA) is another type of system frequently found at this level of automation. It consists of a host computer using an appropriate communication medium and protocol to poll a number of microprocessor-based devices (sometimes called RTUs) located remotely, for status information. On analysis of this information, the host computer may send back commands to be used in control actions. SCADA is popularly used in utilities to monitor and control distribution, such as, power, water and gas. As illustrated in **Figure 1**, it is possible to have a hybrid of cell control/ supervisory control network that can span a production facility with "mixed mode" manufacturing styles. For example, a brewery with a DCS controlling the brewhouse and PLCs running a packaging line will use supervisory control in the brewhouse, and cell control for the packaging line. Both can feed a single operator interface, which can be a PC or a MAC depending on the user's preference. With today's technology, it is also possible to extend this to the production manager, so that he may view current process data gathered from multiple control systems, from different vendors in the context of a familiar desktop analytical tool, for example a spreadsheet.

CAD increases productivity of design of engineers by performing: drafting; sorting and searching through plans; and labeling and develops instructions for use by CNC machines. CAE allows engineers to test their designs with out building expensive prototypes. Both CAD and CAE allow customised products to be easily designed, thus reducing development time and cost and increasing flexibility.

MRP supersedes Materials Requirements Planning (MRP I) and is more a philosophy than a technology. It comprises of the modules: Master Production Schedule, Bill of Materials, Shop Floor Control and MRP(I). MRP(II) generates, among other things, production schedule and information about the necessary raw material orders, based on the data pertaining to the products that need to be completed, their specified time frames and the raw materials, manufacturing processes and labour required to produce them. MRP(II) is now part of *Supply Chain Management*, which models the working of the enterprise on a global basis [SCHE94]. It determines

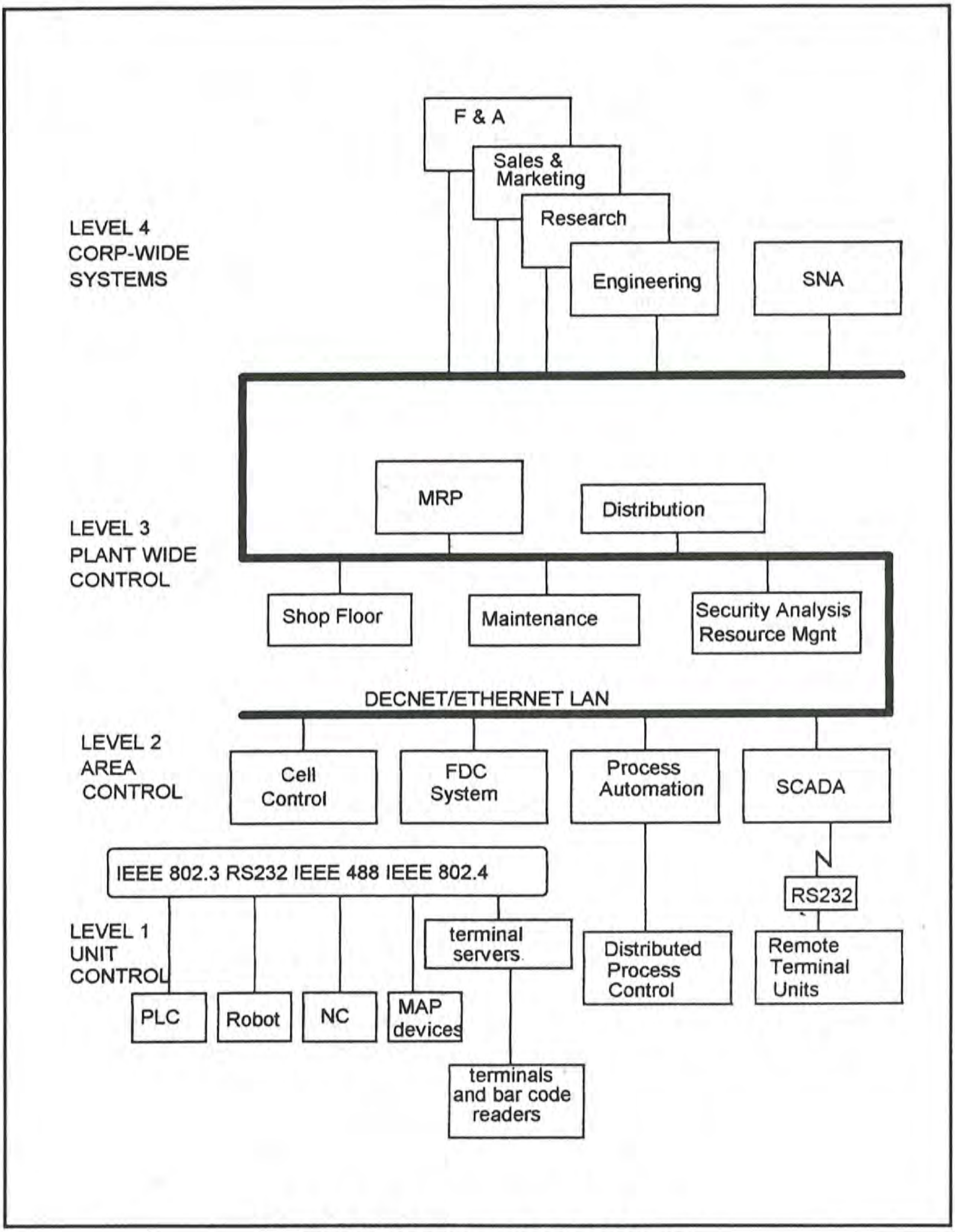

Figure 1: A Hybrid Cell/Supervisor Control Network

the products to be made, at which plants, in what quantities and how they are to be shipped to which distribution centres. It consists of the following modules presented in hierarchical order: Global Planning and Optimisation (GPO), Distribution Resource Planning (DRP), Master Production Scheduler (MPS), MRP, and Execution Level Scheduling (ELS). Both GPO and DPR operate at the corporate level and are responsible for producing global production plans and information on production requirements respectively on both a short-term and a long-term basis. The others operate at the plant level with ELS eventually generating a detailed list of what to make, on which equipment, in what sequence and quantities and a detailed production schedule on an hour-by-hour shift.

In discrete manufacturing, GT operates on a system whereby parts are grouped together into families, thus taking advantage of their similarities in design and / or manufacturing. It can be used to organise the factory floor into ***"Manufacturing Cells"*** each of which concentrates on a particular type of part family. This eliminates much of the moving and queue time that characterises the traditional factory and thus reduces throughput time dramatically. Both GT and Supply Chain Management are considered to be more of a philosophy than a technology.

3.1 Computer Integrated Manufacturing (CIM)

Computer Integrated Manufacturing (CIM) represents the integration of all the elements of AMT. Although there exists a number of definitions based on different perspectives, a term-by-term examination of CIM in reverse order reveals that it applies to ***manufacturing,*** depends on ***integration*** and uses a ***computer*** to accomplish this [WHIT88]. The term *manufacturing* is used broadly and can be described using a two-dimensional matrix, in which the vertical dimension includes product, process and schedule design, and the horizontal dimension includes production, assembly, material-handling, packaging, purchasing, quality, production and inventory control, maintenance and distribution. This reflects current views of CIM which have been extended to include the whole process business in contrast to past views in which it encompassed only the manufacturing process.

Defined broadly, *integration* includes the interface and coordination of functions, the linkage of physical components, and the information hand-offs that occur both vertically and horizontally throughout the entire organisation. It is more than just the integration of two or more workstations or departments. When implemented to its fullest, CIM will incorporate the entire manufacturing enterprise including multiple production plants, suppliers and customers and is expected to increase the performance of the organisation considerably. The term *computer* is also defined broadly to include not only the integration of hardware components but the integration of information subsystems. The technology of CIM, therefore, spans the whole breadth of information technologies, from digital instrumentation to high level executive information systems.

The production structure resulting from the implementation of CIM facilitates the coordinated interlinking of energy flow, material flow and information flow. CIM has also been described as a "philosophy", "a way of life" and a "journey", not a destination. It is not a product or cannot be bought as a "turnkey" system, although, many of its elements can be purchased. CIM is born of the recognition that while any automated device may provide advantages for manufacturing and/or design, truly substantial benefits will be realised only when these devices and systems are integrated and synchronised into a coherent system to achieve a single goal.

4.0 ACHIEVING AN INTEGRATED PLANT WIDE SOLUTION

Striving to make manufacturing a monolithic indivisible continuum, requires plant wide integration in order to allow the organisation to apply comprehensive operating strategies and access the information required to effectively manage the business. However, [JAIK86] and [BLOC88] reveal that US industries in comparison to their Japanese competitors have purchased sophisticated hardware to replace existing tools rather than integrating into a new system or providing a new approach. With the expanding complexity of the manufacturing process, there is a need to look at the process as an integrated system and optimise it as a total process, from product design to marketing instead of suboptimising on a tool-by-tool or machine-by-machine basis.

A typical example is the purchase of the DCS by Chemical Process Industries to solely automate the same functions performed by the pneumatic systems they replace, such as, regulatory, sequential and batch monitoring and control. An analysis of past implementations reveal that although 75% of the cost of control is incurred in the installation of the Distributed Control System (DCS), its gains are small at this level ranging from 3-5%. The additional cost of Advanced Control Strategies (ACSs), such as, multivariable and closed loop optimisation usually considered some time after, are relatively small approximating to 25% of the cost, but realises the majority of the benefits of automation. This approach is encouraged as ACSs are usually implemented on a Process Computer System (PCS) and linked to the DCS via a gateway to obtain the relevant data, thus allowing its requirements to be detailed after the design and configuration of the DCS. This results in the basic regulatory control and sequential control not being tightly integrated with advance control.

This level of integration is becoming mandatory as today's markets are forcing plants to become smaller (less capital expenditure), more tightly integrated, more heat-intensive and more flexible in order to expeditiously handle changes to feedstocks and final products. Single loop control (pressure, temperature, level etc.) with at most cascades and the like have dominated for some time. However, they look after themselves and ignore all that is around them and the consequences of their actions. As a result, operating targets have to be conservative running in what is called the *"comfort zone"*. This represents a cost which limits product variability and translates through to quality, price, throughput and energy and materials utilisation. According to [REEV93], regulatory control runs the plant but advance process control makes the profit. The latter allows processes to run at or close to their constraints, thus, maximising the utilisation of their capital investment. They are, however, a lot harder to operate and as illustrated in Figure 2, most users' sites are at the DCS level running in the comfort zone away from any constraints.

To facilitate a more integrated approach to control, the processing capability of new generation DCSs has been increased to provide spare capacity for the implementation of advance control. A number of advantages are presented with this approach, including the elimination of the problems associated with dual window operator interface, consistency of databases residing on the DCS and the PCS, and vulnerability [ARON90]. However, a number of issues relating to

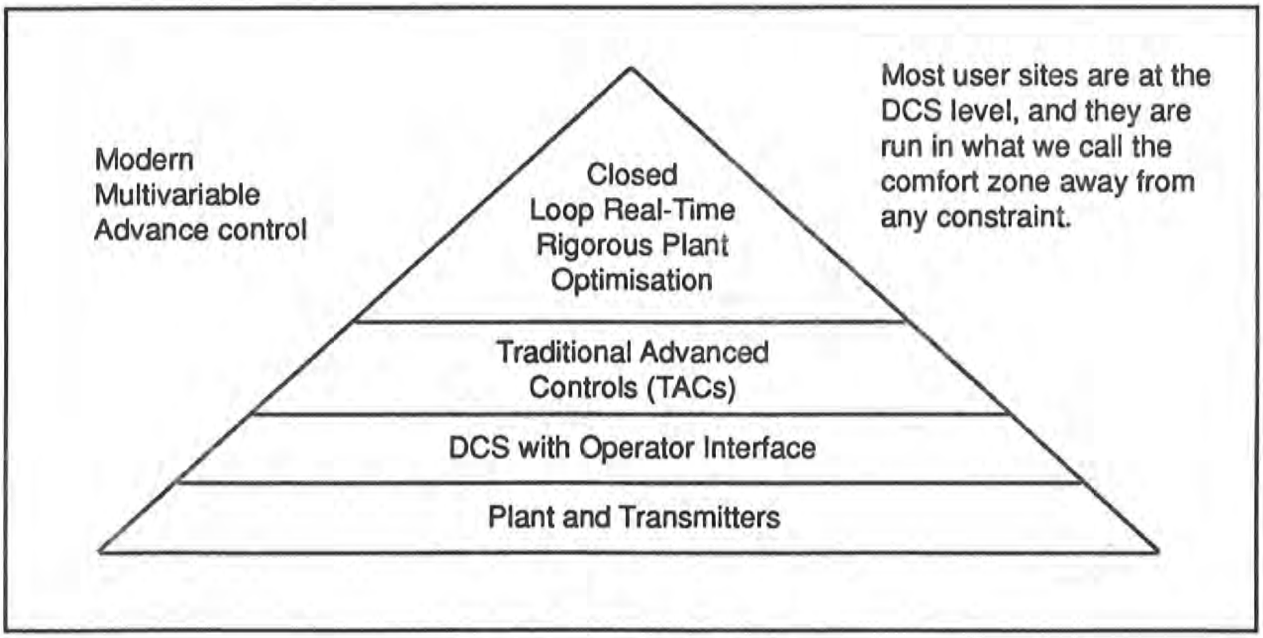

Figure 2: The "Comfort Zone"

advance control must be considered including the capabilities and implementation cost for advance control, as they vary considerable from vendor to vendor, and the flexibility of its implementation in terms of taking advantage of the evolving technology for DCSs to provide better and more enhanced features. It is therefore mandatory that advance control be considered very early in order to allow the appropriate strategies to be detailed during the conceptual design of the DCS. This together with the significant amount of engineering effort required for database design, and construction, controller configuration, algorithm and graphics construction associated with new generation DCS, are often not anticipated, resulting in inadequate engineering resources provided for this effort.

Apart from advanced control, other high level applications for trending, historical analysis and reporting were also implemented traditionally on separate supervisory computers, due to the functional limitations and proprietary nature of industrial Distributed Control Systems. However, with the move from closed, limited and proprietary DCS to highly efficient, cost-effective, more functional and open systems capable of more than just control, integrating information from all parts of the plant in real time to facilitate enterprise wide data sharing from the board room to the shop floor is becoming a reality. *Automation Technology*, such as, DCS, SCADA, Cell/Supervisory Control, CNC, etc., now forms an integral part of the IT solution for the organisation. As a result, traditional approaches which involved its procurement separate and distinct from the rest of the IT subsystems are today inappropriate.

Achieving the desired level of integration, however, was problematic and depended on the approach taken. In the past, information was locally managed and confined within the departmental boundaries resulting from the piecemeal automation that occurred within the organisation creating the proverbial "Islands" of "Information". In most organisations, it was perceived that integration could be achieved through the purchase of off-the-shelf hardware and software, which was also perpetrated by vendors. These Islands of Information, however, were not designed for integration with each other as linkages were not considered at the time of their creation. Initially, the I in CIM was an attempt to bridge the gap between Process control functions (e.g., DCS) and managerial sales and scheduling systems. However, as CIM evolved into a philosophy that applied to the complete enterprise, it could not be bought but must be achieved using applied Information Technology. In addition, a system design methodology must be deployed that will address the complete horizontal and vertical integration of field measurement and control products, process management systems and plant computing networks.

4.1 Interfacing vs. Integration

In their eagerness to solve pertinent and timely business problems, many organisations attempted to integrate these "islands" of "information", by interconnecting systems which resided on separate computers on separate networks from different vendors running on different operating systems and written in different languages using gateways and software packages. The resulting architecture is illustrated in Figures 3(a) as opposed to the architecture illustrated in Figure 3 (b) which represents an integrated solution. [FREE89] illustrates the difference between an "Integration" and "Interfacing" (Interconnecting). An Integrated system continually supplies data elements from the originating source to all executing systems requiring real time control (time required for action) data with assured correctness. There is no confusion as to whether executing programmes or users are using most current data. "Interconnected" systems differ in design in that they are not real time and are usually batch transfers from one system to another. Each Island or system stores it own data and creates files that are transferred to other using Islands. The data can be "out-of-sync" with current data and can lead to erroneous decisions. Correcting data in different files, in order to ensure to its consistency, became a timely and formidable task consuming too much human resources. In addition, original software had to be developed or existing packages heavily customised to meet the specific interfacing needs of the organisation. This translated into high cost, very long time to implementation and benefits that could not be realised soon enough, resulting in the Return on Investment being lower than expected. Although the capital cost was lower for the non-integrated approach, the support cost was higher and was proportional to the number of non-integrated links.

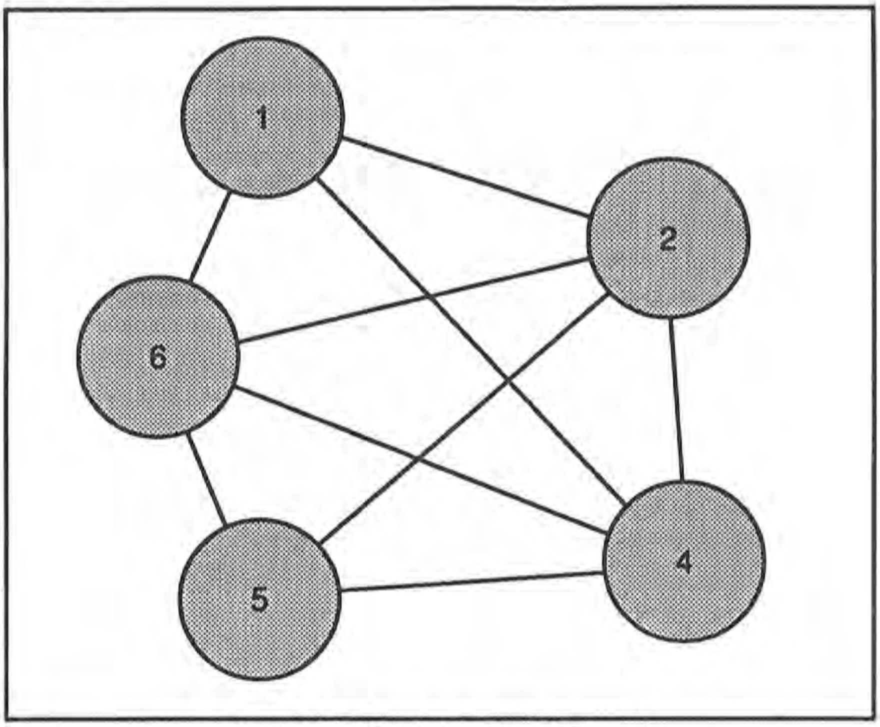

Figure 3 (a): **Non-Integrated Approach**

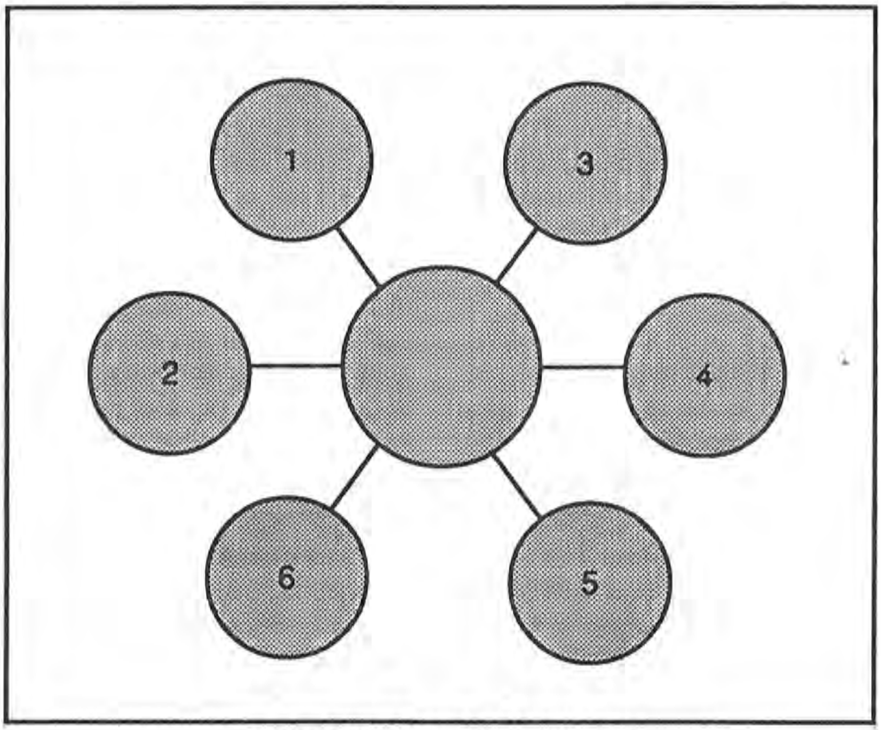

Figure 3 (b): **Integrated Approach**

5.0 CONTINUOUS QUALITY IMPROVEMENT

Given the dynamics of the environment, there must be a *philosophy of Continuous Quality Improvement.* In order to maintain a competitive advantage, activities pertaining to the continuous monitoring and the derivations of ways of improvement of the process must become quotidian to engineers charged with this responsibility. Traditional automation solutions did not allow *on-line configuration*, and thus the effect of the control system on quality as defined by the initial system configuration, remained constant until a major shut-down [WILL91]. During this time, engineers accumulated proposed changes to be implemented during this shut-down. Cognisant of this, vendors have started deploying a number of tools that provide on-line configuration for continuous quality improvement, such as, *what-if-scenarios* to allow users to design and test control schemes, *on-line graphical configuration* and *database integrity* schemes.

Apart from being integrated, today's plant wide solutions must therefore be modular, open and standard, in order to allow users the type of access and control required to facilitate the timely implementation of user driven solutions in response to a dynamic and competitive environment.

6.0 TECHNOLOGY TRENDS

In achieving a plant wide integrated solution that is flexible for continuous quality improvement and modular to facilitate cost effective phased implementations, leading vendors have initiated radical changes to their products. Typically, DCS vendors are no longer only concentrating on the control aspects but are providing *total plant wide solutions* that are *modular* and *"open"*. They have extended the scope of application of their products to embrace management information and business control functions. Vendors have reflected this by changing their product names from DCS to Real Time Management (RTM), Process Management Information (PMI) and Intelligent Automation Series. These accomplishments can be attributed to the technology trends in Networking, Graphical User Interfaces (GUIs), Client/ Server Computing, Real Time and Relational Databases and Object Oriented Design which emanated and realised substantial benefits in the commercial sector. These diverse technologies are evolving to facilitate their integration and the implementation of user driven solutions. To complement this, there exists a number of collaborative efforts engendering the formation of strategic alliances between vendors, and vendors and third party software houses. Differentiation between vendors can now be characterised by support, service and effective customer relationships. Vendors still adopting a proprietary approach will not survive. These trends are facilitating the implementation of long-term automation strategies, that span multiple years, multiple projects and utilise multiple vendors.

The following sections discuss some of the important trends in the above-mentioned technologies and attempt to illustrate how they are being incorporated into emerging industrial automation solutions, and more important how they can be harnessed to provide flexible, cost-effective and integrated solutions that are long-term and utilise multiple vendors.

6.1 Networking Trends

In manufacturing and process control, computing power is distributed and concentrated in accordance with the structure of the control strategy, resulting in the communication architecture illustrated in **Figure 4.** The Plant Wide backbone networks is based on the Manufacturing Automation Protocol (MAP), the first user defined and internationally accepted standard for OSI communication between manufacturing devices sourced from different vendors. MAP's LAN technology was based on the IEEE 802.4, due to its requirements for shielded coaxial cable and a MAC technique that is deterministic, guarantees message delivery, facilitates message prioritisation and is robust in that its operation is not affected by failing devices. MAP was spearheaded by General Motors in collaboration with other users in 1984 after realising that the cost of base level communication software accounted for as much as 50% of the total cost of integration software development.

Attempting to meet the critical real time requirements, particularly at the lowest levels, led to the development of MAP/EPA proposal and the mini-map specification which is based only on layers 1, 2 and 7 of the OSI model. Since communication at these

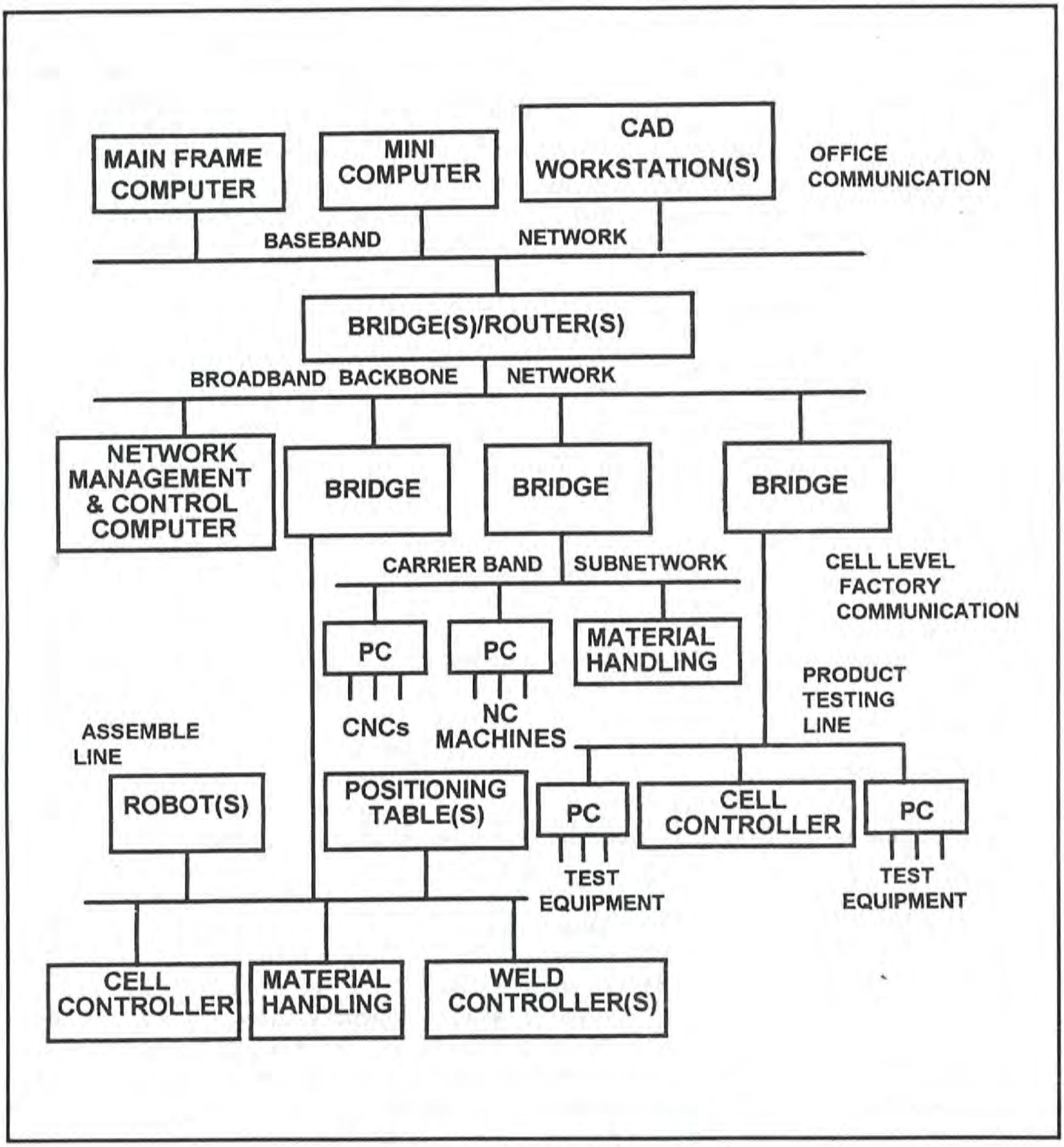

Figure 4: **Conventional Networking for CIM**

levels consists of short and urgent messages, the majority of the overheads associated with sophisticated dialogue was not required and therefore could be eliminated using a collapsed architecture. However, in spite of all of these efforts, Mini Map still did not meet all the critical requirements, justifying the existence of a number of vendor proprietary-based networks at the lower levels which kept users *locked-in* to at least some subset of vendor specific equipment. MAP also did not penetrate at the highest level of the hierarchy, as a number of MIS networks at that time were either ethernet or SNA based. Around the same time, corporate wide networks began adopting the Technical Office Protocol (TOP) standard which was initiated by Boeing Corporation after users started demanding interconnectivity in the office environment. Since the upper layers are similar to MAP, this connectivity was provided by the emerging OSI-based Bridge technology. It facilitated the download of production schedules from the corporate network to the plant network and the upload of real time data for timely informed decision-making.

6.1.1 High Speed Local Area Networks (HSLANs)

The majority of vendors provided 10Mbps plant wide networks. However, an evaluation of the bandwidth required in the context of the real time requirements of today's plants will prove that this capacity is limited. In addition, it has also proven to be inadequate for some of the emerging CIM applications, associated with CAD/CAM, file transfer, and image data, which in some cases demand the interconnectivity of multiple subnetworks. As a result, vendors have begun to adopt emerging industrial Gbps fibre optic technology, which is currently high in cost but is expected to become affordable at the turn of the century. Fibre can go as much as 100km without the need for repeaters. This together with its immunity to EMI increases the reliability and quality of transmission allowing much lower Bit Error Rates (BERs) to be realised. It is a secure transmission medium thus eliminating the fears associated with using coaxial cable networks in hazardous areas. Fibre Distributed Data Interface (FDDI) is an example of a HSLAN that has started entering the plant floor. Adhering to the ANSI X3T9.5 standard, it uses a multimode fibre and is based on the IEEE 802.5 token ring medium access technology but with a modified priority scheme. Its dual ring configuration has increased the reliability and the degree of fault tolerance and thus is ideal as a backbone tying together multiple subnetworks including backplane systems.

To further realise the benefits of this technology, however, there is a need for *"lighter weight protocols"*, with overheads more in line with the quality and speed of HSLANs. Traditional internetworking and transport protocols were designed to cope with an older, potentially unreliable internetworking environment, paying considerable attention to error control and retransmission. The resulting complexity of such protocols has a direct impact on the computational overheads of protocol implementation. The best implementation of OSI products on fast front end processors do not seem to be able to satisfy low delay and high throughput requirements. In order to meet the requirements of integration, low delay and high throughput, a number of light-weight protocols have begun to emerge, such as, GAMT, DETA X, XTP and VTP.

6.1.2 Field Bus Technology

HSLAN technology together with new age micro-processors running at lightening speed and reducing in size has accelerated the acceptance of fieldbus technology. Originally, field bus was conceived as the digital replacement for the ubiquitous 4-20mA analog signalling standard. Embedding new age micro-processors into field instrument devices, is allowing simple control tasks to migrate to the field. Many vendors have already started implementing sophisticated but lighter weight protocols at higher data rates on field-based microprocessors capable of cooperating to execute a distributed control strategy. Interoperability and interchangeability will become an everyday experience as field bus protocols will be used to interconnect major control subsystems from different vendors. Fieldbus systems will allow companies to collect, store and process large amounts of data in real time and provide the final link from the board room to the field.

6.1.3 Backplane Systems

Backplane systems will also have a major impact on the emerging communication architecture. Traditional backplane systems were considered to be resource partitioned, as it interconnected all resources, such as, CPU, memory and I/O to form a single computer. It was single processor (Default Master) and memory bus oriented. Such systems required optimal matching of CPU and bus signals and were dependent on the architecture of the processor. Currently, backplane systems are functionally partitioned as they connect loosely coupled boards that perform a semi-independent function. Each board consists of a processor, memory and I/O connected via a local bus to provide CPU-memory traffic. The system bus can then be used to provide communication between intelligent functions. Communication can therefore be indirect, and thus based on a message mechanism that has its own hardware support. The bus architecture is processor independent, as messages are queued in buffers and allows standard light weight protocols to be deployed to provide intelligent, reliable and timely communication. An example of a Backplane system that is used in the industrial environment is MULTIBUS II, which in comparison to MULTIBUS I, the communication protocol is based on a token passing bus access method.

6.1.4 Integrated Networking Architecture

Adoption of the above-mentioned technologies collectively, has engendered the emerging networking architecture, illustrated in **Figure 5**. In comparison to the conventional hierarchical architecture, illustrated in **Figure 4**, this architecture facilitates direct communication between devices, with each other via a common network medium (without any bridges or routers) to share the common resources. This type of architecture provides a high degree of flexibility and modularity in manufacturing automation, as it allows the shop facilities to be partitioned into virtual cells in which dynamic production control structures permit time sharing of workstation level processing systems [RAY88]. As a result, the same robot(s) or machine tool(s) may be assigned to different virtual cells from time to time. Given that the network is highly reliable and fault-tolerant, the efficiency of manufacturing operation is enhanced as a result of the following :

(1) Improved Flexibility in which common resources can be used by different control areas.

(2) Increased utilisation of individual workstations and shop floor equipment.

(3) Reduced downtime due to the failure and scheduled maintenance of computing.

(4) Reduced network-induced delays and increased data throughput.

The above concept is similar to what is encountered in integrated control systems of advanced aircraft, where a single reliable high-speed network allows communications between diverse but inter-related functions ranging from fly-by-wire active control to management support and information display [RAY87]. The flight and propulsion control systems in advanced aircraft could be considered to be analogous to real-time multi-robot or multi-machine control processes in a factory environment and the flight, mission and weapons management to engineering design and manufacturing plant management. Illustrated in **Figure 6** is an example of a vendor using the integrated networking concept.

6.2 Client/Server Computing

Client/Server(C/S) computing is a system design methodology that integrates hardware and software in multivendor environments that are transparent to the user. It employs distributive cooperative processing to distribute components and support cohesive interaction between clients and servers in a cooperative fashion. Together with open systems, Client/Server computing is responsible for the evolution of a new generation of software where the application, the database and the user interface have been separated to facilitate multivendor integration (**Figure 7**). The User Interface portion of the system is known as the Presentation Processing Logic (PPL). It interacts with the end user's terminal or device and is responsible for screen-formatting, window management and mouse-handling. The application portion of the system is known as the Business Processing Logic (BPL) as it deals more with the business of the application. The database portion

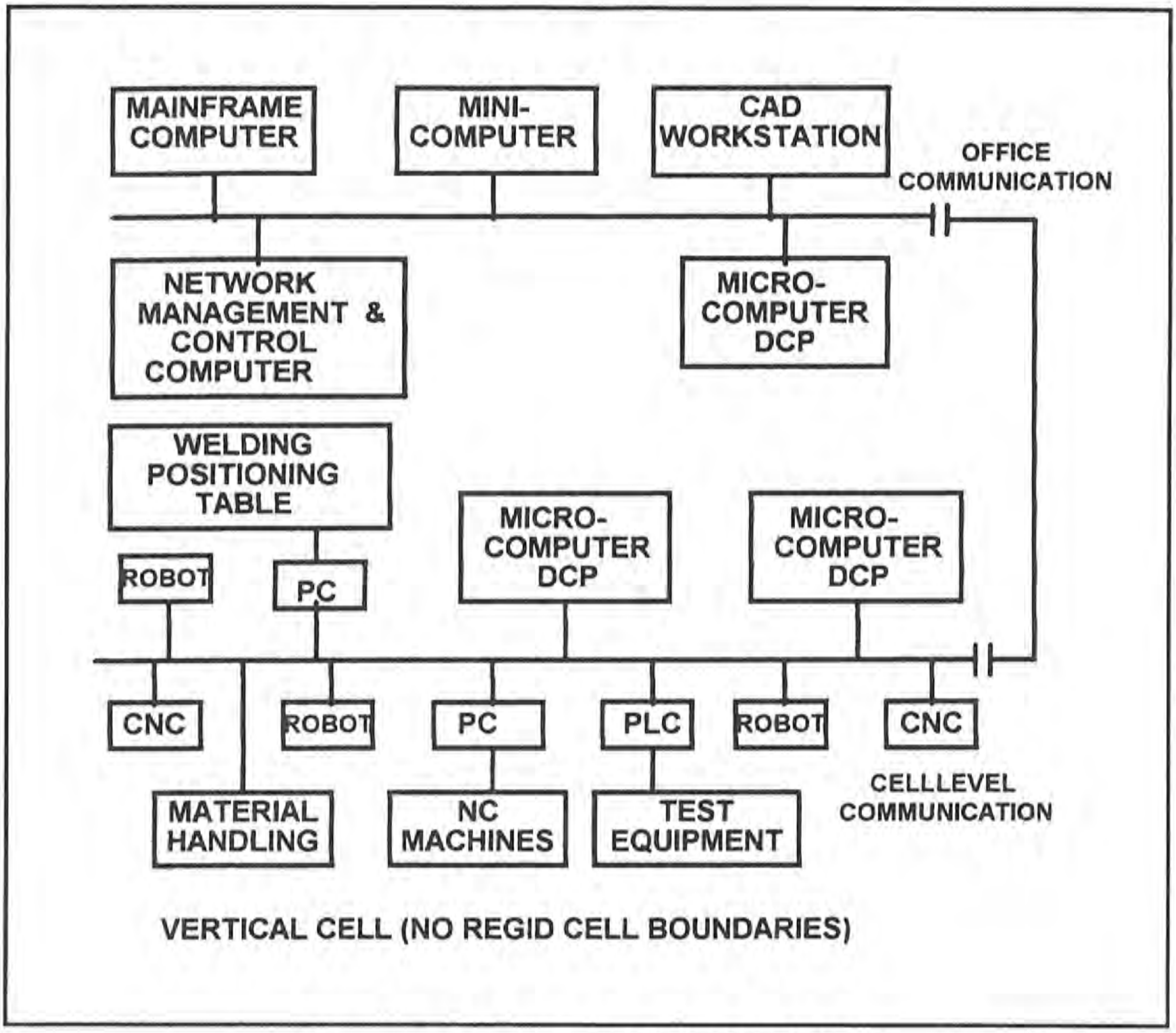

Figure 5: Integrated Networking Concepts for CIM

comprises of the DBMS and the Database Processing Logic (DPL) which is the portion of the application code that manipulates the data using some dialect of SQL. These fragments of the application can then be distributed across a network of client and servers, and by using an appropriate Interprocess Communication (IPC) mechanism, coordinate their activities and exchange the necessary information. The Foxboro software architecture illustrated in **Figure 6** is based on C/S computing and was used to increase the level of horizontal integration.

6.3 Database Management Systems

Data Transparency provided by Distributed Databases are also essential to accomplishing application integration. It allows portions of a file to be distributed across multiple network nodes local to users who access the information frequently, yet providing one logical view to all users who need access to this data. It is important that Distributed Databases are implemented using the relational model to achieve the level of flexibility required to make a true distributed implementation possible, as it stores data in tables with no regard to positioning relative to data stored in other tables[BOUR89]. Relational and Distributed Databases are finding its way into more and more process control applications. Although most users are aware that such systems are being shipped as part of their control system, they fail to realise the power and potential they have purchased, in terms of flexibility, modularity and

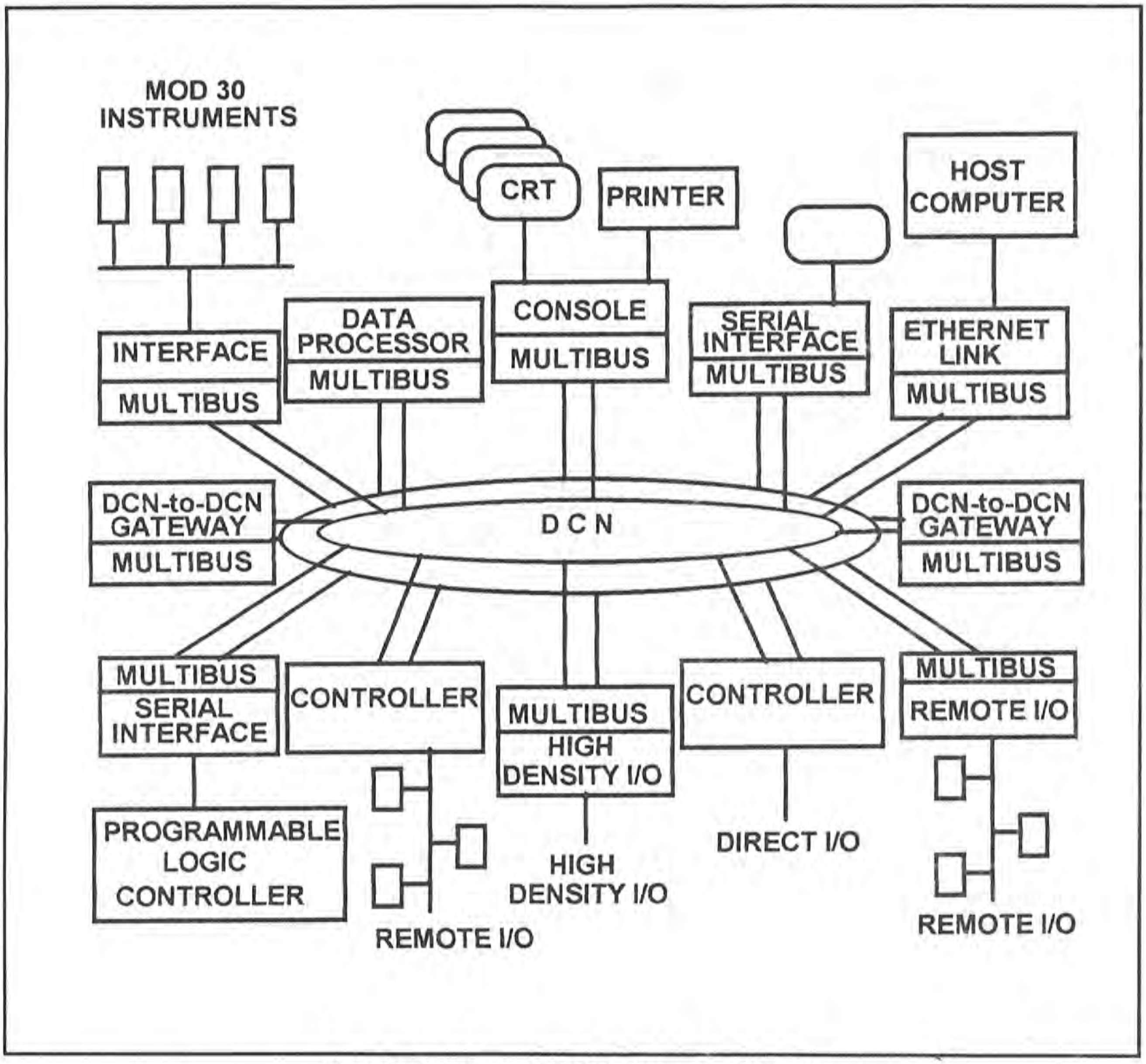

Figure 6: Abb-Taylor MOD300 System Architecture

expandability[BUTL91]. Some of the other benefits of relational databases in process control, include, ease of understanding and use, data integrity, access security and ease of adaptation to user specific applications. In addition, since it is now a standard "state-of-the-art" technology, users can benefit tremendously from efforts of third party vendors developing application specific software compatible with this technology.

It is also important that such databases have a high degree of interoperability to facilitate connectivity with existing databases and thus facilitate the sharing of data across multiple platforms. The information required to automate plants tend to reside on a variety of different computers and databases. Most companies will not be willing to rewrite their existing applications to take advantage of a common database. Therefore, it is far more important for a DBMS to be able to share data with existing files and database systems. An example of this is Shell's Excel Lubricants Plant in Rockville, Ontario Canada, which required a system that provided fully-integrated information flow from order receipt to the plant level, to operations scheduling ,bulk and additive receiving, production (blending and packaging), an shipping (bulk and packaged) [PHAI93]. Existing at the plant level was a TDC 3000 Distributed Control System (DCS). Also existing, is a number of Ethernet Local Area Networks featuring multiple Oracle relational databases, each dedicated to tasks, such as warehouse management, production scheduling and laboratory management.

Recognising the need for an integrated approach to maximise the benefits, a simple integration process was adopted. In creating a flexible and supportable solution, existing standard products and solutions was used, in order to avoid the emergence of a green-field software development project. It was concluded that a relational database should be the basis for the integrated solution allowing for the implementation of a client-server solution with a standard access mechanism to the data via SQL. The data that needed to be interchanged among applications would be placed in a common *virtual data base* so it could be accessed easily by other applications. Oracle was selected as the relational data- base and a System Integrator (SI) selected to integrate the information and control systems.

The first step involved the development of a general data model illustrated in **Figure 8** which is based on the functional requirements of users and applications. From this, a more detailed model can be derived based on the specific designs of the system and existing third party applications. In order to shorten the time to implementation, the SI was required to build upon existing software modules and experience to meet the required functionality. As a result, Oracle-based third party software packages would be used to integrate the various tasks. The SI was therefore required to develop software tools that facilitated the interchange of data between the Oracle-based third party applications and the TDC 3000 DCS. **Figure 9** illustrates the typical data flows for the system. Each application still had its own database (Oracle or otherwise, e.g., file-based systems) and in many cases its own front end for the user. A global Oracle database addresses the data interchange requirements for the differing applications and allows front-end applications access to data via SQL queries.

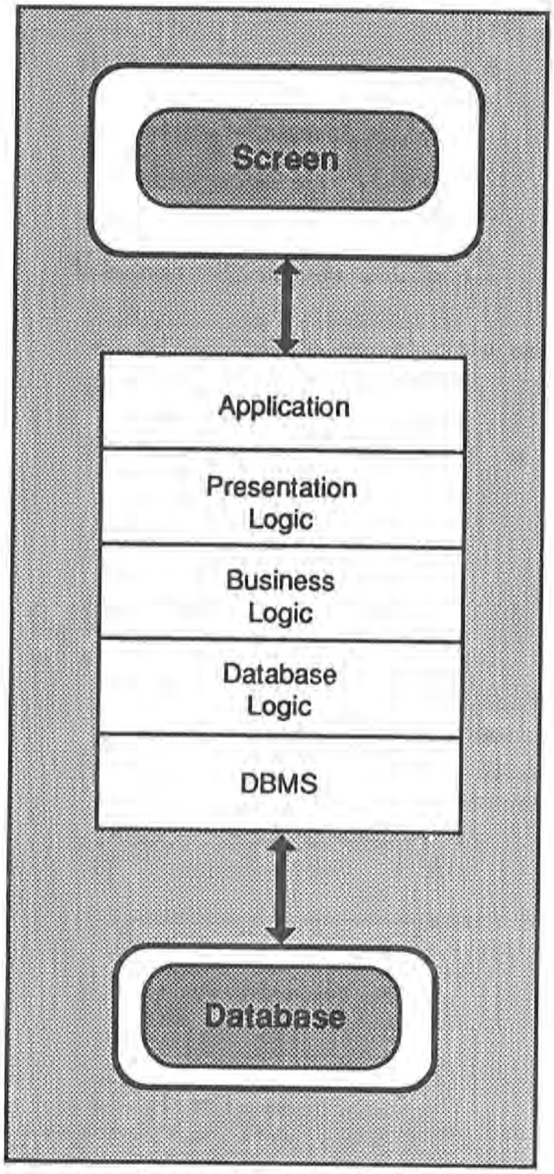

Figure 7: Structure of An Application

It is expected that future integration projects will become easier as improvements and standardisation efforts continue in relational database technology. Applications will be able to work with different databases with only minor changes. The emergence of the Generic Database Interface (GDBI) will facilitate the integration of the real time database residing at the plant level and the relational database management system residing at the upper levels. As more and more vendors base the design of their products on relational databases, the architecture illustrated in **Figure 9** will become more prevalent, facilitating the simple "plug in" of applications, such as, production management applications and information analysis type of applications, as deemed necessary.

6.4 Graphical User Interfaces (GUIs)

In line with the organisation's goal to increase productivity, operator interfaces emerged which allowed operators to be better informed about their manufacturing processes and to initiate decisions to increase output or efficiency [DUMO89]. They became more workstation based, programmable, adaptable, supported a broad range of technologies and was based on a fully integrated systems approach, heavily weighted towards information retrieval. The term Man Machine Interface (MMI) emerged to describe this user-friendly device, which consisted of a hierarchy of menus, which users could step through to access a particular option, eliminating the need to remember long sequences of key words. Unfortunately, as systems became more complex and the number of menus through which a user must step through increased, the time taken for a user to execute a given option increased to the point where it became a major irritant [FISH89]. More significantly, this increase led to both gross inefficiencies and potentially dangerous delays in response time.

Multiple window systems, GUIs, eliminated the problems associated with navigating through menu structures, by allowing information to be displayed simultaneously in different windows, iconic information representation, command selection via pull-down and pop-up menus and a pointing device, such as, a mouse for selecting choices from a menu or indicating items of interest in a window. Due to its complexity, the cost of engineering of a GUI is much greater than its simple textual interface, and thus a significant fraction of the resources devoted to application development must be spent on building the user interface. Until relatively recently, most vendors offered their own interface management systems, and these were incompatible with each other. Enormous effort was required to port applications from one machine to another and in many cases involved extensive modifications as a result of different interface conventions. However, there has been a welcomed

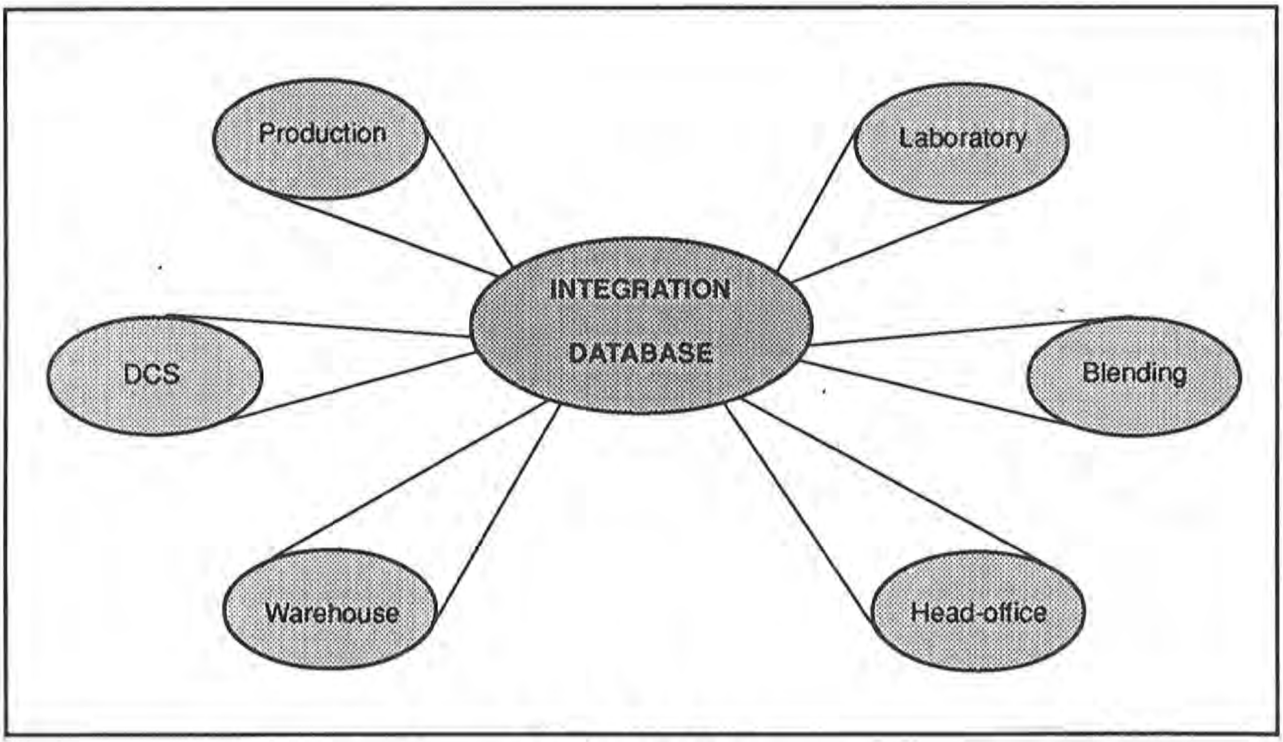

Figure 8: **Data Model**

move to standardisation on the X-Window interface with the Motif interface toolkit, further increasing the level of flexibility in designing process control architectures.

GUIs based on X-Windows are providing an industry-standard, icon-and-windows-based operator interface to applications, such as cell/supervisory control, MRP, production and scheduling[VETT91]. The X-Window standard allows the sharing of interfaces across a variety of systems from MS-DOS, OS/2, MAC workstations and UNIX. Any application compatible with the X-Windows standard can be accessed from any other X-Terminal node on the network, increasing the availability of the organisation's computing resources to a wider range of users. In addition, a single X-Windows operator interface can present multiple windows displaying information from different applications. Together with its consistency and ease of use, GUIs are expected to increase productivity of plant personnel.

An example of an operator station that is based on X is the Honeywell's TDC 3000 Universal Station ^{X}. With its X-Windows capability, the user has the option of operating it like any of the TDC 3000 Universal Stations that provided operator, engineering or maintenance functions. Via X-Windows on the Universal Station^{X}, operators have access to a wealth of higher level information running on third party devices including: plant procedures, production schedules, order entry systems, spreadsheets, advanced control applications, lab information, historical data, trend data and statistical analysis tools. In addition, the vendor has also been able to identify a number of commercially available third party packages that reside on external computing devices (Mac, PC) that permit the transfer of information. Although the simultaneous display of information in multiple windows was an objective, the assurance of process security was a primary objective. Consequently, the TDC 3000 control is given highest priority at all times and allows the LCN window to be configured by the engineer that it is not covered or overlapped by any other window. In addition, the station automatically returns to a full-screen process view should problems with the plant level network occur.

Taylor's ABB process automation and Foxboro's I/A series are examples of other DCSs that are also utilising X-Windows, OSF/Motif-based, user-intuitive

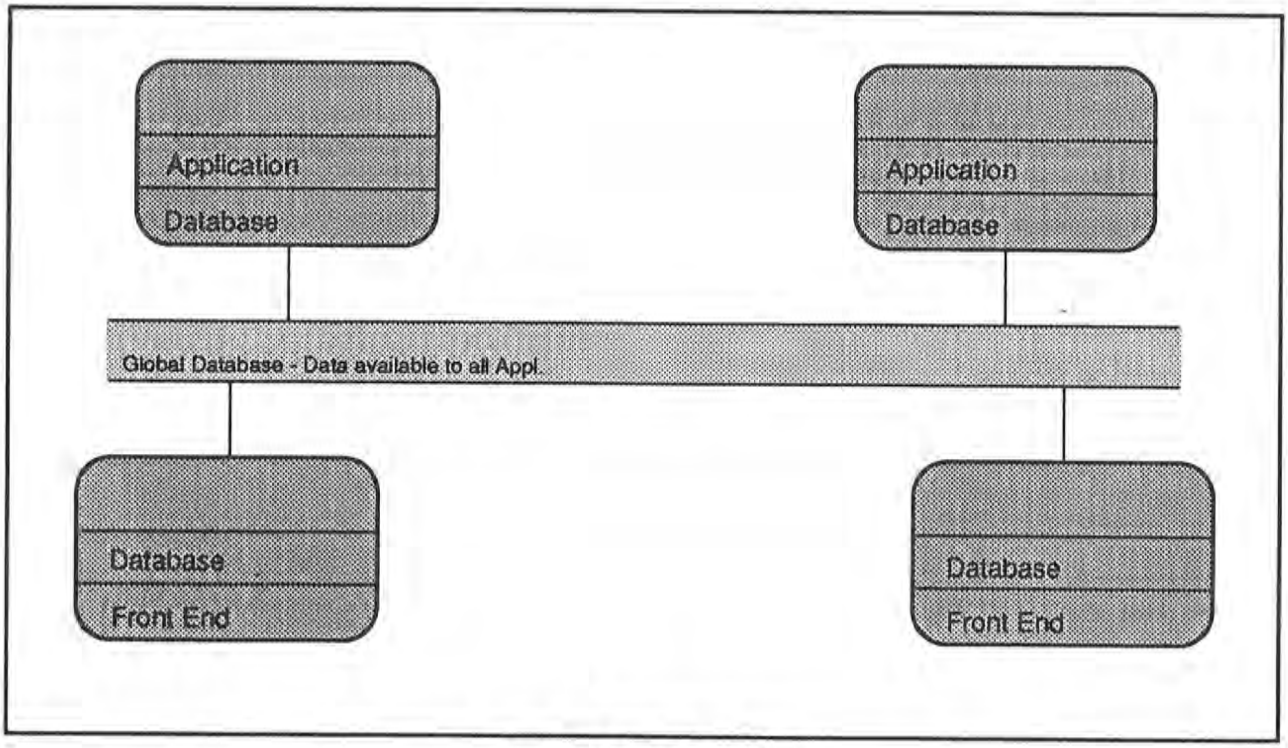

Figure 9: Typical Data Flow

operator workstations to provide operators with real time process information. In the case of the former, integration software has been provided to allow these interfaces to access third party or proprietary application software. The move by vendors to adopt more open and standard interfaces has allowed the term "human interface" to be more popularly used to designate workstation hardware and software intended for use by several classes of personnel including, operations, managerial, maintenance, technical and software development. These approaches to MMIs represent substantial advances over early systems.

6.5 Object Oriented Methodology

Traditional approaches to the development of software were based on function-oriented methodologies, as exemplified by the methodologies of Yourdon [YOUD89] and De Marco [DEMA79]. In these methodologies, primary emphasis is placed on specifying and decomposing system functionality. Although such an approach might appear to be the most direct way of implementing a desired goal, the architecture derived is fragile. As requirements change, systems based on decomposing functionality require massive restructuring. As a result, the control software developed and embedded in automated systems required complex and time-consuming modifications for the slightest change in requirements. It is the major reason why the maintenance and upgrade of a DCS was considered to be complex and expensive. For many years, both vendors and users recognised the need for a software development approach developed on the underlying framework of the application domain itself, rather than the ad-hoc functional requirements of a single problem. Such an approach will allow the software to hold up better to the evolving requirements of a dynamic environment.

The Object Oriented Approach (OOA) to software development, solves this problem by encouraging software developers to work and think in terms of the application domain through most of the software engineering lifecycle [RUMB91]. The tools provided by OOA, such as, *encapsulation, inheritance and abstraction,* support modularisation. Encapsulation forces good modularity as it provides the ability to combine data structures (attributes) and behaviour (operations and instructions) in a single entity, which facilitates the development of multipurpose and symbolic declarations. Also known as *information hiding*, it separates the external aspects of an object, which are accessible to other objects, from the internal implementation details, which are hidden from other objects. Providing a well-defined interface allows the internal details of an object to be changed without affecting the applications that use it, increasing the flexibility of the system. Inheritance facilitates reuse of models, since carefully designed general models can be saved in libraries for reuse. These models or model components can be used as superclasses of more specialised model objects. The subclass is then free to add additional attributes or to redefine inherited attributes. Facilitating the sharing of information and offering the prospect of reusing designs and code on future projects reduce development time and cost. Abstraction preserves the freedom to make decisions as long as possible by avoiding premature commitments to details.

6.5.1 OOA and Prototyping

Prototyping is a process that enables the developer to create a model of the software that must be built. Customer and developer meet and define the overall objectives for the software, identify whatever requirements are known and outline areas requiring further definition. A quick design then occurs which focuses on a representation of those aspects of the software that will be visible to the user (e.g., input approaches and output formats). The quick design leads to the construction of a prototype, which is evaluated by the customer/user and is used to refine the requirements for the software to be developed. A process of iteration occurs, as the prototype is "tuned" to satisfy the needs of the customer while at the same time enabling the developer to better understand what needs to be done.

OOA can lead to extremely effective prototyping and *"evolutionary software engineering"* techniques. The objects that are specified and ultimately implemented for a current project can be catalogued in a library. Objects are inherently reusable and over time, the library of reusable objects will grow. When OOA is applied to new projects, the analyst can work to specify the system using existing (implemented) objects contained in the object library, rather than inventing new ones. This practice is common place in hardware design; systems engineers specify existing integrated circuits, rather than requiring custom design.

By using existing objects during analysis, specification time is reduced substantially and a rapid prototype of the system can be created and reviewed by the customer. Even more important, the prototype can evolve into a working product or system because the building blocks that created it are objects that have already been proven in practice.

6.5.2 Application of OOA to Dynamic Plant Models

Historical approaches to process and process control design have been based on steady state analysis of production capacity combined with evolutionary engineering based on past experience - a form of trial and error. This approach has proven to be inadequate, even more so now, given the emerging worldwide trends in product excellence, energy efficiency, safety and environmental impact [CHAM91]. Past failures in plant design, including poor process performance or start up difficulties can be attributed in many cases to insufficient analysis of plant dynamics. In many cases, it has led to oversizing and undersizing of components, inadequate process turndown ratio, non-linear characteristics, unmeasurable critical operating parameters and incorrect matching of process equipment gains.

Dynamic simulation was tried in the mid Seventies as a design tool, but did not gain acceptance due to the high cost incurred and the long times for implementation, typical of the development of complex and large-scale projects based on function-oriented methodologies. Instead, it gained acceptance in the early 1980's as an excellent operator training tool. It motivated operators to learn not only the operations of the process but also the functionality of the DCS keyboard. The models derived using a function-oriented methodology were procedural and not declarative or equation-based, resulting in most of today's simulation tools being too specialised and too low a level to allow reuse of models for tasks other than simulation [MATT91]. The models developed to be used in one package could not without extensive re-working be used in another. To justify the development of a dynamic plant model as a preliminary design tool, vendors recognised the need to for good structuring facilities and a powerful modularisation concept, to facilitate an understanding of large complex models and the reuse of parts of these models in the building of other models.

OOA has allowed dynamic models to move towards the front end of process design, facilitating the identification of control problems which in some cases can be removed rather than using advance control strategies to overcome them at the end of the design process [MCGA91]. The same dynamic models can then migrate through to the detailed design process and down to the DCS configuration check-out. Once the process is put on-line, dynamic models can be applied to on-going plant evaluation and optimisation. The driving forces of lower operating costs and lower process emissions coupled with higher quality products will inevitably push the application of dynamic simulation towards the front end of process design. This is becoming more of a reality, as a number of dynamic models based on OOA , which can be easily used and transported to other applications exist. More sophisticated and flexible models are expected to emerge in the near future, as both users and vendors continue to explore OOA concepts. In addition, OOA allows the power of these complex models to be placed in a form suitable for users who are not computer or dynamic simulation experts. Utilising the same model for process design, control studies, training, real time optimisation and what if studies, will further reduce the cost and time from process conception to implementation to ongoing support, and will allow users to become more intimately involved in each of these stages.

6.6 Open Systems

Open Systems include standards in the areas of Operating Systems, User Interfaces, Network Protocols, and more recently Application Programming Interfaces (APIs) and Software Design Methodologies. Traditionally, deploying an "open system" meant that operating systems, communication protocols and the user interface adhered to standards, such as, UNIX, OSI and X-Windows. However, with the rapid pace of technology, industries must increasingly rely on de facto standards. As a result, the definition of open systems has been extended to include the capability of co-existing with proprietary systems in order to avoid vendor *"lock-ins"* and to ensure that user's investment in existing technology are better leveraged.

Apart from users, the major beneficiaries of open systems include hardware and software vendors. For hardware vendors, the cost of operating system development will be substantially reduced and time to market new products shortened. Their efforts will be deployed in improving the architecture, features and functionality of new products instead of proprietary systems. Competition will be based on adding value and improving quality of service. For software vendors, compliance with standard interfaces will guarantee new and wider markets. The end user is the major beneficiary as more off-the-shelf products at competitive prices will become available. The user will have increased flexibility in choosing products and systems and should have no fear of buying the "wrong box". In addition, being assured of the same operating environment with any system purchased will simplify mixed vendor interoperability and networking capability.

7.0 PARTNERING WITH INSTRUMENTATION VENDORS

With the adoption of *open systems*, the traditional approach to the selection of a supplier based on evaluating technical merit is no longer applicable as there is less disparity among vendors. As industry standards continue to emerge and buyers become more knowledgeable, technical merit will continue to become a less meaningful criteria. With the current technology situation, vendors are taking turns in coming out with new technology. For a short time, each vendor's offerings appear state-of-the-art, until it is *"leap-frogged"* by another vendor with a new product. The implementation of multivendor long-term automation strategies is changing the role of the supplier to one of a *partnership*. Selecting a supplier as a partner requires an evaluation of [STAB91]:

(1) *Vendor's product migration strategy* - It is possible for an automation solution to have a useful life of 10-15 years, even when the technology it utilises advances every six (6) months. The vendor should provide a clear *migration path* to keep the user's solution current and have *system life planning tools* in place to help the user optimise the return on investment.

(2) *Strategic Alliances* - Many of today's control problems and integrated manufacturing strategies require a team effort among vendors. *Multi-vendor solutions* are greatly facilitated if strategic alliances are already established at the time of project implementation.

(3) *Business Issues* - This includes an evaluation of issues, such as, corporate personality, quality, industry orientation, financial security and the cost of doing business.

In order to achieve high levels of plant integration, the selected vendor should understand the problems in such an undertaking, provide a product architecture designed for integration and be committed to open systems.

8.0 CONCLUSION

Typical automation approaches involved costly inflexible and proprietary solutions and were plagued with the problems of obsolescence. As a result of the old proprietary, closed and tiered technologies, the automation solution could not advance or even keep pace. It was not *agile* enough to facilitate a change in strategies on a moment's notice, in response to changing market demands. To maintain a competitive edge, there has been a paradigm shift towards *agile manufacturing*. Greater agility is achieved through the implementation of a unified platform for control and real time information management facilitating more effective interoperability of vendor's equipment, networks and applications. This requires standard distributed database management, windowing, and application programme interfacing, all across multiple networks and operating systems.

A new generation of software has emerged, where business processing logic, database and the user interface have been separated. The rapid developments of these technologies were stimulated by the demand for the sharing of applications, resources, functionality and power transparently across networks. It provides the portability, interoperability and scaleability of applications mandatory to achieving an integrated solution practically and cost effectively, and through its flexibility facilitates a phased implementation. However, to reap these benefits, users must have a good grasp of these underlying technologies and their trends in order to effectively develop and manage a *long-term automation strategy, that span multiple years, multiple projects and utilise multiple vendors*. Part 2 of this paper investigates some of the emerging approaches, methodologies and techniques that can be used to develop a realisable long-term automation/information technology strategy and to further to maximise the benefits.

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