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An Investigation Into Manufacturing Execution Systems

by

K W Duley

A Thesis Submitted in Partial Fulfilment of the Requirements for

the Award of

Bachelor of Science Honours (Computer Science)

at the

Faculty of Science, Technology & Engineering

Edith Cowan University

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USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

ABSTRACT

Hardware and software developments of this decade have exposed an hiatus between business/management applications and process control in heavy industry in the implementation of computer technology.

This document examines the development of discrete manufacturing and of relevant implementations of computing. It seeks to examine and to clarify the issues involved in a perceived current drive to bridge this gap, to integrate all the systems in a manufacturing enterprise in a Manufacturing Execution System (MES) in order to address two hypotheses:

1) That overseas trends towards the development of manufacturing execution systems have application in the Australian industrial context.
2) That significant gains in production efficiency and quality may be achieved by the application of an MES.

It became apparent early in this study that any understanding the function of an MES requires an understanding of the context in which it works. Following the Introduction, therefore, Section Two contains a brief overview of the history and development of modern industry with particular attention to the subject of inventory and inventory management. Since the 1970s, three main streams of change in manufacturing management methodology developed, these are dealt with in some detail in Section Three. Section Four outlines a variety of areas of increasing computerisation on the shop floor while Section Five addresses the integration of the whole system, management and shop floor, seeking to demonstrate the complexity of the subject and to discover current trends and developments. Section Five includes a survey of some of the software and hardware options currently available and Section Six summarises the work and presents some observations and conclusions.

Three appendices provide more detailed information on MES software availability, pricing and market penetration.

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education; and that to the best of my knowledge and belief it does not contain any material previously published or written by any other person except where due reference is made in the text.

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GLOSSARY OF ACRONYMS

ABS : Australian Bureau of Statistics

ADC : Automatic Data Collection

AGI : Avraham Y. Goldratt Institute

AGV : Automated Guided Vehicle

API : Application Programming Interface

APICS : American Production and Inventory Control Society

APT : Automatically Programmed Tooling (Language)

AS/RS : Automatic Storage and Retrieval Systems

ASME : American Society of Mechanical Engineers
ASUG : American SAP User Group
ATE : Automatic Test Equipment
CAD : Computer Aided Design (or Drafting)
CADD : Computer Aided Design and Drafting
CAE : Computer Aided Engineering
CAI : Computer Aided Inspection
CAM : Computer Aided Manufacture
CCR : Critical Constraint Resource
CIM : Computer Integrated Manufacturing
CMM : Coordinate Measuring Machines
CNC : Computerised Numerically Controlled
COPICS : Communications Oriented Production Information and Control System
CPA : Critical Path Analysis
CRP : Capacity Requirements Planning
CWQC : Company-Wide Quality Control
DBMS : Database Management System
DBR : Drum-Buffer-Rope logistical system
DCS : Distributed Computer System
DEC : Digital Equipment Corporation
DNC : Direct (or Distributed) Numerical Control
EOQ : Economic Order Quantity
FCS : Finite Capacity Scheduling
FOE : Factory Operations Executive
FMC : Ford Motor Company
FMS : Flexible Manufacturing Systems
FS : Final Schedule
GCU : Graphic Configuration Utility
GKS : Graphics Kernel System
GM : General Motors Corp.
GT : Group Technology
HIP : High-Inventory Plant
HR : Human Resources
IBM : International Business Machines
IED : Inside (Internal) Exchange of Die
IGES : Initial Graphics Exchange Specification
ISO : International Standards Organisation
JIT : Just-In-Time
JUSE : Union of Japanese Scientists and Engineers
LIP : Low-Inventory Plant

LSI : Large Scale Integration
MAP : Manufacturing Automation Protocol
MES : Manufacturing Execution Systems
MIS : Management Information System
MIT : Massachusetts Institute of Technology
MMI : Man-machine Interface
MPS : Master Production Schedule
MRP : Materials Requirement Planning
MRP *II* : Manufacturing Resource Planning
MTBF : Mean Time Between Failures
NC : Numerically Controlled
OED : Outside (external) Exchange of Die
OPT : Optimised Production Technology
PC : Programmable Controller (or Personal Computer)
PCCM : Production Capacity Control Model
PERT : Program Evaluation and Review Technique
PICS : Production, Inventory and Control System
PS : Primary Schedule
QC : Quality Control
QC : Quality Circles
QIS : Quality Information System
R&D : Research and Development
ROI : Return on Investment
RP : Resource Profiler
RTD : Research and Technological Development
SAP : Systeme, Anwendungen, Produkte in der Datenverarbeitung, (Systems, Applications, and Products in Data Processing).
SCADA : Supervisory Control and Data Acquisition
S/R : Storage and Retrieval machine
SM : Synchronised (or Synchronous) Manufacturing
SPC : Statistical Process Control
SQC : Statistical Quality Control
TOP : Technical and Office Protocols
TPS : Toyota Production System
TQC : Total Quality Control
TQM : Total Quality Management
UL : Underwriters Laboratories
VLSI : Very Large Scale Integration
WIP : Work in Process

1. INTRODUCTION

Various commentators ((Adlemo,Andreasson, et al. 1995), (Wenstrup & Appleby, 1995), (Appleby, 1994), (Gergeleit, Kaiser, et al., 1995),(Hill, 1993), (Jasany, 1992) and others) highlight the need to flexibly integrate planning and process control, in real-time, in order for companies to gain or retain a competitive edge.

Modern manufacturing plant schemata imply at least three closely-coupled layers (Hill, 1993, p. 67) :

1. Planning: includes forecasting, budgeting, logistics, order management and manufacturing requirements planning (MRP) supported by Computer Operations and Management Information Systems (MIS).
2. Control: includes process and machine control performed by distributed control system (DCS) equipment supported by Computer Operations and Engineering.
3. Management: Hill (1993) describes the positioning of the Manufacturing Execution System (MES) layer, the functions of which include finite capacity scheduling, recipe management, quality management, product tracking, operator interface, process and production data management and supervisory control.

Chance echoes this concept, citing Friscia (president of Advanced Manufacturing Research) as saying that MES exists as "*the point of integration between the transaction processing and real-time cultures that have traditionally operated independently of one another.*" (Chance, 1994, p. 31) Chance elaborates:

"Upper-level planning systems track business variables (for example, product cost, forecasts, customer delivery dates) in terms of days or weeks, while process control systems manipulate process variables (eg., temperature, pressure, flow) on a second-to-second basis. The MES unites production operations by linking these two systems and controlling production variables-materials, equipment, personnel, process instructions/documentation, and facilities."

1.1 Terminology

1.1.1 Manufacturing Execution System

"Business systems, characterised by the ability to deal with large databases, typically deals [sic] *with operations such as order entry, production scheduling and inventory control. Process control, on the other hand, deals with operations requiring real-time control such as production operations and materials handling. There exists, however, a mutual need by both business systems and process control to interact with each other as well as with other plant operations. This need for enterprise-wide interaction defines the realm of Manufacturing Execution Systems (MES)"* (Wenstrup & Appleby, 1995)

"A MES is the link between a plant's corporate planning/business support systems and its process control systems." (Hill, 1993)

Post-proposal research has failed to reveal the term *Manufacturing Execution System* in any major text. It appears that the term is simply another addition to the plethora of descriptive expressions and acronyms which plague this, and other, areas of the computer industry. Compare the following with the above:

1.1.1.1 COMPUTER INTEGRATED MANUFACTURING (CIM)

> *"Computer Integrated Manufacture (CIM) is concerned with providing computer assistance, control and high level integrated automation at all levels of manufacturing (and other) industries, by linking islands of automation into a distributed processing system."* (Ranky, 1990, p. 12)

> *"The term computer integrated manufacturing (CIM) has been coined to denote the pervasive use of computers to design the products, plan the production, control the operations, and perform the various business related functions needed in a manufacturing firm."* (Groover, 1987, p. 4-5)

> *"Under this term* [CIM], *we mean the future data and information processing in industry, carried out by the integrated implementation of computers and communications techniques between men, computers and controllers at all levels."* (Bernold & Guttropf, 1988, p. 2)

It is suggested by the author that the terms CIM and MES are synonymous. Ranky's definition of CIM is also given in his widely-quoted work Computer Integrated Manufacturing (Ranky, 1986, p. 2) considerably pre-dating the earliest use of the term MES revealed by my research (Hill, 1993). This lends force to the argument that *"CIM"* should be adopted as the generic term but both expressions are used in this document.

1.1.1.2 FLEXIBLE MANUFACTURING SYSTEMS (FMS)

Another common acronym in this field is FMS but it should be understood that the term has a rather more narrow definition, being confined to the implementation of computerised systems at the shop floor, *'coal-face'*, level.

> *"Implementation of manufacturing principles by means of distributed control of computer controlled machines and cells, integrating material handling, data processing, part processing and testing and other functions in a reprogrammable fashion for the purpose of low batch, highly productive manufacture."* (Ranky, 1990, p. 244)

> *"A Flexible Manufacturing System (FMS) is an individual machine or group of machines served by an automated materials handling system that is computer controlled and has tool handling capability. Because of its tool handling capability and computer control, such a system can be continually reconfigured to manufacture a wide variety of parts."* (Goetsch, 1990, p. 262)

> *"A number of workstations, comprising computer-controlled machine tools and allied machines, which are capable of automatically carrying out required manufacturing and processing operations on a number of different workpieces, with the work stations being linked by a work-handling system under the control of a computer that schedules the production and the movement of parts both between the workstations and the system load/unload stations."* (Talavage & Hannam, 1998, p. 62)

1.1.2 Other Common Terms

1.1.2.1 MANUFACTURING AND COMPUTERISATION

Throughout this project the term *"Manufacturing"* has been taken to mean the production of goods in discrete manufacturing as distinct from process manufacturing which is understood to involve continuous, or very long run, processes producing a single product with little direct human, tradesperson, involvement (for examples pharmaceutical, petrochemical, smelting, water or sewerage treatment), and which is already highly computerised. *"Manufacturing"* should be taken to mean such industries as metal trades, clothing, footwear, ceramics or electronics where products are diverse and are produced individually or by batch. *"Computerisation"* should be taken to mean the introduction and employment of digital computers and communications.

1.1.2.2 PUSH AND PULL

"Push" manufacturing, as this document will explain, was the common practice in manufacturing at the end of the 1970s. It refers to the concept of manufacturing to stock or to guaranteed order (as in the case of an expanding economy with a burgeoning market) where raw materials and parts were pushed into one end of the manufacturing process and forced at maximum rate out onto the market. *"Pull"* manufacturing is governed by market demand, responding by producing just enough, but producing it in time to meet a specific order.

2. MANUFACTURING METAMORPHOSIS

"Industrial manufacturing is witnessing an intensification of the race for market dominance: the life-cycles of products are shortening; zero-defects is becoming a goal of quality; new machine technology is being introduced each year and systems to control production replace each other at an unprecedented rate." (Goldratt & Fox, 1986, p. 144)

2.1 An American Revolution

In 1910, the United States of America witnessed a revolution perhaps as significant as that which ended in 1783: Henry Ford moved the production of the Model T to a purpose-built factory at Highland Park (IL, USA) and changed the face of manufacturing. (Batchelor, 1994) Prior to the move, mechanical manufacturing had been an expansion of the craft system with its roots in the European Guilds of the Middle Ages, enhancing production by gathering together more individuals. In 1903 the Ford Motor Company (FMC) sold 1,708 Model A cars at US$850 (runabout) and US$950 (tonneau) – in their first year at Highland Park, with the staff level raised from 1,908 to 4,110 (up 215%), FMC sold 34,528 Model T touring cars at $US780 (down 8.2%). (Ford, 1991) This represents better than nine-fold increase in productivity.

Henry Ford's dedication to the concepts of market dominance, shortened product life-cycles, quality and new technology is legendary. He consistently (annually) reduced the price of his vehicles (dominance), produced more of them

faster (life-cycles), advanced their reliability (quality) and mechanically upgraded both plant and product (technology). (Ford, 1991) In this he foreshadowed Goldratt and Fox by five decades. Ford's practices also foreshadowed the modern Just-in-Time manufacturing by virtually eliminating long-term inventory – FMC did not own or use a single warehouse. (Robinson, 1991, p. 121)

> *"No manufacturer anywhere in the world was able to exactly repeat Henry Ford's extraordinary success with mass production. This is hardly surprising. In the history of commerce there have been few opportunities to exploit such an enormous, untapped and reasonably homogeneous market. Yet mass production – modified to accommodate different markets and labour conditions... was... widely imitated."* (Batchelor, 1994, p. 66)

At the same time as Ford was revolutionising the mechanical side of manufacturing, Frederick Winslow Taylor was revolutionising the human side. Taylor established the idea that management should become a science, and that by the application of scientific principles to process of working productivity could be significantly enhanced. He coined the term *"soldiering"* to describe the idea that in a grouped workforce, with a uniform rate of pay, the average productivity tends to be that of the slowest.

> *"Under this plan the better men gradually but surely slow down their gait to that of the poorest and least efficient. When a naturally energetic man works for a few days beside a lazy one, the logic of the situation is unanswerable. 'Why should I work hard when that lazy fellow gets the same pay that I do and does only half as much work?'* " (Taylor, 1967, p.19)

Taylor developed the study of time and motion, a process which identifies the atomic parts of a task and then discovers the most efficient way to perform that atom of work and the minimum time that efficient atom should take a suitable person without injuring that person's health or wellbeing.(Taylor, 1967) Part of Taylor's ethos was *"functional management"* in which the shop-floor workforce should not be required to do the planning. Describing the traditional foreman he wrote:

> *"His duties may be briefly enumerated as follows: He must lay out work for the whole shop, see that each piece of work goes in the proper order to the right machine, and that the man at the machine knows just what is to be done and how he is to do it. He must see that the work is not slighted, and that it is done fast, and all the while he must look ahead a month or so, either to provide more men to do the work or more work for the men to do. He must constantly discipline the men and readjust their wages, besides fixing piece work prices and supervising the timekeeping."* (Taylor, 1993, p. 1388)

Believing planning work to be clerical in nature and that every detail of a job should be thought out in a *"planning department"* Taylor developed an extensive hierarchy of middle management under the planning department to ensure that each task was carried out precisely according to plan. (Taylor, 1993)

Fordism and Taylorism, as the contemporary philosophies became known, established the foundation for the evolution of modern manufacturing. It should be remembered, however, that around the turn of the century the United States were booming, population, industry and wealth were expanding rapidly creating a burgeoning market. Organisations only had to do one activity well, eg make cloth or steel, provide transport or retail goods, and they could be confident of profitability.

This profitability and expansion led to the evolution of the multidivisional corporation, decentralised and developed to capture economies of scope and requiring new measures and systems to coordinate activities. (Johnson & Kaplan, 1991)

Engineers and accountants around 1900 used information about standard material and labour costs to:

1. monitor physical labour and material efficiencies and
2. control operations using variations between standard and actual costs.

Johnson and Kaplan point to a third purpose for standard cost information which soon developed; the simplification of inventory evaluation using standard costs.

> *"By 1925 virtually all management accounting practices used today had been developed:...evolved to serve the informational and control needs of managers of increasingly complex and diverse organisations. At that point the pace of development seemed to stop.*[1]*"* (Johnson & Kaplan, 1991, p. 12)

2.2 Inventory

> *"The term inventory refers both to goods that are awaiting sale and to those that are in the various stages of production. It includes... the finished goods, the work in process and the raw materials of the manufacturer."* (Mitchell & Granof, 1981, p. 195)

---

[1] The emphasis is mine – kwd

Inventory, intrinsic to conventional manufacturing management, is a concept with two faces – on the one hand it provides a means by which company accountants can compute return on investment (ROI) from capital tied up in the running of the company and any excess of income over expenses, on the other it provides security of production by ensuring prompt delivery (to the customer or a downstream process) regardless of disruption of production.

2.2.1 Inventory and Accounting

Prior to 1800, outputs of separate processes were regularly exchanged in the marketplace. For example, the products of shearing, spinning, weaving and finishing changed ownership between the farmer and the various craftspeople involved and each was, therefore, able to compute profit and loss by simple comparison of outlay and income (costs being defined by market forces). Under this regime, businesses used accounts primarily to record the results of these market exchanges. By the start of the nineteenth century, textile merchant/entrepreneurs were taking control of spinning, weaving and finishing within a single enterprise. This change necessitated an emphasis on accounting for interests within the company and on the use of accounting records in administrative control of the enterprise.

> *"The aggregation of capital equipment in one place in a changing technological environment resulted in problems of calculating depreciation for inclusion in product costs, the valuation of inventories and the determination of income."* (Mathews, Perera, et al., 1991, p. 16)

Management was forced to synthesise intermediate product values to replace those defined by the market to provide a rational basis for the evaluation of internal

conversion costs, according a share of labour and factory overhead costs to each product (usually on the basis of the employee hours spent on each process).

> "[Such accounts] *do devote some attention to an organisation's total costs and profit. They give primary attention, however, to the outlay on internally controlled resources per unit of intermediate output.*" (Johnson & Kaplan, 1991, p. 22)

Increasing complexity in manufacturing processes (such as those which produced reapers, sewing machines and typewriters) made it difficult to gather precise information about the efficiency of specialised workers but by the 1880s systems had been developed by such groups as the American Society of Mechanical Engineers (ASME) similar to those in the textile and steel mills. Frederick W. Taylor's '*scientific management*' techniques provided a basis on which standard costs could be established, and variation between actual and standard costs provided an analytical basis for operations control.

Accountants of the era recognised the convenience of standard costing for inventory valuation and by the start of World War I the emphasis in accounting had swung from the provision of information about underlying processes, transactions and events as the basis for managerial decisions to be replaced with the valuation of inventory for external financial reports (notably for shareholders and taxation calculation).

> "*In* [the place of procedures for computing managerially relevant product costs] *appeared the costing procedures that twentieth-century accountants developed to value inventories for financial reports. While those procedures yield cost information that apparently aids financial*

reporting, the same information is generally misleading and irrelevant for strategic product decisions." (Johnson & Kaplan, 1991, p. 126)

"As overhead has increased and direct labour has decreased the use of direct labour [hours]*for allocation of overhead has become inappropriate."* (Linnegar, 1988, p. 9)

From the 1920s to the 1960s, when America's domestic market was relatively isolated from world competition, a period of growth in wealth and market size in which rates of production were a primary concern, this subtle change made little difference. Large organisations with diversified products kept the problems of collecting managerial information under control by creating multiple divisions, responsible to the parent company in terms of ROI, acting as small, individual companies. By 1970, however, William A. Paton was pointing out that pricing of the basis of costs (including the capital cost of inventory) attached *"like barnacles"* to the materials being processed was at odds with valuation in a free market[2]. Market price might be above or below a calculated cost figure. However:

"Acceptance of the inventory costing view of cost accounting is today so complete that all memory or knowledge of cost and managerial accounting practices in pre-1914 American manufacturing firms seems dead. (Johnson & Kaplan, 1991, p. 140)

"A survey of information preparers and users in an automated manufacturing environment indicated that 54 percent of preparers were

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[2] Stone, Willard E. (1971). Foundations of Accounting Theory. Gainesville, FL (USA): University of Florida Press --- cited in (Johnson & Kaplan, 1991, p. 139)

dissatisfied with their costing methodologies, and 62 percent of users were similarly dissatisfied." (Linnegar, 1988, p. 39)

Two significant factors are apparent, then, from the situation in western industrial management at the start of the 80s: firstly, as demonstrated above, management lacked specific information relevant to intimate control of productive processes and, secondly, inventory was an accepted part of the industrial scene, good in that it was considered to be an asset of the company concerned. Horngren (1982) lists total inventories (finished goods plus work in process plus materials and supplies) as part of a manufacturer's total current assets, an opinion reflected in Australian texts:

"Businesses also have assets and these would include... inventories or stock of goods they own..." (Kirkwood, Ryan, et al., 1989, p. 13)

"Proper accounting for inventories is critical not only because they often comprise a substantial portion of a firm's assets..." (Mitchell & Granof, 1981, p. 195)

"If the balance sheet is to represent the financial position of an entity... all assets including inventories..." (Mathews, Perera, et al., 1991, p. 160)

This view was supported at the theoretical level:

"The Australian Accounting Research Foundation provides that an asset shall be recognised in the financial statements when, and only when,: (a) it is probable that service potential or economic benefits embodied in the asset will eventuate, and (b) it possesses a cost or other value that can be measured reliably." (Mathews, Perera, et al., 1991, p. 133)

Furthermore, inventory was entrenched in industry by the practice of forward-ordering stock or raw materials in lots of a calculated size (Economic Order Quantity (EOQ)). Horngren (1982) cites the following formula for the calculation:

$$E = \sqrt{\frac{2AP}{S}}$$

Equation 1 : Economic Order Quantity[3]

where 'E' is order size, 'A' the annual quantity used in units, 'P' the cost per purchase order and 'S' the cost of carrying one unit in stock for one year. Obviously, 'E' increases with increase in 'A' or 'P', or with decrease in 'S'.

2.2.2 Inventory and Production

Production process thought in conventional (western) (push-style) manufacturing demanded the presence of inventory to achieve smooth production flow, reasonable machine utilisation and material handling costs.

> *"Inventories serve the vital function of decoupling the various operations in the sequence at each stage of both manufacturing and distribution...*[and] *make the required operations between each pair of activities in this sequence sufficiently independent of each other that low cost operations can be carried out."* (Buffa, 1977, p. 371)

[3] cp *(Buffa, 1977, p. 379)* $Q_O = \sqrt{\frac{2C_pR}{C_H}}$ *where 'C_H' is optimal order quantity, 'C_p' is order preparation costs and 'R' is demand.*

"We have traditionally clung to inventory as a security blanket to protect us against the complexities and disruptions of our plants and the vagaries of customer demand." (Goldratt & Fox, 1986, p. 68)

Push system production is not governed by market demand but rather by a perceived need to keep inventory at certain levels and an order may be placed with no knowledge of timing or quantity or future demand. Excessive stocks may alternate with needless stockouts because of the unavailability of managerially significant inventory information referred to above. Process variability exacerbates this problem where conventional materials flow management is based on mathematical queuing theory. If the mean arrival rate of batches at a workstation is 'λ' and the mean service rate is 'μ', and if any random variations exist in either, then where '$\mu = \lambda$' the length of the queue (size of the inventory) will build to infinity. Intuitively, this is because the server will not, in the long run, be able to catch up after random periods of idleness due to lack of supply. Mathematically, 'T_Q' (waiting time in the queue) and 'L_Q' (length of the queue) are found, where a batch arrival may occur at any random time interval, by

$$T_Q = \frac{\lambda}{\mu(\mu - \lambda)}$$

Equation 2 : Waiting Time in Queue

and

$$L_Q = \frac{\lambda^2}{\mu(\mu - \lambda)}$$

Equation 3 : Length of Queue

(where $\mu = \lambda$ then $\mu(\mu - \lambda) = 0$ so T_Q and L_Q are infinite). (Gibson, Greenhalgh, et al, 1995, p. 75) To avoid this infinite build-up, therefore:

> *"The only means by which we can arrange for the output of the second production resource to equal the input to the first production resource is by deliberately interposing a buffer stock between the two resources."* (Gibson, Greenhalgh, et at., 1995, p. 77)

> *"If a plant manager misses his shipping targets a couple of months in a row by as little as 10% the plant will probably lose money... Consequently, he's likely to keep lots of inventory just in case it's needed... if inventory is reduced too much, some operations might be starved for work, causing operating expenses to go up. Our performance measurements rivet our attention on these short-term measures, keeping inventory high..."* (Goldratt & Fox, 1986, p. 68)

Inventory, then, is an accepted part of conventional manufacturing management thinking and is accorded respectability by its treatment as a company asset. It tends, however, to excess on two grounds:

1. the presence of safety stock
2. the presence of production smoothing stock.

This excess inventory was acceptable in the production-oriented manufacturing processes which were standard in the western world prior to the 1980s, however, during the first half of the 1980s, the competitive environment changed completely. Although western manufacturers at first believed that foreign, particularly Japanese, inroads into their traditional markets could be attributed to lower wages. It is now recognised that innovative practices including Total Quality Control (TQM), just-in-time inventory systems (JIT) and Computer Integrated

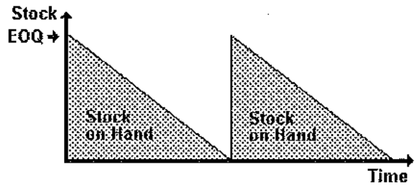

Figure 1 : Consumption of Inventory

Manufacturing (CIM) were at the root of the Japanese success. (Johnson & Kaplan, 1991, p. 210)

2.2.3 EOQ and Inventory

Conventional, western-style manufacturing requires inventory.

> *"If production and delivery of goods were instantaneous, there would be no need for inventories except as a hedge against price changes. Despite the marvels of computers, processes still do not function quickly enough to avoid the need for having inventories... production operations cannot flow smoothly without having inventories of direct materials, work in process, finished parts, and supplies."* (Horngren, 1982, p. 756)

In a case where demand is constant a consumption graph can be developed which will show the stock on hand at any given time (Figure 1 on page 17). Given that the timespan between issuing the order and receiving the goods is predictable, it is then easy to define the stock level at which a re-order must be placed allowing sufficient stock to carry-over to the next delivery (Figure 2 on page 17). In this

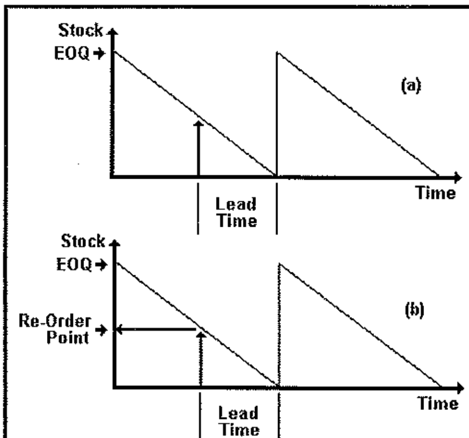

Figure 2 : Calculating Re-Order Point

scenario, new stock arrives at the same time as the old stock runs out.

Uncertainties over consumption, however, require that allowances be made (on statistical theory) for the situation where consumption suddenly leaps during the lead time. Figure 3 page 18 shows the increased consumption as the heavy, dotted line and that, without a level of safety stock, that inventory would be used up before the new supply could be expected. Safety stock, then, allows processes to continue (whether sales or production) regardless of reasonable variation in stock consumption. Safety stock buffer size, then, is the difference between '$\overline{D}$' the average demand and 'D_{max}' the reasonable maximum demand (for the lead time), but given that

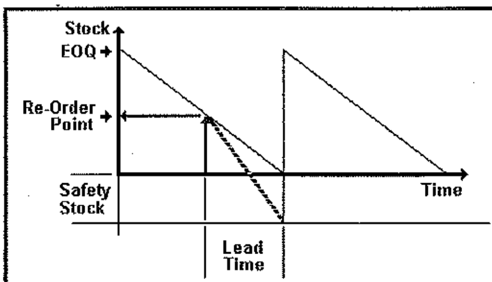

Figure 3 : Effect of Increased Consumption

$$D_{max} = \overline{D} + n\sigma_D$$

Equation 4 : Maximum Demand

where 'n' is an arbitrary safety factor and 'σ_D' is standard deviation of demand, we can calculate buffer size 'B' by

$$B = D_{max} - \overline{D} = \left(\overline{D} + n\sigma_D\right) - \overline{D} = n\sigma_D \quad \text{(Buffa, 1977, p. 386)}$$

Equation 5 : Buffer Size

An additional order can be placed to cover the excess consumption.

"In principle, it is possible to ensure a regular flow of material to the factory departments by suitably sizing the safety stocks: the higher the

minimum inventory, the lower the probability of stockouts while waiting for new supplies.: (Sartori, 1988, p. 159)

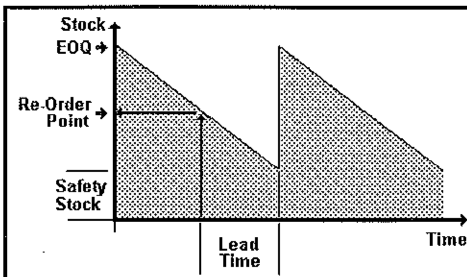

Figure 4 : Effect of Safety Stock on Inventory

Figure 4 page 19 shows the effect this safety stock has on inventory – stock on hand is represented by the shaded area under the graph, a significant increase in area (stock) over that shown in Figure 1 (page 17). Substantial capital investment, therefore, can be tied up in inventory which may never be used. It must be asked whether this investment in safety stock inventory, calculated on the basis of a safety factor and estimated possible fluctuations in demand, which offers only marginal potential to deliver a return, would have become acceptable had not conventional accounting wisdom ruled that the goods in question could be counted as an asset.

> *"The inventory control system is able to provide an acceptable level of effectiveness only through a heavy buffer in terms of inventory investments, whose cost threatens to offset any benefits obtained."* (Sartori, 1988, p. 159)

This view was not universally shared. Eero Eloranta and Juha Raisanen of the Helsinki University of Technology found:

> *"A common belief in discrete, make-to-stock manufacturing is to believe that high inventories would imply good service level. This axiomatic belief, even though intuitively reasonable, does not follow the material found in our case studies."* (Yoshikawa & Burbridge, 1987, p. 23)

Toyota had come to a view of their own.

"Inventory, in Toyota's view, is a 'waste'." (Bignell, Dooner, et al., 1985, p. 152)

3. The Current Climate of Change

3.1 Toyota Production System

"...Japanese production system made planning for the manufacture of automobiles the most modern process in the world including the Ford system." (Portera, Cole, et al., (1991))

Just-In-Time (JIT) is an inventory flow control system for manufacturing developed by Toyota in the early 1970s under the leadership of Vice-President Taiichi Ohno. Often alternatively referred to as the *"Kanban"* system (after the inventory flow control cards used in the system), JIT is inextricably bound to the philosophy of Total Quality Management (TQM) which it expresses in terms of the concept of zero defects.

"If you do not take your quality control seriously and yet try to adopt the kanban system, your factory will simply stop operating." (Ishikawa & Lu, 1985, p. 168)

"A JIT process cannot work without strict quality standards, as the need to rework a production lot or to eliminate a few defective parts can upset the delicate balance of flows into and out of each cell." (Sartori, 1988, p. 206)

"Nothing makes quality problems with suppliers and in the factory more evident than a Just-in-Time system... A Just-in-Time manufacturer has no choice but to procure quality parts for the company's process. The

manufacturer also has to run a quality process in his or her operation; otherwise, Just-in-Time will bring the production line to a screeching halt." (Hernandez, 1993, p. 9)

"Unless there is an assurance that parts flowing through all the processes are good products, the kanban system itself will collapse." (Japan Management Association (eds), 1985, p. 88)

TQM (zero defects) philosophy is beyond the scope of this document but its relevance to JIT demanded that the point be made at the outset and not lost in the explanation of a system.

3.1.1 Evolution

Commentators quote a variety of reasons for the rise of the JIT system:

- *"reconciling maximum efficiency with a reasonable level of flexibility "* (Sartori, 1988, p. 200)
- *"a crusade to increase productivity by eliminating waste in all its forms"* (Hernandez, 1993, p. 10)
- *"through* [Toyota management's] *incessant efforts in management control, particularly in quality control"* (Ishikawa & Lu, 1985, p. 169)
- *"The most apparent goal of the JIT system is... to minimise work-in-progress [WIP] inventory."* (Dyck, Varzandeh, et al., 1991, p. 452)
- *"The Toyota system is a series of activities that promote cost reduction through the elimination of waste to achieve enhanced productivity."* (Japan Management Association (eds), 1985, p. 30)

All the above quotations appear to relate to the situation in which Japan was left at the end of World War II. Sartori (1988) lists the major differences between the industrial situations in the USA and Japan during the later part of the Japanese reconstruction as shown in Table 1 on page 23.

USA vs Japan - Industrial Scenario		
	USA	Japan
Natural Resources	plentiful	scanty
Market	mature	developing
Industrial Base	well rooted	recent
Workforce	mobile	loyal

Table 1 : USA vs Japan - Postwar Industrial Scenario

Scarcity of natural resources and the need to compete in international markets appear to be the forces behind the move to innovative methods, while the newness of the plants and the cultural context of social tradition motivating the workers produced the environment in which the new concepts could take root.

In contrast, a combination of high inflation and a weak [US] dollar sheltered US manufacturers from foreign competition. International demand for US products was high allowing higher costs and, occasionally, substandard quality to be passed on to the customer. That situation changed suddenly and substantially in the early 1980s. (Johnson & Kaplan, 1991, p. 209)

"After World War II, Japanese planners developed strategies for competing with the United States and Western Europe... Growing international price competition forced continual reductions in manufacturing and marketing costs. When Japan's competitive advantage derived from low-cost labour became exhausted, purchasing and inventory management systems became a focus for cost reductions. This led to JIT, although it did

not become widespread throughout Japan until the OPEC embargo in 1973." (Meredith, Ristroph, et al., 1991, p. 448)

Japan's economy collapsed to a state of zero growth under the effects of the 1973 oil crisis yet Toyota's earnings increased and the widening gap between it and other companies, many of whom had continued to use the conventional American-style system of mass production, generated interest in the Toyota system. (Robinson, 1991, p. 133)

3.1.2 More Than Just an Inventory Control System

Shigeo Shingo (described by Norman Bodek (President of Shingo's US publishers) in a foreword to Shingo (1988) as the *"dean of productivity and quality consultants"*) has been instrumental in the productivity improvements of hundreds of companies including Toyota, Honda, Kanzai, Matsushita, Sony, Sharp and Nippon Steel. He makes the point that there is more to the Toyota Production System (TPS) than the kanban card system of just-in-time production control.

> *"Without an understanding of the system's basic concepts and implications... truly effective innovation in production management will not be achieved."* (Shingo, 1988, p. 3)

An overview of some of the ramifications of the JIT system is presented in the following sections.

3.1.2.1 ELIMINATION OF WASTE

> *"Principle 4* [of Quality Management]- *Process Approach:*

All activities within an organisation should be organised, managed and conducted as a process." (WG15 of ISO TC 176 on Quality Management and Quality Assurance, 1995)

JIT systems take an attitude to waste quite different to the traditional which considers the term in the context of rework and scrap.

"Just-in-Time defines waste as any activity that doesn't add any value to the product." (Hernandez, 1993, p. 10)

Transport time, inspection time, work-in-progress (WIP) inventory and material stored in stock are all included under the title of *'waste'*.

Major companies frequently have large amounts of capital invested in parts and supplies which are in the process of being transported from supplier to factory, from one division to another or from factory to customer. General Motors (GM) has more than 3,500 suppliers and at any one time more than half the company's $USbillion inventory may be being transported. While GM may have suppliers spread from California to Connecticut and beyond, Japanese manufacturers tend to deal with fewer suppliers (Toyota has less that 250) whose premises are close to hand and from whom several deliveries can be expected in any one day. (Sartori, 1988) JIT manufacturers also tend to deal with suppliers who are themselves committed to JIT and TQM.

"Working with suppliers whose processes are under control, and working with as few suppliers as possible, helps reduce the variability of input and ensure a stable input to the manufacturing process." (Luciano, 1993, p. 37)

Travelling time according to the JIT philosophy, however, also includes the time the product under process spends in the factory. Many factories use buffers to store semi-processed product between stages of the process – JIT seeks to eliminate that *waste* by transferring the product of one stage of the process directly to the next stage in precise job-lots, thereby reducing WIP inventory to a minimum. (Hernandez, 1993)

> *"Workers on the assembly lines drew components only as and when they were required, leaving a form requesting the same number of components to be manufactured... In this way, it was possible to avoid tying up useful capital in stocks of parts waiting to be used."* (Batchelor, 1994, p. 86)

3.1.2.2 Shopfloor Organisation

Workers' time is carefully orchestrated.

> *"Each worker has his own personal movement pattern, prepared by the foreman to avoid workers getting in each other's way and to share out the work load fairly."* (Sartori, 1988, p. 205)

This echoes the theories of F W Taylor developed as *'Scientific Management'* at the turn of the century and involving the concept of the study of time and motion. He insisted that this orchestration was the function of the foremen and the planning department and should not be left to the workers themselves. (Taylor, 1993). Professor Kaoru Ishikawa believed that the legacy of extreme implementation of the Taylor system was largely responsible for labour alienation and lack of worker concern for the company.

"*The* [Frederick W.] *Taylor method does not recognise the hidden abilities workers possess. It ignores humanity and treats workers like machines. It is no wonder that workers resent being treated that way and show no interest in their work.*" (Ishikawa & Lu, 1985, p. 25)

He proposed the voluntary organisation of the workforce into groups with common work interests and experience who could be trained in problem solving and given time to identify and recommend opportunities for improvements and, where possible, to implement them. Ishikawa's *'Quality Circle'* system has had significant influence in the restoration of craftsmanship, pride in the job and in the motivation and involvement of the workforce in the future of the company. Westerners sometimes mistake this involvement for some form of cultural difference between Japanese workers and their Western counterparts. (Hutchins, 1988) Some cultural

Country	Abbrev-iation	Individualism		Power Distance		Uncertainty Avoidance		Masculinity	
		Index	Rank	Index	Rank	Index	Rank	Index	Rank
Australia	AUL	90	49	36	13	51	17	61	30-31
Germany (FR)	GER	67	36	35	10-12	65	23	66	41-42
Great Britain	GBR	89	48	35	10-12	35	6-7	66	41-42
Japan	JPN	46	28-29	54	21	92	44	95	50
New Zealand	NZL	79	45	22	4	49	14-15	58	34
U.S.A.	USA	91	50	40	16	46	11	62	36

Table 2 : Cultural Differences

dimension in the human component of manufacturing is seen to exist:

Table 2 on page 27 (ref: (Hofstede, 1984, p. 85)) is part of a larger chart containing indices and rankings for 50 countries on:

1. Individualism rated as a preference for a loosely knit social framework in society,
2. Power Distance ranking a society's acceptance of unequal power distribution,
3. Uncertainty Avoidance as the degree to which members of a society feel uncomfortable with uncertainty and ambiguity and
4. Masculinity as a preference in society for achievement, heroism, assertiveness, and material success.

These index scores are relative with the lowest country around zero and the highest around 100 (eg Japan scores the highest ranking out of fifty for masculinity with an index of 95). While the figures do indicate broad spectrum differences between cultures, Hofstede does not conclude that these changes preclude the importation/exportation of systems and concepts across cultural boundaries, instead that:

> *"Effectiveness within a given culture, and judged according to the values of that culture, asks for management skills adapted to the local culture."* (Hofstede, 1984, p. 98)

Others are more opinionated:

> *"Cultural differences between Japan and the U.S. will affect implementation strategies in the U.S., but they clearly do not preclude the use of JIT in the U.S."* (Meredith, Ristroph, et al., 1991, p. 448)

Indeed, the translocation of JIT into the USA has frequently been highly successful, notably in that US bikie icon Harley-Davidson. Other cases listed may

include Apple, GM, General Electric, Gillette, Xerox and Hewlett Packard. (Meredith, Ristroph, et al., 1991, p. 448) Ford (UK) failed to introduce Quality Circles in 1981 (Storey, 1994, p. 177) yet Schonberger[4] in a study of the Kawasaki plant at Lincoln, Nebraska, concluded:

> *"Management technology is a highly transportable commodity."*
>
> *"The attitude that Toyota's management and workers bring to each of these issues is not inherent to their 'culture'. In fact, a sizeable number of American firms have both the same philosophy and similar results."*
>
> (Bignell, Dooner, et al., 1985, p. 154)

[4] Schonberger, R.J.. (1982) Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity, Free Press, New York – cited in (Storey, 1994, p. 177)

3.1.2.2.1 Form Follows Function

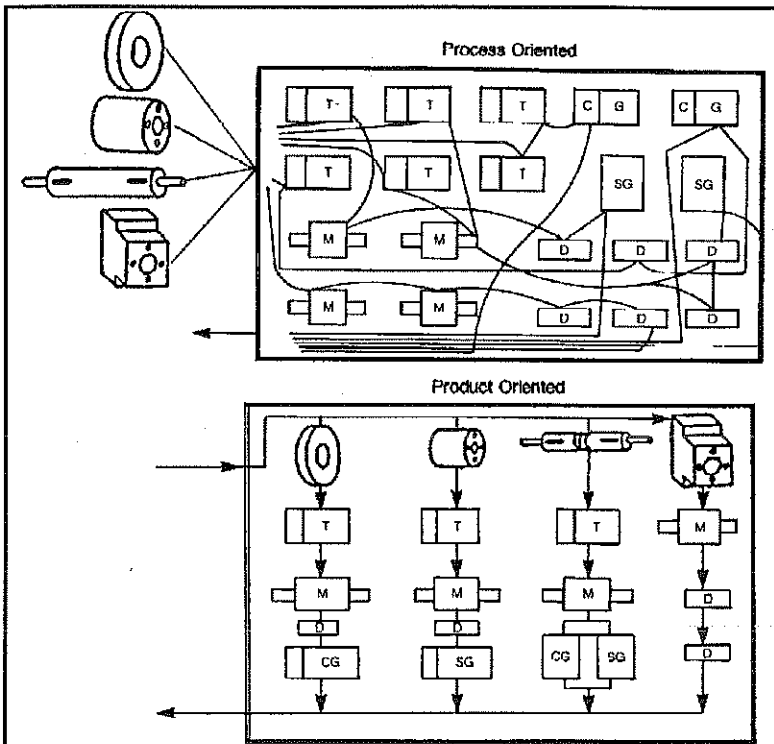

Figure 5 : Process vs Product Flow Design

A corollary to Ishikawa's Quality Circles is the organisation of machines into production cells, often laid out in a U-shaped line, inside which the workers move and in which the arrangement of the machines reflects the sequence of operations reducing transit times and allowing robotic materials handling. This establishes a functional independence between the cells and allows each cell to represent a single, higher-level machine. (ref: Figure 5 on page 30, (Kerr, 1991, p. 28)) Kerr does not identify the machine types but I would suggest they represent:

1.T = Turning (Lathes)

2.M = Milling

3.D = Drilling

4.CG = Centerless Grinding

5.SG = Surface Grinding.

"A change to production-oriented layout can result in much simpler material flow patterns... Stock handling costs are reduced, and coordination greatly improved." (Kerr, 1991, p. 27)

However, if some machines are capable of working faster than the pace of the cell as a whole, JIT forbids saturating them with job lots from outside the cell. JIT requires that machines which are, at a given instant, not required to produce, stay idle. Although this appears inefficient, it is an integral part of the greater concept. (Sartori, 1988) (Silva, 1992)

"Overproduction creates a countless number of wastes, such as over-staffing, pre-emptive use of materials and energy costs, advance payment to workers, interest charges on mechanical devices and products, storage areas needed to accommodate the excess products and the cost of transporting them. In a period of low economic growth, overproduction is a crime." (Taiichi Ohno cited in (Japan Management Association (eds), 1985, p. 20))

3.1.2.3 POKA-YOKE AND ZERO DEFECTS

Inspection time also comes under scrutiny in JIT thinking.

"It has been claimed that:

1. 10 percent of production costs are inspection activity;

2. 90 percent of inspection is visual;

3. 80 percent of inspection has no visual aids of any kind;

4. people miss 15 percent of defects." (Hutchins, 1988, p. 109)

No actual value is added to any part during its time under inspection which merely proves that the part meets the specification. JIT's close association with the process-oriented thinking of TQM (mentioned above) ensures the production of quality parts which do not need double inspection. (Hernandez, 1993) In support of this drive towards zero defects, the concept of *'mistake proofing'* (known as *Poka-yoke*) involves modification of the process or the part being processed such that mistakes are eliminated.

> *"The poka-yoke system is based on the philosophy that zero defects is not an ideal, unattainable goal but a practical, achievable everyday process. It is achieved through the use of simple, inexpensive poka-yoke devices which prevent defects from being possible or catch mistakes before they become defects."* (Cassidy & Sharma, 1992, p. 165)

> *"Two inspectors may be able to catch defects that might slip by one inspector... That issue, however, is unrelated to the question of reducing defects... Since defects are generated during the process, all you are doing is discovering those defects... there's no way you're going to reduce defects without using processing methods that prevent defects from occurring in the first place."* (Shingo, 1986, pp. 35-36)

For example, parts may be shaped, sized or provided with alignment pins so that incorrect assembly is impossible; vending machines may be installed to supply similar parts in correct order for assembly so that an incorrect part cannot be selected. (The JUSE Problem Solving Research Group (eds).(vol. 2), 1991, p. 67) Simplifying an assembly process can also aid productivity and quality;

> *"The simpler it is, the less it can vary and the less that can go wrong. In addition, reducing the number of decisions the operator has to make speeds the process."* (Luciano, 1993, p. 36)

Shingo originally based his quality testing philosophy on the pretext that the worker at each workstation would be the inspector of the work performed on the immediate upstream workstation, reasoning that the objectivity of the testing would be greater than would be the case if each worker inspected his own product. He found, however, that where self-checking was combined with the introduction of poka-yoke tools and jigs the feedback which lead to the change in the process to eliminate defects at the source was much quicker and success rates rapidly outstripped those obtained from statistically-based *'statistical quality control'* (SQC) methods. In the absence of the opportunity to use poka-yoke tools and jigs, he devised the method of *'source inspection'* aimed at eliminating process defects prior to the commencement of production.

> *"I repeatedly heard people say that the SQC system '<u>builds quality into the process.</u>' But where was the evidence? My claim was that a process is a flow in which raw materials are converted into finished products, and that any errors in process standards would naturally generate defects... It follows from this, surely, that it is correct to say that quality is built into the processes."* (Shingo, 1986, pp. 51-52)

Prompt feedback of information obtained from 100% checks of the product is of paramount importance committing poka-yoke lines to immediate line shutdown when defects are detected – a practice regarded as an heresy in conventional manufacturing.

Shingo asserts that shutdowns allow identification and improvement of offending processes immediately and that the lack of defects after the shutdown more than compensates for production losses incurred.

Significantly, few of the poka-yoke tools and jigs detailed in Shingo (1986) cost more than a few hundred dollars to install yet plants using the system regularly run consecutive months without producing defects.

3.1.2.4 SINGLE MINUTE EXCHANGE OF DIES

> *"In the conventional EOQ model, setup cost and lot sizes are at opposite ends – ie. minimisation of setup cost resulted in increases in lot sizes. The Japanese have solved this problem by reducing setup times, thereby enabling them to produce in small lot sizes."* (Dyck, Varzandeh, et al., 1991, p. 453)

> *"In practice, Japanese companies were able to achieve set-up times of three to five minutes in processes that took US manufacturers more than six hours to change over."* (Johnson & Kaplan, 1991, p. 214)

Two types of operation in the process of die changing were identified

- inside exchange of die (IED) including processes that can only be performed when the machine is stopped
- outside exchange of die (OED) including process which can be conducted while machine is in operation. (Shingo, 1985)

OED times are reduced as much as possible with, for example, dies being pre-delivered to the press, placed on rollers at the appropriate height and pre-heated

to working temperature ready for the extraction of the old and insertion of the new using hydraulic rams. Dies are of standard vertical dimension and can be keyed for precise and immediate location. A single fitter often carries out the process. Also, pre-heating means the machine can re-commence production virtually immediately.

IED times are also reduced: standard bolt-head sizes avoid changes of socket; single-turn tightening (sometimes using sectionally threaded bolts which can be dropped into a hole and tightened with one third of a turn) avoids spinning the bolts in by hand; slotted holes in the die can eliminate the need to remove the hold-down bolts; etc.

Shingo gives examples of exchange-time improvements in presses, plastic forming machines and die-cast moulding machines of up to 1/63 and averaging between 1/18..1/20 (Shingo, 1985) , however the major factor is that the reduced times eliminate the need for large production runs to achieve efficiency required under an EOQ system.

3.1.2.5 ANDONS AND AUTONOMATION

> *"Everything is standardised, and the system emphasises only those things that vary from the established standards. In other words, we teach supervisors how to engage in abnormality control."* (Japan Management Association (eds), 1985, p. 155)

One of the features of Japanese JIT manufacturing is the rapid feedback of defect (abnormality) information leading to rapid restructuring of the process – even at the cost of stopping the production line. To assist this process, automatic display boards are installed which display the location of the work stoppage. This enables

workers and supervisors to give the problem immediate attention – to collectively deal with the source of the problem and prevent its recurrence. However, this concept finds echo in the Goldratt-devised Synchronous Manufacturing philosophy dealt with later:

> *"Since the output of the whole factory hinges on the productivity of the CCR*[5]*, set-up times on the CCR must be driven to absolute minimums. Since non-CCR work centers no longer need to be run at high utilisation, personnel can be brought from these areas to assist in set-up time reduction."* (Smith, 1994, p. 5)

Such a display is given the name *'Andon"*, the word for a paper-covered lampstand.

Both workers and machines are accorded this right to stop the line for detected abnormalities – and light the Andon – machines under the system Toyota calls *'automation with a human touch"* or *'autonomation'*. This idea of autonomous automation of machinery was developed by the founder of Toyota, Toyoda Sakichi, who developed a weaving loom which stopped instantly if one of the threads broke. Concepts such as poka-yoke and zero defects obviously integrate with autonomation. (Robinson, 1991, p. 138)

3.1.2.6 RATIONALISATION

Another factor which underpins JIT is a rationalisation of product coding, process coding and plant layout.

5 Capacity Constraint Resource – Described in the chapter on Synchronous Manufacturing (ref: page 71)

> *"Proliferation of part numbers is a parasitical by-product of company growth that often prevents the achievement of economies of scale in purchasing, in inventory management and in quality control efforts, apart from upsetting the orderliness of the actual product structure."* (Sartori, 1988, p. 201)

Sartori (1988) cites a Chrysler subcompact (motor car) which was available with different chrome-plated finishing strips on the doors each type of which required a special fixing device – attendant upon this is the increased inventory overhead, documentation overhead and a proliferation of specialised fixing tools. Surveys show that only 20% of parts in a new product are truly new, the others already exist or can be obtained by minor changes. He proposes a rationalisation strategy culminating in the development of a company-wide data set allowing the selection of parts for a new product based on functionality (eg capacitance or voltage, thread profile or length) rather than part number. (ref: Group Technology, page 59)

> *"Lack of easy access to previous similar designs leads to an unnecessary proliferation of new designs and part numbers."* (Kerr, 1991, p. 25)

3.1.2.7 Load Smoothing

For the Toyota Corona, the range of styles, tyres, colours, options, upholstery etc gives a possible 800,000 combinations. In a given month's production of 20,000 units no more than 50 units will have similar specifications. If all the red-exterior cars are produced in a run, then the line producing white exterior car bodies lies idle, similarly with 1.8 litre and 2 litre engine options. Toyota mix the run on the final assembly line and adjust the allocation of machinery and manpower to the various

upstream processes so that all parts of the factory, and the factories of their suppliers, can be running all the time. This process of *"load smoothing"* is another fundamental to the operation of JIT manufacturing.

> *"At Toyota, we manufacture through load smoothing, we figure out the cycle time and we create standard operations. We then promote our improvement activities. These are the basic steps we have consistently followed."* (Japan Management Association (eds), 1985, p. 56)

3.1.2.8 KAIZEN

JIT philosophy is one of continuous improvement in which each and every facet of production is under constant scrutiny by all members of the workforce. From a workforce of 60,000 Toyota received 2.6 million process improvement suggestions in the calendar year 1986. Of these 96% were implemented.

> *"Nothing is left to chance, and no deficiency, no matter how rare, is ever regarded as a purely random event which should be ignored."* (Hutchins, 1988, p. 10)

> *"The essence of Kaizen is simple and straightforward: Kaizen means improvement. Moreover, Kaizen means ongoing improvement involving everyone, including both managers and workers. I feel that* [people who have studied factors in the Japanese postwar 'miracle' such as TQC, the suggestion system, automation and industrial robots] *have failed to grasp the very simple truth that lies behind the many myths concerning Japanese management."* (Imai, 1986, p. 3)

Terms like Total Quality Control (TQC), Statistical Quality Control (SQC), Quality Circles (QC) and Company-Wide Quality Control (CWQC) often arise in discussions of Kaizen yet, while it is intrinsic to the Quality Movement, it is not the prerogative of the Quality Movement. Kaizen is all-pervading, touching on every facet of the manufacturing processes in which it is implemented – but Kaizen is a philosophy and, as such, may be considered beyond the scope of an investigation of industrial computer systems since there appears to be little scope for computer support except where it might be supplied in the statistical area of the Quality process. This might be expected to be most applicable in the area of raw materials and parts purchasing:

> *"In Japan, where most of the manufacturers purchase about seventy percent of their purchase cost, the importance of this supplier quality cannot be overemphasised. Quality assurance of parts and materials purchased from suppliers is the key to the manufacturer's own quality assurance."*
> (Ishikawa & Lu, 1985, p. 165)

In fact, the Japanese philosophy of dealing with few suppliers (ref: page 25) who also effect JIT practices (including Zero Defects!) may be seen to supersede TQM as practiced in the West.

3.1.2.9 JIT IMPOSSIBLE!

> *"In reality it is almost impossible to achieve just-in-time production in the literal sense, with zero waiting times and zero interprocess stocks. The term is actually used more to represent an ideal which should be aimed for, in order to foster the culture of continuous improvement which is part of the*

broader view of JIT as an important branch of value adding and total quality management." Gibson, Greenhalgh, et al., 1995, p. 169)

3.1.3 Kanban Practice

Figure 6 : Key to JIT Illustrations

JIT/Kanban processes are *'pull'* processes in which product flow through the plant is generated by each successive operation ordering product from its immediate upstream neighbour. Batches of product are organised onto palettes or into specially designed bins which rotate exclusively between one process and its predecessor or successor. Each batch of workpieces is, therefore, subject to short waiting periods prior to delivery to the next process but will arrive at the new process just in time for processing.

> *"The system does not allow material to be pushed forward to the next processing station only to remain idle waiting for available equipment. In an ideal Kanban factory material should only be delivered to a downstream operation when the downstream operation has immediate available equipment capacity to process that material."* (Kraft, 1992, p. 31)

Movement of these batches is controlled by authorisation cards (kanbans) which replace the *'work order'* in the conventional *'push'* system factory and from which they differ in three ways:

1. a kanban is issued when needed and not procedurally and at a pre-determined time, thereby eliminating traditional order states and their administrative overhead
2. kanbans are issued by the downstream process and until an empty palette or bin, with its kanban, arrives at a workstation that workstation remains idle regardless of any theoretical loss of productivity
3. each kanban represents an immediate requirement to be filled in *'real time'* thereby directly connecting the adjacent processes and making superfluous the holding of buffer stocks of materials between departments. (Sartori, 1988)

Inventory level in any area is controlled by the number of kanban cards which Toyota calculates according to:

$$y = D(T_w + T_p)(1+n)a$$

Equation 6 : Number of Kanban Cards

where 'y' is the number of kanban, 'D' is the demand per unit time, 'T_w' is the waiting time for the kanban to be returned to the supplying area, 'T_p' is the process time, 'a' is the container capacity (not more than one tenth of daily requirement) and 'n' is the policy variable which allows some excess stock to accommodate disruptions and variations in usage rate. Toyota's target is to keep 'n' below 0.1 which represents a buffer of one tenth of a day's usage[6]. (Graham, 1988, p. 20)

[6] Compare this inventory buffer level with that suggested by Goldratt in Synchronised Manufacturing (ref: page 69)

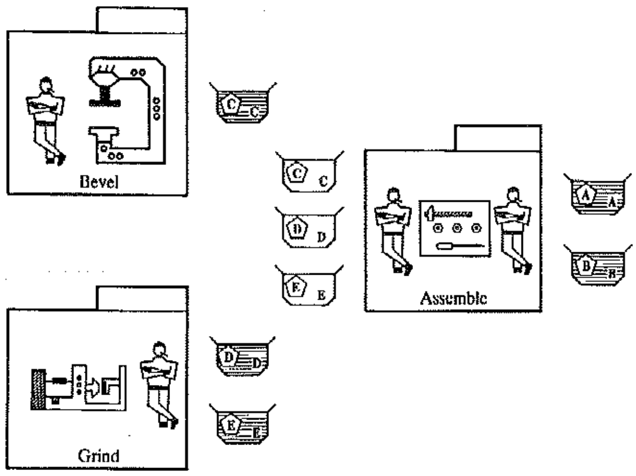

Figure 7 : JIT - Steady State

Note : *The example and illustrations in this section are from Sartori (1988), chapter 7 starting on page 197.*

In this example we consider the case of a factory producing two products, 'A' and 'B' which are assembled from parts 'C', 'D' and 'E'. Product 'A' requires parts 'C' and 'D' while product 'B' requires parts 'D' and 'E'. It is assumed that the bevelling, grinding and assembly operations concerned with a single bin of product take the same length of time.

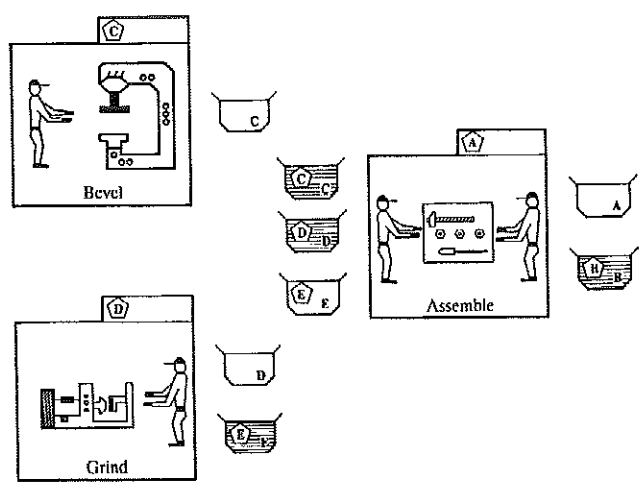

Figure 8 : Shipment of Product 'A'

Each individual product is allocated two bins and two kanbans. Figure 7 on page 42 shows the plant in the *'steady state'* in which has a filled bin of each of its products, with its kanban included, on its downstream side. Each workstation is idle because: 1) there has been no demand issued (no kanban received) from further downstream and 2) no workstation has a kanban in its *'hold box'*

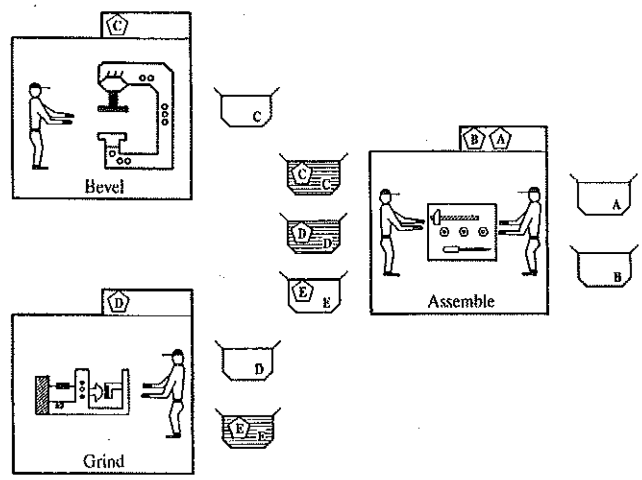

Figure 9 : Shipment of Product 'B'

(represented by the rectangle above each workstation icon). This illustrates the point that JIT is a *'pull'*-type system since no work proceeds in the production chain until downstream demand requires it.

When a bin of product 'A' is sold or moved to a process further downstream it is replaced with an empty bin and the kanban from that bin is placed in the assembly centre's hold box. For work to commence in the assembly centre, parts 'C' and 'D' are required so the empty bins on the upstream side of the assembly centre are replaced with full bins from downstream of the bevel and grind centres. Kanbans from those empty bins are placed in the hold boxes of the bevel and grind centres and work in those centres can also commence (Figure 8). This section of the process is now in full operation in response to downstream demand.

While work proceeds on the assembly of product 'A' (and on the production of parts 'C' and 'D') a batch of product 'B' is moved on (Figure 9), the full bin downstream of the assembly centre is replaced with an empty one from which the kanban is placed in the assembly centre's hold box. Work continues on the assembly of product 'A' until the batch is complete at which stage the bevel centre has filled the bin of product 'C and the grind centre has filled the bin of product 'D'. Kanban 'A' is placed in the full bin and work can now commence on the assembly of product 'B' requiring bins of 'D' and 'E'.

Work ceases at the bevel centre since there is no downstream demand (Figure 10), but proceeds in the grind and assemble centres. Chain stoppage is progressive; when the assemble centre has completed the assembly of product 'B' the grind centre will have filled the bin of 'D', the assemble centre will stop (no downstream demand) and the grind centre will continue producing 'E' until that bin is full. At that stage the situation returns to the *'steady state'* as represented in Figure 7 on page 42.

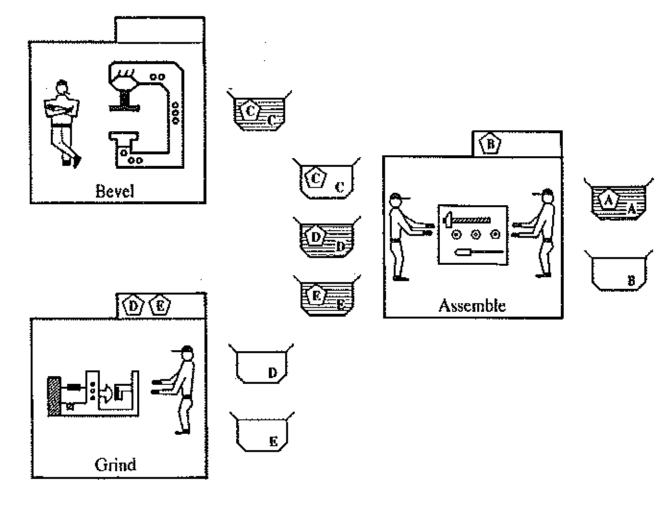

Figure 10 : Assembling Product 'B'

With this single-kanban system the possibility exists for a delay (eg perhaps due to forklift unavailability) as product bins are rotated between centres in response to demand. Toyota's materials handling system seeks to avoid this case by following a different procedure based on two kanbans for each item.

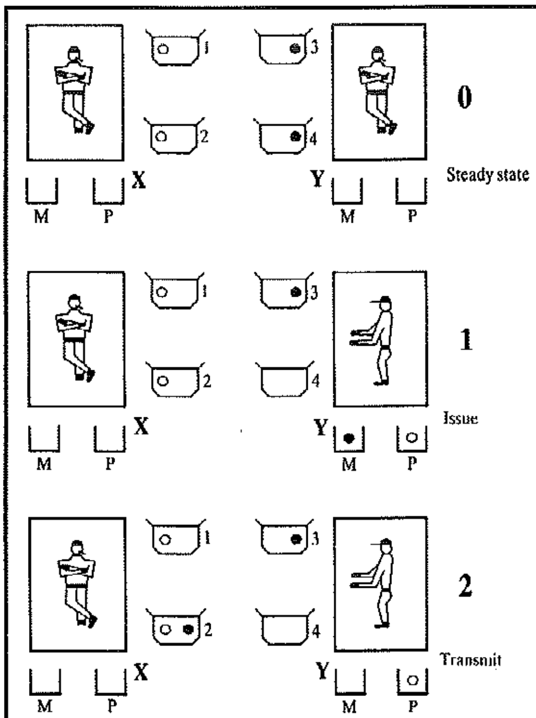

Figure 11: Two-kanban JIT (a)

These two kanbans are designated *'move'* (black dot) and 'produce' (white dot), stage '0' in Figure 11 on page 44 shows the steady state. When centre 'Y' receives a 'produce' kanban, product from bin 4 is utilised and the 'move' kanban is placed in 'Y' centre's move box (stage 1). Whoever is in charge places the 'move' kanban in bin 2 at 'X' centre which causes the 'produce' kanban from bin 2 to be placed in the appropriate hold box at 'X' centre (stage 2), bin 2 to be moved to 'Y' centre (stage 3 in Figure 12 on page 45) and the now empty bin 4 to be moved to 'X' centre (stage 4). When neither centre has kanbans in either hold box, the process returns to the steady state (stage 5).

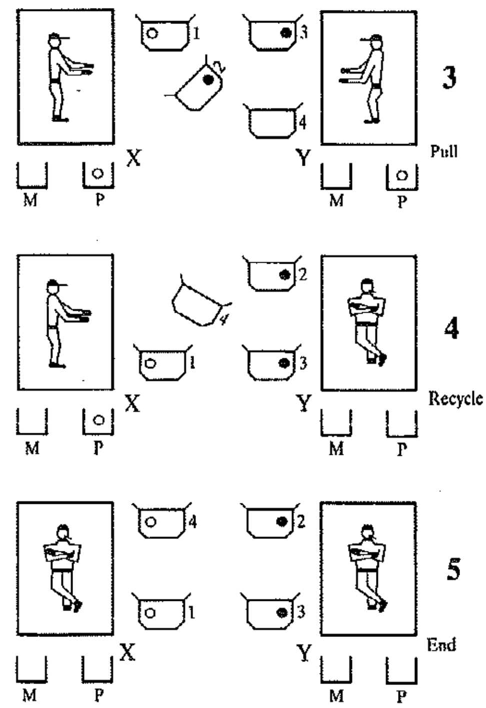

Figure 12 : Two-kanban JIT (b)

While the two-kanban system increases the WIP inventory it eliminates the chance of delay in production while still implementing the *'pull'* technique of process flow control. In both systems, final assembly is the end of the chain, absorbing the product of the upstream work centres and setting the pace of their activity in response to customer demand. However, Toyota's *acceptance* of *built-in* inventory in two-kanban JIT in the face of above-mentioned JIT philosophies might be seen as a pragmatic recognition of the unattainability of theoretical perfection.

"[It is] *the shipment of a lot of finished products which triggers a chain reaction of moves and tasks flowing backwards through work centres*

and departments until it reaches the suppliers of the basic components. This system may be considered a 'living' and therefore much more effective [manufacturing requirements plan], *as the explosion of components and the netting of requirements are not simulated on a computer, but actually performed in practice...JIT logic governs materials flow, while kanbans and their logical or electronic equivalents represent the control and regulation circuit, the so-called feedback."* (Sartori, 1988, pp. 214-215)

3.1.3.1 SIX RULES FOR KANBAN

(Japan Management Association (eds), 1985, pp. 87-92)

1. Do not send defective products to the subsequent process.

   The greatest waste of all, the worst offence against cost reduction. On discovering a defective product take immediate steps to prevent the recurrence of the defect. Machines must stop automatically on production of a defect.

2. The subsequent process comes to withdraw only what is needed.

   This procedure provides each process with the necessary information about time and quantity of delivery, there is no over-supply and minimal inventory.

3. Produce only the exact quantity withdrawn by the subsequent process.

   Do not produce more than shown on the kanban and produce in the order in which the kanban are received. This generates simultaneous, conveyor-belt production along the line.

4. Equalise production using *'load smoothing'*.

   Allocation of equipment and workers is calculated so that individual parts can be supplied at the required rate.

5. Kanban is a means to fine tuning.

   Kanban systems are not designed to compensate for major changes in production flow, this is the function of *"load smoothing"* or *"equalising of production"*. If the production rate of a downstream process is doubled, the process will stand idle waiting on supply once it has used the standard supply inventory – kanban cannot correct this dysfunction.

6. Stabilise and rationalise the process.

   Standardisation guarantees adequate supply to subsequent processes.

3.1.4 Success with TPS

Implementation of JIT regularly produces outstanding results. Silva (1992), describing JIT application to the manufacture of power supplies, cites improved product reliability in terms of Mean Time Between Failures (MTBF) from 110,000 hours to 1.1 million hours, cycle time reduced from 25 to 8 days, on-time delivery up from 60% to 98%, WIP dropping from 7000 units to less than 1000 and manufacturing costs reduced by 20%. Cassidy and Sharma (1992) quote a 40% decrease in time for new product introduction and 50% reduction in manufacturing time – shipping performance improved 84% with many departments routinely having 100% performance months. At the start of 1990 almost one third of shipping dates were missed:

> *"By the end of 1990, the completion of implementing JIT or pull manufacturing together with an increased focus on shipping to request had*

improved our performance to 6.6% misses...In May [1991], the Energy Systems shop set a new record for themselves by missing only 0.2% of the customer requested ship dates. In fact, seventy-five percent of the weeks in the second half of 1991 have been perfect without a single missed shipment." (Cassidy & Sharma, 1992, p. 164)

Venner (1991) reports manufacturing intervals reduced by 75% at AT&T-Network Systems.

"There were similar reductions in WIP, inventories, floor space requirements and material rework." (Venner, 1991)

Application of the Toyota Production System to Omark Industries resulted in:

- lead time for a product reduced from 12 weeks to 4 days
- set-up time for a press reduced from 8 hours to 1 minute 4 seconds
- WIP reduced 50%
- factory floor space opened up 30 to 40%. (Japan Management Association (eds), 1985)

3.1.5 Failure with TPS

Some commentators refer to the disastrous effects of implementing just the kanban system (or, indeed, any other subset of the TPS philosophy) (eg Ford (UK) who failed in 1981 to introduce Quality Circles into its UK plants. (Storey, 1994, p. 177)) but the author's database does not contain a record of failure with a full-scale implementation. It may be arguable that failure in TPS implementation might be the result of a too narrow understanding of the term.

3.1.6 TPS and the West

However, the author's research does support the theory that the success of the Japanese invasion of traditionally Western markets (combined with a concurrent explosion of computer technology) was the catalyst for radical change in long-held Western management theory and practice.

3.2 MRP and MRP *II*

"There are two alternatives in fundamental approach and two corresponding sets of techniques that a manufacturing enterprise may employ for the purposes of inventory management. They are:

1. *Stock replenishment, popularly known as statistical control or order point systems*
2. *Materials requirements planning.* (Orlicky, 1975, p. 21)

"MRP II is a planning system, with the goal of delivering the correct quantity of material at the correct time, based upon orders combined with forecasts. MRP II has been widely used in the U.S. with many cases of success and improvement." (Smith, 1994, p. 1)

Manufacturers have long sought a complete procedure for calculating manufacturing schedules making some compromise between the accumulation of inventory during slack periods and the loss of opportunities in boom times. Such a procedure must consider actual and forecast demand data, realistic quantities for shipments and the use of algorithms to arrange supplies in the best sequence. It must first ask four fundamental questions:

1.	What are we going to make?	Master Production Schedule
2.	What does it take to make it?	Bill of Materials
3.	What do we have in stock?	Inventory Records
4.	What do we need to get?	Materials Requirement Plan

(Storey, 1994, p. 159)

3.2.1 MRP

Material Requirements Planning (MRP) as defined by Joseph Orlicky (1975) is a process which effects to see ahead, to forecast when, where and how many items will be required. MRP has probably existed in some rudimentary form as long as manufacturing. Prior to the 1950s systems usually worked on the basis of an Economic Order Quantity (EOQ) as described elsewhere yet expensive parts would not be purchased until needed – when the Purchasing Officer knew how many would be required and when. Orlicky proposed a system of '*time phased ordering*' which sought to match quantity on hand, quantity on order, quantity required and surplus over a span of time. Over a ten-week span an article's Kardex might appear as Table 3 on page 50.

On hand	30									
Order due	0	0	0	0	25					
Required	0	20	0	35	0	0	0	0	0	10
Surplus	30	10	10	-25	0	0	0	0	0	-10

Table 3 : Time Phased Ordering

There is an open order due in the fifth week; there are requirements in the second, fourth and tenth weeks. A further replenishment order must be issued in time to be completed in the tenth week. He writes:

> *"MRP systems are a highly effective tool of manufacturing inventory management for the following reasons:*
>
> 1. *Inventory investment can be held to a minimum.*
> 2. *An MRP system is change-sensitive, reactive.*
> 3. *The system provides a look into the future, on an item-by-item basis.*
> 4. *Under material requirements planning, inventory control is action-oriented rather than clerical bookkeeping-oriented.*
> 5. *Order quantities are related to requirements.*
> 6. *The timing of requirements, coverage, and order actions is emphasised."*
>
> (Orlicky, 1975, p. 47)

The first working hypothesis, the Primary Schedule (PS), is the series of work orders for the factory.

> *"The Production Capacity Control Model* [PCCM], *called the 'resource profiler'* [RP], *is invoked to check the reliability of manufacturing assumptions and their later variations. This check is, however, only approximate and is carried out only for those production units that, on the basis of experience, are subject to bottle-necks."* (Sartori, 1988, p. 14)

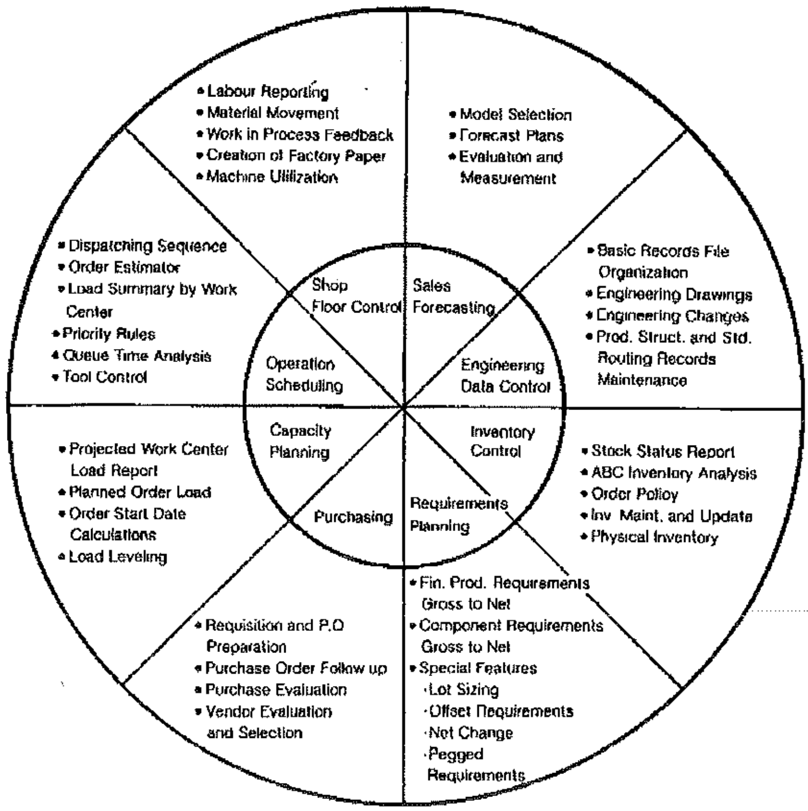

Figure 13 : The PICS Wheel

Shortcomings of the PS are highlighted by the RP indicating the consequences of decisions without proposing solutions allowing the human planner to employ a *'what-if'* technique. Calculating inventory by means of an auxiliary routine he can identity the best compromise which becomes the Final Schedule (FS) now referred to as a Master Production Schedule (MPS). (Sartori, 1988) Software designed for commercial companies may be based simply on EOQ criteria (considering external criteria such as sales demand) but in conventional manufacturing requirements are based on internal decisions such as the release of certain work orders rather than others.

> *"The problem is, therefore, how to translate the final schedule into a replenishment plan that is correct for all internal items."* (Sartori, 1988, p. 16)

In the mid 1960s IBM produced the Production, Inventory and Control System (PICS) which was to support sales forecasting, requirements planning, capacity planning, engineering data control, shop floor control, operations scheduling, purchasing and inventory control (ref: Figure 13 page 52 (Kerr, 1991, p. 18)) and this lead to the evolution of computerised MRP

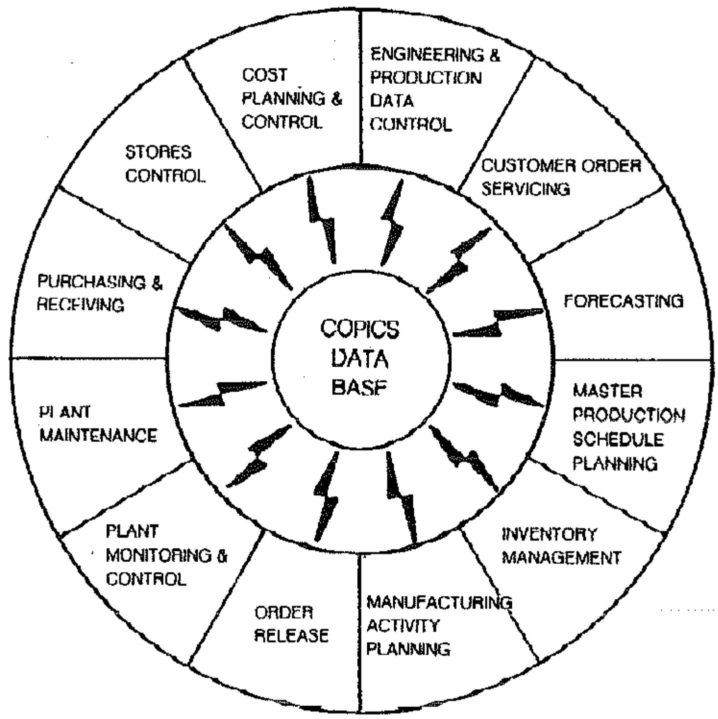

Figure 14 : The COPICS Concept

"[in] *an attempt to use the 'number-crunching' power of the computer to develop a production plan for an entire plant in which the production of each individual item is coordinated with a master production schedule for the production of end products."* (Kerr, 1991, p. 17)

"Time phased materials requirements systems represent a classic computer operation in the sense that here the computer is being used to do something heretofore literally impossible – handling and manipulating vast quantities of data at high speed." (Orlicky, 1975, p. 35)

IBM moved on in the early 1970s to publish a conceptual framework for a Communications Oriented Production Information and Control System (COPICS) which stressed cross-functional communication and a common database. COPICS was not software but a schema which provided a detailed view of the dataflows and functional integration between the eight areas of PICS emphasising the importance of an MPS and feedback from Capacity Requirements Planning (CRP). Much functionality of COPICS was progressively incorporated into MRP systems during the MRP *'crusade'* of the 1970s. (Kerr, 1991)

If an MPS could be fixed and lead times allowed for each process stage this would determine quantities and timing. Workcentres could produce to a schedule linked to requirements for end products rather than on the basis of periodic buffer replenishment.

> *"MRP* [avoids] *producing an item before it is required by backscheduling from the due date ...all items on the bill of materials are on the critical path, since a delay in availability of any one of them will delay the finished product."* (Gibson, Greenhalgh, et al., 1995, p. 115)

MRP generates a 'computer explosion' of the MPS into requirements for components and raw materials at each successive upstream level by calculating requirements and offsetting for lead time. In principle, large buffer stocks could be eliminated except for safety stocks related to uncertainty of demand held at the end-product level.

Storey (1994) postulates that aside from the obvious financial benefit of reduced inventory, visibility of forward product requirements (possibly up to two years) could be passed on to selected vendors giving them improved purchasing power from which further financial benefit could be obtained. Supplier scheduling

might be introduced as a separate function, linking directly with suppliers to maintain and manage delivery schedules. However:

> *"One might imagine that the impressive electronic corporate communication tools now widely in use and the 'common corporate culture' effect would facilitate the building of strong links between affiliates who supply each other, but in practice the opposite is often the case. All too often, dual standards are applied to inter-affiliate business, and object performance indicators show that 'non-captive' but closely linked suppliers perform much better."* (Storey, 1994, p. 159)

MRP is generally perceived to have failed to produce tighter coordination and reduced slack for a variety of reasons.

1. Lack of top management commitment.
2. Lack of MRP education for the users of the system. (Gibson, Greenhalgh, et al., 1995, p. 147)
3. MRP did not allow feedback for revision to cope with unexpected contingencies (although 'closed-loop' MRP – which developed into MRP II – considered this problem (ref: (Gibson, Greenhalgh, et al., 1995, p. 111))).
4. Manual shop floor data collection as a realistic basis for planning in complex factories proved formidable.
5. MRP lacks the ability to take the finite capacity of the plant into consideration. (Kerr, 1991)

Orlicky answered the latter criticism by writing :

"A system can be designed to answer either the question of what can be produced with a given capacity (ie. what the master production schedule should be) or the question of what <u>need</u> to be produced (ie. what capacity is required) to meet a given master production schedule, but not both. An MRP system is designed to answer the latter question." (Orlicky, 1975, p. 46) (ref: Figure 15 page 56 (Orlicky, 1975, p. 13))

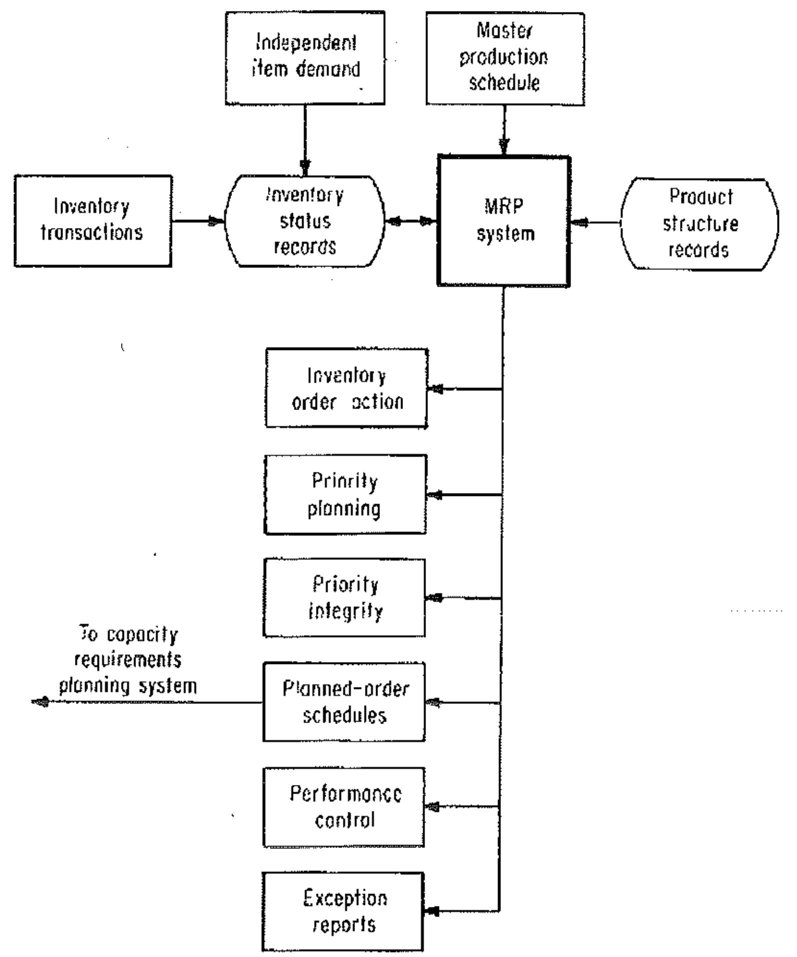

Figure 15 : Schematic of MRP System

"In practice MRP works best for firms with a limited range of products and relatively stable patterns of demand." (Storey, 1994, p. 29)

3.2.2 Capacity Requirements Planning

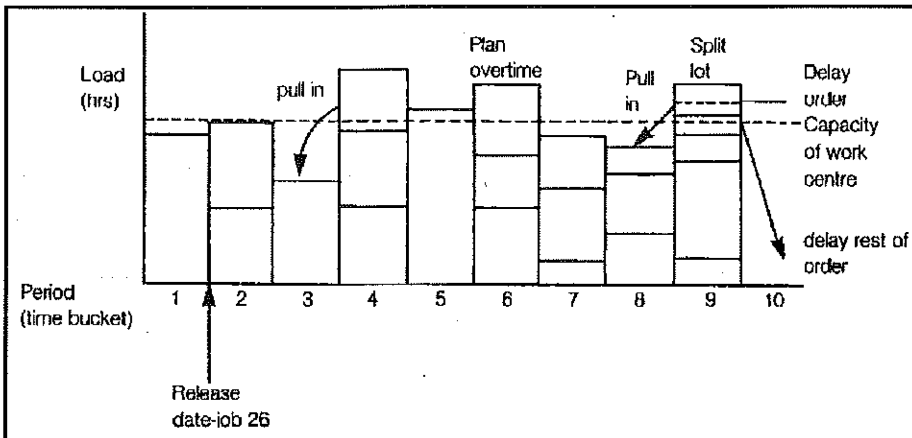

Figure 16 : Shifting Overloads

Limited by the accuracy of forecasted demand and the stability of production schedules CRP should still allow provision of capacity through the use of extra shifts, movement of labour and the revision of the master schedule in a timely and ordered way.

> *"Without a CRP* [sic] *you are in danger of always undertaking short-term costly fixes."* (Storey, 1994, p. 160)

A crude form of capacity planning on a 'time-bucket' basis allowed shifting of work from overload periods to earlier underloaded buckets. (ref : Figure 16, page 57 (Kerr, 1991, p. 21))

> *"In fact, this approach neither indicates whether a capacity problem really exists, nor... whether the problem could be avoided by simple adjustments to the plan which do not threaten the integrity of the master production schedule... The solution of problems is conveniently left to the judgement and local knowledge of personnel on the shop floor."* (Kerr, 1991, p. 21)

3.2.3 MRP II

In the 1970s and '80s attempts were made to extend the concept to cover labour, machine, capital, purchasing, marketing and shipping requirements changing the meaning of the acronym to Manufacturing Resources

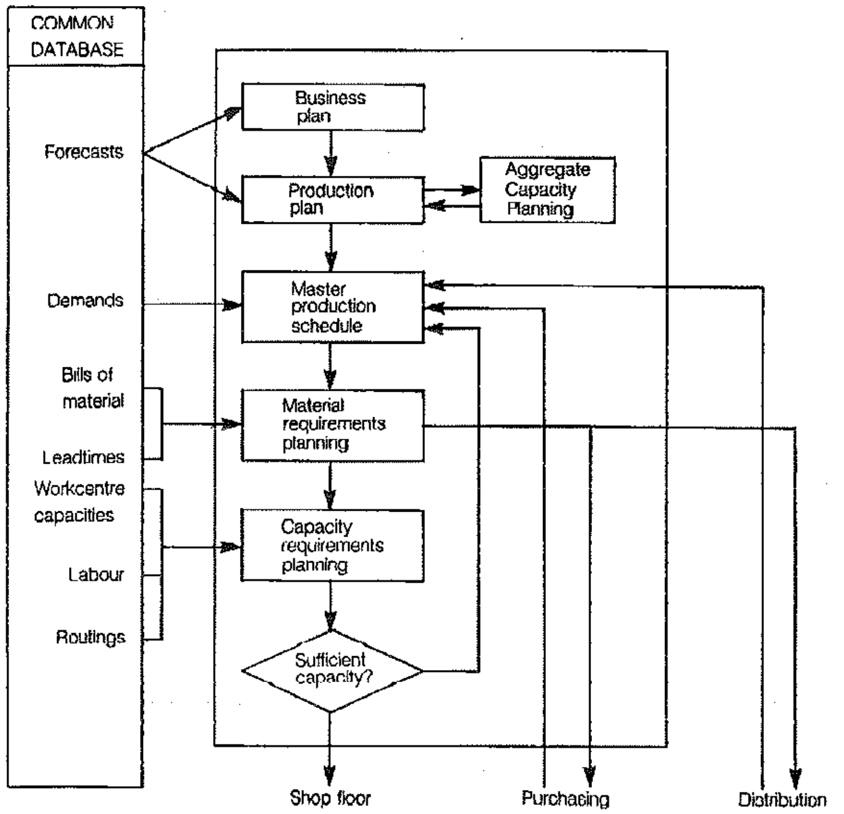

Figure 17 : Schematic of MRP *II*

Planning (generally referred to as MRP *II*). Master data had to be stored and kept current, hence a new emphasis on a common database, allowing integrated planning on the basis of continuously updated information, emerged. (ref : Figure 17, page 58 (Kerr, 1991, p. 23))

Development of CRP as a tool within the MRP *II* loop forces a company to develop policies on who to deal with capacity issues, notably Human Resources [HR]. Decisions are not made for management, but MRP *II* provides a focus on alternatives so that better human decisions may be made in advance. (Storey, 1994)

MRP and MRP *II* tried to solve the problems of manufacturing variety and complexity by massive amounts of computation and information transfer.

> *"The centralised approach...* [of the 1970s]... *strongly oriented toward batch rather than interactive information processing, simply did not provide the flexibility and real-time feedback and control required to cope... with many real world manufacturing operations."* (Kerr, 1991, p. 25)

> *"MRP II systems have been criticised for their complexity and for generating schedules that do not reflect reality on the shop floor."* (Storey, 1994, p. 30)

3.2.4 Group Technology and Product Rationalisation

Proliferation of complexity is largely the result of the functional separation and the lack of standardisation and systematisation in design, factory layout and process planning. (ref: Rationalisation, page 37) Lack of access to previous designs leads to large numbers of new designs and part numbers; processes are planned without regard to the complexity of production scheduling; factory layouts have traditionally grouped machines by function rather than the basis of production scheduling and material flow. MRP *II* does not address the integration of these activities to rationalise and simplify critical operational tasks. This problem caused the rise of Group Technology (GT). (Kerr, 1991)

> *"When a new product is designed, a new set of parts is generated some of which may be very similar to parts used in established products. The new parts will, however, have different part numbers (usually tied in to the product in which they appear) with nothing intrinsic in the part number*

that will indicate any similarity with existing parts. This tends to lead to the familiar 'complexity explosion'." (Gibson, Greenhalgh, et al., 1995, p. 186)

GT identifies underlying similarities in products, parts, processes and resources, structuring them into clusters with common attributes. Codes may be used to describe the geometric shape of the object and its physical dimensions. Similar parts may be selected from the database and compared for suitability. Computer aided design and so-called 'concurrent engineering' techniques allow a more rationalised approach to design and it would not be unusual for such a rationalisation process to reduce the number of separate part numbers in manufacturing plant by a factor of 10 or more. (Gibson, Greenhalgh, et al., 1995)

GT philosophy was first proposed by S. P. Mitrofanov[7] in 1938 and is based on minimising the handling time for a part by grouping the necessary machines. Not until the 1960s was much attention paid outside the USSR. (Talavage & Hannam, 1988)

1.Clusters of machines which can perform all the operations on a family of parts or products form the basis of independent manufacturing cells. Consider Figure 5 on page 30 (ref: (Kerr, 1991, p. 28)).

If machine cell capacity is reasonable related to the demand for the part families they can be dedicated to them, becoming self-contained and autonomous. This concept is sometimes referred to as a *'focused factory'* as distinct from the traditional process-oriented layout in which parts and products must follow complicated, *'bowl of spaghetti'* pathways from machine to machine. (Kerr, 1991) GT

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[7] Scientific Principles of Group Technology (English Translation) in the British Library, cited in (Talavage and Hannam, 1988)

and the concept of Teams should not be confused: the former is a physical arrangement of machines, the latter a social arrangement of workers. (Storey, 1994)

Effective application of the manufacturing cell concept leads to a smooth flow of product in extremely small batches, minimising WIP inventory with the workers doing their own quality inspection. (Hutchins, 1988)

3.3 Synchronous Manufacturing

Optimised Production Technology (a.k.a. Synchronous (or Synchronised) Manufacturing) originated in the writings of Eliyahu M. Goldratt in the early 1980s (concurrently with MRP/MRP *II*). It has been popularised by Goldratt's organisation (the Avraham Y. Goldratt Institute (AGI)) and the American Production and Inventory Control Society (APICS). Goldratt postulated that the goal of manufacturing is to make money and that there were three avenues to that goal: increase throughput, reduce inventory or reduce operating expense.

> "[He noted that] *the opportunities to make more money through reductions in Inventory and Operating Expense are limited by zero. The opportunities to make more money by increasing Throughput, on the other hand, are unlimited.*" [8](Moser, 1996, p. 1)

Very few manufacturing plants have all resources fully utilised, normally a few resources are much more heavily utilised than the remainder. Length of processing time, unreliability or simple overloading make these few processes constraints or botttlenecks.

---

[8] It is pertinent to point out that Throughput still requires Sales!

> *"Bottleneck resources are very significant because it is these resources in particular which limit the total output of a production plant."* (Gibson, Greenhalgh, et al., 1995, p. 69)

Goldratt set about proving that manufacturing viability could be achieved (in the current era of increasing pressure from foreign (mostly Japanese) manufacturers being felt by US industry) by attention to the *'Theory of Constraints'* (TOC) incorporating the concurrently developed principle of a Master Production Schedule (MPS).

3.3.1 Theory of Constraints (1)

TOC describes the behaviour of systems, notably organisations. In this context, a system is defined as a bounded activity which takes input from outside the boundary, transforms it somehow, and sends it back – a constraint is defined as a flow constriction within a system (a bottleneck).

> *"Constraints are inevitable because there's absolutely no way not to have a constraint somewhere in any system. You can eliminate one... another pops up somewhere... or the flow through the system... itself becomes the constraint."* (Introduction to Theory of Constraints, 1996)

Goldratt theorised that, to increase productivity, it was necessary to identify and strengthen the constraint (the weak link in the chain) and also that the rest of the chain had to run in harmony with the constraint. His early work, "The Race" (Goldratt & Fox, 1986) , however, pays primary attention to the question of inventory.

3.3.2 Inventory

Goldratt and Fox (1986) identified six issues in the search for a competitive edge (quality, engineering, margins, costs, delivery and lead-times) and showed how each was profoundly affected by inventory levels.

Consider the flow of product through a plant as shown in Figure 18 (page 63 ref : (Goldratt & Fox, 1986, p. 39)). Conventional manufacturing sees the raw material, in a lot, through progressive processes starting at 'D' (bottom) to completion at 'A' (top). Inventory is shown as the area under the dotted line and levels cannot drop until product comes out of the final process some 2459 plant-hours after raw material enters the plant.

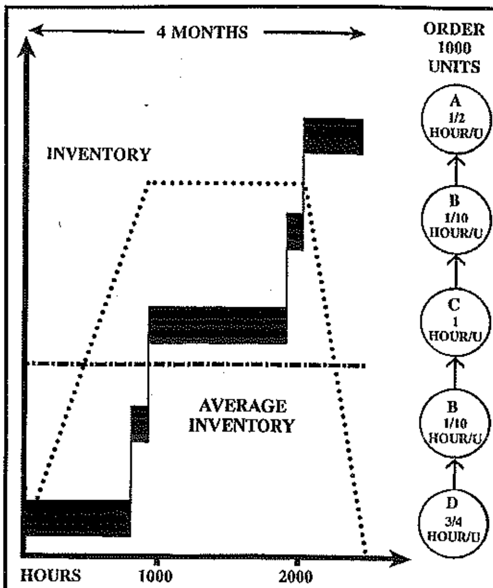

Figure 18 : High Inventory Manufacturing

Goldratt compared this scenario with Figure 19 (page 63 ref : (Goldratt & Fox, 1986, p. 41)) in which the quantity of raw material is broken down into five lots which are individually moved through the

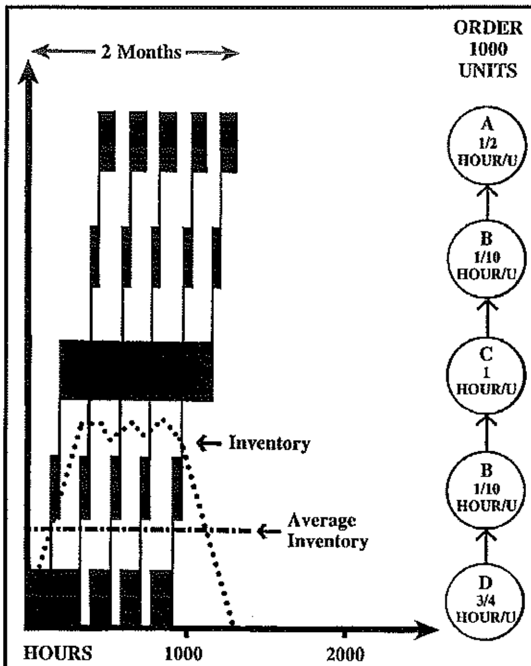

Figure 19 : Low Inventory Manufacturing

plant. Since process 'C' requires more time per unit than any other the upstream processes, 'D' and 'B', are synchronised to keep 'C' continuously busy from the point at which it can commence operation. Lead-time to completion is nearly halved (to 1290 plant-hours) and inventory (the area under the dotted line) reduced by a factor of approximately four. Consider the effects of this procedural change on the six issues for competitiveness.

3.3.2.1 QUALITY

With QC operating as final-delivery testing, product damage in process 'D' in a High-Inventory Plant (HIP) (ref: Figure 18 on page 63) would not be detected for four months, long after the processing of the raw material has been completed at 'D'. In all probability the defect will repeat throughout the product lot. In a Low-Inventory Plant (LIP) (ref: Figure 19 on page 63) the defect-causing fault could be detected and remedied half-way through the lot.

> *"It is probably not possible to have very high quality unless we have low inventories."* (Goldratt & Fox, 1986, p. 44)

3.3.2.2 ENGINEERING

Design changes one month into production would miss the process run in an HIP altogether, but could be integrated into the second half of the run in an LIP.

> "[The portion processed before the change] *will not require scrap or rework... The company with the low inventory environment has the superior product available in the marketplace for a significant period without*

competition and should be able to gain additional sales and market share." (Goldratt & Fox, 1986, p. 48)

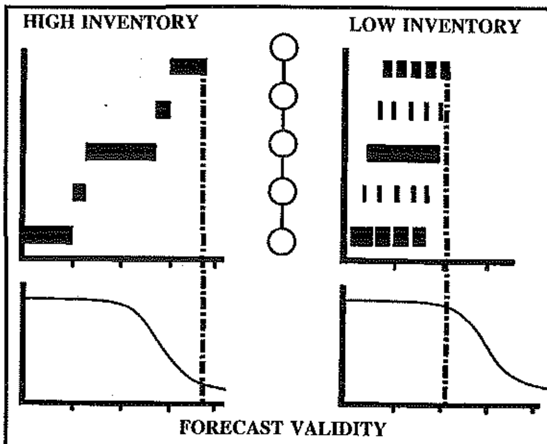

Figure 20 : Batch Size and Successful Delivery Scheduling

3.3.2.3 MARGINS

If marketing promised delivery in three months the HIP would be forced into extensive overtime to comply.

3.3.2.4 COSTS

Process 'A' in the HIP runs at peak load for 500 hours prior to delivery, in the LIP its workload is spread over 900 hours with obvious advantages in the break-down/catch-up scenario or in the expedition of urgent orders, relieving the pressure for excess equipment capacity (investment).

> *"In the low inventory environment the investment in equipment, facilities and inventory are much less and consequently the return-on-investment much higher."* (Goldratt & Fox, 1986, p. 56)

3.3.2.5 DELIVERY

When standard delivery lead-time is two months, customers will often place or confirm orders barely two-and-a-half months in advance.

> *"Even when they place an order for a whole year, they will feel free to change the quantity and ship date two months in advance without risk of*

jeopardising deliveries or placing their vendors in an impossible situation. Consequently the plant's [demand] *forecast for this product will be quite reliable for two months and quite unreliable for a period beyond three months"* (Goldratt & Fox, 1986, p. 60)

A forecast graph (showing a tail-off in dependability) is shown on the lower level in Figure 20 (page 65 ref : (Goldratt & Fox, 1986, p. 61)). Completion date in the LIP means delivery during the accurate period of the forecast – on time.

3.3.2.6 LEAD-TIMES

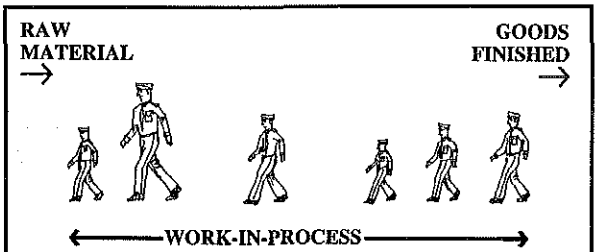

Figure 21 : Route March Analogy

"There is a huge competitive advantage... over foreign competitors because of the time required for ocean freight shipments... there should be no reason for a foreign competitor to beat us in our own market." (Goldratt & Fox, 1986, p. 62)

3.3.3 Theory of Constraints (2)

"TOC first became known in the U.S. through a shop floor planning and control program known as OPT, sold by

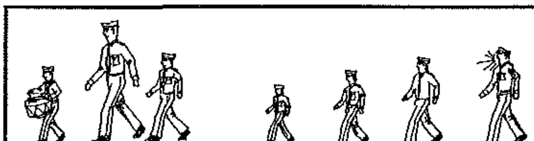
Figure 22 : Paced March Analogy

Creative Output beginning in 1979. The program was developed by Eli Goldratt, who later expanded its principles into the Theory of Constraints, as explained in his books, The Goal, The Race, The Haystack Syndrome, and The Theory of Constraints. The principles embodied in OPT are completely subsumed by TOC." (Smith, 1994, p. 1)

Goldratt uses the analogy of troops on a route march to illustrate his Theory of Constraints (ref : Figure 21 page 66 (Goldratt & Fox, 1986, p. 73)). As the march progresses, stronger, fitter soldiers (processes with excess capacity) move to the front leaving the weaker (bottle-neck processes) behind and the company stretches out along the road (WIP inventory). One solution to this excess inventory is a disciplinary approach which Goldratt characterises as similar to conventional manufacturing management practice – using a drummer (the Materials or Production Manager) to establish a common pace and sergeants (Foremen and Expeditors) to urge the troops to keep to the pace (ref : Figure 22 page 65 (Goldratt & Fox, 1986, p. 79)). This results in the weaker soldier (slower process) being constantly urged to keep up (meet schedules). Under conventional manufacturing management this results in constant conflict because of the tradition that each process should be kept working at maximum rate which results in high inventory levels piling up upstream of the slower processes.

Figure 23 : Roped March Analogy

Goldratt also considers linking the *'soldiers'* like mountain climbers citing Henry Ford's conveyor belts and assembly lines as the use of physical *'ropes'* and Taiichi Ohno's Kanban system as the use of logistical *'ropes'* (ref : Figure 23, page 67 (Goldratt & Fox, 1986,

p. 89) . Disruption at any workcentre poses a major drawback in this system since this will cause overall flow to stop and throughput to be lost. Elimination of these disruptions is no trivial task and requires, amongst other things, better machine maintenance, reduced setup times and prevention of production overloads.

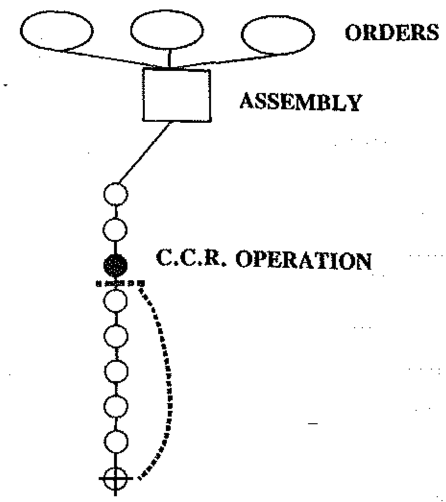

Figure 24 : Single-Line DBR Manufacturing

Goldratt postulates a compromise between the Paced March and Roped March analogies which he calls a Drum-Buffer-Rope system (DBR) – concentrating inventory upstream of the slowest process (the Critical Constraint Resource (CCR)) and orchestrating the upstream processes to produce at the rate of the CCR.

In Figure 24 (page 68 ref : (Goldratt & Fox, 1986, p. 101)) the curved, dotted line between the materials entry (gate) process and the CCR represents the *'rope'* or the timing of the process feed to the CCR, and the heavy, dotted line represents the presence of an inventory buffer which protects the CCR from disruptions in the upstream processes.

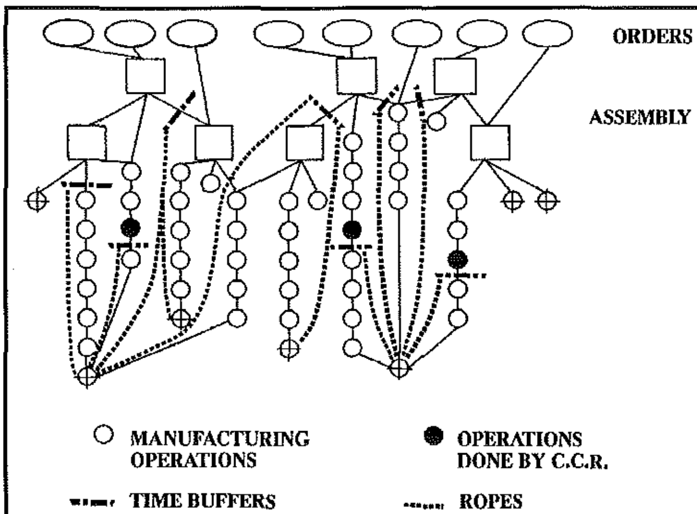

Figure 25 : Complex DBR Manufacturing

Three days demand is suggested for the buffer size[9].

In a more complex operation (ref : Figure 25, page 68 (Goldratt & Fox, 1986, p. 105)) buffers must also be placed at any fork point in the flow downstream of a CCR – processes between the CCR and the forkpoint will also be protected against disruption by the buffer upstream of the CCR.

> *"The combination of the Drum-Buffer-Rope" constitutes TOC's shop floor scheduling. This is in contrast with JIT which pulls material through physical signals, and MRP, which releases material constrained only by the rough cut capacity planning system.*
>
> *TOC is a push system downstream from the CCR and a pull system upstream from the CCR. Obviously, if the market is the CCR, then the whole factory is a pull system, as it is for JIT. But TOC is flexible, and the CCR may be located anywhere in the factory. MRP treats all resources as infinite in capacity, and follows the drum of orders only, pushing material through the factory."* (Smith, 1994, pp. 2-3)
>
> *" The concept of the DBR logistical system is quite clear, but the complexity of this diagram* [Figure 25 on page 68] *illustrates why we will need the aid of a computerised system... the first question... is how we can quickly identify which of the production resources are CCRs."* (Goldratt & Fox, 1986, p. 104)

[9] Compare this inventory buffer level with that aimed for under the Toyota Production System (ref: page 41)

In fact, Goldratt does not deal with this question in *'The Race'* but three common techniques would be applicable – Gantt Charts, Critical Path Analysis (CPA) and the Program Evaluation and Review Technique (PERT).

3.3.3.1 IDENTIFYING CONSTRAINTS

Alex Rogo, harassed manager in Goldratt's *"The Goal"* achieves his first breakthrough with a simple realisation:

> *"The goal of a manufacturing organisation is to make money."*
> (Goldratt & Cox, 1989, p. 40)

This provides Umble and Srikanth with the definition:

> *"A constraint is any element that prevents the system from achieving the goal of making more money."* (Umble & Srikanth , 1990, p. 81)

Every organisation has at least one constraint and the degree to which any system can perform is governed by its set of constraints – market, material, capacity, logistical, managerial and behavioural. Material, capacity and logistical constraints are of major interest in dealing with CCRs.

3.3.3.1.1 Material Constraints

Manufacturing depends on material inputs but systems which are designed to guarantee an overabundance of material usually create more systems than they solve. Causes of external material constraints include non-delivery by vendors, inadequate planning horizons, long purchasing lead times and material shortages in the marketplace. Internally, insufficient WIP inventory, excessive scrap, defective units and workstation reliability can also cripple manufacturing flow.

3.3.3.1.2 Capacity Constraints

> *"A capacity constraint is said to exist when the available capacity at a resource may be insufficient to meet the workload necessary to support the desirea throughput."* (Umble & Srikanth , 1990, p. 83)

A *'bottle-neck resource'* is one whose capacity is equal to or less than the demand placed on it – a *'non-bottle-neck resource'* is one whose capacity is greater than the demand placed on it. Given that the work time of any resource can be categorised in one of four ways:

- Production Time – spent processing a product
- Setup Time – spent preparing to process a product
- Idle Time – not used for setup or processing
- Waste Time – spent processing material that cannot be converted into throughput because of unacceptable quality or lack of downstream demand (Umble & Srikanth , 1990, p. 65)

at a bottle-neck resource all available time should be utilised in production and setup. Any idle or waste time impacts directly on the entire operation. All plants have unbalanced resource capabilities – include both X and Y resources[10]. Being a bottle-neck resource does not necessarily mean being a CCR.

---

[10] By Goldratt's convention, bottle-neck resources are referred to as 'X' resources and non-bottle-neck resources as 'Y'.

3.3.3.1.3 Logistical Constraints

> *"Any constraint that is inherent in the manufacturing planning and control system used by the firm is referred to as a logistical constraint."* (Umble & Srikanth, 1990, p. 84)

Logistical constraints act as a drag on the smooth flow of goods through a system, may take effect at any point from order entry to shipment and may be difficult to change.

3.3.3.2 Critical Constraint Resources

	AVERAGE DEMAND PER 24 HOUR DAY	HOURS OF RESOURCE TIME REQUIRED TO PRODUCE ONE UNIT OF PRODUCT R1	R2	R3	R4
Product A	2 Units	3	2	9	1
Product B	5 Units	5	4	1	1
		REQUIRED AND AVAILABLE CAPACITY R1	**R2**	**R3**	**R4**
	Required Capacity per Day (hours)	31	24	23	7
	Available Capacity per Day (hours)	24	24	24	24

Figure 26 : Processes and Restraints

CCRs are likely to cause the actual flow of goods through the plant to deviate from the planned flow. Consider Figure 26 (page 72, ref : (Umble & Srikanth, 1990)); the required capacity of R1 and R2 makes them, by definition, constraint resources but since the throughput of R1 can be handled by R2, then R1 is the CCR and R2 is not. However, in a case where the order consists of 20 of Product A and 50 of product B, the order being due in 11 days (264 hours), the order of manufacturing becomes significant. Suppose that the plant is free to process the order immediately, that the firm sub-contracts the requisite seven hours per day for R1, that units are passed downstream on individual completion and Product A is to be processed first – R1 completes in

$$[(20\times3)+(50\times5)]-70=240$$

Equation 7 : Processing Time for Product A in Resource R1

hours, R2 four hours later, R3 one hour after than and R4 one hour after that for a total elapsed time of 246 hours. If Product B is processed first, R1 completes processing Product B after

$$[((8\times31)+2)-(8\times7)]=194$$

Equation 8 : Processing Time for Product B in Resource R1

194 hours, the first unit of Product A leaves R1 three hours later, and R2 two hours after that. Now R3 requires 180 hours to process Product A and R4 can complete the processing one hour later. Total processing time is 380 hours and the order is 116 hours late! In this second case, R3, though not a bottle-neck, is clearly a CCR. (Umble & Srikanth, 1990)

Goldratt defined a five-step algorithm for identifying and scheduling for CCRs which clearly could become an extremely complex problem:

1. IDENTIFY the system's constraint
2. Decide how to EXPLOIT the system's constraint
3. SUBORDINATE everything else to the above decisions
4. ELEVATE the system's constraint
5. If in any of the previous steps, the constraint has been broken: Return to step 1 -- don't let INERTIA become the system's constraint! (Moser, 1996)

Umble and Srikanth apply this algorithm to a plant producing Product C and Product D with the selling price etc shown in Figure 27 (page 74, ref : (Umble & Srikanth , 1990, p. 96). Since Product D has a higher selling price, lower material cost and requires less labour it would seem to be the more profitable and the one to on which to concentrate. Many managerial decisions are made on the basis of this type of accounting information. Product flow through the plant must, however be considered.

	PRODUCT C	PRODUCT D
Selling Price	$90	$100
Material Cost	$45	$ 40
Labor Required per Unit	55 Minutes	50 Minutes
Market Demand	Unlimited	Unlimited
Total Available Labor Hours for the Focused Factory	160 Hours per Week	

Figure 27 : Product Details

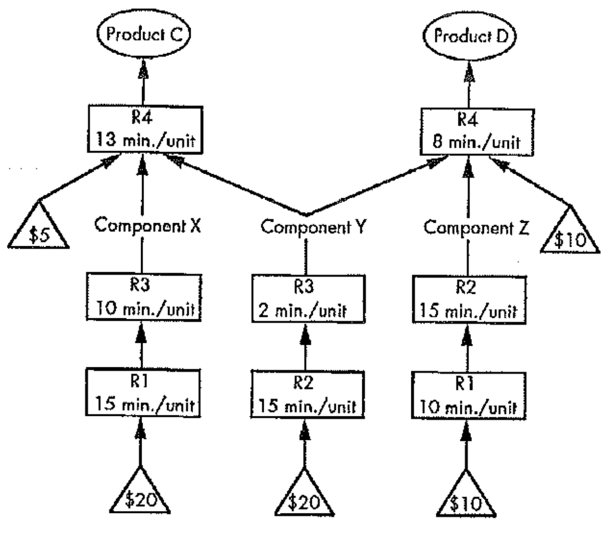

Figure 28 : Product Flow through the Plant

Product flow for the plant is shown in Figure 28 (page 74, ref : (Umble & Srikanth , 1990, p. 97)). If management were to divide the total resource time for all four resources by the time required to process Product D they could expect

$$[(160 \times 60) \div 50] = 192$$

Equation 9 : Postulated Production, Product D

192 units to be produced at a profit of

$$(192 \times 60) = 11{,}520$$

Equation 10 : Postulated Profit on Sole Production of Product D

$11,520. However, it can be shown that total product flow through the plant for Product D is controlled by CCR R2 with 30 minutes being required per unit giving 80 units per week. With plant costs at $5000 per week the total profit is calculated by

$$P = \left[I - \left(C + E_O \right) \right]$$

Equation 11 : Profit Calculation (General)

where P is Profit, I Income, C Costs and E_O the Operating Expenses. If Income is calculated by

$$I = \left[T \times P_S \right]$$

Equation 12 : Income Calculation

where T is Throughput and P_S is Selling Price then

$$P = \left[\left(T \times P_S \right) - \left(C + E_O \right) \right]$$

Equation 13 : Profit Calculation (Specific)

and

$$P_D = \left[(80 \times 100) - \left((80 \times 40) + 5000 \right) \right] = -200$$

Equation 14 : Loss on Sole Production of Product D

a loss of $200.

Umble and Srikanth show by similar calculations that the profit on the sole production of Product C is $2,200 per week, yet (if the capacity of R2 is tripled breaking the bottle-neck) a best product mix of 200 units of Product D and 26 units of Product C would yield a profit of $8,070. (Umble & Srikanth , 1990, pp. 87-101)

Clearly the problem of supply, effort allocation and synchronisation (development of an MPS) to yield maximum return is complex and it would seem well suited to become one task of an MES.

> *"The attempt, in the pre-computer era, to solve manufacturing coordination problems... was largely a consequence of the information processing limitations of the unaided human brain. Manufacturing operations were sufficiently complex that... it was not possible to institute the centralised storage, manipulation and retrieval of detailed information... and the instant transmission of this information to relevant staff. The only practical solution was a 'divide and conquer' approach in which each subunit made its own decisions..."* (Kerr, 1991, p. 16)

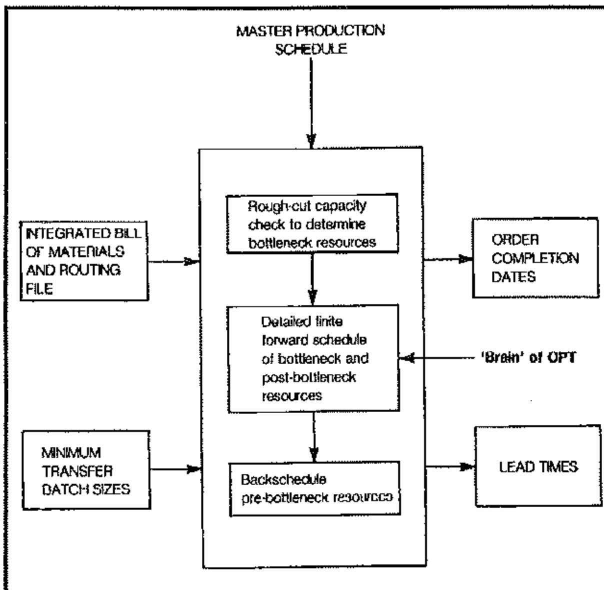

Figure 29 : Schema of OPT

Umble and Srikanth consider the development of an MPS unique from the concepts of Materials Requirements Planning (MRP) and Manufacturing Resources Planning (MRP *II*) because these latter two are designed to optimise production at individual workcentres and not globally across the plant.

3.3.3.3 DBR Approach and Strategy

In summary, DBR differs from other planning and control systems in that:

- it begins with an analysis of requirements for smooth, fast flow of goods through the plant on a global, not local, basis
- infrastructure conflicts are explicitly recognised and resolved
- systematic procedures are developed and used.

This is based on three strategic considerations:

- develop an MPS consistent with the system constraints (drum)
- provide protective buffers at critical points (buffer)
- limit production at each resource to that required (rope). (Umble & Srikanth , 1990, p. 138-139)

Two main criticisms of OPT are:

- that it relies on the existence of a well-defined bottle-neck
- that it provides tight schedules which must be adhered to if the plan is to maintain its integrity. (Kerr, 1991, pp. 23-24)

3.3.4 Successes and Failures with OPT

After a search of literature and the customers of the Avraham Goldratt Institute (AGI), Smith (1994) found no examples of negative results, however a survey of 185 companies found 5% using OPT-based systems.

"Of these 5%, about half had less than spectacular results, with the worst performances in the job shop environment. The best OPT performers were in the process industries."[11]

"[OPT] *has not enjoyed such widespread success as MRP... Instead of conventional... financial measures...* [it] *uses throughput... inventory costs, and operating expenses. Such measures have not diffused widely, nor, however, has OPT,"* (Sillence & Sykes, 1993, p. 25)

3.3.5 Inter-System Compatibility

"Because MRP II arrived before TOC, TOC has generally been installed with an MRP II system already in place. Reviewing the literature, TOC is generally viewed as complementary to MRP, supplying finite shop floor scheduling while MRP generates the overall demand." (Smith, 1994, p. 1)

[11] Newman, William, Sridharan, V. (1992, Jan). Manufacturing Planning and Control: Is there One Definitive Answer?. Production and Inventory Management Journal 50-53 – cited in (Smith, 1994)

Functions	*Categories*	*Kanban system*	*MRP II*
Rates of output	Families of products	Levelling	Production Plan
Products to be built	Finished goods for make-to-stock, customer orders for make-to-order	Master Production Schedule	Master Production Schedule
Materials required	Components – both manufactured and purchased	Kanban Cards	Material Requirements Planning (MRP)
Capacity required	Output for key work centres and vendors	Visual	Capacity Requirements Planning (CRP)
Executing capacity plans	Producing enough output to satisfy plans	Visual	Input/Output Controls (I/O)
Executing material plans – manufactured items	Working on right priorities in factory	Kanban Cards	Dispatching Reports
Executing material plans – purchased items	Bringing in right items from vendors	Kanban Cards and unofficial orders	Purchasing Reports
Feedback information	What cannot be executed due to problems	Andon	Anticipated Delay Reports

Note: The same functions are performed by every manufacturing company; however, the tools used by Kanban differ greatly from the MRP II tools. Under Kanban, the tools are manual – Kanban Cards, Andon lights, visual checks and oral orders. Under MRP II, the most important tool is the computer.

Table 4 : Kanban and MRP II - Manufacturing Functions

Originally, there appeared to be less compatibility with TPS.

"There is more than distance separating Japan and America. In the field of production planning and inventory management, the two countries are going in different directions. To the east, it is Kanban; to the west, it is Manufacturing Resource Planning (MRP II).

The goals of each are identical... Spectacular results can be cited by companies employing each. However, the tools used by Kanban are dramatically different from the tools used by MRP II." (Bignell, Dooner, et al., 1985, p. 151) (ref: Table 4 on page 79 (ref: (Bignell, Dooner, et al., 1985, p. 154)))

This distinction is supported from both sides.

"*An important difference* [between MRP/MRP II and JIT] *is that MRP (of which MRP II represents a more sophisticated extension) is a computer-based planning system, whereas JIT is manual and control- rather than planning- oriented.*" (Sillence & Sykes, 1993, p. 18)

Osamu Kimura[12] (albeit a decade ago) was rather more forthright.

"*We should be careful not to centralise the system by means of mammoth computers and information networks which may only lead to death by strangulation.*" (Yoshikawa & Burbridge, 1987, p. 18)

He illustrated his reasoning:

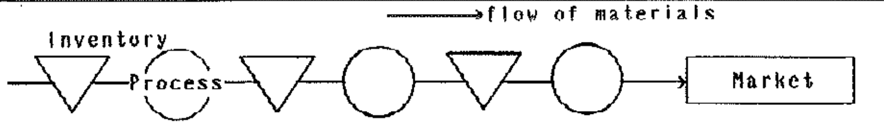

Figure 30 : Multi-Stage Manufacturing Process

Figure 30 on page 80 shows a schematic of a multi-stage manufacturing process where the sub-processes are shown as circles and the inter-process inventory as triangles.

[12] Osamu Kimura; General Manager, Transportation Administration Office, Toyota Motor Corporation

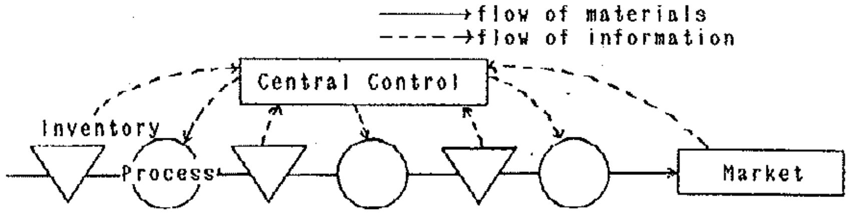

Figure 31 : Control in a Centralised System

Figure 31 on page 81 shows the flow of control in such a plant under a centralised system, whether computerised or not.

Figure 32 on page 81 shows the corresponding flow in a plant using Kanban control. (Yoshikawa & Burbridge 1987, p. 13) Kimura points out that the centralised system required inventory because of the impossibility of predicting lead-time and inventory consumption and that large systems make rapid schedule changes difficult.

> *"As you can see in [Figure 32], calculating and forecasting the required quantity of inventories becomes unnecessary in the 'Kanban System'".* (Yoshikawa & Burbridge, 1987, p. 13)

> *JIT is more inclined towards a fundamental restructuring of the manufacturing environment to make it sufficiently simple and predictable that the complexities of the MRP and OPT solutions are not required."*

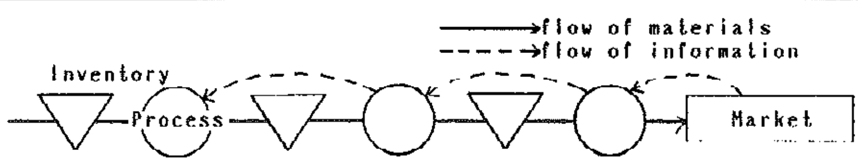

Figure 32 : Control in a Kanban System

(Gibson, Greenhalgh, et al., 1996, p. 198)

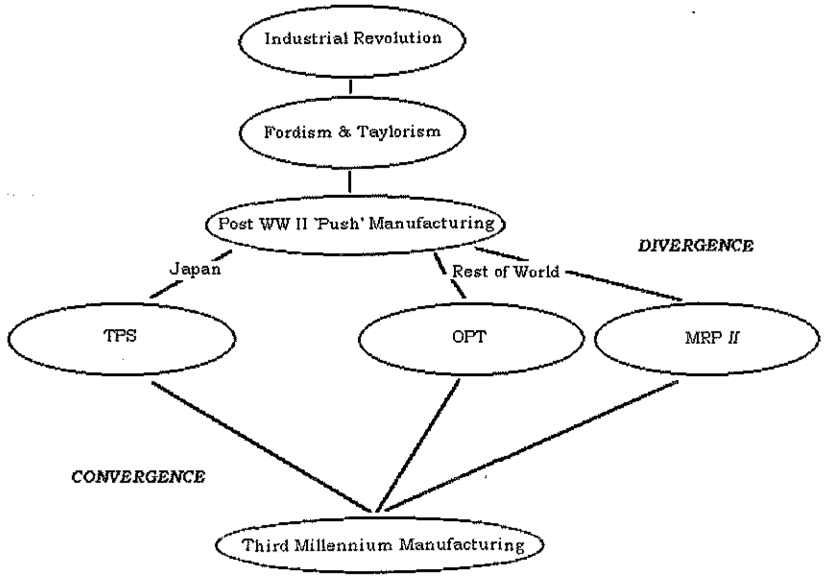

Figure 33 : Origin of Third Millennium Manufacturing

As can be seen from Table 4 on page 79, both JIT and MRP *II* systems depend on the establishment of an MPS which appears to conflict with Kimura's assertions – also, Sillince and Sykes (1993) concluded that MRP and JIT should complement each other which supports the conflict. This is hardly surprising since commentators frequently refer to international visits in which members of one company in one country study the methods of other companies in other countries. It would seem that many Western companies are incorporating greater or lesser parts of the TPS into their management methodology and that author has seen television documentary footage which shows increasing levels of computerisation and automation (Western-style) in Japanese manufacturing. This research has left the author with the general impression that the late '90s is producing a tendency to merge the three main manufacturing management streams of thought, an incorporation of the TPS philosophy with the sophisticated computer support developed in the West heading towards what might be called '*Third Millennium Manufacturing*' (ref: Figure 33 on page 82).

If a conclusion is to be drawn here it might be that any effort to support forecasting, planning and purchasing in other than a JIT environment would definitely benefit from computerised support. Further complication for full computer integration of the systems of a manufacturing enterprise, however, comes from the proliferation of computer systems on the shop floor itself.

4. SHOP-FLOOR COMPUTERISATION

"When a process is automated, the first general efforts are toward the measurement of process variables and simple hardware automation techniques are used to establish basic control over the operation of the plant by controlling a few specific variables. As process control functions become more elaborate and higher levels of plant automation are undertaken, there begins to be a shift of focus toward automating more and more of the management of the plant." (Murrill, 1988, p. 124)

Murrill goes on to suggest that the rate of increase in computer use in process management is now beginning to overtake the rate of increase of computerisation in process control.

Significant increases in the numbers of computers integrated into the manufacturing process over the past 25 years has been concurrent with the increase in the extent and complexity of the integration. Large productivity gains have been made by automating control, planning and diagnostic functions, in many cases fundamentally changing the manufacturing process itself. *Efficiency* and *Effectiveness* are two keywords:

"The refinement of a manufacturing process or the refinement of a problem-solving methodology is referred to as a gain in efficiency... a technological advance with redefines a process or a problem solving methodology is referred to as a gain in effectiveness. To date, most of the exploitation of [computer] *technology has been in improved efficiency."* (Prett & Garcia, 1988, pp. 177-178)

4.1 Development of Automation

"A landmark of early manufacturing automation was the A. O. Smith Corporation's fully automated automobile frame production facility built in 1921. Over 350 operations in the facility were synchronised via line shafts. There was, of course, no computer." (Bollinger, 1988, p. 1)

A. O. Smiths may have produced a landmark, but the origins of modern, industrial automation are usually traced back to 1804 when the French inventor Joseph Marie Jacquard unveiled a loom which was to alter the weaving industry. Chains of punched cards automatically controlled the weaving of complex patterns and changing a card changed the pattern. American Christopher Spencer built a programmable lathe in 1830. Controlled by interchangeable cams, the lathe could be programmed to produce screws, nuts or gears. (Time-Life Books (eds), 1986, pp. 34-35)

Electronic measurement, control and actuation technology had achieved "*a marginal level of 'credibility'*" by the 1950s though most were analog in nature (with electronic inputs and outputs proportional to the physical properties in question). Numerically controlled (NC) machine tools appeared in the mid-1950s and the 1960s saw an explosion of electronic technology with the widespread use of electronic transducers and the advent of the digital computer. '*Smart sensors*', (with built-in micro-computer-based calibration, computation and decision-making power) arrived in the 1980s.

"Developments in the use of laser and micro-electronic sensors make possible rapid measurement of physical properties that were previously difficult to measure. Actuator technology continues to improve through

developments in servo drives, torque and force motors, and piezoelectric actuators for high-precision positioning systems." (Bollinger, 1988, p. 2)

4.2 Computer Aided Manufacturing

With the realisation, around 1960, that mass production is only about 20 to 30% of the total output and the continuing market shift towards personalised products, Research and Development (R&D) concentrated on the automation of small and medium batch manufacturing methods. (Ranky, 1986)

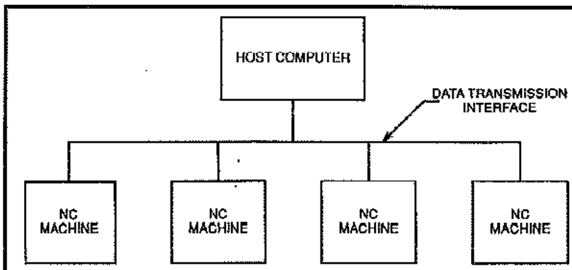

Figure 34 : Direct Numerical Control

4.2.1 Numerical Control

"Numerical Control (NC) is a form of programmable automation in which the processing equipment is controlled by means of numbers, letters and other symbols. The numbers, letters and symbols are coded in an appropriate format to define a program of instructions for a particular workpart or job. When the job changes, the program of instructions is changed." (Groover, 1987, p. 199)

Numerical control development began with the United States Air Force and the early aerospace industry during the 1940s and a contract was awarded to the Massachusetts Institute of Technology (MIT) who successfully demonstrated 3-axis motion control on a milling machine in March 1952. MIT went on to develop the

Automatically Programmed Tooling Language (APT) on which many part programming languages are based and which is seen as a major accomplishment in programmable automation. Early machines were given instructions in the form of one-inch-wide punched tape, initially of paper but later of more robust material suitable for repeated use and the instructions control the tool position in *x*, *y* (and where applicable *z*) axes, cutting speed, feed etc. (Groover, 1987)

NC machines were reasonably reliable and productive in the 1960s and Direct Numerical Control (DNC) (in which the machines receive their instructions directly from the host computer – (ref: Figure 34, page 86 (Goetsch, 1990, p. 155))) –appeared in the mid-1960s in Japan and in Hungary in 1973. (Ranky, 1986)

> "[DNC's] *original purpose was to reduce the amount of hardware required to provide NC. One host computer could serve as the controller instead of having a controller for each individual NC machine*" (Goetsch, 1990, p. 154)

Elimination of punched or magnetic tape controllers at individual machines did not eventuate since the failure of the host computer would have disabled all the NC machines it controlled. Effective, dependable data transmission was also important since poor transmission could cause NC machines to lie idle waiting for instructions from the host. Stationing a microcomputer at each NC machine, to avoid this problem, led to the development of

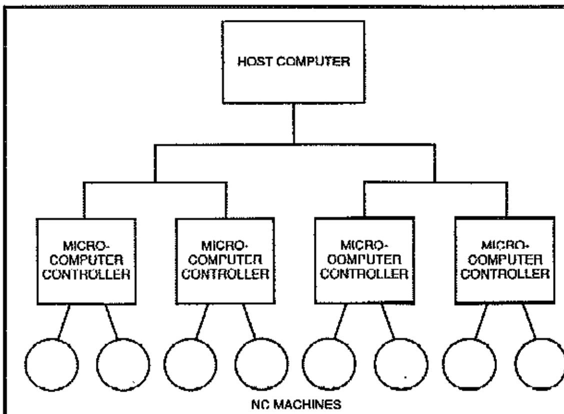

Figure 35 : Distributed Numerical Control

Computerised Numerical Control (CNC). Distributed Numerical Control, with a microcomputer linked to the host controlling each NC machine gave the best of both worlds. (ref: Figure 35 , page 87 (Goetsch, 1990, p. 156)) Personal Computer (PC) development, especially the storage capacity of the PC, was perhaps the most important development:

> *"Personal computers allow parts programs to be written using variables instead of specific values. This allows branching within programs based on the value of the variables. This allows one-part programs to be used to make a variety of parts... CNC also solves the problems associated with paper or plastic tape as well as the problems associated with downtime in the host computer."* (Goetsch, 1990, p. 160)

A further advantage is, perhaps, less obvious:

> *"The N/C* [sic] *machine allows every operator to perform at the level of the best master machinist... One set of instructions derived by one master machinist can be duplicated to run a multitude of N/C machines."* (Koenig, 1990, pp. 52-53)

Group Technology (discussed page 59) and the tendency of vendors to have proprietary systems led to the gathering of equipment into the so-called *'islands of automation"*. Groups of machines began to be linked by mechanical transfer systems, despite their high initial cost, creating the *'fixed automation'* which was a feature of the '60s, '70s and '80s. (Talavage & Hannam, 1988)

4.2.2 Computer Aided Design and Drafting

Another *'island of automation'* arising concurrently was Computer Aided Design and Drafting (CADD).

> *"If we were to try to locate a single historical point of origin for CAD, then it would surely have to be the revolutionary SKETCHPAD developed by Ivan Sutherland at the Massachusetts Institute of Technology (MIT.) in 1962/63... What was new in SKETCHPAD was that the designer could for the first time interact with the computer graphically, via the medium of a display screen and light-pen."* (Rooney & Steadman, 1987, pp. 1-2)

General Motors (GM) announced DAC-1 (Design Augmented by Computer) in 1964 using IBM hardware and in 1965 Bell Telephone Laboratories announced GRAPHIC1 using a DEC340 display and a PDP5 control processor connected to an IBM 7094. DAC-1 produced hard copies of drawings while GRAPHIC1 was used for geometrically arranging printed-circuit components and wirings, schematic circuit design and the interactive[13] placement of connective wiring. A system called GOLD was developed in 1972 at RCA for integrated circuit mask layout.

> *"The first half of the '70s was a time of much enthusiasm among the early CAD scientists and system developers. Much theoretical work was done, laying down the fundamentals of CAD as we know it today... The late '70s may be characterised as the time of CAD's break-through from a scientific endeavour to an economically attractive – and in many areas –*

[13] The emphasis is mine - kwd

indispensable tool in industry." (Encarnacao & Schlechtendahl, 1983, pp. 9-10)

By 1980 almost 100 companies manufactured and marketed CADD systems covering a wide variety of applications. (Goetsch, 1986, p. 29) In Computer Aided Manufacturing (CAM) a link is established between the CAD system and the manufacturing side via DNC. (Ranky, 1986)

4.2.2.1 GKS/IGES

Any CADD system depends on a database containing at least

1. the final shape of the component including part dimensions and tolerances
2. a Bill of Materials
3. materials prescription
4. functional description
5. manufacturing, testing and assembly procedures
6. part classification.

Cross-package communication became possible in 1982 with the introduction of the Graphics Kernel System (GKS) standard which allowed portability of the graphics packages themselves and also to permit portability of data from one platform to another. This was achieved by providing device independence, language independence and standard display management utilising a set of primitive functions. GKS offered these services at the cost of increased machine overhead, whereas the Initial Graphics Exchange Specification (IGES) is an independent data format providing compatibility at a lower level. IGES has major shortcomings including:

1. It is complex and wordy, requiring transfer of three records of data for a simple line segment transfer.
2. File sizes are estimated at five times larger than equivalent picture files.
3. Geometric entity definition is limited in some areas including 3D solid modelling.

"However, most companies offer the IGES interface as an option, even if their networks do not use it because of the above mentioned reasons." (Ranky, 1986, p. 148)

4.3 Further Complication

Proliferation of CNC and CADD equipment was not the only case which encouraged, even demanded, the computerisation of the manufacturing workshop. Computer control, support and assistance was desirable or required in several other fields.

4.3.1 Robotics

"An industrial robot is a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or special devices through variable programmed motions for the performance of a variety of tasks." (Groover, 1987, p. 301) (quoting a definition developed by the Robot Institute of America)

The International Standards Organisation (ISO) defines an industrial robot in ISO/TR/8373-2.3:

> *"A robot is an automatically controlled, reprogrammable multipurpose, manipulative machine with several reprogrammable axes, which may be either fixed in place or mobile for use in industrial automation applications."* (Rehg, 1992, p. 5)

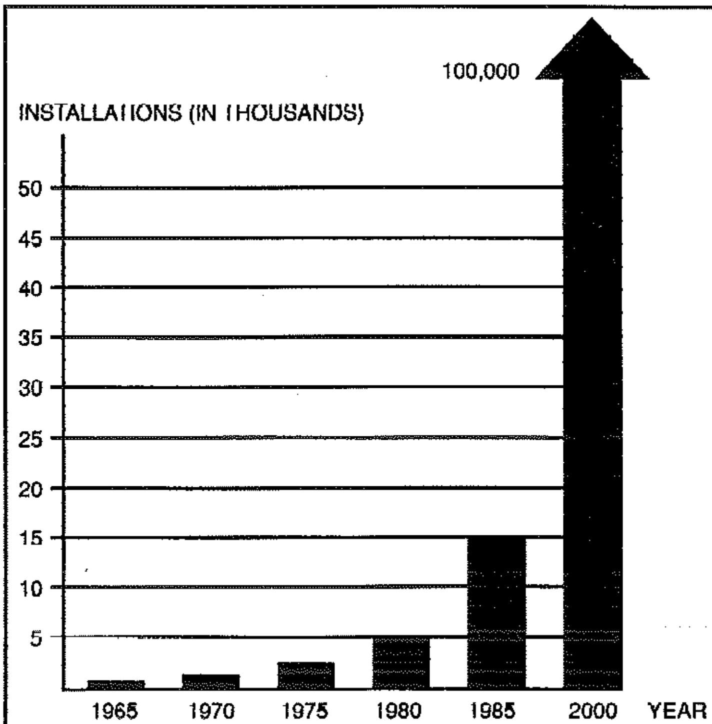

Figure 36 : Growth of Robot Installations in the United States

United States' inventor George Devol recognised that less than half the world's goods were mass produced, the rest being made in batches too small to justify special automatic machines for each step in their manufacture. Even in mass production, unskilled workers did nothing except move objects from place to place, feeding parts to machines, assembling them into products and packing the products. In 1954 he filed for US Patent 2,988,237 – a control system for a single, all-purpose machine which could be programmed for a variety of tasks. Program Controlled

Article Transfer, as he called it, led to the development of the industrial robot we know today. (Time-Life Books (eds), 1986)

Commercial robot production started in 1959. General Motors installed the first robot (produced by *Unimation*, the company founded by Devol) on a production line in 1962. Cincinnati Milacron (now part of ASEA Brown Boveri) produced the T-3 industrial robot which was the first to be controlled by a minicomputer.

> *"In present-day robots, the most obvious anthropomorphic characteristic is the robot's mechanical arm. Less obvious human-like characteristics are the robot's capability to make decisions, respond to sensory inputs, and communicate with other machines. These capabilities permits robots to perform a variety of useful tasks in industry."* (Groover, 1987, p. 301)

Robophiles list the advantages of robot use:

- increased productivity
- improved product quality
- more consistent product quality
- reduced scrap and waste
- reduced reworking costs
- reduced raw goods and inventory
- direct labour cost savings
- savings in related costs such as lighting, heating and cooling
- savings in safety-related costs

- savings from correctly forecasting production schedules. (Goetsch, 1990, pp. 175-176)

Robophobes, however, tell stories like:

> *"...an army of 260 robots would help 5000 human workers turn out 60 new cars per hour. One year later the factory was still producing only 35 cars per hour, largely because of malfunctioning of its automated spray-painting system. At times the computer controlled paint booths became the scene of a high-tech shoot-out as robot painters took aim at each other instead of the cars."* (Time-Life Books (eds), 1986)

Potential applications for robots include:

- working in environments hazardous to human beings
- repetitive work
- handling difficult or heavy for human beings
- multishift operations

Justification of robot installation, however, usually requires relatively long production runs since changeover (re-training) times are often extended and precise part position and orientation (although continuing improvements in robot vision and perception must be reducing this requirement). (Groover, 1987, p. 339)

Robot use is experiencing exponential growth in major manufacturing countries (ref: Figure 36, page 92 (Goetsch, 1990, p. 175)). Unfortunately, no similar statistics are available from the Australian Bureau of Statistics (ABS). Reporting to the Prime Minister (Malcolm Fraser) in 1982, the Technological Change Committee of the Australian Science and Technology Council cited a count of 50 robots in Australia in December 1979 increasing to 181 in May 1981.

> *"On the basis of the May 1981 figures, the number of robots per head of population in Australia is comparable with that in several European countries and exceeded only by Sweden, Japan and the Federal Republic of Germany."* (Australian Science and Technology Council, 1982, p. 21)

Manufacturing - WA		1990-91	1991-92	1992-93
Establishments at 30 June	No	3,510.00	3,645	p3,384
Persons employed at 30 June	000	64.5	62.5	p62.3
Turnover	$m	13,114.60	12,903.00	p13,477.0

Table 5 : Manufacturing Statistics for WA

Table 5 on page 95 gives the most recent ABS statistics for Western Australia. Since the predicted figures for 1992-3 showed an average of 18.4 employees/workplace I would suggest that the number of workplaces in WA into which robot technology had been introduced would be relatively insignificant – the workplaces would not be big enough to support the investment.

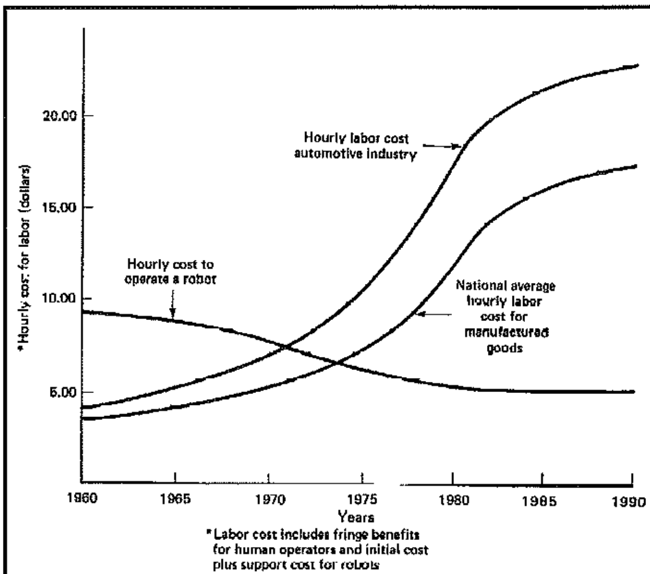

Figure 37 : Robot and Human Labour Costs

Costs, however, are becoming more competitive as is shown in Figure 37 on page 95 (ref: (Rehg, 1992, p. 4).

4.3.2 Automated Storage/Retrieval Systems

Database systems servicing storage and inventory control are ubiquitous, only the smallest companies adhering to the Kardex or similar system, and do not come into a discussion of shop floor automation. Automated storage/retrieval systems, however, are concerned with the physical article, rather than numbers or values.

Automatic Storage and Retrieval Systems (AS/RS) are defined by the [US] Materials Handling Institute as:

> *"A combination of equipment and controls which handles, stores and retrieves materials with precision, accuracy and speed under a defined degree of automation."* (Groover, 1987, p. 401)

Cranes (called Storage and Retrieval (S/R) machines) traverse aisles loading and unloading *storage modules* of materials from a *storage structure*. Controlling computer systems must keep account of the location of goods and of empty storage and may be integrated with the supporting information and record-keeping system. Inventory records may be accurately maintained since storage transactions are entered in *real-time*. Transfer of goods to and from the store may make use of automated guided vehicles or automatic conveyor systems.

4.3.2.1 AUTOMATED GUIDED VEHICLES

Materials handling is predicted to see widespread introduction of the Automated Guided Vehicle (AGV) which is a computer-controlled driverless vehicle

used for transporting materials from point to point in a manufacturing setting. They may be used for any and all materials handling tasks and the modern, optically-guided ones replace the wire-guided ones which have been around for more than twenty years. They include towing vehicles, unit load vehicles, pallet trucks, fork trucks and vehicles designed especially to service an assembly line. (Goetsch, 1990, p. 43)

4.3.3 Distributed Computer Systems

MES/CIM implementations, by nature, operate across a range of platforms, operating systems and software (ref: Figure 39 on page 115) as Distributed Computer Systems (DCSs). Sloman and Kramer (1987) state that distributed processing is a relatively new field with no agreed definition but Akkihebbal and Srinivasan (1990) provide a definition of a DCS containing five components:

1. A multiplicity of general-purpose resource components, possibly heterogeneous and including both physical and logical resources which can be assigned to specific tasks on a dynamic basis. Reconfiguration or reassignment of resources must not affect the operation of those resources not directly involved.
2. Physical distribution of these resources with interaction through a communication network utilising two-party co-operative protocols for information transfer. Co-operative protocols contrast with gated transfer where a *master* unit can force a *slave* to accept a message – a process which precludes unit autonomy.

3. A high-level operating system unifying and integrating the distributed components each of which may have its unique local operating system. Complete system information in a DCS will never be available and there will always be a time delay in its collection so the system must be designed to work even with erroneous or inaccurate status information.
4. System Transparency permitting services to be requested by name without server identification. Users should be able to develop programs and handle databases as if communicating with a single, centralised system.
5. Co-operative autonomy characterising the operation and interaction of resources. Operations of all components or resources retain autonomy while following a *master plan* defined in the high-level operating system. (Akkihebbal & Srinivasan, 1990)

"These properties and operating characteristics are present in a number of systems to varying degrees, providing some of the benefits listed... However, only the combination of all the criteria uniquely defines distributed data processing systems." (Akkihebbal & Srinivasan 1990, p. 6)

Issues in the software development of a DCS include:

- Safety and Reliability: especially where human life is concerned, the system must be failure resistant, fail-safe and have very low undetected error rates.
- Performance: even in failure situations, the system must be able to give guaranteed, predictable response times – commonly achieved by over-dimensioning the system.

- Flexibility and Extensibility: software must be constructed to permit occasional, on-line modification and extension to cope with environmental changes and altered demands on the information system.
- Maintenance and Diagnostics: stations should be capable of both remote and self-diagnostics to warn of possible future faults and permit preventative maintenance. (Sloman & Kramer, 1987)

4.3.3.1 For and Against DCS

Potential benefits of DCS implementation include:

- Cost Reduction: while the cost of computing power progressively reduces, peripheral device costs have not declined as dramatically. Sharing of expensive resources can, therefore, result in significant savings. Reduction in communications by use of local intelligence also reduces physical networking costs.
- Modularity: simpler local system design, installation, maintenance and verification may be products of increased modularity.
- Flexibility and Extensibility: upgrading, extending and altering systems is also simplified by modularity.
- Availability: failure of one module in a DCS need not mean the failure of the whole system with built-in redundancy allowing rapid recovery.
- Performance: local intelligence and databasing can permit faster response times to local problems.

These must, however, be weighed against perceived disadvantages such as:

- Economies of Scale: it may be cheaper to increase the power of a central computer than to use multiple computers, although LSI/VLSI technology costings make this doubtful.
- Capability: some programs are so large that they must be run on large computers with operating systems and software which might not be available for smaller machines. It must be asked whether the availability of a large machine obviates the necessity for a complex network of smaller ones as well.
- Operating Costs: 24-hour support, security and installation management (such as air conditioning) may be simpler in a centralised system.
- Negative Effects of Autonomy: enforcement of standards, avoidance of duplicated facilities and module incompatibility and the ability to attract experienced staff may all be simpler with a large, central machine. (Sloman & Kramer, 1987)

Today, DCSs are increasingly common to the extent that they are a serious competitor to analog systems and are being implemented world-wide. (Popovic & Bhatkar, 1990) However, justifying installation of such a system requires the establishment of attainable and verifiable goals. (Wentworth, 1993)

4.3.4 Quality

> *"Japanese Industrial Standard JIS Z 8101-1981 defines Quality as the totality of the characteristics or performance that can be used to determine whether or not a product or service fulfils its intended application."* (Asaka & Ozeki, 1990, p.4)

Quality assurance systems, culminating in ISO 9000, were created in response to supply problems during and following the Second World War. In the 1970s the UK Defence Standards, Quality procedures that had to be documented and implemented by designers, manufacturers and suppliers of equipment to the UK Military, were incorporated into the Allied Quality Assurance Publication (AQAP) Standards still used by the NATO countries. These standards provided the base for BS 5750 which was introduced in 1979. In 1987, ISO 9000 (a direct equivalent of BS 5750) was introduced as an international standard for Quality systems. The Australian equivalent is AS 3902. (Mirams & McElheron, 1994, p. 11)

> "[This] *series is a set of five individual, but related, international standards on Quality management and Quality assurance. They are generic, not specific to any particular products. They can be used by manufacturing and service industries alike. These standards were developed to effectively document the Quality system elements to be implemented in order to maintain an efficient Quality system in your company. The ISO 9000 Series standards do not themselves specify the technology to be used for implementing Quality system elements."* (ANSI-ACS Z-1 Committee, 1995)

ISO 9001 consists of 20 clauses which cover Quality systems relating to design, development, production, inspection and testing, installation and servicing. It is appropriate to organisations which designs, produces and delivers products to the customer and carries out installation and after-sales servicing. (Mirams & McElheron, 1994, p. 14)

4.3.4.1 STATISTICAL SUPPORT

Both Statistical Process Control (SPC) and Statistical Quality Control (SQC) originated in the work of Dr Walter Shewhart of Bell Laboratories in the 1920s.

> *"On May 16, 1924, Dr Walter Shewhart.. wrote a note to the head of Western Electric's Inspection Engineering Department, which said: 'The attached form of report to indicate whether or not the observed variations in the percent of defective apparatus or a given type are significant; that is, to indicate whether or not the product is satisfactory.'"* (Messina, 1987, p. 102)

Included in the report was a chart which became known as the Shewhart control chart which became the basis of SQC (Messina, 1987) and SPC (Wetherill & Brown, 1991, p. 1). That both concepts should relate to the same origin is understandable if it is accepted that the aim of both is to produce product of acceptable standard but the parallel trails do not end there. Both were employed extensively during the Second World War, both fell into disfavour in the western world during the boom times following the war, both trace their rediscovery to the work of W. Edwards Deming and Joseph M. Juran with Japanese industry in the 1950s. (Capezio & Morehouse, 1993), (Asaka & Ozeki, 1990), (Ishikawa & Lu, 1985), (Robinson, 1991), (Hutchins, 1988), (Beauregard, Mikulak, et al., 1992).

Both concepts employ statistical methods to analyse identified areas of the production process on the basis of collected data. Messina (1987) list four characteristics a data collection system must satisfy:

1. the data integrity or validity must be extremely high (95% or higher)
2. data traceability must be present
3. the right type of data needs to be collected

4. the system must be on line and on time.

Given that item three is the responsibility of the human in charge of the data collection, computerisation of the shop floor would seem to provide an ideal vehicle for the others.

4.3.4.1.1 Automatic Data Collection

> *"There has been a great increase in the use of more sophisticated approaches, such as the computerised shop-floor dimensional gauging systems... These usually accept direct input from sensors applied to components. The computer then indicates conformance to specification, and calculates SPC performance for process control."* (Tannock, 1992, P. 13)

Tannock (1992) says that these systems tend to be inflexible and incapable of integration with other systems. Coordinate Measuring Machines (CMMs), machine vision and Automatic Test Equipment (ATE) are major themes of advance in this area and are sure to result in a large increase in the amount of product and process quality data made available. In many manufacturing companies, CMM has largely taken over from traditional methods.

> *"The biggest gains to be made by an MES* [Manufacturing Execution System] *system comes in the form of the fundamental pieces of information that previously were collected and assimilated by hand."* (McDonough, 1995, p. 68)

There are two types of data; measured (or continuous) and counted (or discrete) (The JUSE Problem Solving Research Group (eds) (vol. 1), 1991, p. 30) both

of which could be collected and statistically analysed on-line and in real-time by a shop-floor computer system. It remains a human task to act on that information:

> *"A statistical chart detects the existence of a cause of variation that lies outside the system. It does not find the cause."* (Deming, 1960, p. 312)

Data collection alone is insufficient without the management of quality information.

> *"Automation in quality systems should be a support to the human factors themes of TQM, and, rather than undermining teamwork, it will emphasise the importance of strong self-managing teams...* [providing] *them with a far superior level of quality information."* (Tannock, 1992, p. 19)

4.3.4.2 TOTAL QUALITY CONTROL/TOTAL QUALITY MANAGEMENT

> *"Total Quality Control, Japanese style, is a thought revolution in management."* (Ishikawa & Lu, 1985, p. 1)

> *"Total Quality Management refers to a management process and set of disciplines that are coordinated to ensure that the organisation consistently meets and exceeds customer requirements."* (Capezio & Morehouse, 1993, p. 1)

> *"Total Quality represents a competitive strategy."* (Hutchins, 1988, p. 24)

If Quality issues are perceived to be a management strategy, process or thought revolution, it can be argued that little can be supplied in the way of direct

computer support. Certainly, the opportunity must exist on a computerised shop floor for the collection and communication of accurate, real-time data on which decisions may be made, but strategic decisions must be human decisions.

Stand-alone software support for the seven Quality Control Tools

1. Cause-and-Effect Diagrams
2. Pareto Charts
3. Check Sheets
4. Histograms
5. Scatter Diagrams
6. Control Charts
7. Graphs

may be provided, but these may be seen to be ancillary to the main computer system of the factory although they may need to access the company databases.

4.3.4.3 MAP AND TOP

Digital communication between different machines and different sections of an enterprise was now crucial which led to General Motors setting up workgroups in 1979 to investigate and identify common communications standards for plant-wide systems. Objectives for the Manufacturing Automation Protocol (MAP) Task Force, set up in November 1980 were:

1. To define a MAP *message standard* to support application to application communications.
2. To identify *application functions* to be supported by the messages conforming to MAP standards.

3. To recommend protocols that would meet the functional requirements. (Rodd & Deravi, 1989, p. 69)

Six versions of the MAP protocols were published between 1982 and 1988.

> *"The overall goal of MAP is the total integration of islands of automation in manufacturing, regardless of the producer of the hardware and software used in the system. With MAP fully developed and in place, a user will have access to any computer within a manufacturing facility from any other computer within that facility, regardless of the make, model, or vendor of that computer."* (Goetsch, 1990, p. 308)

GM were using a Token Bus LAN to satisfy the real-time requirements of machine control (with a deterministic, worst-case performance) and MAP was an adaptation of the ISO/OSI 7-layer network protocol for that purpose. At the same time, Boeing (who used an Ethernet system – 747 production is not a real-time process) was interested in standards for office automation. Boeing produced the Technical and Office Protocols (TOP) which differ slightly from MAP in the lower OSI levels but they worked closely with GM to ensure full compatibility in the middle and upper layers. (Tanenbaum, 1989)

MAP and TOP may have eventually been overshadowed by ISO/OSI and other ubiquitous protocols, but research in telecommunications for industry continues:

> *"Beginning in FY* [February] *1994, NIST*[14] *will establish an Advanced Manufacturing Systems and Networking Testbed to support research and development in high performance manufacturing systems and to test high performance computer and networking hardware and software in a*

[14] (US) National Institute of Standards and Technology

manufacturing environment. The testbed will serve as a demonstration site for use by industrial technology suppliers and users, and to assist industry in the development and implementation of voluntary consensus standards. Research and testing will be conducted at the NIST testbed as well as at testbeds funded through the NIST Advanced Technology Program." (National Institute of Standards and Technology (USA), 1994)

NIST seek to support the integration of advanced manufacturing systems and networking software in a manufacturing systems environment. Workshops, training materials and electronic media will be used to disseminate results and pre-commercial prototypes made available for test and evaluation.

"A standards-based data exchange effort for computer integrated manufacturing will focus on improving data exchange among computer aided design, process, and manufacturing activities. Prototype systems and interface specifications will be communicated to appropriate standards organisations." (National Institute of Standards and Technology (USA), 1994)

European Community nations have combined in a project called ESPRIT to provide funding and other support for Research and Technical Development (RTD) work in a variety of fields including Industrial Computing.

"Industrial RTD projects cover research and technological development work (RTD work), aimed at strengthening European industrial competitiveness, with the focus on the development of the information infrastructure and on making new information technologies available to industry and society.

The guiding principle in the programme is industrial relevance of RTD projects to be achieved through co-operation of a wide range of organisations across national boundaries including suppliers of IT products, services and users. This co-operation should lead to innovation in products and services which in turn benefits both the European economies and society." (European Commission, 1996)

Proposals from non-EU countries including Australia are eligible subject to the relevant ESPRIT contract and fields of study include

- Software-Intensive Systems Engineering
- Emerging Software Technologies
- Distributed Systems and Database Technology
- Human Comfort and Security
- Software Best Practice.

5. System Integration Factors and Trends

"It is perhaps unfortunate and likewise quite telling that quantification of Manufacturing Execution Systems (MES) is really just so much black art." (McDonough, 1995)

Previous chapters demonstrate the complexity of the systems in the manufacturing industry which must be supported by any MES. An MES is not a single program, rather an alchemy of many programs and information systems integrated into a coordinated system. It follows irrevocably that any computer system which seeks to integrate all the facets of manufacturing computing will also be complex.

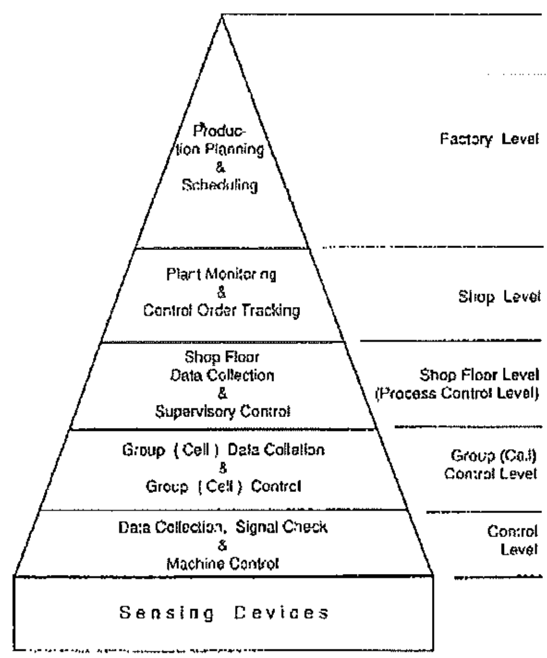

Figure 38 : Hierarchical system for Manufacturing Automation

"MES systems are arguably one of the more complex Computer Information Systems in existence. This is not to say that you can't think of several other systems that you personally consider more complex, perhaps you can and it's not that the code is necessarily complex

either, but rather that the whole system itself is. The interaction of all the components is critical to the net result." (McDonough, 1995)

5.1 Functions of an MES

The function of an MES is twofold: (1) collection and distribution of plant data and (2) supervision of production... Data gathered by MES from any connected plant operation is made available to make reports and support queries. Within MES reports are generated that show manufacturing details, process trends, production economics, production status or any other reports that combine manufacturing processes and process data. The production situation or status of individual orders can also be reported and made available to all areas of the plant." (Wenstrup & Appleby, 1995)

Some typical goals are:

- Improving plant production through improved process control.
- Reducing operating costs through the combination of operational tasks and automatically retrieving and organising plant data.
- Providing access to current and historical process data to enable prompt operational decision making. (Wentworth, 1993)
- Providing access to safety and hazards documents such as material safety data sheets.
- Eliminating paper overhead in transferring operating procedures, records and recipes to the operators.

- Improving customer service, product quality and availability, productivity, unit cost reduction and compliance management. (Chance, 1994)
- Providing support for failure detection, failure localisation, failure elimination and failure prevention. (Adlemo, Andreasson, 1995)
- Speeding product changeover.
- Reducing product lead times. (Appleby, 1994)
- Reduction of Work-In-Process (WIP) inventory by speeding the progress of the product through the plant. (Groover, 1987, p. 7)
- Improving quality by monitoring technical compliance.
- Increasing efficiency in product shipping. (Koenig, 1990, p. 9)
- Increasing flexibility in coping with system disturbances and changed economic factors. (Ranky, 1990, p. 14)
- Enhancing evaluation and development of product strategies. (Ranky, 1986, p. 3)

Achievement of these, and other, goals depends on the MES being able to access a number of databases possibly residing on machines with a range of architectures, operating systems and data storage methods.

> *"Virtually no two computers handle data in the same way, and therefore a database developed by a materials requirement planning system will probably be found to be totally incompatible with the database being used to produce master production schedules."* (Rodd & Deravi, 1989, p. 3)

This compounds the complexity of the overall system by requiring the establishment of plant-wide communication protocols but the distributed nature of

the system, especially in a scenario including localised production databases implemented in the shop floor computer systems, has a major advantage over a centralised, one-computer system in that selection of data to be transferred may be based on defined policy and take place at the source.

5.1.1 Plant-wide Integration Expensive

Figure 38 on page 109 (ref: (Popovic & Bhatkar, 1990, p. 40)) shows an hierarchy of computer systems within a manufacturing plant, all of which must be considered in the process of full integration. Koenig (1990) lists the following generic requirements for integrated systems:

1. Access available in an equal manner regardless of the access point.
2. An easy method of transferring information between functional users.
3. A fast response time, usually three seconds or less.
4. Access to the common database at will with no intolerable delay.
5. Capability of easy multi-user simultaneous communication.

> *"Many early systems were rapidly bogged down by the inability to get data transmitted quickly enough. On examining many of these systems, it was discovered that a large percentage of the data which was being transmitted around a plant was never actually used!.. The size of what is often called the 'active' or 'real-time' database is surprisingly small compared with the total amount of information which is being produced by the various data sources... One large chemical company has estimated that some 98% of their data stored for later processing or general archival needs*

was never used, illustrating only too graphically the concept of 'write-only storage'." (Rodd & Deravi, 1989, p. 5)

"The point is that in undertaking any CIM exercise, the various parties who might require access to parts of the whole integrated system must be consulted, and their needs met. It is often found that understanding of the needs... permits the data or information flow between computing devices to be very carefully restricted to the absolute minimum." (Rodd & Deravi, 1989, p. 20)

While these factors can be seen to be relevant to integrated systems in a commercial environment, the real-time imperative in manufacturing computer systems must impose a higher level of implementation difficulty, which, in turn, makes the implementation of an MES an expensive, long-term process.

"In very general terms, you can expect to spend in the neighbourhood of $500,000 [US] *to apply an MES to a department, on up to $5 or 6 million over several years to apply an MES to several process plants."* (Hill, 1993)

"It is very clear that many large CIM applications might take five to ten years to complete." (Rodd & Deravi, 1989, p. 22)

Nor do costs vary much with the size of the plant in which MES is implemented:

"MES systems that run on large main-frame/mini-frame types of hardware have significant costs and support issues that have a life all their own, independent of the MES software running on them. These costs are

very similar whether helping to run the new billion dollar fab or the 50 million dollar fab producing 5 micron CMOS in volume...

And here in lies the rub for most of the mid-size and smaller facilities. How do they justify the very large installation/ implementation/ support costs when they essentially are paying a price that is similar to that paid by a larger foundry producing 5 times more product than they are. And on the other hand how do they dare not to implement. That is in fact what has been going on for the longest time in the medium and smaller fabs. They run with home brewed systems or no systems at all rather than incur the costs of a typical MES implementation." (McDonough, 1995)

McDonough (1995) talks in terms of a US$2 million project with a maintenance budget of US$1 million, but in large companies such investment must be balanced against large potential savings:

"Du Pont, for example, estimated that the modernisation of control facilities worldwide could save the company $400 million [US] *annually."* (Doyle, Morari, et al., 1995)

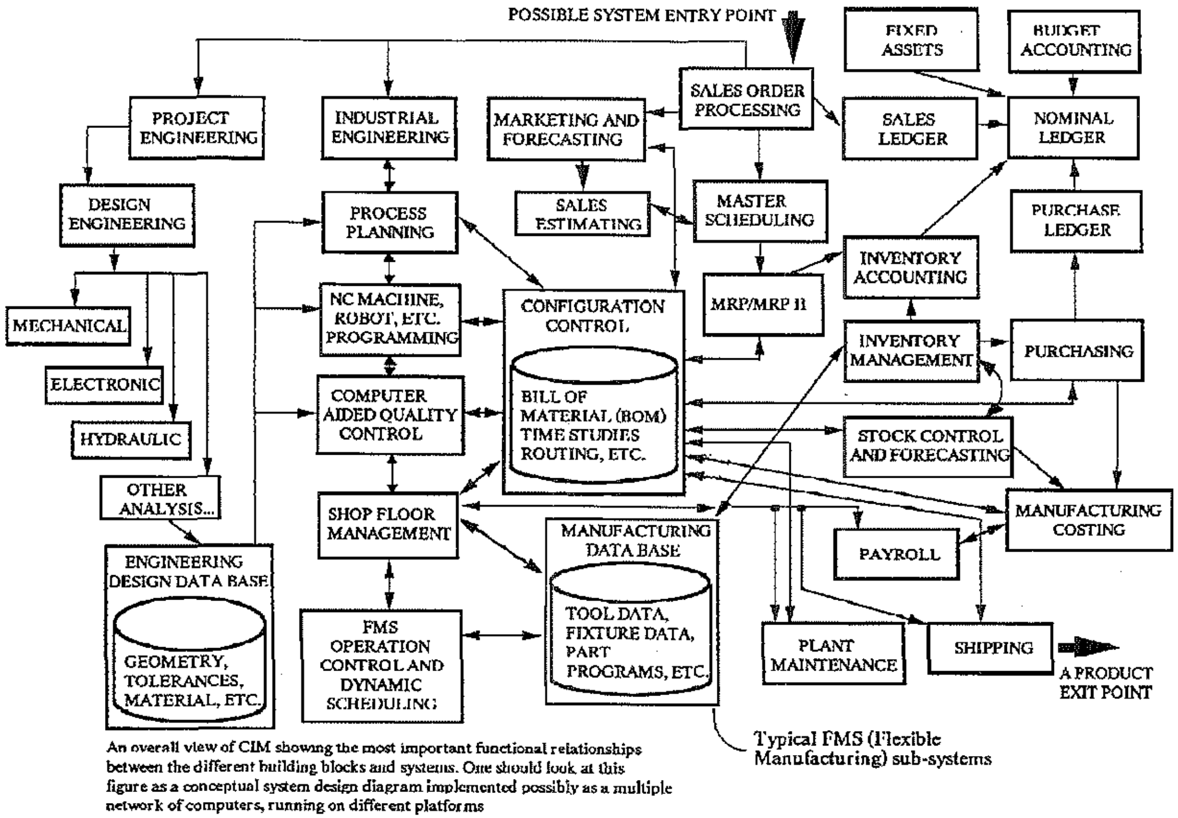

Figure 39 : System Integration in Manufacturing Computer Systems

5.2 Implementation Issues

"Distributed computer systems have a number of potential advantages over large centralised systems. However, some of the complexities involved can threaten and overwhelm all of these benefits. Concurrency, communication and synchronisation of distributed components can increase the complexity rather than provide a panacea if they are not well structured and controlled." (Sloman & Kramer, 1987, p. 41)

Dynamic configuration of a DCS from autonomous components requires definition of roles within specific scenarios, assignment of functions, stipulation of rules of co-operation and of interaction models...

"These components were purchased from different manufacturers for efficiency reasons or because of the manufacturers' limited range of products. Thus, we must expect heterogeneity at all hardware and software levels." (Tschammer, Eckert, et al., 1988, p. 24)

5.2.1 Communication and Synchronisation

DCS components execute concurrently requiring synchronisation and communication primitives to provide co-ordination and co-operation between them.

5.2.1.1 SYNCHRONISATION

Coordinating actions of two or more software components, with respect to time, is called *synchronisation* including the prevention of interference between components accessing a shared resource and assurance that actions are performed in the correct order.

5.2.1.2 COMMUNICATION

Exchange of information between components of a DCS, which need not necessarily imply synchronisation, is referred to as *communication.*

In a loosely-coupled system, such as a DCS, communication primitives such as message passing must be used to implement both communication and synchronisation. These must deal with such issues as naming, addressing and routing of data and information, segmentation and reassembly of longer messages, error control and recovery, congestion and flow control and, especially in real-time systems, message priority. Also they must take into account the topology of the network (eg star, ring, mesh, tree or bus architecture). (Sloman & Kramer, 1987)

5.2.2 Database Compatibility

Figure 39 on page 115 (ref: (Ranky, 1990, p. 17)) also appeared in his earlier work (Ranky, 1986) and might, a decade later, be considered simplistic given the increase in computer implementation. Even so, it does indicate the number of software packages and databases involved in an integrated manufacturing computer system. Rodd and Deravi (1989) suggest two classifications of databases:

1. <u>Real-Time Databases</u>: localised to production and typically used to make on-line, real-time decisions. Updated data may overwrite current data unless it is required for historical reasons or further analysis, but provides the user with a complete, consistent picture of activities on that plant.
2. <u>Historical Databases</u>: inherently non-time-critical and providing an historical record of the activities of the factory, stock, WIP, financial logging, financial models etc. These databases can be extremely large and their importance lies in the value of the information itself.

Two problems emerge in the transfer of data from the real-time databases to the historical:

1. Deciding which data should/must be transferred.
2. Standardising the data format for transfer.

Problem one is a policy decision which would have to be discussed in the context of a particular plant. Low-level information such as temperature, speed or pressure, is of little value to management who are mainly concerned with production rate so it is sensible to calculate at the low level the information required higher up, and to send only the pre-calculated information. Naturally, this depends on the availability of processing power at the low level.

Problem two relates to the early tendency of computer vendors to keep to proprietary operating systems and data storage formats. MAP (ref: page 105) application revealed a serious deficiency in that it could not match real-time requirements, particularly at the lower levels which require on-line, immediate decisions, which many experts consider essential even at higher levels of the hierarchy. Only recently has some other form of standardisation emerged, initially

with the use of MS-DOS on increasingly powerful personal computers but, more significantly, with UNIX on larger systems. (Rodd & Deravi, 1989)

5.2.3 Data Consistency

Critical to the use of distributed database systems is the requirement that duplicated data is consistent, ie. that a datum should have exactly the same value regardless of storage location.

> *"The particular computer systems which was responsible for the creation or 'authorship' of a piece of data must also accept responsibility for ensuring that its value is, indeed, updated elsewhere in the CIM system. This implies that at the earliest stage in the design of a CIM system, the design team must establish where data is created, and exactly where it is required to be used."* (Rodd & Deravi, 1989, p. 12)

5.2.4 Database Distribution

Physically partitioning a total database over a number of autonomous machines may be justified as follows:

1. *"Many application environments require the sharing of data among diverse users with different computing facilities.*
2. *Partitioning can improve access time if local data is stored locally. Delays due to transmission time for queries and responses can be reduced by keeping the data close to the users. Also individual databases can be reduced in size. This results in less contention for access from many users.*

3. *Control of the data can be retained where the local responsibility lies...*

4. *Reliability can be improved by maintaining multiple copies at different locations. This provides security against natural disasters such as fire or flood, but it can lead to updating problems (consistency).*" (Sloman & Kramer, 1987, p. 14)

5.2.5 Fault Recovery

"A fault is an event that causes 'incorrect' operation of a system component." (Simons & Spector, 1990, p. 5)

"In order to attain the desired level of reliability... [real-time] *DCSs must be designed to possess effective fault tolerance capabilities."* (Kim, 1988, p. 318)

Given that an average single-board computer can be shown to have a mean time between failures (MTBF) of some two and a half years, a factory with, say, one hundred such machines can expect a failure every couple of weeks. There should never be one piece of equipment or software which can cause the total system to fail. Machine redundancy and back-up data may allow a system to cope with failure but it must be remembered that real-time systems cannot recover by going back to a previous state (as can, for example, accounting systems). (Rodd & Deravi, 1989)

Communications faults include messages lost, delayed, duplicated or corrupted, messages arriving in incorrect order or changed by random noise picked up in a data link. A faulty process may cease operation and notify other processes (failstop), cease operation and not notify other processes (crash), arbitrarily omit sending some messages (omission) or continue to operate and send arbitrary messages (Byzantine). (Simons & Spector, 1990, pp. 6-7)

Recovery schemes in real-time DCSs must be able to recover from both hardware and software faults within stringent time constraints and this requires, in turn, that there be a process for detecting faults bearing in mind that faults tend to propagate through a network from one failed node to others. Kim (1988) lists a variety of detection and recovery schemes including *checkpointing* which saves the computation state at various execution points (a process which appears to conflict with the opinion on previous state recovery from Rodd and Deravi (1989) above). Other systems listed include *comparing pairs* which utilises duplicate redundancy and triple modular redundancy which compares three copies of a computing component and '*votes*' on execution result discrepancies. (Kim, 1988)

5.2.6 Development

DCS development for MES/CIM, in common with most computer engineering projects, may be commenced from scratch with a completely new system (the green field approach) or proceed by incremental modification of an existing system.

> *"Two basic approaches are possible:*
>
> *partial plant automation, which first removes the bottlenecks within an existing plant, and then can gradually be extended to complete plant automation without total plant shutdown (the so called bottom up approach)*
>
> *complete plant automation, usually suitable for new plants to be installed, generally known as the top down approach."* (Popovic & Bhatkar, 1990, p. 6)

In either case it would seem that the collection of software would include a range of proprietary packages (including database management systems (DBMSs), forecasting and planning packages, Computer Aided Design and Drafting (CADD),

Computer Aided Engineering (CAE), Management Information Systems (MISs), office software, operating and communications systems) and a variety of specific, in-house software accommodating the company's products, processes and services.

5.3 Currently Available Commercial Software

Even a cursory investigation of the availability of proprietary software for MES application reveals a wealth of packages and implementations for a wide variety of platforms and purposes. Appendix A (page 156) shows the European market penetration (and costs) of proprietary Finite Capacity Scheduling (FCS) software; Appendix B (page 159) shows capabilities, requirements and costs of Decision Analysis software; Appendix C (page 162) is a list of software houses supplying software for specific, MES-related applications. All these listings were prepared by APICS, are available on-line and are used with the kind permission of Lionheart Publishing.

Some significant packages are considered below.

5.3.1 Large Computers and UNIX Systems

Given the complexity of the overall concept, and the fact the large, multi-national companies are prospective clients, it is to be expected that some of the larger players should be in the game. Three such are the Digital Equipment Corporation (DEC), International Business Machines (IBM) and SAP.

5.3.1.1 DEC & FRIENDS

DEC markets BASEstar Open Client Version 2.0:

> *"A realtime, distributed manufacturing industry platform for integration of shop floor control that runs on multiple platforms. BASEstar services provide comprehensive support application integration, device connection, and control of plant equipment. Many third parties write to its integration specification, which is now extended for integration with SAP R/3."* (Digital Equipment Corporation, 1995)

BASEstar used an open client/server architecture allowing access to all services from any client node through TCP/IP network communications. It is available in versions for:

1. OpenVMS VAX V2.0A
2. OpenVMS VAX Alpha v2.0
3. OSF/1 AXP V2.0A
4. Windows NT V 2.0
5. MS Windows V2.0A

Versions for Windows NT and MS Windows operate on Intel 80386 and later CPUs with a requirement of only 1.5 MB of disc space. Services provided by the package include:

1. Data Management : with application independent data control via discrete data elements (Data_Points) referenced by name providing *"a standard mechanism for defining, organising, and accessing data in a distributed manufacturing environment from a variety of sources including plant devices and area, plant, and work cell applications."*

2. Packet Services : delivering information packets in a protocol-independent manner also independent of users and ports involved.
3. Named Objects : *"which represent plant devices and Data_Points-alarms, data status, production counts, and so on. Manufacturing applications can therefore access these resources using meaningful functional names, rather than in a system-dependent manner which would require, for instance, information on physical locations."*
4. Open Interfaces : including Application Programming Interface (API) and Graphic Configuration Utility (GCU). (Digital Equipment Corporation, 1995)

BASEstar is part of a portfolio of systems integration software designed to enable the development of complex enterprise systems specifically including "*manufacturing planning, operations and execution*'. Digital has also formed an "*Alliance for Enterprise Computing*" with Microsoft and partnerships with ORACLE, SyBase, Informix, Software AG and others to develop 64-bit database software for high performance applications on Alpha Systems. (Digital Equipment Corporation, 1995)

5.3.1.2 IBM

"Factory Operations Executive (Factory Ops) handles the overall execution and coordination of plant floor activities by capturing, processing, and disseminating information about manufacturing operations on a real-time basis. It provides the current status of jobs and factory conditions without having to search the manufacturing floor for such information." (International Business Machines (IBM), 1995)

Factory Operations Executive (FOE) was designed for manufacturing enterprises that use discrete flow manufacturing techniques, such as electronics, automotive, semiconductor, computer, and general fabrication and assembly to control line operations and record and display information about the line and work in process.

> *"When a manufacturing order is received, it is entered into a materials requirements and planning (MRP) system and is then downloaded into Factory Ops or is entered directly into Factory Ops. The order is then released to the manufacturing floor, and the system tracks the progress of the order through the operations specified by the process plan. Instructions for performing a particular operation can be viewed electronically by shop floor personnel. Released orders can be split, merged, held, re-routed or re-prioritised to optimise manufacturing resources and ensure on-time delivery."* (International Business Machines (IBM), 1995)

Sequential, non-sequential, subset, and concurrent operations are supported and FOE records production data (process time, first-class yield, scrap, rework etc.) as the order moves down the line. FOE is client/server based with two types of client nodes:

1. Administration Nodes : used by engineers and administrators to configure FOE by identifying tools, operations, bills of material and other resources FOE will control.
2. Execution Nodes :

   for line personnel to monitor and control progress of jobs on the line.

IBM claim low cost with 21-shift reliability and the ability to run on existing systems or to be installed as a turn-key system. FOE has a capability to implement a Kanban style of process control.

FOE Requirements		
Operating systems	AIX server	AIX 3.2.5 or 4.1 with the REXX/6000 Language Processor, Help Manager, XL C++ and XL C runtime libraries, and X Window System (**)
	OS/2 client	OS/2 2.11 or OS/2 Warp 3.0
Communica-tions	AIX server	IBM TCP/IP 3.2 or IBM SNA Services 1.2
	OS/2 client	IBM TCP/IP 2.0, LAN Support Program 3.0, or IBM Communication Manager/2 (APPC)
Database management	AIX server	IBM DB2/6000 1.2

FOE Requirements (cont.)		
Hardware requirements	AIX server	IBM RS/6000 50MHz clock speed (Model 560 or larger) with at least 128MB RAM and 800MB available disk space and with a 1/4 inch or 8mm 150MB cartridge tape drive to unload installation tapes.
	OS/2 client	IBM PC 486 50MHz clock speed with 8MB storage, 100MB available disk space, and a 3.5 inch diskette drive
Communications adaptors	LAN	IBM Token-Ring Network IBM PC Network Ethernet

Table 6 : Factory Operations Executive Requirements (International Business Machines (IBM), 1995 (a))

FOE Communications Protocols					
Communications Adaptors	APPC LU 6.2	MAP 3 (ACSE).0	NetBIOS	IBM TCP/IP	DECnet
AIX					
Ethernet (802.3)	X			X	
IBM Token-Ring Network	X			X	
MAP		X			
OS/2					
Ethernet (802.3)	X	X	X	X	X
IBM PC Network	X		X	X	
IBM Token-Ring Network	X		X	X	X
MAP		X			

Table 7 : Factory Operations Executive Communications Protocols (International Business Machines (IBM). (1995 (a))

5.3.1.3 SAP[15]

SAP AG was founded in 1972 and specialises in software for nearly all business applications in middle and large-sized companies. As well as being of considerable significance in Europe, especially its native Germany, the corporation is

[15] SAP stands for Systeme, Anwendungen, Produkte in der Datenverarbeitung, which freely translates into Systems, Applications, and Products in Data Processing. (ref: http:// www. informatik. uni-oldenburg. DE/ ~bartelt/ sap/ sap-faq.html#sap-ag-corporation. what-is-sap)

expanding world-wide with branches in Thailand, Japan and Canada and in the US with the support of the American SAP User Group (ASUG) chaired by Richard Lloyd of DuPont.

SAP R/2, the first compact software package for the whole spectrum of business applications from the corporation, runs on mainframes including IBM, BS2000 (Siemens) and Amdahl. Over 2000 implementations are in place world-wide. It includes modules for:

1. (RF) Financial Accounting (Finanzbuchhaltung)
2. (RA) Assets Accounting (Anlagenbuchhaltung)
3. (RK) Cost Accounting (Kostenrechnung)
4. (RK-P) Projects (Projekte)
5. (RP) Human Resources (Personal)
6. (RM-INST) Plant Maintenance (Instandhaltung)
7. (RM-QSS) Quality Assurance (Qualitaetssicherung)
8. (RM-MAT) Materials Management (Materialwirtschaft)
9. (RM-PPS) Production Planning and Control (Produktion)
10. (RV) Sales and Distribution (Vertrieb, Fakturierung, Versand)

Since 1995, SAP R/3 (which was designed for open systems and runs on most types of UNIX, WindowsNT and O/S400) has gained a rapidly increasing deployment. R/3 can use ORACLE, Informix Online, ADABAS-D, DB2 for UNIX, DB2/400 and Microsoft SQL Server 6 databases and includes the modules:

1. (AM) Asset Management (Anlagenwirtschaft)
2. (CO) Controlling (Controlling)
3. (FI) Financial Accounting (Finanzwesen)

4. (HR) Human Resources (Personalwesen)

5. (IS) Industry Specific Solutions (Industriespezifische Loesungen)

6. (PM) Plant Maintenance (Instandhaltung)

7. (PP) Production Planning (Produktionsplanung)

8. (PS) Project System (Projektsystem)

9. (QM) Quality Management (Qualitaetssicherung)

10. (SD) Sales and Distribution (Verkauf/Versand/Fakturierung)

11. (MM) Materials Management (Materialwirtschaft)

12. (WF) Business WorkFlow

operating with a central module(BC) - Basis.

More than 100 R/2 clients (including Fresenius AG (Bad Homburg : dialysis systems, infusion therapy, enteral nutrition, arthroscopy and other interests) and Ciba-Geigy GmbH (chemicals and pharmaceuticals)) have made the change to the R/3 open systems suite with nearly 80% completing the changeover within a 12-month timespan. (Hochlenhert & Magura, 1996)

5.3.1.4 MARCAM CORPORATION

PRISM , MAPICS and Maintenance Management products from the Marcam Corporation in Massachusetts (USA) have been installed in more than 15,000 customer locations worldwide and operate on a variety of platforms, including IBM's RISC System/6000 and AS/400 Advanced Series, Hewlett-Packard's HP-9000, Digital Equipment Corporation's AlphaServer Systems, and Intel-based personal computers. PRISM applications are intended for process manufacturing while the MAPICS XA suite is suited to discrete manufacturing. These applications are designed to

improve their production, logistics, maintenance management, and financial operations with packages dealing with Demand Management, Engineering Management, Resource Planning, Operations Management, Financial Management, Maintenance Management and Business Management. They incorporate advanced patented resource management and production model concepts, giving users greater control of costs and all production resources including materials and capacity with fully integrated quality management and activity costing features, as well as a complete maintenance management product line. (Marcam Corporation, 1996) (Marcam Corporation, 1996)

5.3.2 *Use of Distributed Systems and PCs*

Pursuit of flexibility and reactivity has brought with it open, distributed processing architectures with localised CPUs connected through industry-standard fieldbus protocols. (Collins, 1993) Jasany cites John Leonardo (Executive Vice-President, Texas Microsystems Inc.) :

> *"Personal Computers provide exponentially more processing power, at significantly lower cost, to more users, than any other class of computer... Membrane keyboards, industrial enclosures, and add-on boards can toughen the PC. Single board or embedded PCs can give you the rugged industrial PC system you need."* (Jasany, 1992)

PC-based systems offer easy system connectivity and open architecture. They are simple to upgrade, support is guaranteed, and compatible hardware is always available. (Royer, 1994)

Increasing emphasis on open systems has seen a recent upsurge in interest in industrially hardened PCs to operate software for common operating systems like Windows 3.1 and Windows NT. IBM are active in the hardware field.

5.3.2.1 INDUSTRIAL HARDWARE

5.3.2.1.1 IBM

"IBM has announced that it is expanding its line of industrial computers for embedded applications. The two new computers include a 5-slot passive backplane computer and an industrial computer with a Pentium processor (100mhz to 200mhz).

Responding to customers' need for a powerful ISA bus computer that is easy to panel or wall mount, Big Blue has developed the 7587 Industrial Computer, a 5-slot ISA/PCI passive backplane computer that is PICMG compliant. The 7587 comes with moulded covers that include flanges for easy mounting on vertical and horizontal surfaces. To make the unit easily accessible for repair, IBM has made all components accessible from the top of the unit. Additionally , the unit features a filtered fan at the front that pushes cool air over the internal components for operating ranges from 0? C to 50? C.

The other new box is the 7585 Industrial Computer Model P02, which is based on the PC350 model 6587 and offers up to 160MB of installed parity memory, up to four installed IDE hard drives - up to 1.6GB - and enhanced SVGA monitor support.

The new systems support a number of operating systems, including: OS/2 Warp, DOS, Windows for Workgroups 3.11, Windows 95 and Windows NT." (International Business Machines (IBM), 1996)

5.3.2.1.2 EMPaC

Another machine designed for industrial applications, the EMPaC R/T is an PC/AT compatible computer chassis with a 14-slot PC-bus compatible passive backplane platform and high efficiency switching power supply in a dual-fan cooled chassis. EMPaC claim that the R/T withstands the shock, vibration, dust and extreme operating temperatures found in harsh industrial environments. Implementing a 350W Underwriters Laboratories (UL) approved power supply with an external switching capability of 95-130/180-264 VAC, 52CFM exhaust fan , voltage levels supported are 7A minimum with a maximum 40A @ +5V, 1A min. to 9A max @ +12V, 0.5A @ -5V and 0.5A @ -12V. Two 85CFM push-pull cooling fans venting through a grilled dual stage removable/replaceable dust filter, pressurise the case to deliver fresh air from the front to exclude dust and dirt, and then expelled out the rear of the chassis. A lockable door protects drives and switches from tampering and foreign particles. EMPaC R/T includes a POST 80 card with dual 7-segment LED readouts, visible from the rear of the chassis, displaying HEX fault codes for diagnostic purposes. (EMPaC R/T Industrial PC Chassis, 1995)

5.3.2.2 SOFTWARE FOR PC OPERATING SYSTEMS

5.3.2.2.1 BusinessWorks (20/20 Software)

BusinessWorks is currently available in Version 10.0 for DOS and Version 11.0 for Windows, BusinessWorks is a modular system with seven modules plus a System Manager: General Ledger, Accounts Payable, Accounts Receivable, Inventory Control and Purchasing, Order Entry, Payroll and Job Cost. Most modules are '*stand-alone*' allowing initial purchase of some with later expansion to incorporate the others. BusinessWorks integrates with over 30 popular business productivity applications like Word, Excel, Access, Quattro Pro, Paradox (Version 11.0 for Windows). (20/20 Software, 1996)

BusinessWorks System Details	
BusinessWorks 10.0 for DOS	
System Requirements	1. IBM 386/12 PC or compatible with 640K of memory. If expanded memory is available, BusinessWorks for DOS will take advantage of it. 2. MB disk drive 3. Hard disk drive with 15 MB free disk space 4. MS-DOS® 3.3 or higher 5. Monochrome grey scale or colour monitor (with a CGA, EGA, or VGA video card) 6. 80-column printer or laser printer 7. BusinessWorks System Manager
Network Support	1. Novell 3.11 or higher 2. LANtastic 4.0 or higher

BusinessWorks System Details (cont.)	
BusinessWorks 11.0 for Windows	
System Requirements	All requirements are the same as for DOS with the following exceptions: 1. IBM 386/12 PC or compatible with 640K of memory (486SX25 recommended) 2. MB memory (8 MB recommended) 3. Hard disk with 25 MB free disk space 4. Microsoft Windows® version 3.1, 3.11 or Windows 95 5. Colour VGA monitor or better 6. Mouse or pointing device is highly recommended
Network Support	1. Novell 3.11 or higher 2. LANtastic 5.0 or higher (Windows 3.1 or higher) 3. LANtastic for Windows 95 4. Window for Workgroups 3.11 or higher 5. Windows NT (Version 11.0 only)

Table 8 : BusinessWorks System Details (20/20 Software, 1996)

5.3.2.2.2 Intellution's FIX32

Windows 95 and Windows NT are the platforms for Intellution's FIX32 automation software which provides full 32-bit processing on Intel 80486 and Pentium machines with a requirement for 16 MB of RAM and 200MB of disc space. FIX32 features Distributed, Client/Server Architecture, Intuitive Man-Machine Interface (MMI), 100% Data Integrity, Real-Time Process Monitoring, SQL/ODBC Relational Database Connectivity, Alarming and Alarm Management, Comprehensive, Accurate Reporting, Real-Time and Historical Trending, Statistical Process Control and Supervisory Control and Data Acquisition (SCADA) solutions for all size applications. ORACLE, SyBase, SQL Server, Ingress, Access and other popular databases can be accessed using Microsoft's Open Database Connectivity.

Intellution claim to have more 32-bit installations that all other software vendors combined and that FIX32 provides a scalable package with compatibility and connectivity using standard Windows for Workgroups, Novell and IBM LAN systems using either Token Ring or Ethernet TCP/IP. (Intellution, 1996)

5.3.2.2.3 InTouch 5.6

Wonderware market this object-oriented graphical MMI application generator for industrial automation, process control and supervisory monitoring. InTouch follows the standard Windows interface style and operates on Windows 3.11 and Windows 95 connecting through any standard NetBIOS network, Ethernet, Novell DECNet etc. to Microsoft SQL Server, ORACLE, SyBase, dBase and other databases which support the Open Database Connectivity (ODBC) standard. Major users of the package include NASA, Eastman Kodak and the Channel Tunnel project. (Wonderware Corporation, 1966)

6. SUMMARY AND CONCLUSIONS

6.1 Summary

6.1.1 History

Much of this dissertation traced the last nine decades from the time when Taylorism and Fordism provided the basic foundation of production manufacturing. It traced the development of manufacturing accountancy and showed its subtle swing in the emphasis from providing data to monitor and control production (ref: page 9) to being a process which relied, in part, on inventory to provide external financial reports (ref: page 12).

6.1.1.1 INVENTORY

Attention was paid to the conventional concepts of, and mathematical support for, inventory and it was shown that inventory became regarded as essential and acceptable (ref: page 16) despite the fact that some accounting systems which condoned high levels of inventory were already seen by some to be suspect (ref: page 12). It is the author's belief that the reliance on inventory which was evident in the conventional wisdom of the day, but which could require considerable capital investment, was a potential pitfall for Western industry.

6.1.1.2 JAPANESE INITIATIVE

In 1973, the oil crisis brought about the virtual collapse of the Japanese economy (ref: page 24) and precipitated a Japanese reaction which temporarily split the world's concepts of manufacturing management technique. This document has shown how, by turning their backs on conventional management wisdom, rejecting high inventory levels and returning the control of the shop floor to those on it, the Japanese produced the industrial phenomenon of the '80s and '90s.

6.1.1.3 WESTERN REACTION

Western reaction to the Japanese success was depicted in the rise of two systems (MRP/MRP *II* and OPT) which modified existing practices in pursuit of greater efficiency and quality taking advantage of a concurrent boom in computer technology. Only in the current decade has the divergence of management philosophy turned to convergence (ref: page 82).

6.1.2 Computerisation

6.1.2.1 ON THE SHOP FLOOR

Automation and general shop-floor computerisation has been surveyed and was found to be a highly mechanised area. Office systems have been omitted since the author believes that these are generally well understood, but they are implicitly included in the discussion of systems integration, distributed computer systems and

implementation issues (ref: Figure 39 : System Integration in Manufacturing Computer Systems on page 115).

6.1.2.2 Integration and the Role of MES

It has been shown that an MES is not one single piece of software or hardware but an amalgam of computer systems spread throughout all sections of a manufacturing enterprise. Successful implementations have been shown to be enormously complex organisms which have the capacity to incorporate a wide variety of systems, databases and computer platforms. Regardless of this complexity and heterogeneity, it has been shown that they exist within real-time constraints, respond effectively and safely to faults and failures, and that they are adaptable to a variety of management philosophies and production scenarios.

6.1.2.3 Currently Available Software

Finally, specialised software and industrial hardware have been surveyed with three appendices supplying a corpus of current information.

6.2 Conclusions

This study was initiated to address two hypotheses:

1) That overseas trends towards the development of manufacturing execution systems have application in the Australian industrial context.
2) That significant gains in production efficiency and quality may be achieved by the application of an MES.

6.2.1 Overseas Trends and the Australian Context

Given the size of the Australian industries (Western Australian figures are shown on page 95 in Table 5 : Manufacturing Statistics for WA) it would have been inconceivable until recently that MES implementation in Australia would have become widespread. Hardware and software costs in the millions of dollars would have been beyond the reach of all but a few Australian companies.

Recently, however, there has been a swing towards distributed systems using common, reliable and readily available, non-proprietary network systems, operating systems and hardware (ref: page 135). Open systems technology has brought a proliferation of software capable of running on systems such as Windows 3.x, Windows95 and WindowsNT (ref: page 123). Vendors are supplying industrially hardened PC-based computers (ref: page 132). Suddenly it appears that MESs are within the reach of a wide range of Australian industries. Furthermore, modularisation into small hardware and software packages has created a situation where capital outlay can be dispersed over years and the system grow with the needs of the company.

Because overseas trends have resulted in a product that Australian industry can afford, it is submitted that '*overseas trends towards the development of manufacturing execution systems* [<u>now</u>] *have application in the Australian industrial context*'. This research, however, has raised the further question '*Is it necessary?*'

6.2.2 Gains Through Implementing MES

It would be mere frivolity to state that this study and this document have shown that '*gains in production efficiency and quality may be achieved*', both the Japanese and Western systems have documented successes and failures.

Certainly, it is submitted that gains '*may*' be achieved through the implementation of an MES but also that gains in production efficiency and quality can be achieved without the implementation of an MES.

Toyota's Production System achieved its success under trying financial conditions with low-cost answers to vexing problems. By introducing the Kanban system and its associated systems and techniques dealt with in Section 3.1.2 (page 24), changing the systems under which production was achieved, TPS revolutionised industry without massive computerisation. It is submitted that the development of the MES was a '*band-aid*' measure which merely props up an already flawed system and that the three Eastern Australian researchers were correct when, in 1995, they wrote:

> *"A smarter approach seems to be to try and simplify the problem itself through the progressive redesign of products and processes and the simplification of material flows through the identification of focussed factories or production cells, to the point where simplified systems such as JIT/Kanban can be used... Not only does this type of approach provide a potential solution to the scheduling problem, it also provides possibilities for greater employee satisfaction and involvement and a greater degree of fit between strategies for managing individual focussed factories and the competitive posture that the company is attempting to adopt in the market."* (Gibson, Greenhalgh, et al., 1995, p. 198)

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8. INDEX

9. APPENDIX A – FCS SURVEY

1996 Finite Capacity Scheduling Software Survey Survey ordered by Vendor names: Note: Cells left blank indicate no response given by vendor.			
Vendor	Installed Package	User Base	Average Price
Adapta Solutions Inc.	Adapta DLS	180	
Adaptable Business Systems	Adaptable Manufacturing Software	140	N/A
Advanced Planning Systems	OptiPlan Professional	150+	$2,995/use
AT&T Istel	PROVISA	100+	$50,000
AutoSimulations	AutoSched	375	$60,000
ADD+ON Software Inc.	ADD+ON Software	4,000+	See reseller
BENDER Management Consultants Inc.	Computer Aided Optimal Production P	28	$250,000
Berclain	MOOPI	120	
Beyers Innovative Software	GMP-Graphical Mfg.Planner	24	
Bridgeware Inc.	MPSwin	200	$150,000
C-WAY Systems, Inc.	The Production Reservation System	90	$25,000
CFS, Inc.	CFS Manufacturing System	150+	$56,000
CMI-Competitive Solutions, Inc.	TRANS4M	215	Vendor
Chesapeake Decision Sciences, Inc.	MIMI	200+	
CIMCASE International Corporation	MTMS	450+	$175,000
ComMIT Systems Inc.	ComMIT	15	$175,000
DataModes, Inc.	DataModes TM/4	600	Depends
Data Technical Research, Inc.	The Manufacturing Manager	180+	$75,000
DCD Corporation	Vantage	300	$80,000
Effective Management Systems	TCM (Time Critical Manufacturing)		
ESI/Technologies, Inc.	eMIS/2000	300+	$150,000
Fourth Shift	Manufacturing Software System (MSS)	2,200	$50,000
Fygir	GRIP	60	
GRMS, Inc.	GMS (GRMS Mfg. System)	175+	
HarrisData	HarrisData/MMS Mfg. Mgmt. System	126	Vendor
Information Specialists, Inc.	Custom Order Mfging System (COMS)	20+	$33,500
InfoPower International, Inc.	InfoPower	250+	
Insight Solutions, Inc.	INORDA	95	$80,000
Inter-Data Systems, Inc.	Preactor		
Interactive Group, Inc.	Infoflo	250	
Interactive Group, Inc.	JIT		
Intuitive	MRP9000	115	$30,000
Manufacturing Systems i2 Technologies, Inc.	Rhythm	300+	$500,000
J.D. Edwards World Solutions Company	ERPx	Vendor	
JobTime Systems, Inc.	JobTime Plus Finite Sched. Sim.	112	$40,000
Lilly Software Associates, Inc.	VISUAL Manufacturing	450	

Vendor	Installed Package	User Base	Average Price
LK Global Manufacturing Systems	MTMS	450	
Made2Manage Systems,Inc.	Made2Manage for Windows	500	
MACOLA, Inc.	Progression Series Version 6.0	15,000+	
Management Systems,Inc.	Manufacturing Capacity Management System	100+	$30,000
Manugistics	Manugistics FCS	50	
Marcam Inc.	Finite Capacity Plning. & Sched.	57	$70,000
MDSS	Factivity	20	$60,000
Micro Analysis and Design	MICRO SAINT	Thousands	$5,995
Micro-MRP, Inc.	MAX from Micro-MRP	4,000+	$45,000
M&D; Systems, Inc.	Myte-Myke Software		
Northern Computer Systems Inc	RSS Vision 4000	250	$50,000
NRS Consulting	NRS	140	$50,000
Numetrix Ltd.	Schedulex-7	136	
Optimax Systems Corp.	Optiflex	15	$450,000
Paragon Management Systems	Pacemaker		
Pilot Systems, Inc.	Navigator	200+	$30,000
Pivotpoint, Inc.	Point.Man	70	$4k/user
Plymouth Rock			
Technology Inc.	TurboRoughCut		$5K/site
Primavera Systems Inc.	Primavera	35,000	
Pritsker Corporation	Factor Production Manager		
Pritsker Corporation	OrderLinx	350+	
Process Logistix	Prospex		
Process Logistix	Supply Chain Suite	30+	$34,000
ProfitKey Manufacturing International	Rapid Response	900+	$60,000
Promis Systems Corp.	MADEMA	15	
QAD Inc.	MFG/PRO	2,600	$400,000
Qube Connections Inc.	Qube Controller	90	$28,000
Red Pepper Software Corporation	Production/Enterprise Response Mgra	30	
ROI Systems Inc.	MANAGE 2000		
Ross Systems Inc.	Renaissance CS	175	
RWT Corporation	OnTrack FCS		$30,000
Scheduling Technology Corporation	St-Point	100+	$25,000
Scheduling Technology Corporation	OPT21	200+	$100,000
Schlueter Business	SBS Manufacturing		
Systems Inc.	Management System	60-70	$13,000
Shiva Soft Inc.	Shiva	40	$110,000
Small Computer Systems Inc.		100+	$17,800
SPAR Associates Inc	Perception		
Strategic Business			
Solutions	Manufacturing In Time		$25,000
Symix	Symix	2200	
Synquest	Synquest	100	$400,000
Sysmark Information			
Systems	Fabman	125	$20,000
Syspro Group	Impact Award/Encore	5000	$1,800/mod
Systems Modeling Corp.	Preactor		
Tangible Vision Inc.	Imprimis		
Taylor Manufacturing			
Software	TESS	45	$80,000

Vendor	Installed Package	User Base	Average Price
Tetra International Inc.	Tetra CS/3	Beta	
Thru-Put Technologies	Resonance	50	$80,000
TIW Computer	Workshop Factory Management System	400	$1,495/mod
Tyecin Systems Inc.	MS/X OnTime, TS/X OnTime	75	$70,000
User Solutions Inc	Spreadsheet Resource	1200	
User Solutions Inc	Noah	100	
WAM Systems	PICASO	112	$50K/plant
WATERLOO MANUFACTURING	TACTIC	The Scheduler's	
SOFTWARE	Assistant	>100	
The Wright Group	PMSIM	90	

http://lionhrtpub.com/apics/surveys/fcs96/ordered-by-vendor.html
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10. APPENDIX B – DECISION ANALYSIS SURVEY

OR/MS Today 1996 Decision Analysis Survey													
		Operating Systems				Application						Pricing	
Product	Vendor	Windows 95	Windows 3.x	DOS	RAM Required	Objectives Trade-off (1)	Analysis of uncer-tainty (2)	Probabilistic Dependecies (3)	Risk Aver-sion	Sequential decision making	All applications-one model(4)	Commer-cial	Educat-ional
@RISK	Palisade Corp.	y	y	n	4 MB	y	y	y	y	y	y	$395	call
AliahTHINK!	Aliah Inc.	y	y	y	8 MB	y	y	y	y	y	y	$2050	n/a
Analytica	Lumina Decision Systems	n	n	n	4 MB	y	y	y	y	y	y	$695	$100
BestFit	Palisade Corp.	y	y	n	2 MB	n	y	n	n	n	n	$299	call
CADET	AT&T	y	y	n	4 MB	n	y	y	y	y	n	$500	n/a
Criterium Decision Plus	InfoHarvest Inc.	y	y	n	8 MB	y	y	y	n	n	n	$495	$295
Crystal Ball	Decisioneering Inc	y	y	n	4 MB	y	y	y	y	n	n	$395	$69
DPL	Applied Decision Analysis	y	y	n	2 MB	y	y	y	y	y	y	$495-$995	$53.50
DecideRight for Windows	Avantos Performance Systems Inc.	y	y	n	8 MB	y	n	n	n	n	n	$149	n/a
Decision Analysis by TreeAge (DATA)	TreeAge Software Inc.	y	y	n	4 MB	y	y	y	y	y	y	$450	$225
Decision Explorer	Banxia Software Ltd.	y	y	n	4 MB	y	y	y	y	y	y	call	call
ELECTRE III-IV	Lamsade-Ura 0825	n	y	n	4 MB	n	y	n	n	n	n	$1,400	$560

		Operating Systems				Application						Pricing	
Product	Vendor	Windows 95	Windows 3.x	DOS	RAM Required	Objectives Trade-off (1)	Analysis of uncer-tainty (2)	Probabilistic Dependecies (3)	Risk Aver-sion	Sequential decision making	All applications-one model(4)	Commer-cial	Educat-ional
EQUITY for Windows	Krysalis Ltd.	y	y	n	4 MB	y	n	n	n	n	n	$1,350	$225
Expert Choice Professional	Expert Choice Inc.	y	y	n	8 •MB	y	y	y	y	y	y	$595	$416.50
HIVIEW for Windows	Krysalis Ltd.	n	y	n	4 MB	y	n	n	n	n	n	$900	$145
HIPRE 3+	Santa Monica Software	y	y	y	4 MB	y	y	n	y	y	n	$295	$295
Logical Decisions	Logical Decisions	y	y	n	4 MB	y	y	n	y	n	y	$395	$295
MAPPAC and PRAGMA	B. Matarazzo	n	y	y	4 MB	y	n	n	n	n	n	$800	$600
POLICY PC	Executive Decision Services	n	n	y	512 KB	y	n	n	y	n	n	$500	$100
Quick Compare	Blue Blazer Computing	n	y	y	200 KB	y	y	y	n	n	y	$34.95	call
RiskSim (for Excel)	Decision Support Services	y	y	n	4 MB	n	y	n	n	n	n	$29-$300	call
SOS P/G%	Decision Aids Inc	n	n	y	512 KB	y	y	y	y	y	y	$50	$50
Sensit (for Excel)	Decision Support Services	y	y	n	4 MB	n	n	n	n	n	n	$29-$300	call
Sensitivity/Supertree	Strategic Decisions Group - Decision Systems	y	y	y	8 MB	y	y	y	y	y	y	$1500	$75

		Operating Systems			Application							Pricing	
Product	Vendor	Windows 95	Windows 3.x	DOS	RAM Required	Objectives Trade-off (1)	Analysis of uncer-tainty (2)	Probabilistic Dependecies (3)	Risk Aver-sion	Sequential decision making	All applications-one model(4)	Commer-cial	Educat-ional
Team Expert Choice	Expert Choice Inc.	y	y	n	8 MB	y	y	y	y	y	y	$13,295	$9,306
TopRank	Palisade Corp.	y	y	n	4 MB	y	y	y	y	y	y	$249-$395	call
TreePlan (for Excel)	Support Services	y	y	n	4 MB	n	y	n	y	y	n	$29-$300	call
VISA	Visual Thinking International Ltd.	y	y	n	8 MB	y	y	y	n	n	n	$395	University Site Licence –-$999
Which & Why V4.0	Arlington Software Corp.	y	y	y	4 MB	y	y	n	y	y	y	$349	$249

http://lionhrtpub.com/orms/surveys/DAS96.html

Explanation of Questions:

(1) Are there trade-offs amongst multiple objectives?

(2) Is there representation/analysis of uncertainty?

(3) Is there representation/analysis of probabilistic dependencies?

(4) Are all of the above available in one model?

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11. APPENDIX C – SUPPLIERS

MES/CIM Software Suppliers

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11.1 MES Software

Available : http://lionhrtpub.com/apics/apics-2-96/BG/BGPLmes.html

ABBA Computer Systems
Adaptable Business Systems
Advanced Industrial Systems
Allen Bradley Company
Applied Statistics, Inc.
Automated Technology Associates
Automation Resources Corp.
Behera & Associates
BMS, Inc.
Camstar Systems, Inc.
CIM Vision International
CNA
Consilium, Inc.
Crowe Chizek
Cybernostic Inc.
Datalogix
The Development Center Inc.
Draves & Barke Systems, Inc.
Effective Management Systems, Inc.
Expandable Software, Inc.
Expert Choice, Inc.
FACT, Inc.
FASTech Integration, Inc.
FloStor Engineering, Inc.
Focused Approach, Inc.
FORTUNE Personnel of Sarasota
GE Fanuc Automation N.A. Inc.
The Genesis Group, Inc.
Grant Thornton LLP
Greco Systems
Hewlett-Packard Korea
HK Systems
i2 Technologies, Inc.
Indel Software Corporation
Industrial Computer Corp.
Industrial Cybernetics
InfoPower International, Inc.
Intec Controls
JBA International USA
Lexel Corporation
Lilly Software Associates, Inc.
Macatawa Computer Services, Inc.
Made2Manage Systems, Inc.
MAHAR Management Solutions
Managing Automation Software Guides

Manufacturers' Services Ltd.
Manufacturing Action Group
Manufacturing Control Systems Inc.
Marcam Corporation
Material Management Consultants, LLC
MES Solutions, Inc.
Mesa International
Micro Perfect Corporation
Micro-MRP, Inc.
New Dimension Systems
North Highland Company
Northern Computer Systems Inc.
NRS Consulting
Online Software Labs
Oracle Corporation
Partners For Excellence
Power Cerv
Plexus Systems
Pritsker Corporation
PRO:MAN Group
ProMeta Consulting
Promis Systems Corporation
Q-CIM Inc.
R. Michael Donovan, Inc.
R. Shane Company
R.J. Roman & Associates
Real Time eXecutives
Realogic, Inc.
ROI Systems Inc.
RWT Corp.
Salerno Manufacturing Systems
SAP
ScanData Systems, Inc.
Scruggs & Associates, Inc.
Setpoint Inc.
ShivaSoft, Inc.
Software 2000, Inc.
Spar Associates, Inc.
SSA Southeast
Strategic Business Solutions, Inc.
Studebaker Technology Inc.
Sysmark Information Systems, Inc.
Tangible Vision Inc.
Taylor Manufacturing Systems
Telesis Computer Corp.
Trillium Software, Inc.
TYECIN Systems Inc.
USData Corporation
User Solutions, Inc.
Waterloo Manufacturing Software
Wonderware Corporation
The WRIGHT Group

11.2 MRP/MRP II Software

Available : http://lionhrtpub.com/apics/apics-2-96/BG/BGPLmrp.html

1Base Computer
ABBA Computer Systems
Adaptable Business Systems
ADD+ON Software Inc.
Advanced Data Systems
Advanced Manufacturing Research
Advanced Planning Systems, Inc.
AIM Computer Solutions, Inc.
Alliance Manufacturing Software, Inc.
American Software
Antalys, Inc.
Applied Micro Business Systems Inc.
ASC Systems
AT&T, Integrated Application Systems
Aurora Technologies, Inc.
The Austin Company
Automation Resources Corp.
Avalon Software Inc.
AXIS Computer Systems, Inc.
BatchMaster Software Corp.
Behera & Associates
BioComp Systems, Inc.
Buker Inc.

Business Forecast Systems, Inc.

Business Systems Consultants, Inc.

CAMM, Inc.

Carolina Cipher

CFS, Inc

CIM Bar Code Technology, Inc.

CIMCASE International Corp.

CIMPAC Inc.

Cincom Systems, Inc.

CMI-Competitive Solutions, Inc.

CMS Manufacturing Systems

CNA

Command Line Corp.

ComMIT Systems Inc.

Computer Associates Int'l Inc.

Computer Source Inc.

Crowe Chizek

CTS

Customized Transportation, Inc.

Cybernostic Inc.

Data General Corp.

Data Interface

Data Solutions, Inc.

Data Technical Research, Inc.

Datalogix

DataModes, Inc.

Datasul Inc.

DataWorks Corporation

DCD Corporation

Decision Consultants, Inc.

Decision Servcom, Inc.

The Development Center Inc.

Digital Press

Draves & Barke Systems, Inc.

Effective Management Systems, Inc.

Enhanced Systems & Services

ENTEK Inc.

Enterprise Planning Systems Corp.

Escom Inc.

ESI/Technologies

Expandable Software, Inc.

Experience In Software

Expert Buying Systems, Inc.

Expert Choice, Inc.

EXSYS, Inc.

Facilities Planning Services

FACT, Inc.

Falcon Software

FastMAN Software Inc.

Flynn Associates

Foreman Solutions

Fortune Personnel Consultants of Chapel Hill, Inc.

Fortune Personnel Consultants of Loudoun

FORTUNE Personnel Consultants of New York City Inc.

Fourth Shift Corporation

Friedman Associates

Genesis (J.D. Edwards)

The Genesis Group, Inc.

Genzlinger Associates, Inc.

Graha Mitra Solusi

Grant Thornton LLP

Greco Systems

GRMS, Inc.

GWBA, Inc.

Hal Mather Inc.

HarrisData

Holland & Davis, Inc.

Hunter Consultants

i2 Technologies, Inc.

Industrial Data Technologies

Industrial Technological Associates, Inc.

InfoPower International, Inc.

Integrated Software Design

Intelligent Instrumentation

Intelligent Manufacturing Systems, Inc.

Intentia International

Inter-Data Systems, Inc.

INTERACTIVE Group, Inc.

International Purchasing Service

Intrix Systems Group

Intuitive Manufacturing Systems Inc.

IQR International

Edwards & Company

Jack Gips, Inc.

JBA International USA

JOBSCOPE

Kingwood Systems, Inc.

Wechsler, Ltd.

Lexel Corporation

Lilly Software Associates, Inc.

LXE
Macola Software
Made2Manage Systems, Inc.
MAHAR Management Solutions
MAN-TRAK
Managing Automation Software Guides
Manufacturers Technologies
Manufacturers' Services Ltd.
Manufacturing Action Group
Manufacturing And Computer Systems
Manufacturing Control Systems Inc.
Manufacturing Solutions & Systems
Marcam Corporation
Material Management Consultants, LLC
McMillan Associates, Inc.
MDIS - Chess
Micro Perfect Corporation
Micro-MRP, Inc.
Microcomputer Specialists, Inc.
MRP PAX Inc., Navigator MRP
New Dimension Systems
North Highland Company
NRS Consulting
OakTree Associates, Inc.
Obvious Professional Services, Inc.
OHM Systems, Inc.
Oliver Wight Companies
OnBase Technology Inc.
Online Applications, Inc.
Online Software Labs
Operations Concepts, Inc.
Oracle Corporation
The Paradigm Group, Inc.
Paragon Management Systems, Inc.
Partners For Excellence
PeopleSoft
Pilot Systems Inc.
Plexus Systems
Power Cerv
Printronix
PRO:MAN Group
Production Solutions Inc.
Productivity Concepts Inc.
Professionals for Technology, Inc. (Pro-Tech, Inc.)
ProfitKey International, Inc.
PROLOGIC Management Systems, Inc.
ProMeta Consulting
PT Publications, Inc.
Q-CIM Inc.
QAD Inc.
Quantel Technologies, Inc.
Qube Connections, Inc.
Michael Donovan, Inc.
Roman & Associates
Real Time eXecutives
Realogic, Inc.
Red Pepper Software Company
Relevant Business Systems, Inc.
Rinehart Engineering
ROI Systems Inc.
Ross Systems
Royal 4 Systems, Inc.
Inc.
SAP
Schlueter Business Systems (SBS) Inc.
Scruggs & Associates, Inc.
SCS, Inc.
SE Technologies Inc.
Sextant Corporation
Software 2000, Inc.
Software AG of North America
Software PM, Inc.
Source Data Inc.
Spectrum Associates
SSA
SSA Southeast
The Summit Group
Symix Computer Systems, Inc.
Sysmark Information Systems, Inc.
Tangible Vision Inc.
Team Solutions
Technology Solutions Company
Telesis Computer Corp.
The Operational Excellence Forum
TIW
Trillium Software, Inc.
TRW Systems Integration Group
TTW Inc.
TXbase Systems Inc.

TYECIN Systems Inc.
United Barcode Industries, Inc.
Unitronix Corporation
User Solutions, Inc.
Visibility Inc.
W5 Associates, Inc.
Weigh-Tronix
Western Data Systems
The WRIGHT Group

11.3 Planning & Scheduling

http://lionhrtpub.com/apics/apics-2-96/BG/BGPLplan.html

1Base Computer
ABBA Computer Systems
Adapta Solutions Inc.
Adaptable Business Systems
ADD+ON Software Inc.
Advanced Data Systems
Advanced Manufacturing Research
Advanced Planning Systems, Inc.
AIM Computer Solutions, Inc.
ALT-C Systems Inc.
American Software
Antalys, Inc.
Applied Micro Business Systems Inc.
ARvee Systems, Inc.
Astea International Inc.
AT&T Istel
AT&T, Integrated Application Systems
The Austin Company
Automated Technology Associates
Automation Resources Corp.
AutoSimulations
Avalon Software Inc.
Avyx, Inc.
AXIS Computer Systems, Inc.
BDM Technologies
Behera & Associates
BENDER Management Consultants Inc.
Berclain USA Ltd.
Beyers Innovative Software
BioComp Systems, Inc.
Bridgeware, Inc.
BSA SYSTEMS, INC.
Buker Inc.
Business Forecast Systems, Inc.
Business Systems Consultants, Inc.
C-WAY Systems, Inc.
Carolina Cipher
CACI Products Company
CFM, Inc.
CFS, Inc
Chesapeake Decision Sciences
CIMCASE International Corp.
Cimmation Advanced Manufacturing Technologies
Cimnet Systems Inc.
CIMPAC Inc.
Cincom Systems, Inc.
Clear Software
Client Server Technologies, Inc.
CMI-Competitive Solutions, Inc.
CNA
Command Line Corp.
ComMIT Systems Inc.
Compass Modeling Solutions Inc.
Computer Associates Int'l Inc.
Computer Decisions International
Computer Sciences Corporation (CSC)
Computer Source Inc.
Consilium, Inc.
Control Module Inc.
Coopers & Lybrand/SysteCon Div.
Crowe Chizek
Customized Transportation, Inc.
Cybernostic Inc.

Cyclesoft
Data Interface
Data Technical Research, Inc.
Datalogix
Datamatics
DataModes, Inc.
Datasul Inc.
DataWorks Corporation
DCD Corporation
Decision Associates, Inc.
Decision Dynamics, Inc.
Decision Servcom, Inc.
Demand Management Inc.
The Development Center Inc.
Draves & Barke Systems, Inc.
E/Step Software, Inc.
Effective Management Systems, Inc.
Elsevier Science Ltd.
Enterprise Planning Systems Corp.
Escom Inc.
ESI/Technologies
Expandable Software, Inc.
Experience In Software
Expert Choice, Inc.
EXSYS, Inc.
Facilities Planning Services
FACT, Inc.
Falcon Software
FastMAN Software Inc.
Fleming Systems Corporation
FloStor Engineering, Inc.
Flynn Associates
Focused Approach, Inc.
FoodPro International, Inc.
Foreman Solutions
Fortune Personnel Consultants of Chapel Hill, Inc.
Fortune Personnel Consultants of Loudoun
FORTUNE Personnel Consultants of New York City Inc.
FORTUNE Personnel of Sarasota
Fourth Shift Corporation
Friedman Associates
Genesis (J.D. Edwards)
The Genesis Group, Inc.
Graha Mitra Solusi
Grant Thornton LLP
Greco Systems
GRMS, Inc.
GSI Logistics and Distribution
GWBA, Inc.
Hal Mather Inc.
HarrisData
Helmco Consulting Assoc.
Heuristima Corporation
Hewlett-Packard Korea
Holland & Davis, Inc.
Hollander Associates
Hunter Consultants
i2 Technologies, Inc.
IHE
IMB/People-Planner
Industrial Cybernetics
Industrial Technological Associates, Inc.
InfoPower International, Inc.
Insight Solutions Inc.
Integrated Software Design
Intelligent Instrumentation
Intelligent Manufacturing Systems, Inc.
Intentia International
Inter-Data Systems, Inc.
INTERACTIVE Group, Inc.
International Purchasing Service
International TechneGroup, Inc.
Intrix Systems Group
Intuitive Manufacturing Systems Inc.
IQR International
J.D. Edwards & Company
Jack Gips, Inc.
JBA International USA
JOBSCOPE
JobTime Systems, Inc.
Josalli Inc.
Kingwood Systems, Inc.
KnowledgeWare Systems Group
Lexel Corporation
Lilly Software Associates, Inc.
LPA Software, Inc.
Luman Consultants
LXE
Macola Software
Made2Manage Systems, Inc.

MAHAR Management Solutions
MAN-TRAK
Managing Automation Software Guides
Managing Change Associates
Manufacturers Technologies
Manufacturers' Services Ltd.
Manufacturing Action Group
Manufacturing Control Systems Inc.
Manufacturing Management Systems, Inc. (MMS)
Manugistics, Inc.
Marcam Corporation
Material Management Consultants, LLC
McMillan Associates, Inc.
MDIS - Chess
Mesa International
Micro Analysis & Design Simulation Software, Inc.
Micro Perfect Corporation
Micro-MRP, Inc.
Microcomputer Specialists, Inc.
Minidata Ltd.
MPA
New Dimension Systems
North American Business Services
North Highland Company
Northern Computer Systems Inc.
NRS Consulting
Numetrix Ltd.
OakTree Associates, Inc.
OHM Systems, Inc.
Oliver Wight Companies
Online Applications, Inc.
Online Software Labs
Operations Concepts, Inc.
Optimax Systems Corp.
Oracle Corporation
P-E International
Paragon Decision Technology B.V.
Paragon Management Systems, Inc.
Partners For Excellence
PeopleSoft
Pilot Systems Inc.
Plexus Systems
Plymouth Rock Technology, Inc.
Power Cerv
Premenos Corp.
Primavera Systems Inc.
Printronix
Pritsker Corporation
PRO:MAN Group
Process Logistix
Production Solutions Inc.
Productivity Concepts Inc.
Productivity Press Inc.
Professionals for Technology, Inc. (Pro-Tech, Inc.)
ProfitKey International, Inc.
ProMeta Consulting
Promis Systems Corporation
PROMODEL Corporation
PT Publications, Inc.
Q-CIM Inc.
QAD Inc.
Quantel Technologies, Inc.
Qube Connections, Inc.
R. Michael Donovan, Inc.
R. Shane Company
R.J. Roman & Associates
Raytheon Engineers & Constructors
Realogic, Inc.
Red Pepper Software Company
Relevant Business Systems, Inc.
Repacorp Label Products
Resource Optimization Inc.
Rinehart Engineering
ROI Systems Inc.
Ross Systems
Royal 4 Systems, Inc.
RWT Corp.
SAITECH, Inc.
SAP
SAS Institute Inc.
SATCOM
Scheduling Technology Corporation
Schlueter Business Systems (SBS) Inc.
Scruggs & Associates, Inc.
SCS, Inc.
Setpoint Inc.
Sextant Corporation
ShivaSoft, Inc.
Smart Software, Inc.

Software 2000, Inc.
Software AG of North America
Software PM, Inc.
Software Solutions, Inc.
Source Data Inc.
Spar Associates, Inc.
Spectrum Associates
SSA
SSA Southeast
Stone & Webster ASDS, Inc.
Strategic Business Solutions, Inc.
Studebaker Technology Inc.
The Summit Group
Superior Software Products
Symix Computer Systems, Inc.
SyntegraTech, Inc.
Sysmark Information Systems, Inc.
Systems Modeling Corporation
Tangible Vision Inc.
Taylor Manufacturing Systems
Team Solutions
TechnoLogix Decision Sciences Inc.
Technology Solutions Company
Telesis Computer Corp.
The Operational Excellence Forum
Thru-Put Technologies
TIW
Tompkins Associates
Trillium Software, Inc.
TRW Systems Integration Group
TSW International
TTW Inc.
TXbase Systems Inc.
TYECIN Systems Inc.
Unitronix Corporation
User Solutions, Inc.
W5 Associates, Inc.
Waterloo Manufacturing Software
Weigh-Tronix
Western Data Systems
Wolverine Software Corporation
The WRIGHT Group
Xytec Corporation

11.4 Product Data Management

http://lionhrtpub.com/apics/apics-2-96/BG/BGPLpdm.html

1Base Computer
A.C.C. Systems
ABBA Computer Systems
ACS Telecom
Action Systems Associates, Inc.
Allen Bradley Company
AnewTech, Inc.
Antalys, Inc.
ARvee Systems, Inc.
The Austin Company
B.A. Intelligence Networks
Behera & Associates
CIMCASE International Corp.
Cimmation Advanced Manufacturing Technologies
Computer Innovations
Control Data Systems, Inc.
Crowe Chizek
Customized Transportation, Inc.
Cybernostic Inc.
Data Interface
Datasul Inc.
The Development Center Inc.
Draves & Barke Systems, Inc.
Effective Management Systems, Inc.
Enteo Corporation
Expandable Software, Inc.
Experience In Software
EXSYS, Inc.
Facilities Planning Services
Foreman Solutions
Genesis (J.D. Edwards)

Greco Systems
ImageWave Corporation
Indel Software Corporation
Industrial Cybernetics
Industrial Data Technologies
InfoPower International, Inc.
Infoscan, Inc.
Intelligent Instrumentation
Intentia International
J.D. Edwards & Company
JBA International USA
King Computer Services, Inc.
Kingwood Systems, Inc.
Lexel Corporation
Managing Automation Software Guides
Manufacturers' Services Ltd.
Manufacturing Action Group
Manufacturing Solutions & Systems
Marcam Corporation
MES Solutions, Inc.
Micro Perfect Corporation
New Dimension Systems
North Highland Company
North Mountain Software
OHM Systems, Inc.
Online Software Labs
Oracle Corporation
PeopleSoft
Plexus Systems
Power Cerv
PQ Systems, Inc.
PRO:MAN Group
ProMeta Consulting
QAD Inc.
Real Time eXecutives
Realogic, Inc.
SAP
SAS Institute Inc.
ScanData Systems, Inc.
Schlueter Business Systems (SBS) Inc.
Scruggs & Associates, Inc.
Sextant Corporation
Sherpa Corporation
Software 2000, Inc.
Software PM, Inc.
Spar Associates, Inc.
SSA
SSA Southeast
Studebaker Technology Inc.
Technology Solutions Company
The Operational Excellence Forum
TIW
TRW Systems Integration Group
TTW Inc.
UES, Inc.-Knowledge Integration Center
Unitronix Corporation
Videx, Inc.
Western Data Systems
Wieland, Inc.
Zontec Inc.

11.5 Production Control

http://lionhrtpub.com/apics/apics-2-96/BG/BGPLprod.html

1Base Computer
ABBA Computer Systems
AbTech Corporation
Acatech Solutions, Inc.
Accu-Sort Systems, Inc.
Acromag, Inc.
Actuality Corporation
Adaptable Business Systems
ADD+ON Software Inc.
Advanced Barcode Tech.
Advanced Data Systems
Advanced Industrial Systems
Advanced Manufacturing Research

AIM Computer Solutions, Inc.
Allen Bradley Company
Alliance Automation Systems
Alliance Manufacturing Software, Inc.
American Software
Americode Technologies Analog Technology Corp.
AnewTech, Inc.
Antalys, Inc.
Applied Micro Business Systems Inc.
ASC Systems
Aurora Technologies, Inc.
The Austin Company
Automation Resources Corp.
AXIS Computer Systems, Inc.
BatchMaster Software Corp.
Behera & Associates
Beyers Innovative Software
BioComp Systems, Inc.
Buker Inc.
Business Systems Consultants, Inc. C-WAY Systems, Inc.
CACI Products Company
Carolina Cipher
CFS, Inc
CIE America, Inc.
CIM Bar Code Technology, Inc.
CIMCASE International Corp.
Cimmation Advanced Manufacturing Technologies
Cimnet Systems Inc.
CIMPAC Inc.
Cincom Systems, Inc.
CMI-Competitive Solutions, Inc.
CNA
Command Line Corp.
ComMIT Systems Inc.
Computer Associates Int'l Inc.
Computer Decisions International
Computer Innovations
Computer Source Inc.
Control Concepts, Inc.
ControlSoft Inc.
Controlware Technologies Corp.
Crowe Chizek
Customized Transportation, Inc.
Cybernostic
Data Capture Institute
Data Collection Systems, Inc.
Data Interface
Data Net Corporation
Data Solutions, Inc.
Datalogix
Datasul Inc.
DataWorks Corporation
Decision Servcom, Inc.
The Development Center Inc.
Digi Matex, Inc.
Draves & Barke Systems, Inc.
Effective Management Systems, Inc.
Electronic Identification Devices, Ltd.
Emery Winslow Scale Co.
Entron Industrial Computers
Escom Inc.
ESI/Technologies
Expandable Software, Inc.
Expert Choice, Inc.
Express, Inc.
EXSYS, Inc.
FACT, Inc.
Falcon Software
FASTech Integration, Inc.
FloStor Engineering, Inc.
Flynn Associates
FoodPro International, Inc.
Foreman Solutions
Forté Technology Inc.
Fortune Personnel Consultants > of Chapel Hill, Inc.
Fortune Personnel Consultants of Loudoun
FORTUNE Personnel Consultants of New York City Inc.
FORTUNE Personnel of Sarasota
Fourth Shift Corporation
Friedman Associates
GE Fanuc Automation N.A. Inc.
Genesis (J.D. Edwards)
The Genesis Group, Inc.
Graha Mitra Solusi
Grant Thornton LLP
Greco Systems
GRMS, Inc.
GWBA, Inc.

Hal Mather Inc.
Hemco Corporation
Holland & Davis, Inc.
Hunter Consultants
i2 Technologies, Inc.
Iconics
Indel Software Corporation
Industrial Cybernetics
Industrial Data Technologies
Industrial Programming, Inc.
Industrial Technological Associates, Inc.
InfoPower International, Inc.
Infoscan, Inc.
Intec Controls
Integrated Software Design
Intelligent Instrumentation
Intelligent Manufacturing Systems, Inc.
Intentia International
Inter-Data Systems, Inc.
INTERACTIVE Group, Inc.
International Technologies & Systems
International Thomas Publishing
Intrix Systems Group
Intuitive Manufacturing Systems Inc.
ITI Qualitek
J.D. Edwards & Company
Jack Gips, Inc.
JBA International USA
JOBSCOPE
Kingwood Systems, Inc.
Least Cost Formulations, Ltd.
Lexel Corporation
Lilly Software Associates, Inc.
LubeCon Systems, Inc.
LXE
Macola Software
Made2Manage Systems, Inc.
MAHAR Management Solutions
MAN-TRAK
Managing Automation Software Guides
Managing Change Associates
Manufacturers' Services Ltd.
Manufacturing Action Group
Manufacturing And Computer Systems
Manufacturing Control Systems Inc.
Manufacturing Solutions & Systems
Marcam Corporation
Material Management Consultants, LLC
McMillan Associates, Inc.
MDIS - Chess
Mesa International
Metrscope
Micro Analysis & Design Simulation Software, Inc.
Micro Perfect Corporation
Micro-MRP, Inc.
Microcomputer Specialists, Inc.
Minitab Inc.
MPA
New Dimension Systems
Norman N. Axelrod Associates
North Highland Company
Northern Computer Systems Inc.
NRS Consulting
OakTree Associates, Inc.
OHM Systems, Inc.
Online Applications, Inc.
Online Software Labs
Operations Concepts, Inc.
Oracle Corporation
P-E International
Paragon Management Systems, Inc.
PeopleSoft
Pfeiffer Engineering Co. Inc.
Pilot Systems Inc.
Plymouth Rock Technology, Inc.
Plexus Systems
Power Cerv
PQ Systems, Inc.
Printronix
PRO:MAN Group
Productivity Concepts Inc.
Productivity Press Inc.
Professionals for Technology, Inc. (Pro-Tech, Inc.)
ProfitKey International, Inc.

PROLOGIC Management Systems, Inc.
ProMeta Consulting
PROMODEL Corporation
PT Publications, Inc.
QAD Inc.
Quantel Technologies, Inc.
QNX Software Systems Ltd.
Qube Connections, Inc.
R. Michael Donovan, Inc.
R.J. Roman & Associates
Realogic, Inc.
Relevant Business Systems, Inc.
Rinehart Engineering
ROI Systems Inc.
ROLS
Ross Systems
Royal 4 Systems, Inc.
RWT Corp.
SAP
SAS Institute Inc.
ScanData Systems, Inc.
Schlueter Business Systems (SBS) Inc.
Scruggs & Associates, Inc.
SCS, Inc.
Setpoint Inc.
Smart Software, Inc.
Software 2000, Inc.
Software AG of North America
Software PM, Inc.
Software Solutions, Inc.
Source Data Inc.
Spalding Software, Inc.
Spar Associates, Inc.
Spectrum Associates
SSA
SSA Southeast
Statware, Inc.
Strandware, Inc.
Strategic Business Solutions, Inc.
Studebaker Technology Inc.
The Summit Group
Symix Computer Systems, Inc.
SyntegraTech, Inc.
Sysmark Information Systems, Inc.
Systems Modeling Corporation
T.L. Ashford & Associates
Tangible Vision Inc.
Team Solutions
Tele-Denken Resources
Telesis Computer Corp.
The Operational Excellence Forum
TIW
Trigesta Americas, Inc.
Trillium Software, Inc.
TRUMATCH, INC.
TRW Systems Integration Group
TTW Inc.
Turck Inc.
TXbase Systems Inc.
United Barcode Industries, Inc.
User Solutions, Inc.
Videojet Systems International, Inc.
W5 Associates, Inc.
Waterloo Manufacturing Software
The Way Corporation
Weigh-Tronix
Wieland, Inc.
The WRIGHT Group

11.6 Purchasing

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1Base Computer
ABBA Computer Systems
Adaptable Business Systems
ADD+ON Software Inc.
ADR Int'l. Purchasing Consultants
Advanced Data Systems

Advanced Distributions Systems
AIM Computer Solutions, Inc.
American Software
Applied Micro Business Systems Inc.
Armor Systems Inc.
Automation Resources Corp.
AXIS Computer Systems, Inc.
Barclay Consulting Assoc.
BatchMaster Software Corp.
Behera & Associates
BENDER Management Consultants Inc.
BioComp Systems, Inc.
Bonner & Moore Associates, Inc.
Buker Inc.
Business Forecast Systems, Inc.
Business Systems Consultants, Inc.
Cambar Software
Carolina Cipher
CFS, Inc
CIE America, Inc.
CIMCASE International Corp.
Cimnet Systems Inc.
CIMPAC Inc.
Cincom Systems, Inc.
Client Server Technologies, Inc.
CMI-Competitive Solutions, Inc.
Command Line Corp.
ComMIT Systems Inc.
Compass Modeling Solutions Inc.
Computer Associates Int'l Inc.
Computer Decisions International
Computer Sciences Corporation (CSC)
Computer Source Inc.
Coopers & Lybrand/SysteCon Div.
Crowe Chizek
Customized Transportation, Inc.
Cybernostic
Data Interface
Data Solutions, Inc.
Data Technical Research, Inc.
Datalogix
DataModes, Inc.
Datasul Inc.
DataWorks Corporation
Decision Consultants, Inc.
Decision Dynamics, Inc.
Decision Servcom, Inc.
The Development Center Inc.
Draves & Barke Systems, Inc.
Dun & Bradstreet Information Services
Dynamic Software
EBBS - Electronic Buyers Bulletin Service
Ebeling Associates, Inc.
Effective Management Systems, Inc.
Elsevier Science Ltd.
Escom Inc.
ESI/Technologies
Expandable Software, Inc.
Experience In Software
Expert Choice, Inc.
EXSYS, Inc.
FACT, Inc.
Falcon Software
FastMAN Software Inc.
Foreman Solutions
Fortune Personnel Consultants of Chapel Hill, Inc.
Fortune Personnel Consultants of Loudoun
FORTUNE Personnel Consultants of New York City Inc.
FORTUNE Personnel of Sarasota
Fourth Shift Corporation
Friedman Associates
Genesis (J.D. Edwards)
Graha Mitra Solusi
Grant Thornton LLP
GRMS, Inc.
GSI Logistics and Distribution
GWBA, Inc.
Hal Mather Inc.
The Hayo Consultants
Hunter Consultants
IMC Systems Group, Inc.
Industrial Cybernetics
InfoPower International, Inc.
Integrated Software Design
Intelligent Manufacturing Systems, Inc.
Intentia International
Inter-Data Systems, Inc.

INTERACTIVE Group, Inc.

International Purchasing Service

Intrix Systems Group

Intuitive Manufacturing Systems Inc.

IQR International

Irwin Professional Publishing

J.D. Edwards & Company

Jack Gips, Inc.

JBA International USA

JOBSCOPE

Josalli Inc.

Kenhar Products Inc.

Kingwood Systems, Inc.

KnowledgeWare Systems Group

Least Cost Formulations, Ltd.

Lilly Software Associates, Inc.

Lexel Corporation

Luman Consultants

Macola Software

Made2Manage Systems, Inc.

MAHAR Management Solutions

MAN-TRAK

Managing Automation Software Guides

Manufacturers' Services Ltd.

Manufacturing Action Group

Manufacturing And Computer Systems

Manufacturing Control Systems Inc.

Manufacturing Solutions & Systems

Marcam Corporation

Material Management Consultants, LLC

McMillan Associates, Inc.

MDIS - Chess

Micro Perfect Corporation

Micro-MRP, Inc.

Microcomputer Specialists, Inc.

MicroWest Software Systems, Inc.

MPA

National Association of Purchasing Mgmt. (NAPM)

New Dimension Systems

North American Business Services

North Highland Company

NRS Consulting

OHM Systems, Inc.

OnBase Technology Inc.

Online Applications, Inc.

Online Software Labs

Oracle Corporation

Ormandy, Inc.

Partners For Excellence

PBBS - Paper Buyers Bulletin Service

PEBBS - Print Equipment Buyers Bulletin Service

PeopleSoft

Pilot Systems Inc.

Power Cerv

Plexus Systems

Printronix

PRO:MAN Group

Productivity Concepts Inc.

Productivity Press Inc.

Professionals for Technology, Inc. (Pro-Tech, Inc.)

ProfitKey International, Inc.

PT Publications, Inc.

QAD Inc.

Quantel Technologies, Inc.

QED Information Systems

Qube Connections, Inc.

R. Michael Donovan, Inc.

R.J. Roman & Associates

Raytheon Engineers & Constructors

Realogic, Inc.

Relevant Business Systems, Inc.

Repacorp Label Products

Rinehart Engineering

ROI Systems Inc.

Ross Systems

Royal 4 Systems, Inc.

SAP

SATCOM

Schlueter Business Systems (SBS) Inc.

Scruggs & Associates, Inc.

SCS, Inc.

Sextant Corporation

Software 2000, Inc.

Software AG of North America

Software PM, Inc.

Software Solutions, Inc.

Source Data Inc.
Spar Associates, Inc.
Spectrum Associates
SSA
SSA Southeast
Storeroom Solutions
The Summit Group
Symix Computer Systems, Inc.
Sysmark Information Systems, Inc.
Tangible Vision Inc.
Telesis Computer Corp.
The Operational Excellence Forum
Trillium Software, Inc.
TRW Systems Integration Group
TRY US Resources, Inc.
TSW International
TTW Inc.
TXbase Systems Inc.
UES, Inc.-Knowledge Integration Center
United Barcode Industries, Inc.
Unitronix Corporation
User Solutions, Inc.
Visa
W5 Associates, Inc.
Walmil Company
Weigh-Tronix
Western Data Systems

11.7 Quality Control

http://lionhrtpub.com/apics/apics-2-96/BG/BGPLqual.html

ABBA Computer Systems
ABS Quality Evaluations, Inc.
AbTech Corporation
Acatech Solutions, Inc.
Action Systems Associates, Inc.
Acuity Imaging Inc.
Adaptable Business Systems
Advanced Barcode Tech.
Advanced Industrial Systems
Americode Technologies
Antalys, Inc.
Applied Automation Techniques, Inc.
Applied Micro Business Systems Inc.
Applied Statistics, Inc.
ASC Systems
The Austin Company
Automated Technology Associates
Automatic Identification Systems
AXIS Computer Systems
BatchMaster Software Corp.
Chatillon
CIM Vision International
CIMCASE International Corp.
Cimmation Advanced Manufacturing Technologies
Cimnet Systems Inc.
Clear Software
Compsee
Computer Associates Int'l Inc.
Computer Source Inc.
Controlware Technologies Corp.
The Crosby Company
Crowe Chizek
CTR Systems
Customized Transportation, Inc.
Cybernostic
Data Collection Systems, Inc.
Data Net Corporation
Datalogix
DATAMAX Bar Code Products Corporation
DataMyte/Allen-Bradley
Datasul Inc.
DataWorks Corporation
The Development Center Inc.
Draves & Barke Systems, Inc.
Ebeling Associates, Inc.
Effective Management Systems, Inc.
Epstein Associates
Experience In Software

EXSYS, Inc.
Facilities Planning Services
FASTech Integration, Inc.
FoodPro International, Inc.
Foreman Solutions
FORTUNE Personnel Consultants of New York City Inc.
FORTUNE Personnel of Sarasota
The Genesis Group, Inc.
Graha Mitra Solusi
Grant Thornton LLP
Howard Way & Associates
InfoPower International, Inc.
Instrument Technology, Inc.
Int'l Qual-Tech Ltd.
Intec Controls
Intelligent Manufacturing Systems, Inc.
Intentia International
International Thomas Publishing
Irwin Professional Publishing
ITI Qualitek
JBA International USA
John A. Keane And Associates, Inc.
Kalmia Company Inc.
Least Cost Formulations, Ltd.
Macatawa Computer Services, Inc.
MAHAR Management Solutions
Managing Automation Software Guides
Manufacturers' Services Ltd.
Marcam Corporation
Mesa International
Micro Perfect Corporation
Minitab Inc.
MPA
National Technology Services
Norel Systems, Inc.
Norman N. Axelrod Associates
NRS Consulting
OHM Systems, Inc.
Online Applications, Inc.
Online Software Labs
Operations Concepts, Inc.
Oracle Corporation
Partners For Excellence
Pilot Systems Inc.
Plexus Systems
Power Cerv
PQ Systems, Inc.
PRO:MAN Group
Production Process
Productivity Concepts Inc.
Productivity Press Inc.
ProMeta Consulting
Promis Systems Corporation
PT Publications, Inc.
Q-CIM Inc.
Quality America, Inc.
Quality International Limited
Quality Resources
Raytheon Engineers & Constructors
Real Time eXecutives
Reality Interactive
Realogic, Inc.
Repacorp Label Products
RJS, Inc.
ROI Systems Inc.
ROLS
Salerno Manufacturing Systems
SAP
SAS Institute Inc.
Scruggs & Associates, Inc.
Setpoint Inc.
Sextant Corporation
Software 2000, Inc.
Source Data Inc.
Spar Associates, Inc.
SQL Software
SSA
SSA Southeast
St. Lucie Press
Statware, Inc.
Stochos Incorporated
SyntegraTech, Inc.
Sysmark Information Systems, Inc.
TA Engineering Co., Inc.
Tangible Vision Inc.
Tompkins Associates
Trillium Software, Inc.
TRUMATCH, INC.
TTW Inc.
Unitech Systems, Inc.
User Solutions, Inc.
Verbex Voice Systems Inc.
Western Data Systems
Zontec Inc.

11.8 Relational Database Software

http://lionhrtpub.com/apics/apics-2-96/BG/BGPLreldb.html

1Base Computer
ABBA Computer Systems
Action Systems Associates, Inc.
Adaptable Business Systems
Advanced Industrial Systems
AIM Computer Solutions, Inc.
American Software
ARvee Systems, Inc.
ASC Systems
AT&T, Integrated
Application Systems
Automatic Identification Systems
Automation Resources Corp.
Cimnet Systems Inc.
CIMPAC Inc.
Computer Associates Int'l Inc.
Computer Innovations
Crowe Chizek
CTR Systems
Customized Transportation, Inc.
Data Technical Research, Inc.
Datasul Inc.
The Development Center Inc.
Draves & Barke Systems, Inc.
Dun & Bradstreet Information Services
Dynamic Software
Ebeling Associates, Inc.
Enteo Corporation
EXSYS, Inc.
Fourth Shift Corporation
FloStor Engineering, Inc.
IMC Systems Group, Inc.
Industrial Data Technologies
InfoPower International, Inc.
Intentia International
Intuitive Manufacturing Systems Inc.
King Computer Services, Inc.
Kingwood Systems, Inc.
KnowledgeWare Systems Group
Lilly Software Associates, Inc.
Lincoln Systems
Made2Manage Systems, Inc.
Manufacturers' Services Ltd.
Manufacturing Action Group
Marcam Corporation
MDIS - Chess
Micro Perfect Corporation
New Dimension Systems
Norel Systems, Inc.
NRS Consulting
Obvious Professional Services, Inc.
Online Software Labs
Oracle Corporation
Pilot Systems Inc.
Plexus Systems
Power Cerv
PRO:MAN Group
Productivity Concepts Inc.
ProMeta Consulting
QAD Inc.
R. Shane Company
Real Time eXecutives
Realogic, Inc.
Rinehart Engineering
ROI Systems Inc.
Royal 4 Systems, Inc.
SAP
SAS Institute Inc.
SATCOM
ScanData Systems, Inc.
Scruggs & Associates, Inc.
Somerset Automation, Inc.
Spar Associates, Inc.
SQL Software

SSA Southeast
SyntegraTech, Inc.
Sysmark Information Systems, Inc.
Telesis Computer Corp.
Trillium Software, Inc.
TTW Inc.

11.9 Shop Floor Control

http://lionhrtpub.com/apics/apics-2-96/BG/BGPLshop.html

1Base Computer
A.C.C. Systems
ABBA Computer Systems
Acatech Solutions, Inc.
Accu-Sort Systems, Inc.
Accu-Time Systems, Inc.
AccuScan, Inc.
Action Systems Associates, Inc.
Adaptable Business Systems
ADD+ON Software Inc.
Advanced Data Systems
Advanced Industrial Systems
Aidlin Automation
AIM Computer Solutions, Inc.
Allen Bradley Company
Alliance Automation Systems
American Software
Americode Technologies
Analog Technology Corp.
Anca Associates
Applied Automation Techniques, Inc.
Applied Micro Business Systems Inc.
ARvee Systems, Inc.
ASC Systems
AT&T, Integrated Application Systems
Aurora Technologies, Inc.
The Austin Company
Auto-Soft Corporation
Automated Solutions Corp.
Automated Technology Associates
Automatic Identification Systems
Automation Resources Corp.
Avalon Software Inc.
AXIS Computer Systems, Inc.
Bar Code Equipment Software Systems
Behera & Associates
Berner International Corp.
BioComp Systems, Inc.
BMS, Inc.
Buker Inc.
Business Systems Consultants, Inc.
C-WAY Systems, Inc.
CACI Products Company
Camax Manufacturing Technologies
Carolina Cipher
Casco Development, Inc.
CFS, Inc
CIM Bar Code Technology, Inc.
CIM Vision International
CIMCASE International Corp.
Cimmation Advanced Manufacturing Technologies
Cimnet Systems Inc.
CIMPAC Inc.
Cincom Systems, Inc.
CMI-Competitive Solutions, Inc.
CNA
Columbia Labeling Machinery
Command Line Corp.
ComMIT Systems Inc.
Computer Associates Int'l Inc.
Computer Decisions International
Computer Identics Corp.

Computer Innovations
Computer Source Inc.
ComputerWise Inc.
Consilium, Inc.
Control Concepts, Inc.
Control Module Inc.
Controlware Technologies Corp.
Crowe Chizek
CTR Systems
Customized Transportation, Inc.
Cybernostic
Data Collection Systems, Inc.
Data Net Corporation
Data Technical Research, Inc.
Datamatics
DataModes, Inc.
Datasul Inc.
DataWorks Corporation
DCD Corporation
Decision Servcom, Inc.
The Development Center Inc.
Digi Matex, Inc.
Draves & Barke Systems, Inc.
Ebeling Associates, Inc.
Effective Management Systems, Inc.
Escom Inc.
ESI/Technologies
Expandable Software, Inc.
Expert Buying Systems, Inc.
Expert Choice, Inc.
Express, Inc.
EXSYS, Inc.
FACT, Inc.
Falcon Software
FASTech Integration, Inc.
Flynn Associates
FloStor Engineering, Inc.
Foreman Solutions
Fortune Personnel Consultants of Loudoun
FORTUNE Personnel Consultants of New York City Inc.
Fourth Shift Corporation
Fred Fenster Associates
Friedman Associates
G.S.D. Associates, Inc.
GE Fanuc Automation N.A. Inc.
Genesis (J.D. Edwards)
The Genesis Group, Inc.
Grant Thornton LLP
Greco Systems
GRMS, Inc.
GWBA, Inc.
Hal Mather Inc.
HarrisData
Heuristima Corporation
Hewlett-Packard Korea
HK Systems
Hunter Consultants
Iconics
Indel Software Corporation
Industrial Cybernetics
Industrial Data Technologies
Industrial Technological Associates, Inc.
InfoPower International, Inc.
Infoscan, Inc.
Int'l Qual-Tech Ltd.
Integrated Software Design
Integration Technology Systems
Intelligent Instrumentation
Intelligent Manufacturing Systems, Inc.
Intentia International
Inter-Data Systems, Inc.
INTERACTIVE Group, Inc.
Interlink Technologies, Inc.
International Technologies & Systems
Intrix Systems Group
Intuitive Manufacturing Systems Inc.
ITP Business Communications
J.D. Edwards & Company
Jack Gips, Inc.
JBA International USA
JOBSCOPE
Kingwood Systems, Inc.
Kraft Technologies, Inc.
KRONOS Incorporated
Lexel Corporation
Lowry
Lilly Software Associates, Inc.
LXE
Macatawa Computer Services, Inc.
Macola Software
Made2Manage Systems, Inc.

MAHAR Management Solutions
MAN-TRAK
Managing Automation Software Guides
Managing Change Associates
Manufacturers Technologies
Manufacturers' Services Ltd.
Manufacturing Action Group
Manufacturing And Computer Systems
Manufacturing Control Systems Inc.
Manufacturing Solutions & Systems
Manufacturing Systems Associates, Inc.
Marcam Corporation
Material Management Consultants, LLC
MDIS - Chess
Merry Mechanization Inc.
MES Solutions, Inc.
Mesa International
Metrscope
Micro Perfect Corporation
Micro-MRP, Inc.
Microcomputer Specialists, Inc.
MPA
National Technology Services
New Dimension Systems
North Highland Company
Northern Computer Systems Inc.
Novalog Informatique Inc.
NRS Consulting
OHM Systems, Inc.
Oliver Wight Companies
Online Applications, Inc.
Online Software Labs
Operations Concepts, Inc.
Oracle Corporation
Partners For Excellence
The Peak Technologies Group, Inc.
PeopleSoft
Pilot Systems Inc.
Plexus Systems
Power Cerv
PQ Systems, Inc.
Premier Electronics Inc.
Printronix
PRO:MAN Group
Production Solutions Inc.
Productivity Concepts Inc.
Productivity Press Inc.
Professionals for Technology, Inc. (Pro-Tech, Inc.)
ProfitKey International, Inc.
PROLOGIC Management Systems, Inc.
ProMeta Consulting
Q-CIM Inc.
QAD Inc.
Quantel Technologies, Inc.
QED Information Systems
QNX Software Systems Ltd.
Qube Connections, Inc.
R. Michael Donovan, Inc.
R. Shane Company
R.J. Roman & Associates
Realogic, Inc.
Relevant Business Systems, Inc.
Repacorp Label Products
Rinehart Engineering
ROI Systems Inc.
Ross Systems
Royal 4 Systems, Inc.
RWT Corp.
Salerno Manufacturing Systems
SAP
SAS Institute Inc.
ScanData Systems, Inc.
Schlueter Business
Scruggs & Associates, Inc.
Systems (SBS) Inc.
SCS, Inc.
SE Technologies, Inc.
ShivaSoft, Inc.
SISCO, Inc.
Software PM, Inc.
Software Solutions, Inc.
Source Data Inc.
Spar Associates, Inc.
Spectrum Associates
SSA
SSA Southeast
Statware, Inc.
Stochos Incorporated
Strandware, Inc.

Strategic Business Solutions, Inc.
Studebaker Technology Inc.
The Summit Group
Sy-Con Systems, Inc.
Symix Computer Systems, Inc.
SyntegraTech, Inc.
Sysmark Information Systems, Inc.
Systems Modeling Corporation
TA Engineering Co., Inc.
Tangible Vision Inc.
Tapeswitch Corporation
Team Solutions
Teklogix
Telesis Computer Corp.
The Operational Excellence Forum
TIW
Trillium Software, Inc.
TRW Systems Integration Group
TTW Inc.
Turck Inc.
TXbase Systems Inc.
TYECIN Systems Inc.
United Barcode Industries, Inc.
Unitronix Corporation
USData Corporation
User Solutions, Inc.
Verbex Voice Systems Inc.
Vertex Industries Inc.
W5 Associates, Inc.
Waterloo Manufacturing Software
The Way Corporation
Weigh-Tronix
Western Data Systems
The WRIGHT Group
Xytec Corporation

11.10 Simulation

http://lionhrtpub.com/apics/apics-2-96/BG/BGPLsim.html

Actuality Corporation
Alliance Automation Systems
ALT-C Systems Inc.
ASC Systems
AT&T Istel
AutoSimulations
BioComp Systems, Inc.
BSA SYSTEMS, INC.
CACI Products Company
Camax Manufacturing Technologies
CIMCASE International Corp.
Cimnet Systems Inc.
CIMPAC Inc.
Cincom Systems, Inc.
Clear Software
CMS Research Inc.
ComMIT Systems Inc.
Computer Source Inc.
ControlSoft Inc.
CNA
Customized Transportation, Inc.
Cybernostic Inc.
Datasul Inc.
The Development Center Inc.
E/Step Software, Inc.
Enterprise Planning Systems Corp.
F&H Simulations, Inc.
Facilities Planning Services
FastMAN Software Inc.
Focused Approach, Inc.
Frog Navigation Systems, Inc.
The Genesis Group, Inc.
HEI Corp.
Helmco Consulting Assoc.
Heuristima Corporation
Hewlett-Packard Korea
HK Systems
Howard Way & Associates
Imagine That, Inc.
InfoPower International, Inc.
Insight Solutions Inc.
Intec Controls

John A. Keane And Associates, Inc.
Lilly Software Associates, Inc.
Managing Automation Software Guides
Managing Change Associates
Manufacturers' Services Ltd.
Marcam Corporation
MDIS - Chess
Micro Analysis & Design
Simulation Software, Inc.
Minuteman Software
New Dimension Systems
Norman N. Axelrod Associates
NRS Consulting
Online Applications, Inc.
Online Software Labs
Operations Concepts, Inc.
Oracle Corporation
P-E International
Palisade Corporation
Paragon Decision Technology B.V.
PeopleSoft
Pritsker Corporation
PRO:MAN Group
PROMODEL Corporation
QNX Software Systems Ltd.
Quality America, Inc.
ROI Systems Inc.
SAP
Sapling Corp.
SAS Institute Inc.
Spar Associates, Inc.
SSA Southeast
Strategic Business Solutions, Inc.
Systems Modeling Corporation
Tangible Vision Inc.
Telesis Computer Corp.
TYECIN Systems Inc.
Waterloo Manufacturing Software
Wolverine Software Corporation
The WRIGHT Group

11.11 Supply Chain Management

http://lionhrtpub.com/apics/apics-2-96/BG/BGPLsupply.html

1Base Computer
ABBA Computer Systems
ABC Technologies Inc.
Action Systems Associates, Inc.
Adapta Solutions Inc.
ADR Int'l. Purchasing Consultants
Advanced Manufacturing Research
Advanced Planning Systems, Inc.
ALT-C Systems Inc.
American Software
Antalys, Inc.
Applied Micro Business Systems Inc.
AT&T, Integrated Application Systems
Avyx, Inc.
Barclay Consulting Assoc.
Behera & Associates
BENDER Management Consultants Inc.
Bridgeware, Inc.
BSA SYSTEMS, INC.
CAPS LOGISTICS
CFM, Inc.
Chesapeake Decision Sciences
CIMCASE International Corp.
Cimmation Advanced Manufacturing Technologies
Clear Software
CMI-Competitive Solutions, Inc.
CNA
ComMIT Systems Inc.
Computer Associates Int'l Inc.

Computer Sciences Corporation (CSC)
Coopers & Lybrand/SysteCon Div.
Crowe Chizek
Customized Transportation, Inc.
Cybernostic Inc.
Data Collection Systems, Inc.
Data Interface
Datalogix
Datasul Inc.
DataWorks Corporation
Demand Management Inc.
The Development Center Inc.
Draves & Barke Systems, Inc.
E/Step Software, Inc.
Effective Management Systems, Inc.
Encompass
ESKAY Corporation
Expandable Software, Inc.
Experience In Software
EXSYS, Inc.
Facilities Planning Services
FACT, Inc.
FASCOR
FastMAN Software Inc.
FORTUNE Personnel Consultants of New York City Inc.
FORTUNE Personnel of Sarasota
Fourth Shift Corporation
Genesis (J.D. Edwards)
The Genesis Group, Inc.
Grant Thornton LLP
GSI Logistics and Distribution
GWBA, Inc.
Hal Mather Inc.
The Hayo Consultants
i2 Technologies, Inc.
IMC Systems Group, Inc.
Industri-Matematik International
Industrial Cybernetics
InfoPower International, Inc.
Information Strategies Inc.
Insight Solutions Inc.
Intentia International
J.D. Edwards & Company
Jack Gips, Inc.
JBA International USA
King Computer Services, Inc.
KnowledgeWare Systems Group
Lexington Engineering Associates
Lilly Software Associates, Inc.
LPA Software, Inc.
LubeCon Systems, Inc.
LUCAS BEAR
Luman Consultants
Macola Software
Managing Automation Software Guides
Manhattan Associates
Manufacturers' Services Ltd.
Manufacturing Control Systems Inc.
Manugistics, Inc.
Marcam Corporation
Material Management Consultants, LLC
Micro Perfect Corporation
MPA
New Dimension Systems
North Highland Company
NRS Consulting
Numetrix Ltd.
Oliver Wight Companies
Online Software Labs
Optimax Systems Corp.
Oracle Corporation
Partners For Excellence
PeopleSoft
Plexus Systems
Power Cerv
Printronix
Process Logistix
Productivity Concepts Inc.
ProMeta Consulting
PT Publications, Inc.
Q-CIM Inc.
QAD Inc.
R. Michael Donovan, Inc.
R.J. Roman & Associates
Red Pepper Software Company
Relevant Business Systems, Inc.
ROI Systems Inc.
ROLS
Ross Systems
SAP
ScanData Systems, Inc.
Scruggs & Associates, Inc.

SSA
SSA Southeast
Tangible Vision Inc.
TechnoLogix Decision Sciences Inc.
Technology Solutions Company
Think Systems Corp.
Tompkins Associates
TXbase Systems Inc.
UES, Inc.-Knowledge Integration Center
Western Data Systems
The WRIGHT Group

11.12 Training

http://lionhrtpub.com/apics/apics-2-96/BG/BGPLtrain.html

1Base Computer
ABBA Computer Systems
Adaptable Business Systems
Advanced Distributions Systems
AIM Computer Solutions, Inc.
Allen Bradley Company
Alliance Automation Systems
American Industrial Marketing
American Software
Anca Associates
AnewTech, Inc.
AT&T, Integrated Application Systems
Automation Resources Corp.
AXIS Computer Systems
Bar Code Systems & Supplies
Barclay Consulting Assoc.
Behera & Associates
BioComp Systems, Inc.
Buker Inc.
Business Systems Consultants, Inc.
Business Systems Specialties, Inc.
C-WAY Systems, Inc.
CA Software, Inc.
CAPS LOGISTICS
Carolina Cipher
Catalyst International Inc.
CFS, Inc
CIMCASE International Corp.
Cimmation Advanced Manufacturing Technologies
Cimnet Systems Inc.
Clear Software
CNA
CMI-Competitive Solutions, Inc.
Command Line Corp.
Computer Associates Int'l Inc.
Computer Decisions International
Control Data Systems, Inc.
The Crosby Company
Crowe Chizek
CS Report Inc.
Customized Transportation, Inc.
Cybernostic Inc.
Data Capture Institute
Data General Corp.
Data Technical Research, Inc.
Datalogix
Datasul Inc.
Decision Consultants, Inc.
The Development Center Inc.
Digi Matex, Inc.
Digital Press
Draves & Barke Systems, Inc.
Dun & Bradstreet Information Services
Effective Management Systems, Inc.
ENTEK Inc.
Expandable Software, Inc.
Experience In Software
EXSYS, Inc.
Falcon Software
Flynn Associates
Footlik & Associates
Foreman Solutions

Foresight Survey Systems International
Friedman Associates
The Genesis Group, Inc.
GMI Engineering & Management Inst.
Graha Mitra Solusi
Greenbrier & Russel
GRMS, Inc.
GSI Logistics and Distribution
GWBA, Inc.
Hal Mather Inc.
Holland & Davis, Inc.
Hunter Consultants
Industrial Data Technologies
InfoPower International, Inc.
Int'l Qual-Tech Ltd.
Integrated Software Design
Intentia International
Inter-Data Systems, Inc.
Interlink Technologies, Inc.
International TechneGroup, Inc.
International Thomas Publishing
Intrix Systems Group
Intuitive Manufacturing Systems Inc.
Irwin Professional Publishing
Jack Gips, Inc.
JBA International USA
JC-I-T Institute of Technology
JIT Hands-On Workshop
John A. Keane And Associates, Inc.
Kearney Systems, Inc.
KnowledgeWare Systems Group
Kraft Technologies, Inc.
LubeCon Systems, Inc.
Luman Consultants
Macola Software
Made2Manage Systems, Inc.
MAHAR Management Solutions
MAN-TRAK
Managing Automation Software Guides
Managing Change Associates
Manufacturers' Services Ltd.
Manufacturing Action Group
Manufacturing Control Systems Inc.
Manufacturing Systems Consultants
Material Management Consultants, LLC
MDIS - Chess
Merry Mechanization Inc.
MGI Management Institute
MHR Consultants, Inc.
Microcomputer Specialists, Inc.
Micro Perfect Corporation
Micro-MRP, Inc.
Multi-CAD, L.L.C.
New Dimension Systems
Norel Systems, Inc.
Norman N. Axelrod Associates
North American Business Services
North Highland Company
NRS Consulting
OakTree Associates, Inc.
OHM Systems, Inc.
Oliver Wight Companies
Online Applications, Inc.
Online Software Labs
Operations Concepts, Inc.
The Paradigm Group, Inc.
Partners For Excellence
Pilot Systems Inc.
Plexus Systems
PQ Systems, Inc.
Premier Electronics Inc.
Printronix
PRO:MAN Group
Process Logistix
Production Solutions Inc.
Productivity Concepts Inc.
Productivity Engineering Services
Productivity Press Inc.
Professionals for Technology, Inc. (Pro-Tech, Inc.)
ProfitKey International, Inc.
ProMeta Consulting
PT Publications, Inc.
Quality International Limited
Quality Resources

R. Michael Donovan, Inc.
R.J. Roman & Associates
Raytheon Engineers & Constructors
Reality Interactive
ROI Systems Inc.
Royal 4 Systems, Inc.
Saksham Consultants
Sanders & Associates
SAP
SAS Institute Inc.
SE Technologies, Inc.
Scruggs & Associates, Inc.
Source Data Inc.
SPC Press/Statistical Process Controls
Spectrum Associates
SSA Southeast
St. Lucie Press
Stochos Incorporated
The Summit Group
Superior Software Products
Sysmark Information Systems, Inc.
Tangible Vision Inc.
Team Solutions
Technical Software
Technology Solutions Company
Telesis Computer Corp.
Tompkins Associates
TRY US Resources, Inc.
TTW Inc.
Unbeaten Path International
United Barcode Industries, Inc.
The Way Corporation
Weigh-Tronix
Zontec Inc.

11.13 Transportation/Distribution

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1Base Computer
A.C.C. Systems
Acatech Solutions, Inc.
Accu-Sort Systems, Inc.
AccuScan, Inc.
Action Systems Associates, Inc.
American Software
Applied Micro Business Systems Inc.
Armor Systems Inc.
ASC Systems
Astea International Inc.
Astechnologies Material Handling
Aurora Technologies, Inc.
The Austin Company
Automated Distribution Design, Inc.
Automotion, Inc.
Aztech America
Bar Code Equipment Software Systems
Barclay Consulting Assoc.
Bayhead Products Corp.
BDM Technologies, Inc.
BENDER Management Consultants Inc.
Berner International Corp.
Beyers Innovative Software
Bigelow Packaging
BSA SYSTEMS, INC.
Business Systems Consultants, Inc.
Carolina Cipher
Catalyst International Inc.
CFS, Inc
Chep USA
Chesapeake Decision Sciences
CIE America, Inc.
CIMCASE International Corp.
Client Server Technologies, Inc.
CNA
CodeWriter Industries
Columbia Labeling Machinery
Compass Modeling Solutions Inc.
Compsee

Computer Associates Int'l Inc.
Computer Decisions International
Computer Innovations
Computer Identics
Computer Sciences Corporation (CSC)
Control Concepts, Inc.
Control Module Inc.
Coopers & Lybrand/SysteCon Div.
Crowe Chizek
Crown Equipment Corp.
CS Report Inc.
Customized Transportation, Inc.
Cybernostic Inc.
Data Capture Institute
Data Collection Systems, Inc.
Data Net Corporation
Datamatics
DATAMAX Bar Code Products Corporation
DataModes, Inc.
Datasouth Computer Corp.
Datasul Inc.
Decision Consultants, Inc.
The Development Center Inc.
Draves & Barke Systems, Inc.
Elsevier Science Ltd.
Encompass
Eric C. Baum & Associates
ESI/Technologies
Experience In Software
Expert Choice, Inc.
EXSYS, Inc.
Facilities Planning Services
FACT, Inc.
FASCOR
FoodPro International, Inc.
Fortune Personnel Consultants of Chapel Hill, Inc.
Fortune Personnel Consultants of Loudoun
FORTUNE Personnel Consultants of New York City Inc.
FORTUNE Personnel of Sarasota
Foxware
Friedman Associates
Gateway Data Sciences Corp.
Genesis (J.D. Edwards)
The Genesis Group, Inc.
Grand Rapids Label Co.
Grant Thornton LLP
GSI Logistics and Distribution
Helmco Consulting Assoc.
Hunter Consultants
i2 Technologies, Inc.
IHE
IMC Systems Group, Inc.
Industrial Data Technologies
Industrial Technological Associates, Inc.
InfoPower International, Inc.
Information Strategies Inc.
Infrapak, Inc.
Integrated Software Design
Integrating Data Systems
Intelligent Instrumentation
Intelligent Manufacturing Systems, Inc.
Intentia International
Inter-Data Systems, Inc.
International Technologies & Systems
IQR International
J.D. Edwards & Company
JBA International USA
King Computer Services, Inc.
KnowledgeWare Systems Group
Kositzky & Associates, Inc.
Kraft Technologies, Inc.
Lambert Material Handling
LDS, Inc.
Lexington Engineering Associates
Lowry
LPA Software, Inc.
LXE
Macola Software
Managing Automation Software Guides
Manhattan Associates
Manufacturers' Services Ltd.
Manufacturing Control Systems Inc.
Manugistics, Inc.
Marcam Corporation
Marprint, Inc.

Material Management Consultants, LLC

McMillan Associates, Inc.

MDIS - Chess

Micro Analysis & Design Simulation Software, Inc.

Micro Perfect Corporation

MicroAnalytics

Mt. Valley Farms & Lumber Products Inc.

Munck Automation Technology

National Technology Services

New Dimension Systems

Norel Systems, Inc.

North American Business Services

North Highland Company

NRS Consulting

Numetrix Ltd.

OHM Systems, Inc.

Oliver Wight Companies

Online Applications, Inc.

Online Software Labs

Oracle Corporation

Ormandy, Inc.

P-E International

Package Research Laboratory

Paragon Decision Technology B.V.

Partners For Excellence

The Peak Technologies Group, Inc.

Power Cerv

Printronix

Productivity Press Inc.

Professionals for Technology, Inc. (Pro-Tech, Inc.)

ProMeta Consulting

PROMODEL Corporation

QAD Inc.

QED Information Systems

Quality Software Systems Inc. (QSSI)

The Raymond Corp.

Recognition Equipment Brokers, Inc.

Red Pepper Software Company

Repacorp Label Products

Resource Optimization Inc.

REYcomp Incorporated

RF Link Systems

Roberts Express, Inc.

ROI Systems Inc.

ROLS

Ross Systems

Royal 4 Systems, Inc.

SAITECH, Inc.

SAP

SAS Institute Inc.

SATCOM

ScanData Systems, Inc.

Scruggs & Associates, Inc.

Sedlak Management Consultants, Inc.

Smurfit Pallet Systems

Software Solutions, Inc.

Spalding Software, Inc.

SSA

SSA Southeast

Strandware, Inc.

The Summit Group

Superior Handling

Equipment Inc.

Symix Computer Systems, Inc.

SyntegraTech, Inc.

Sysmark Information

Systems, Inc.

Systems Modeling Corporation

T.L. Ashford & Associates

Tangible Vision Inc.

Tech Conveyor, Inc.

TechnoLogix Decision Sciences Inc.

Teklogix

Telxon Corporation

Tompkins Associates

Trigesta Americas, Inc.

Trillium Software, Inc.

United Barcode Industries, Inc.

Verbex Voice Systems Inc.

W5 Associates, Inc.

Wolverine Software Corporation

11.14 Warehousing Systems

http://lionhrtpub.com/apics/apics-2-96/BG/BGPLware.html

1Base Computer
A-B Products Inc.
A.C.C. Systems
Acatech Solutions, Inc.
Accu-Sort Systems, Inc.
AccuScan, Inc.
ACRA Incorporated
Action Systems Associates, Inc.
Adaptable Business Systems
Advance Storage Products
Advanced Distributions Systems
Advanced Industrial Systems
Aero-Motive Company
American Software
Americode Technologies
Analog Technology Corp.
Anca Associates
Ann Arbor Computer
Applied Automation Techniques, Inc.
Applied Micro Business Systems Inc.
Armor Systems Inc.
ASC Systems
Astea International Inc.
Astechnologies Material Handling
The Austin Company
Auto-Soft Corporation
Automated Distribution Design, Inc.
Automated Solutions Corp.
Automatic Identification Systems
Automotion, Inc.
Bar Code Equipment Software Systems
Bar Code Resources
Barclay Consulting Assoc.
Bayhead Products Corp.
BDM Technologies
Berner International Corp.
BioComp Systems, Inc.
Bigelow Packaging
BMS, Inc.
The Borne Co. Inc.
CACI Products Company
Cambar Software
Carico Systems
Catalyst International Inc.
CFS, Inc
Chep USA
CIE America, Inc.
CIM Vision International
CNA
CodeWriter Industries
Columbia Labeling Machinery
Command Line Corp.
Compsee
Computer Associates Int'l Inc.
Computer Decisions International
Computer Identics Corp.
Computer Innovations
Coopers & Lybrand/SysteCon Div.
Corecon, Inc.
Crowe Chizek
CS Report Inc.
CTR Systems
Customized Transportation, Inc.
Cybernostic Inc.
Data Capture Institute
Data Collection Systems, Inc.
Data General Corp.
Data Net Corporation
DATAMAX Bar Code Products Corporation
DataModes, Inc.
Datasouth Computer Corp.
Datasul Inc.
Decision Consultants, Inc.
Decision Servcom, Inc.
Deluxe Storage Systems Inc.
Denstor Mobile Storage
Designer Metal Products Inc.

The Development Center Inc.

Diamond Phoenix

Draves & Barke Systems, Inc.

Entron Industrial Computers

Equipto

Eric C. Baum & Associates

ESI/Technologies

ESKAY Corporation

Exeter Software Ltd.

Expandable Software, Inc.

Expert Buying Systems, Inc.

EXSYS, Inc.

F&H Simulations, Inc.

Facilities Planning Services

FACT, Inc.

FASCOR

FloStor Engineering, Inc.

FoodPro International, Inc.

Footlik & Associatesv

Forté Technology Inc.

Fortune Personnel Consultants of Chapel Hill, Inc.

Fortune Personnel Consultants of Loudoun

FORTUNE Personnel Consultants of New York City Inc.

Foxware

Fred Fenster Associates

Friedman Associates

Frog Navigation Systems, Inc.

G/S Data Solutions

Gardner Denver Machinery Inc.

Gateway Data Sciences Corp.

Genesis (J.D. Edwards)

Grand Rapids Label Co.

Grant Thornton LLP

GSI Logistics and Distribution

Hand Held Products

Haushahn Systems & Engineers

The Hayo Consultants

Helmco Consulting Assoc.

Hi-Line Storage Systems

HK Systems

Howard Way & Associates

Hunter Consultants

IHE

IKG Industries

Industri-Matematik International

Industrial Data Technologies

Industrial Kinetics Inc.

Industrial Technological Associates, Inc.

InfoPower International, Inc.

Information Strategies Inc.

Infoscan, Inc.

Infrapak, Inc.

Integrated Software Design

Integrating Data Systems

Intek Integration Technologies

Intelligent Manufacturing Systems, Inc.

Intentia International

Interlake Material Handling

Interlink Technologies, Inc.

International Technologies & Systems

INTERROLL CORP.

J.D. Edwards & Company

JBA International USA

JEKA USA Services

K-RAM Corporation

Kardex Systems, Inc.

Kearney Systems, Inc.

King Computer Services, Inc.

KnowledgeWare Systems Group

Kraft Technologies, Inc.

Lambert Material Handling

LDS, Inc.

Lexington Engineering Associates

Lowry

LXE

MAN-TRAK

Managing Automation Software Guides

Manhattan Associates

Manufacturers' Services Ltd.

Manufacturing Control Systems Inc.

Manufacturing Systems Associates, Inc.

Marcam Corporation

Marprint, Inc.

Material Management Consultants, LLC

Mathews Conveyor Division

McMillan Associates, Inc.

Micro Analysis & Design Simulation Software, Inc.

Micro Perfect Corporation
Mt. Valley Farms & Lumber Products Inc.
Munck Automation Technology
National Technology Services
Norel Systems, Inc.
North American Business Services
North Highland Company
NRS Consulting
Numetrix Ltd.
OHM Systems, Inc.
Online Applications, Inc.
Online Software Labs
Operations Concepts, Inc.
Oracle Corporation
Ormandy, Inc.
P-E International
Parker Industrial Corp.
The Peak Technologies Group, Inc.
Plexus Systems
Power Cerv
Precision Automation Co., Inc.
Premier Electronics Inc.
Printronix
Professionals for Technology, Inc. (Pro-Tech, Inc.)
ProMeta Consulting
PROMODEL Corporation
QAD Inc.
QED Information Systems
Quality Software Systems Inc. (QSSI)
The Raymond Corp.
Realogic, Inc.
Recognition Equipment Brokers, Inc.
Repacorp Label Products
Retrotech, Inc.
REYcomp Incorporated
RF Link Systems
ROI Systems Inc.
ROLS
Royal 4 Systems, Inc.
SAP
SAS Institute Inc.
SATCOM
ScanData Systems, Inc.
Scruggs & Associates, Inc.
Sedlak Management Consultants, Inc.
Setpoint Inc.
Smetco Inc.
Smurfit Pallet Systems
Software Solutions, Inc.
Solve Needs International
Somerset Automation, Inc.
Source Data Inc.
Spalding Software, Inc.
SSA
SSA Southeast
Storax, Inc.
Storeroom Solutions
Strandware, Inc.
The Summit Group
SyntegraTech, Inc.
Systems Modeling Corporation
T.L. Ashford & Associates
Tangible Vision Inc.
Tech Conveyor, Inc.
Technology Solutions Company
Teklogix
Telxon Corporation
Tips, Inc.
Tompkins Associates
Trillium Software, Inc.
TSW International
Unarco Material Handling
Unitech Systems, Inc.
United Barcode Industries, Inc.
Uniteq Application Systems, Inc.
USData Corporation
Variant Microsystems, Inc.
Vanderlande Industries
Verbex Voice Systems Inc.
Vertex Industries Inc
Videx, Inc.
Weigh-Tronix
West Weigh Scale Co.
Westfalia Technologies, Inc.
White Storage & Retrieval Systems
Whitney Rand Mfg. Corp.
Wisconsin Box Company
Wolverine Software Corporation