

1996

## An investigation into manufacturing execution systems

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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

Date of Submission: November 30, 1996

## 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	: <u>Systeme, Anwendungen, Produkte in der Datenverarbeitung</u> , (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

---

# I. 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 Friscla (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:

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*“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)*

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## 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

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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."* (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)

---

<sup>1</sup> 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



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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*

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*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 on 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<sup>2</sup>. 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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<sup>2</sup> 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<sup>3</sup>

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)

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<sup>3</sup> cp (Buffa, 1977, p. 379)  $Q_o = \sqrt{\frac{2C_p R}{C_H}}$  where 'C<sub>H</sub>' is optimal order quantity, 'C<sub>p</sub>' is order preparation costs and 'R' is demand.

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*"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 ' $\lambda$ ' and the mean service rate is ' $\mu$ ', 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

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(where  $\mu = \lambda$  then  $\mu(\mu - \lambda) = 0$  so  $T_0$  and  $L_0$  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 al., 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

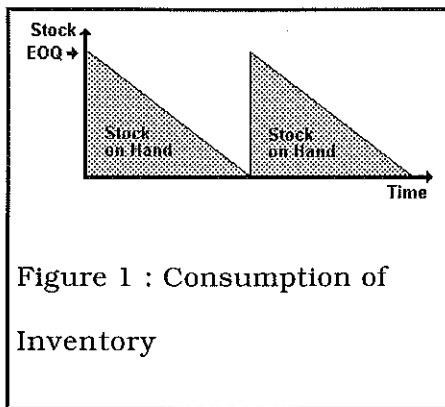


Figure 1 : Consumption of Inventory

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

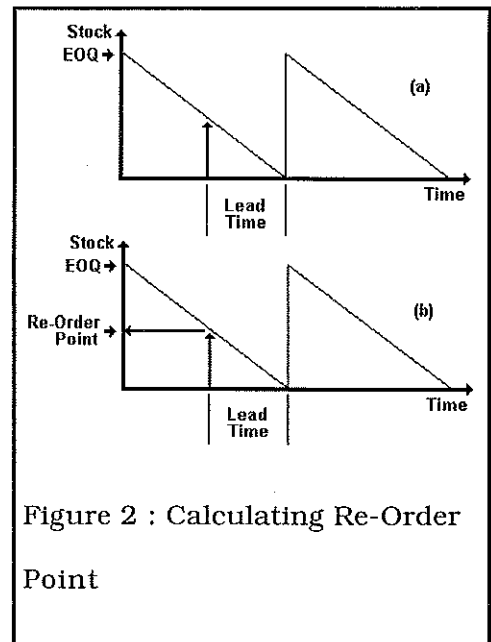


Figure 2 : Calculating Re-Order Point

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,

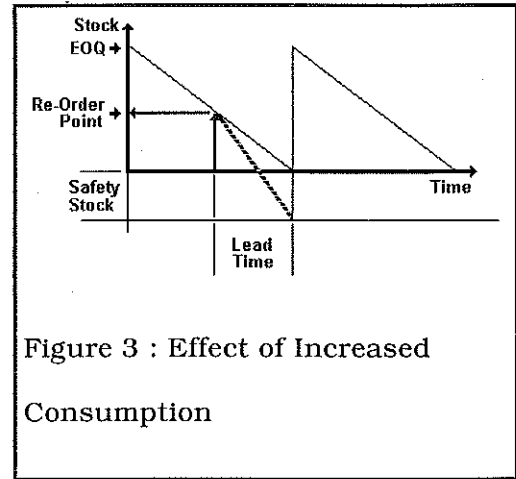


Figure 3 : Effect of Increased Consumption

allows processes to continue (whether sales or production) regardless of reasonable variation in stock consumption. Safety stock buffer size, then, is the difference between ' $\bar{D}$ ' the average demand and ' $D_{max}$ ' the reasonable maximum demand (for the lead time), but given that

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

Equation 4 : Maximum Demand

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

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

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 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

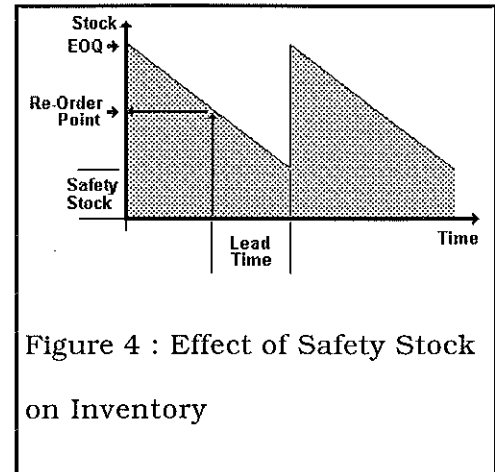


Figure 4 : Effect of Safety Stock on Inventory

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 & Burbidge, 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)*

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## 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*

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*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

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

and Japan during the later part of the Japanese reconstruction as shown in Table 1 on page 23.

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*

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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:*

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*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 than 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)

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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	Abbreviation	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:

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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 bike icon Harley-Davidson. Other cases listed may

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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<sup>4</sup> 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)

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<sup>4</sup> 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

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

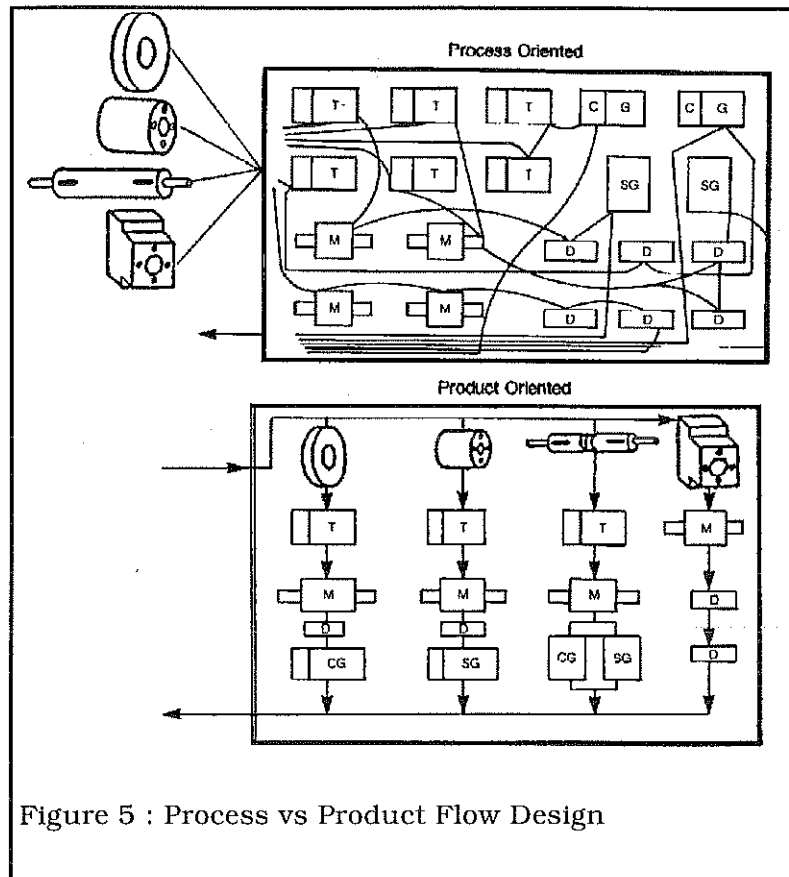


Figure 5 : Process vs Product Flow Design

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.

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*"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)*

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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;

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*"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 'builds quality into the process.' 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.

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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



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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

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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<sup>5</sup>, 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.

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

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*"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

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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)

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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.

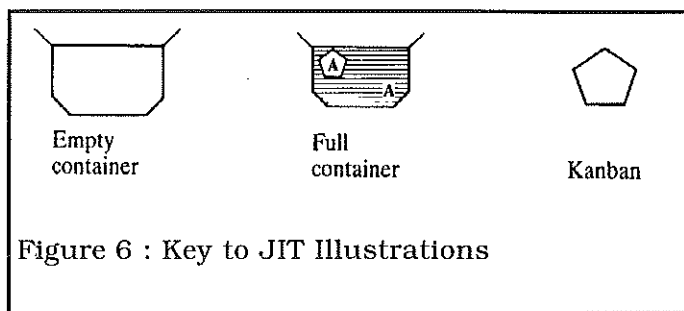
### 3.1.2.9 JIT IMPOSSIBLE!

*“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

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<sub>w</sub>' is the waiting time for the kanban to be returned to the supplying area, 'T<sub>p</sub>' 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<sup>6</sup>. (Graham, 1988, p. 20)

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<sup>6</sup> Compare this inventory buffer level with that suggested by Goldratt in Synchronised Manufacturing (ref: page 69)

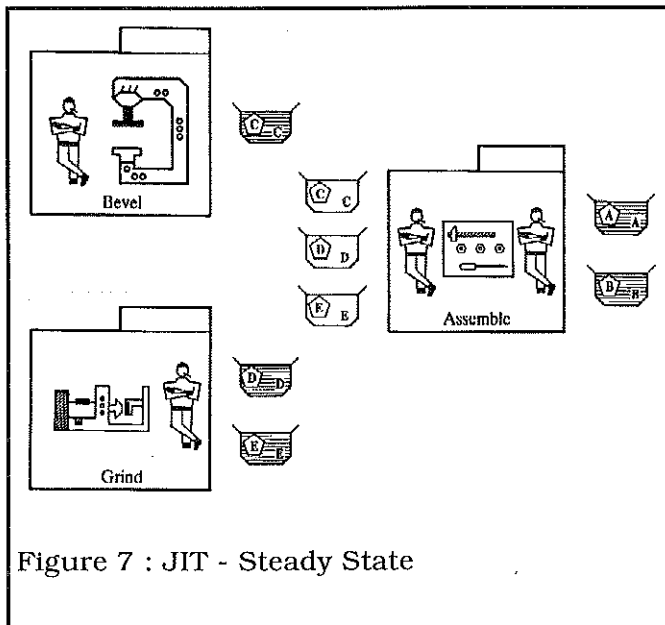


Figure 7 : JIT - Steady State

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.

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'

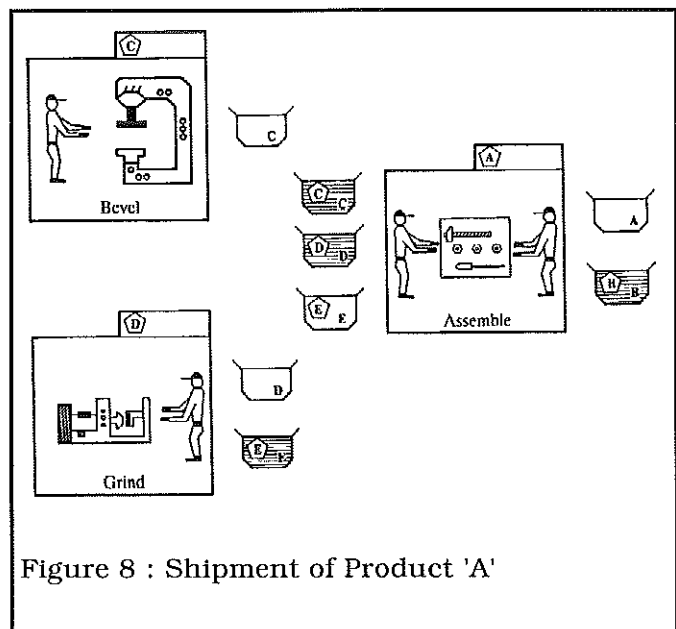


Figure 8 : Shipment of Product 'A'



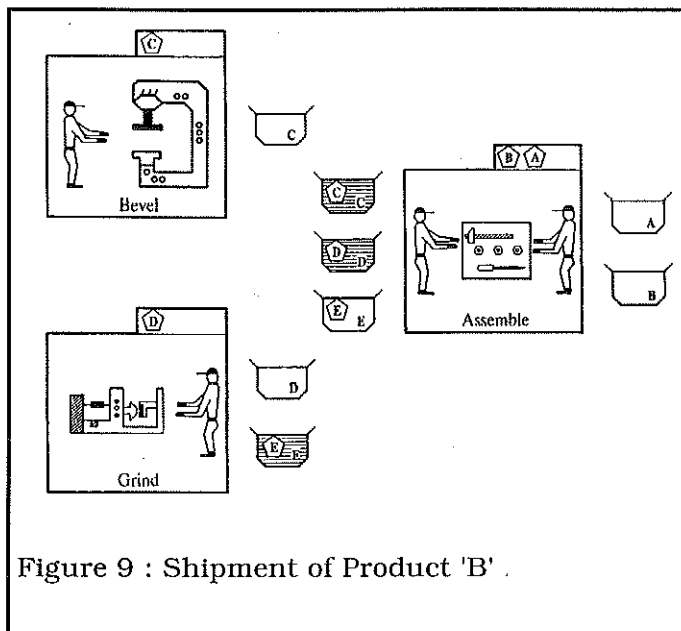


Figure 9 : Shipment of Product 'B' .

(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

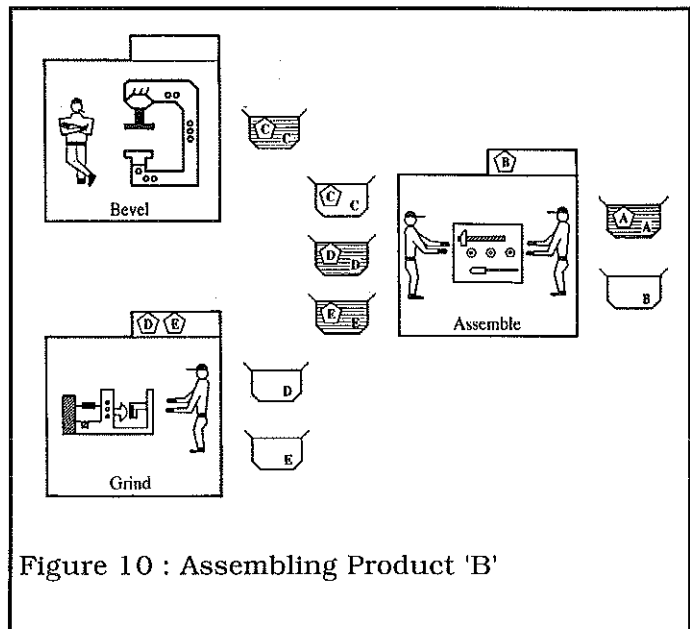


Figure 10 : Assembling Product 'B'

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.

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.

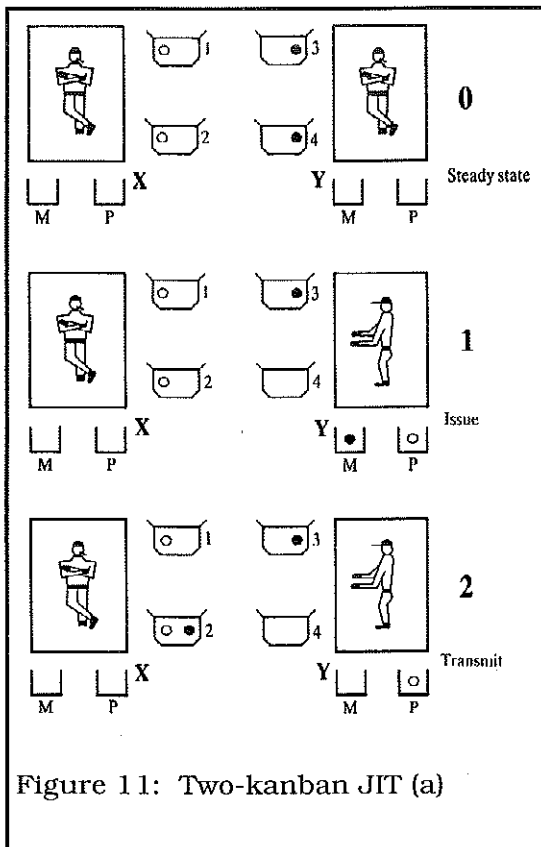


Figure 11: Two-kanban JIT (a)

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).

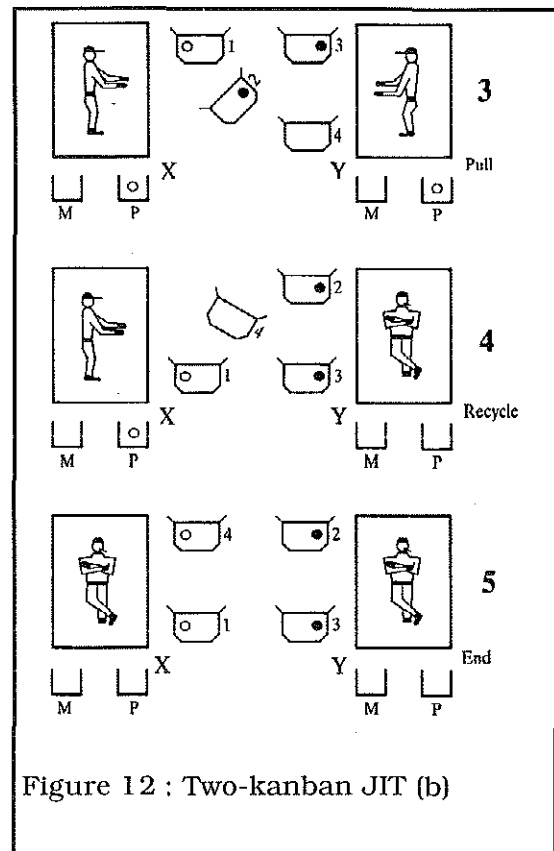


Figure 12 : Two-kanban JIT (b)

When neither centre has kanbans in either hold box, the process returns to the steady state (stage 5).

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*

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*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.

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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*

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*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.

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### 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



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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)*

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 identify the best compromise which

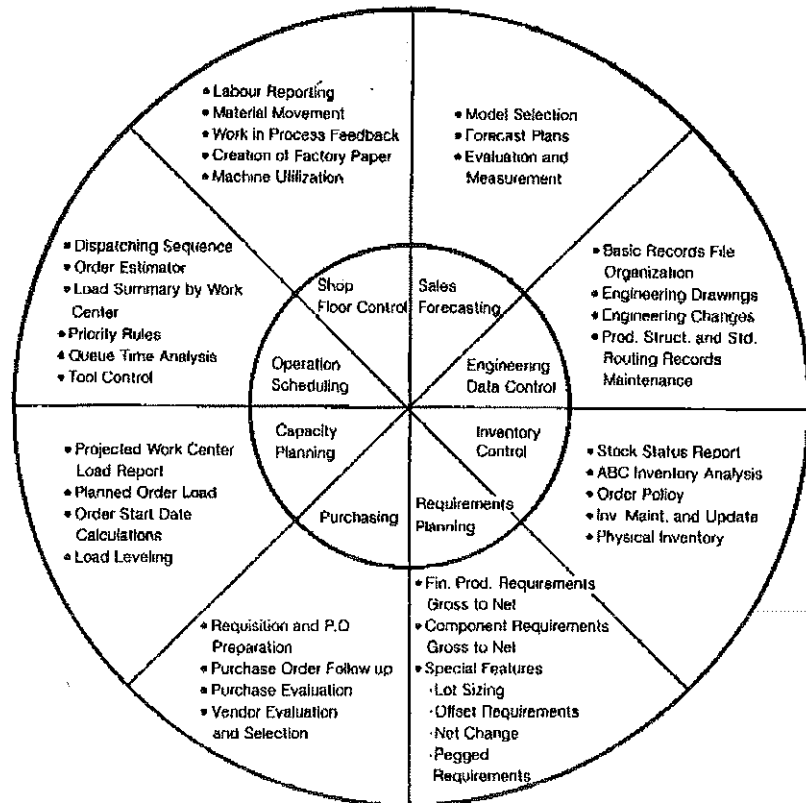


Figure 13 : The PICS Wheel

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

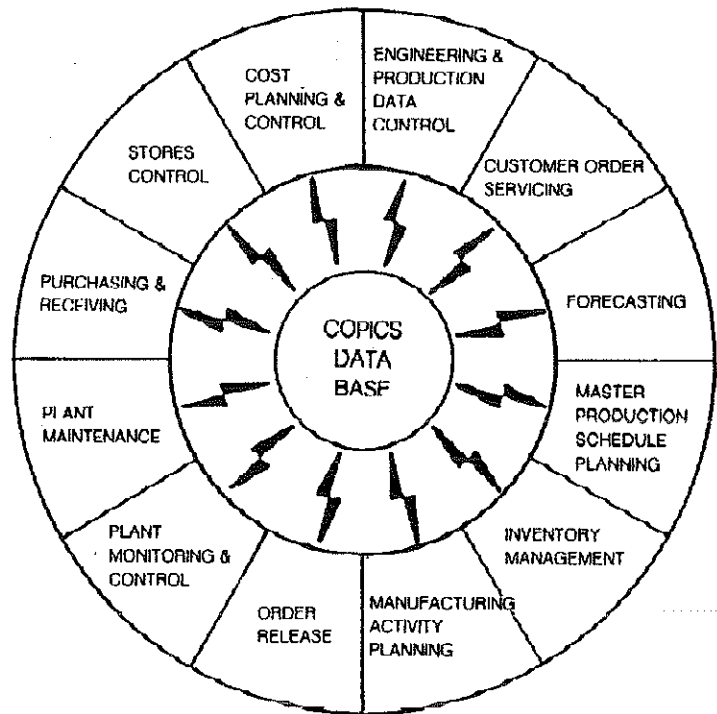


Figure 14 : The COPICS Concept

*"[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 backcheduling 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

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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

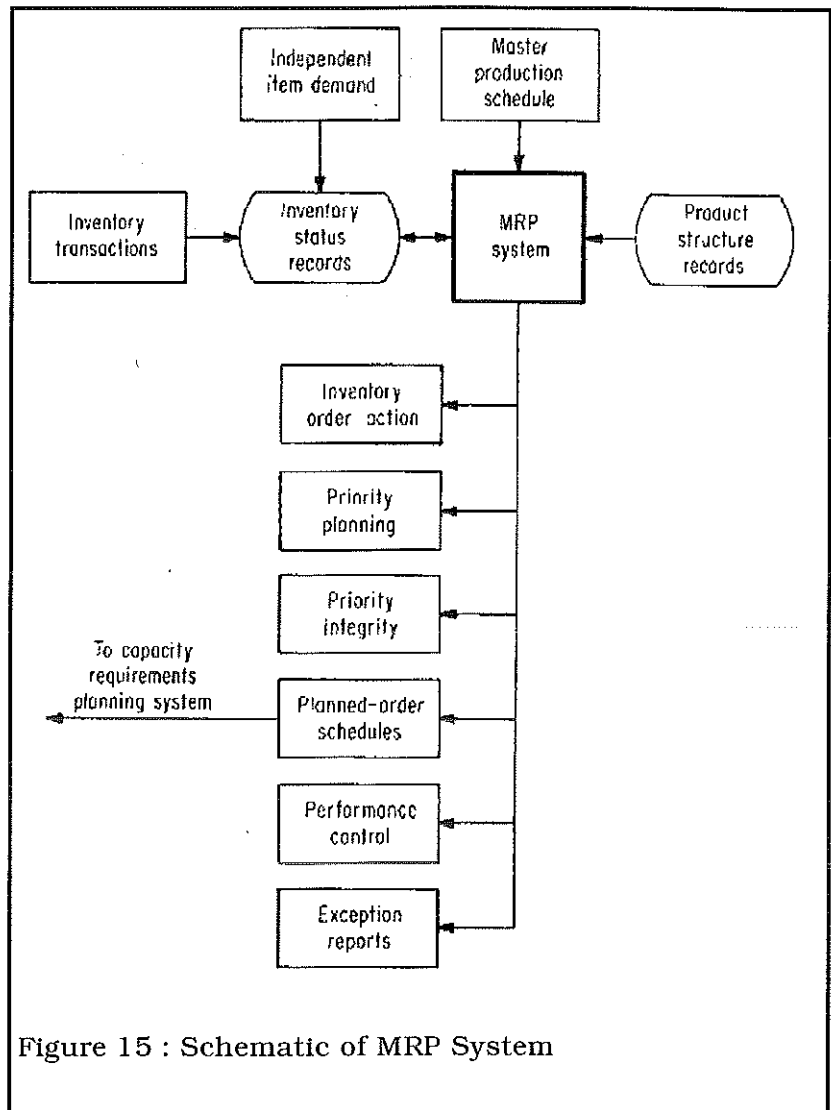
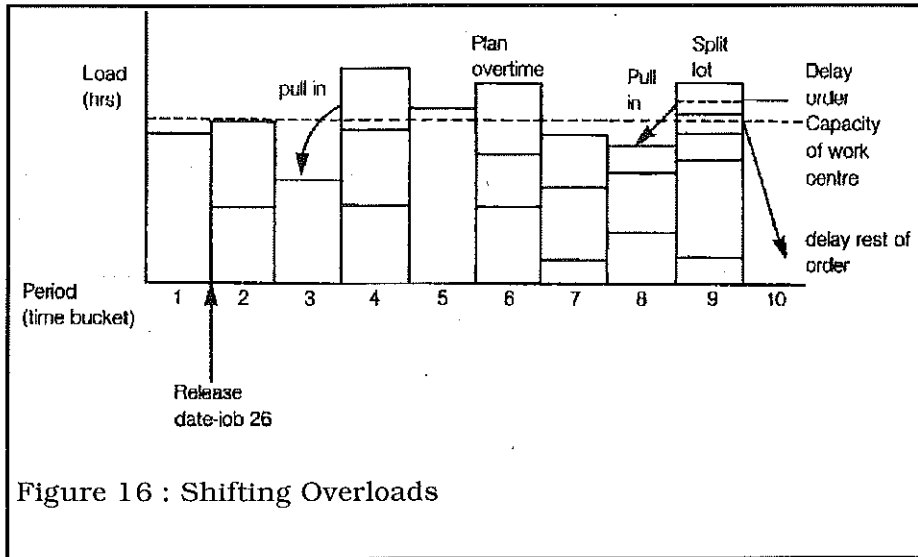


Figure 15 : Schematic of MRP System

production schedule should be) or the question of what need 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 ))

“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



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

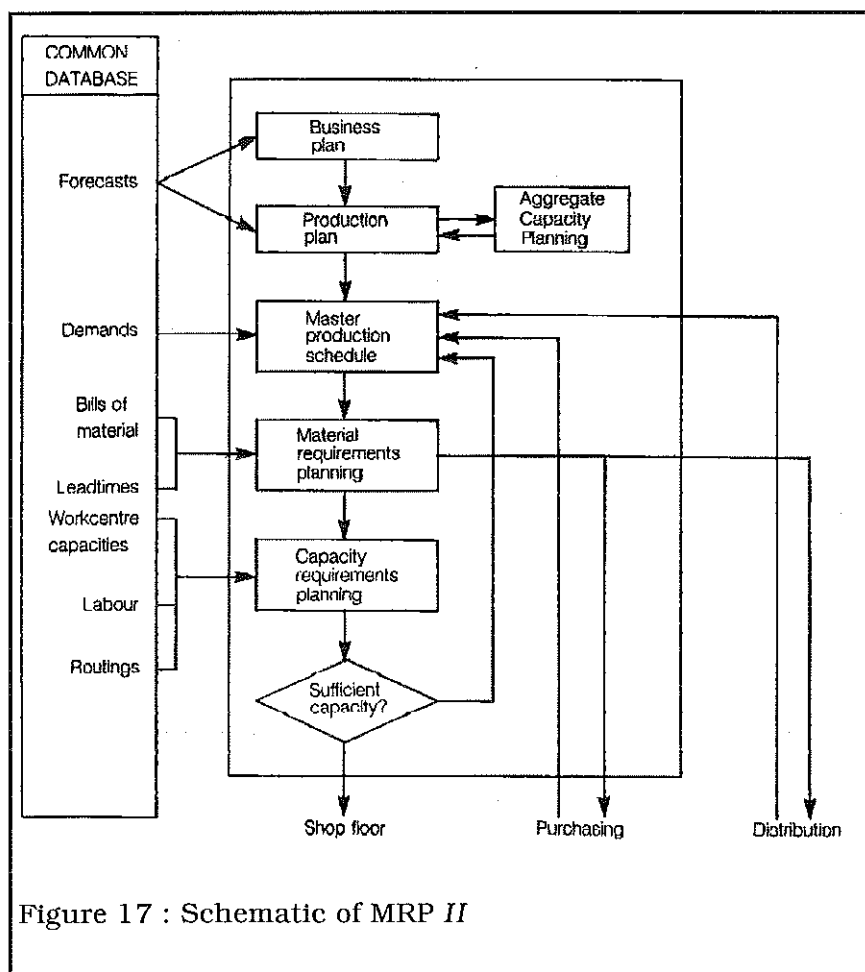


Figure 17 : Schematic of MRP II

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)



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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*

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*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<sup>7</sup> 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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<sup>7</sup> 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."*<sup>8</sup>(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 bottlenecks.

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<sup>8</sup> It is pertinent to point out that Throughput still requires Sales!

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*"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

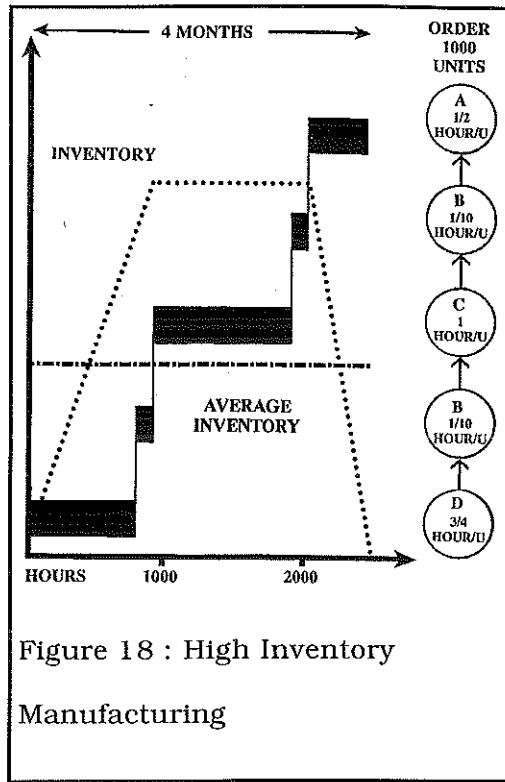


Figure 18 : High Inventory Manufacturing

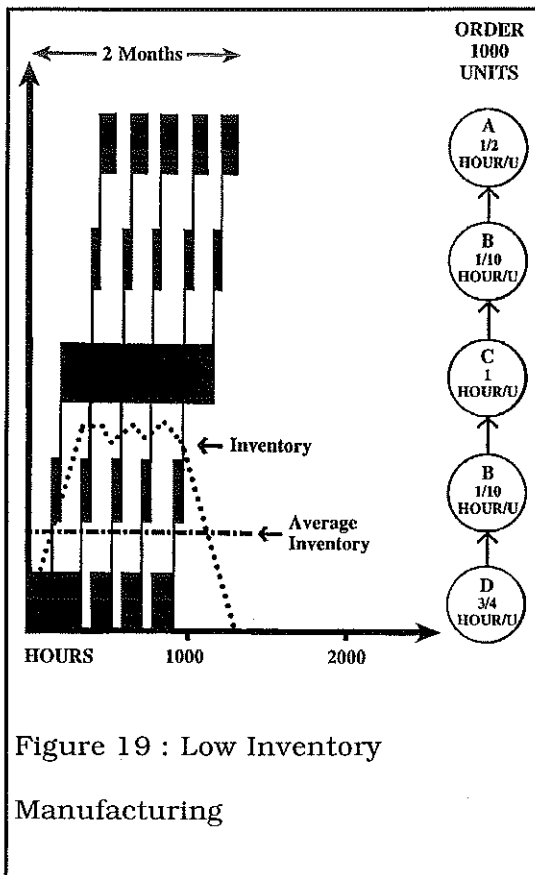


Figure 19 : Low Inventory Manufacturing

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.

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

---

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)

### 3.3.2.3 MARGINS

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

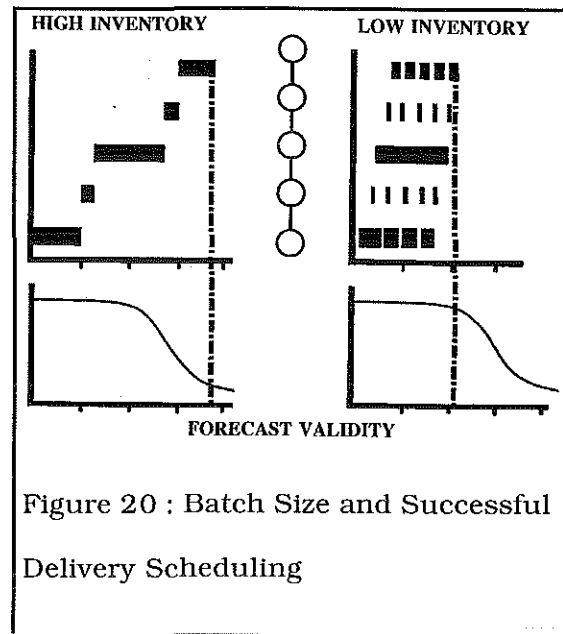


Figure 20 : Batch Size and Successful Delivery Scheduling

### 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

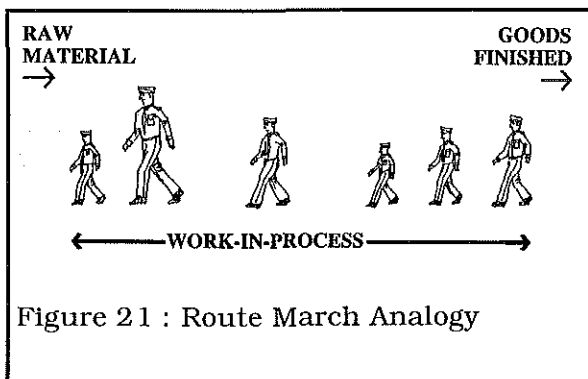


Figure 21 : Route March Analogy

"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

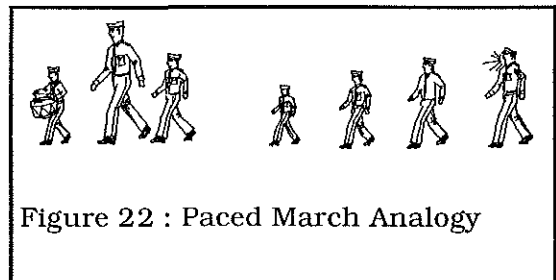


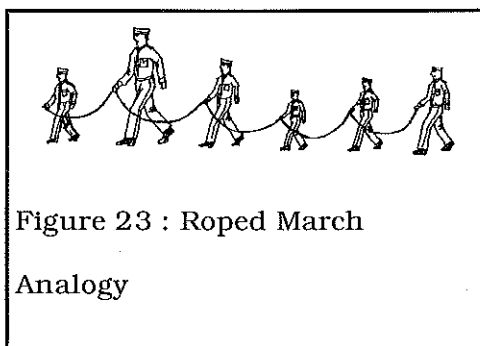
Figure 22 : Paced March Analogy



*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.

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.

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.

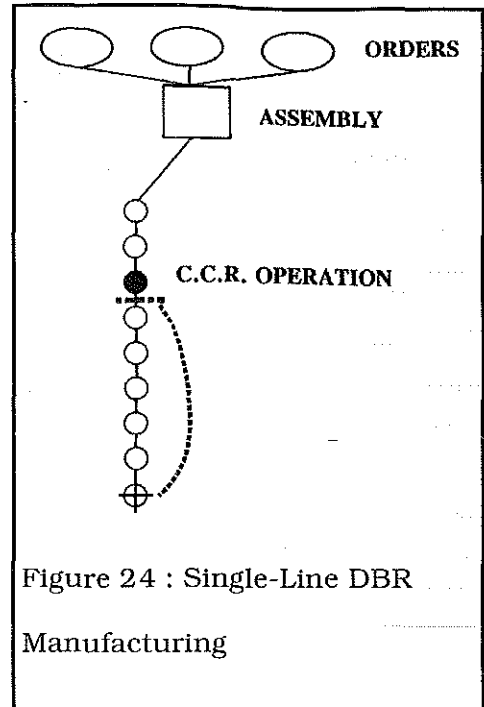


Figure 24 : Single-Line DBR Manufacturing

In Figure 24 (page 68 ref : (Goldratt & Fox, 1986, p. 101) ) the curved, dotted

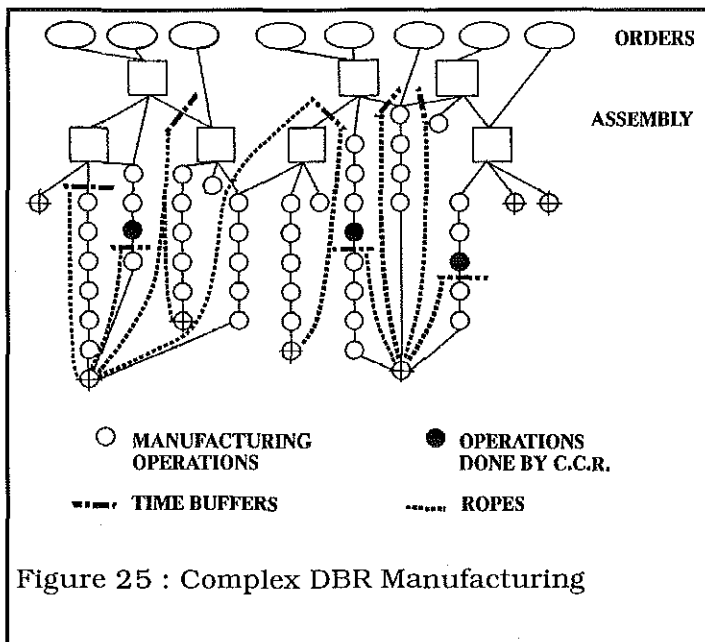


Figure 25 : Complex DBR Manufacturing

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.

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Three days demand is suggested for the buffer size<sup>9</sup>.

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)*

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<sup>9</sup> Compare this inventory buffer level with that aimed for under the Toyota Production System (ref: page 41)

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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.

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### 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 desired 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<sup>10</sup>. Being a bottle-neck resource does not necessarily mean being a CCR.

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<sup>10</sup> 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

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

	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

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

$$[(20 \times 3) + (50 \times 5)] - 70 = 240$$

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

$$[((8 \times 31) + 2) - (8 \times 7)] = 194$$

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

	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

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.

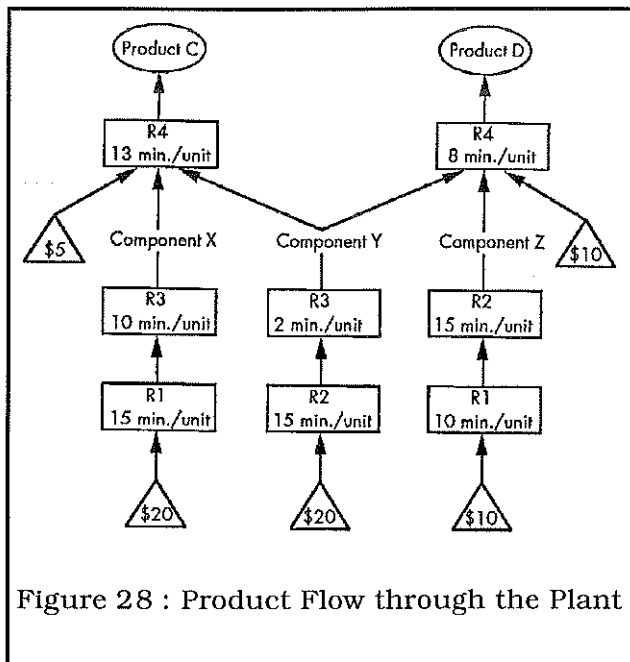


Figure 28 : Product Flow through the Plant

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

$$P = [I - (C + E_o)]$$

Equation 11 : Profit Calculation (General)

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

$$I = [T \times P_s]$$

Equation 12 : Income Calculation

where  $T$  is Throughput and  $P_s$  is Selling Price then

$$P = [(T \times P_s) - (C + E_o)]$$

Equation 13 : Profit Calculation (Specific)

and

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

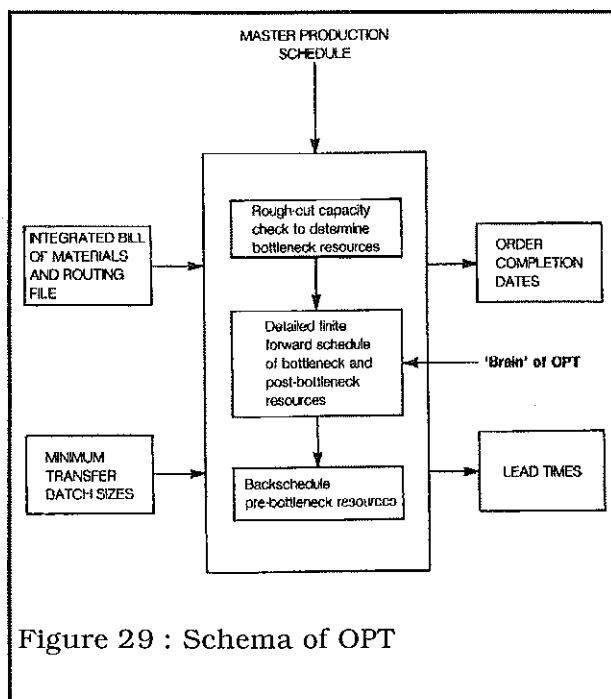
Equation 14 : Loss on Sole Production of Product D

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)*



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.

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*"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."<sup>11</sup>*

*"[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)*

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<sup>11</sup> 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)

<i>Functions</i>	<i>Categories</i>	<i>Kanban system</i>	<i>MRP II</i>
Rates of output	Families of products	Leveling	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<sup>12</sup> (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:

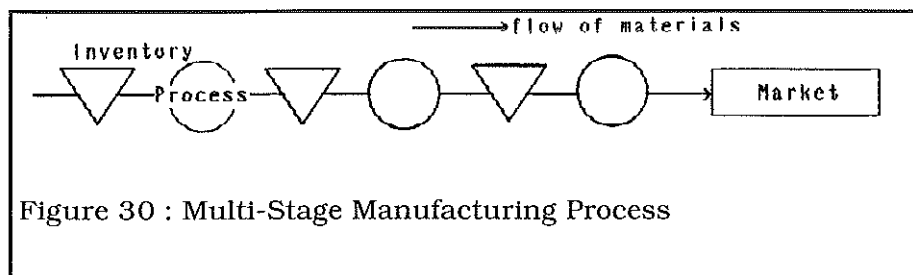


Figure 30 on page 80 shows a schematic of a multi-stage manufacturing process where the sub-processes are shown as circles and the inter-process inventory as triangles.

<sup>12</sup> Osamu Kimura; General Manager, Transportation Administration Office, Toyota Motor Corporation

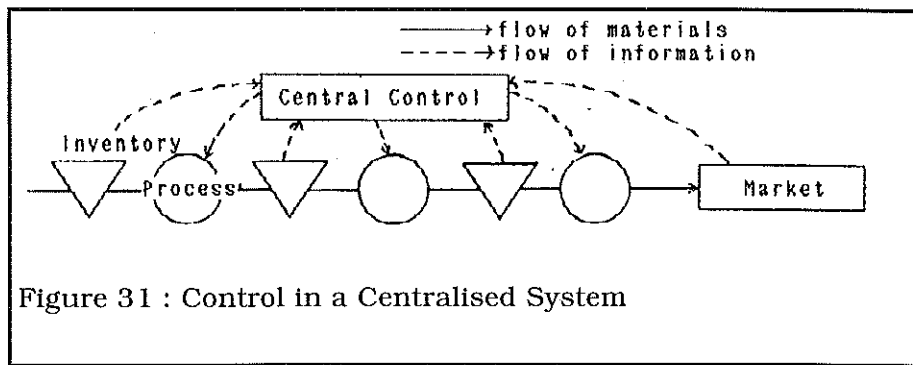
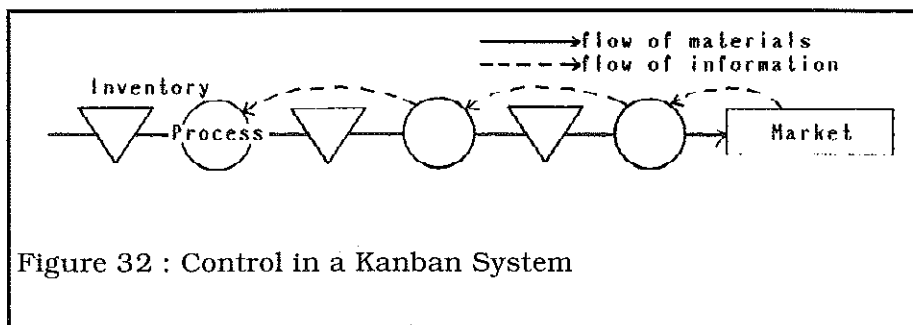


Figure 31 on page 81 shows the flow of control in such a plant under a centralised system, whether computerised or not.

Figure 32 on page 81 shows the corresponding flow in a plant using Kanban control. (Yoshikawa & Burbidge 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 & Burbidge, 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.”*



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

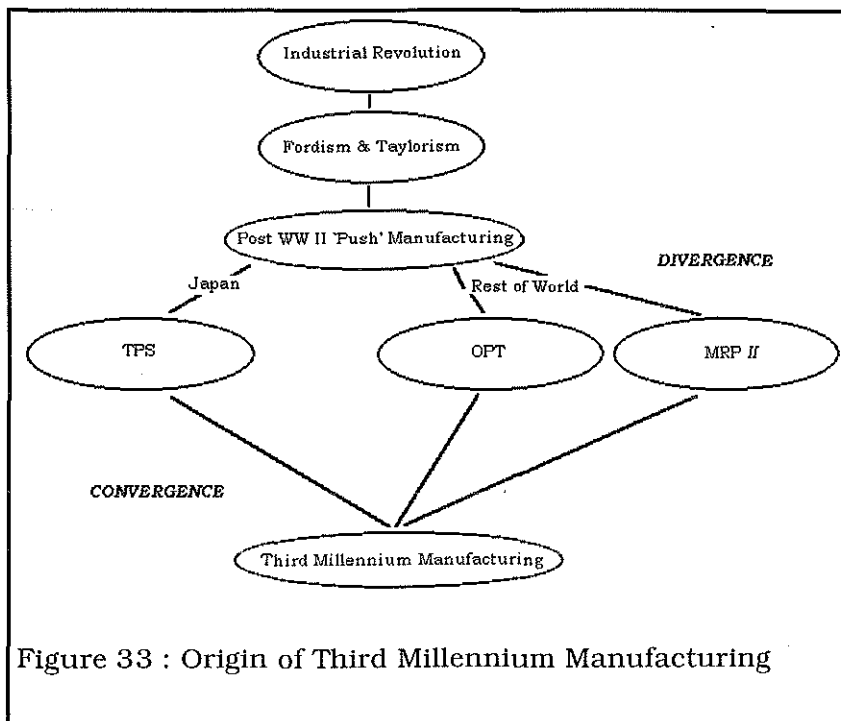


Figure 33 : Origin of Third Millennium Manufacturing

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.

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## 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)

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## 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)

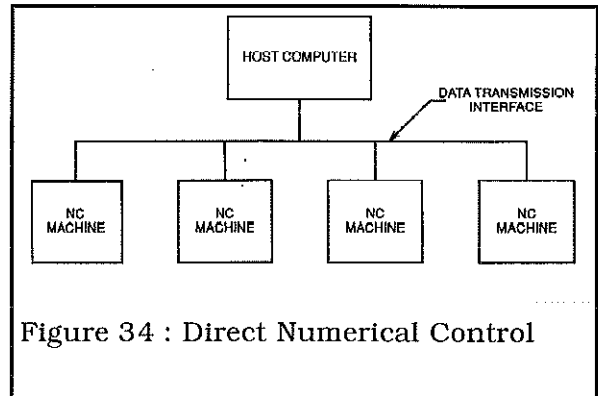


Figure 34 : Direct Numerical Control

### 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)*

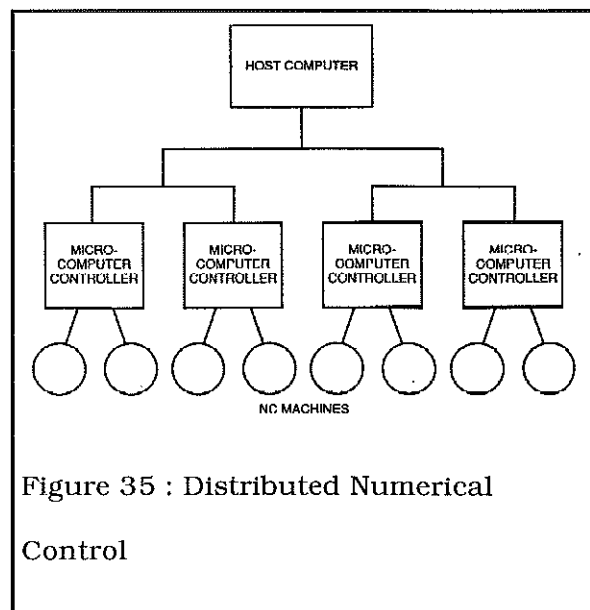
Numerical control development began with the United States Air Force and the early aerospace industry during the 1940s and a contract was awarded to the Massachusetts Institute of Technology (MIT) who successfully demonstrated 3-axis motion control on a milling machine in March 1952. MIT went on to develop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



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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)

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## 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<sup>13</sup> 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 –*

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<sup>13</sup> The emphasis is mine - kwd

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*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:



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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)

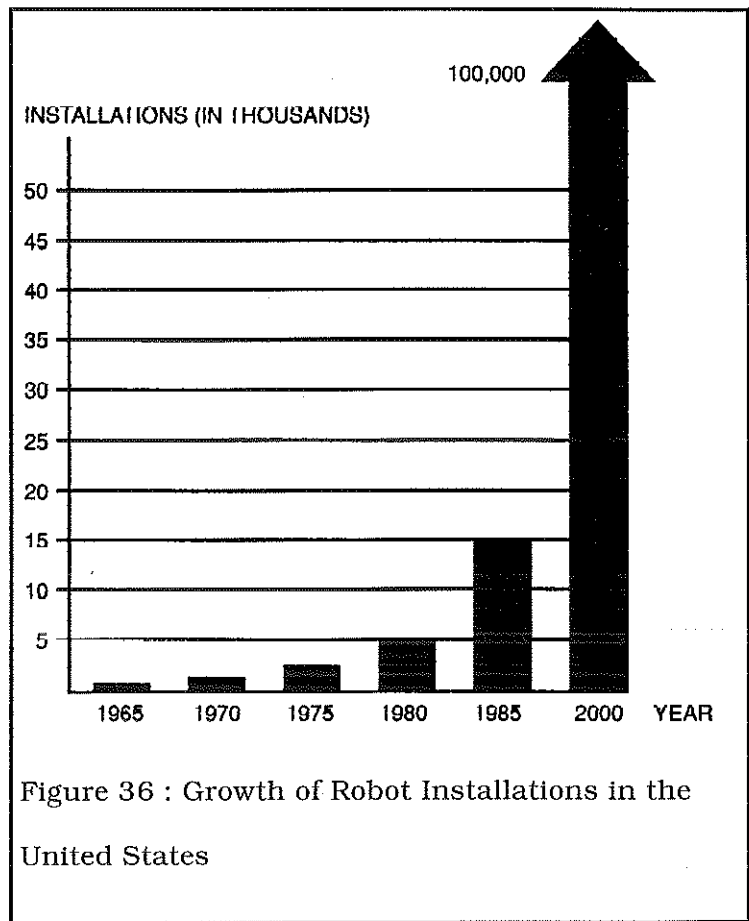


Figure 36 : Growth of Robot Installations in the United States

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

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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.

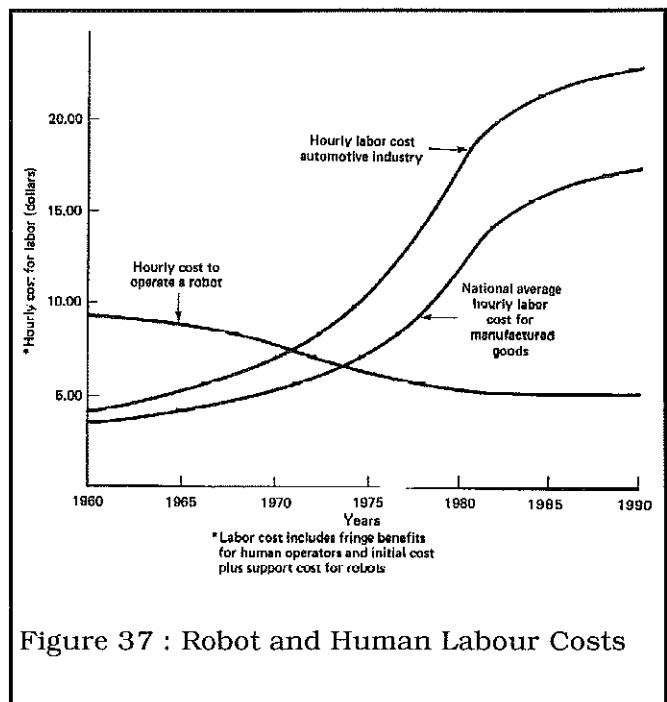


Figure 37 : Robot and Human Labour Costs

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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

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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)

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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)

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#### 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

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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

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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<sup>14</sup> 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*

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<sup>14</sup> (US) National Institute of Standards and Technology



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*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."*

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*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

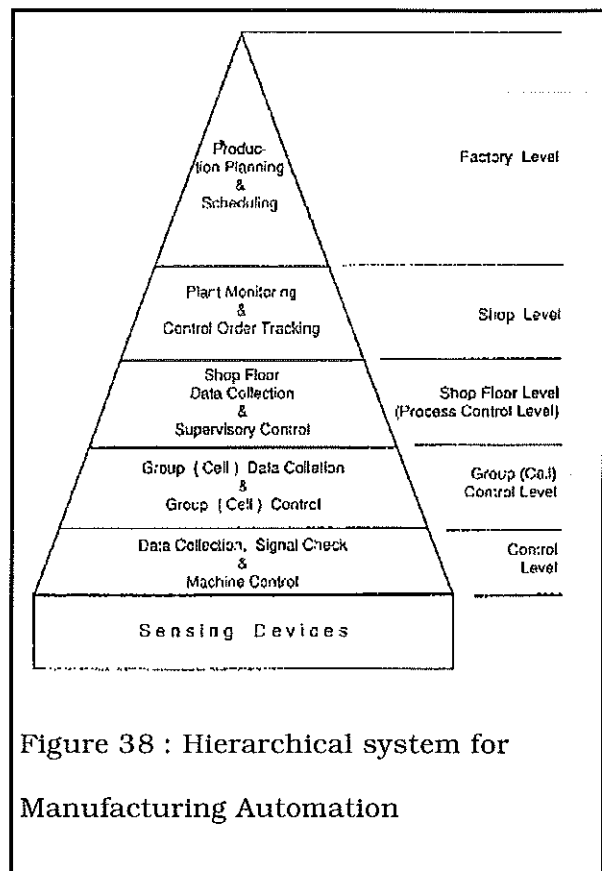
- Software-Intensive Systems Engineering
- Emerging Software Technologies
- Distributed Systems and Database Technology
- Human Comfort and Security
- Software Best Practice.

## 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.

*"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*



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*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.

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- 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

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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*

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*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*

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*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)*



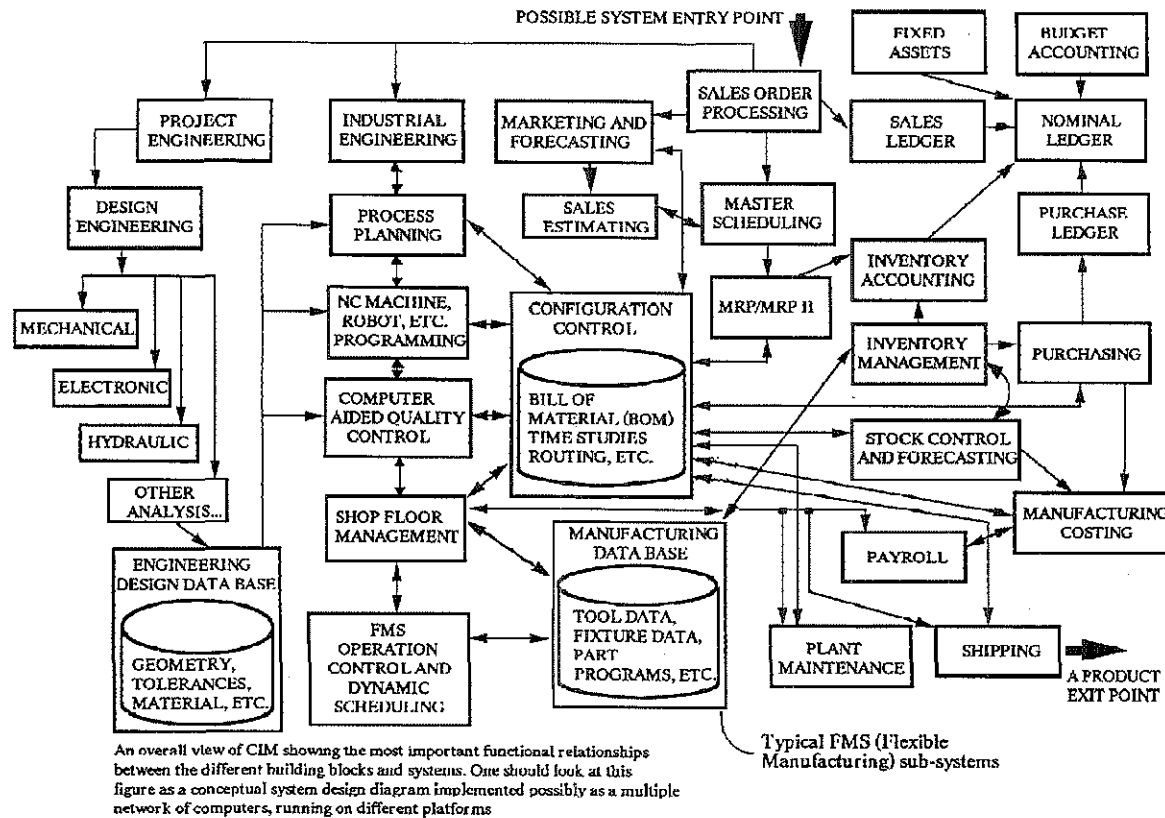


Figure 39 : System Integration in Manufacturing Computer Systems

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## 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.

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### 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. Real-Time Databases: 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. Historical Databases: 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

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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)

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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),

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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.



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### 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)

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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
Communications	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<sup>15</sup>

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

<sup>15</sup> 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](http://www.informatik.uni-oldenburg.DE/~bartelt/sap/sap-faq.html#sap-ag-corporation.what-is-sap))

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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



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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)

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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.*

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*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	<ol style="list-style-type: none"> <li>1. IBM 386/12 PC or compatible with 640K of memory. If expanded memory is available, BusinessWorks for DOS will take advantage of it.</li> <li>2. MB disk drive</li> <li>3. Hard disk drive with 15 MB free disk space</li> <li>4. MS-DOS® 3.3 or higher</li> <li>5. Monochrome grey scale or colour monitor (with a CGA, EGA, or VGA video card)</li> <li>6. 80-column printer or laser printer</li> <li>7. BusinessWorks System Manager</li> </ol>
Network Support	<ol style="list-style-type: none"> <li>1. Novell 3.11 or higher</li> <li>2. LANtastic 4.0 or higher</li> </ol>

BusinessWorks System Details (cont.)	
BusinessWorks 11.0 for Windows	
System Requirements	<p>All requirements are the same as for DOS with the following exceptions:</p> <ol style="list-style-type: none"> <li>1. IBM 386/12 PC or compatible with 640K of memory (486SX25 recommended)</li> <li>2. MB memory (8 MB recommended)</li> <li>3. Hard disk with 25 MB free disk space</li> <li>4. Microsoft Windows® version 3.1, 3.11 or Windows 95</li> <li>5. Colour VGA monitor or better</li> <li>6. Mouse or pointing device is highly recommended</li> </ol>
Network Support	<ol style="list-style-type: none"> <li>1. Novell 3.11 or higher</li> <li>2. LANtastic 5.0 or higher (Windows 3.1 or higher)</li> <li>3. LANtastic for Windows 95</li> <li>4. Window for Workgroups 3.11 or higher</li> <li>5. Windows NT (Version 11.0 only)</li> </ol>

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.

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Intellution claim to have more 32-bit installations than 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, 1996)

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## 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



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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.

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### 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 [now] have application in the Australian industrial context*'. This research, however, has raised the further question '*Is it necessary?*'

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## 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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## 7. BIBLIOGRAPHY

- 20/20 Software (1996) BusinessWorks Accounting Software. [on-line] Available : [http:// www. 20-20. com/ bw/ bw.htm](http://www.20-20.com/bw/bw.htm)
- Adlemo, A., Andreasson, S-A., Fabian, M., Gullander, P., Lennartsson, B. (1995). Towards a Truly Flexible Manufacturing System. Control Engineering Practice 3 (4), 545-554
- Akkihebbal, L. Ananda, Srinivasan, B. (eds) (1990) Distributed Computing Systems: concepts and structure. Los Alamitos, CA (USA): IEEE Computer Society Press
- ANSI-ACS Z-1 Committee (1995) ANSI-ASC Z-1 Committee on Quality Assurance Answers the Most Frequently Asked Questions About the ISO 9000 [ANSI/ASC-Q9000] Series. [on line] Available : [http:// www.asqc.org/ progserv/iso.html](http://www.asqc.org/progserv/iso.html)
- Appleby, David W Jr. (1994, Jul) PLC and DCS: a culture shock? Not Really. Process and Control Engineering 47 (7), 36-40
- Asaka, Tetsuichi., Ozeki, Kazuo (1990) Handbook of Quality Tools : The Japanese Approach. Norwalk, Connecticut (USA): Productivity Press
- Australian Science and Technology Council (1982) Robots. Canberra (ACT): Australian Government Publishing Service
- Batchelor, Ray. (1994) Henry Ford: Mass Production, Modernism and Design. New York, NY (USA): Manchester University Press
- Beauregard, Michael R., Mikulak, Raymond J., Olson, Barbara A. (1992) A Practical Guide to Statistical Quality Improvement. New York, NY (USA): Van Nostrand Reinhold
- Bernold, Thomas, Guttropf, Walter. (eds) (1988) Computer Integrated Manufacturing: Communication/Standardisation/Interfaces. Amsterdam (Netherlands) : Elsevier Science Publishers B.V.
- Bignell, Victor, Dooner, Mike, Hughes, John, Pym, Chris, Stone, Shella (eds), (1985) Manufacturing Systems: Context, Applications and Techniques. Oxford (UK): Basil Blackwell Ltd
- Bollinger, John. G. (1988) Computer Control of Machines and Processes. Reading MS (USA): Addison Wesley
- Buffa, Elwood Spencer. (1977) Modern Production Management: Managing the Operations Function. New York, NY (USA): John Wiley and Sons, Inc
- Capezio, Peter, Morehouse, Debra (1993) Taking the Mystery out of TQM: a Practical Guide to Total Quality Management. Hawthorne, NJ: Career Press

- 
- Cassidy, Michael P., Sharma, Satya P. (February 23-27, 1992) 1990s Revolution in Power Systems Management. APEC'92: 7th Annual Applied Power Electronics Conference and Exposition (Cat. N<sup>o</sup> 92CH3089-0
- Chance, Curtis. (1994, Oct) Special Report: Distributed Process Control. Chilton's I&CS 67 (10), 28-34
- Collins, Robert P. (1993, Oct) The Future is Distributed Control. Production 105 (10) 38-39
- Deming, William Edwards. (1960) Out of the Crisis. New York, USA: Wiley
- Digital Equipment Corporation. (1995) BASEstar Open Client Version 2.0. [on-line] Available : [http:// ftp. digital. com/ pub/ DEC/ DECinfo/ SPD/ 47.80.02.txt](http://ftp.digital.com/pub/DEC/DECinfo/SPD/47.80.02.txt)
- Doyle, John C., Morari, Manfred, Murray, Richard M. (1995) Process Control and Design. [on line] Available [http:// www. che. caltech. edu/ research/ process.html](http://www.che.caltech.edu/research/process.html)
- Dyck, Harold, Varzandeh, Jay, McDonnell, Jack. (October 27-31, 1991) Quality Impacts on JIT Performance Measures: A Factory Simulation. Technology Management - The New International Language (Cat N<sup>o</sup> 91CH3048-6)
- EMPaC R/T Industrial PC Chassis (1995) [on-line] Available: <http://www.empac.com/pcprod>
- Encarnacao, J., Schlechtendahl, E. G. (1983) Computer Aided Design: Fundamentals and System Architectures. Berlin (DE): Springer-Verlag
- European Commission. (1996) Industrial RTD Projects: Guide for Proposers. [on line] Available: [Http:// indis. msu. ru/ ftp/ Cordis/ esprit4\\_industrial\\_projects/ index.html](Http://indis.msu.ru/ftp/Cordis/esprit4_industrial_projects/index.html)
- Ford, Henry. (1991) Ford on Management, Harnessing the American Spirit. Oxford (UK): Basil Blackwell Ltd
- Gergeleit, M, Kaiser, J, Streich, H. (1995) DIRECT: Towards a Distributed Object-Oriented Real-Time Control System. [on-line] Available [http:// borneo. gmd. de/ RS/ Papers/ direct/ direct.html](http://borneo.gmd.de/RS/Papers/direct/direct.html)
- Gibson, P., Greenhalgh, G., Kerr, R. (1995) Manufacturing Management. London, (UK): Chapman and Hall
- Goetsch, David L. (1990) Advanced Manufacturing Technology. Albany, NY (USA): Delmar Publishers Inc.
- Goldratt, Elyahu M., Fox, Robert E. (1986) The Race. New York, NY (USA): North River Press
- Graham, Ian R. (1988) 'Just-in-Time' Management of Manufacturing. Oxford (UK): Technical Communications and Elsevier Advanced Technology Productions
- Groover, Mikell, P. (1987) Automation, Production Systems and Computer Integrated Manufacturing. Englewood Cliffs, NJ (USA): Prentice-Hall, Inc.
-

- 
- Hernandez, Arnaldo. (1993) Just-in-Time Quality. Englewood Cliffs, NJ (USA): PTR Prentice Hall
- Hill, Bob. (1993, Nov) MESs on the Road to Total Quality in the Process Industries. Chilton's I&CS 66(11), 62-69
- Hochlehnert, Bernhard., Magura, Stephan (eds) (1996) SAPInfo. [on-line] Available : [http:// www. sap-ag. de/ r2/ r2\\_sapinfo\\_e. htm](http://www.sap-ag.de/r2/r2_sapinfo_e.htm)
- Hofstede, Geert. (1984, Jan) Cultural Dimensions in Management and Planning. Asia-Pacific Journal of Management, 1 (2) 81-99
- Horngren, Charles T. (1982) Cost Accounting. Englewood Cliffs, NJ (USA): Prentice-Hall Inc.
- Hutchins, David. (1988) Just In Time. Aldershot, Hants. (UK): Gower Technical Press Ltd.
- Imai, Masaaki. (1986) Kaizen: The Key to Japan's Competitive Success. New York, NY (USA): McGraw-Hill Publishing Company
- Intellution Inc. (1996) The #1 Automation Software for Windows 95 and Windows NT. [on-line] Available : [http:// intellution. com/ mmi32bit. html](http://intellution.com/mmi32bit.html)
- International Business Machines (IBM). (1995) General Overview of Factory Operations Executive. [on-line] Available : [http:// wwprodsoln. bocaraton. ibm. com/ soft/ factops/whatsf.htm](http://wwprodsoln.bocaraton.ibm.com/soft/factops/whatsf.htm)
- International Business Machines (IBM). (1995 (a)) Introducing Factory Operations Executive. [on-line] Available : [http:// wwprodsoln. bocaraton. ibm. com/ soft/ factops/ fox1mst.htm #Section\\_2.1](http://wwprodsoln.bocaraton.ibm.com/soft/factops/fox1mst.htm#Section_2.1)
- International Business Machines (IBM) (1996) IBM Announces New Industrial Computers. [on-line] Available : [http:// www. industry. net/ c/ newsstory/ 199625937157CPM/](http://www.industry.net/c/newsstory/199625937157CPM/)
- Introduction to Theory of Constraints (TOC) (1996) [on line] Available : [http:// www.kdcol.com/ tanstaaf/ system/ TOC.html](http://www.kdcol.com/tanstaaf/system/TOC.html)
- Ishikawa, Kaoru, Lu, David J. (1985) What is Total Quality Control? The Japanese Way. Englewood Cliffs, NJ, (USA): Prentice-Hall Inc.
- Japan Management Association (eds). (1985) Kanban: Just-In-Time at Toyota. Stamford, CT (USA): Productivity Press
- Jasany, Leslie C. (1992, Jul) Controls and Systems 39 (7), 12-15
- Johnson, H. Thomas, Kaplan, Robert S. (1991) Relevance Lost: The Rise and Fall of Management Accounting. Boston, MA (USA): Harvard Business School Press
- Kerr, Roger. (1991) Knowledge-Based Manufacturing Management: Applications of Artificial Intelligence to the Effective Management of Manufacturing Companies. Sydney, NSW: Addison-Wesley Publishing Company
-

- 
- Kim, K. H. (14-16 September, 1988) Designing Fault Tolerance Capabilities into Real-Time Distributed Computer Systems. Workshop on the Future Trends of Distributed Computing Systems in the 1990s
- Kirkwood, L., Ryan, C., Falt, J., Stanley, T. (1989) Accounting: An Introductory Perspective. Melbourne, VIC: Longman Cheshire Pty Ltd
- Koenig, Daniel T. (1990) Computer Integrated Manufacturing. New York, NY (USA): Hemisphere Publishing Corporation
- Kraft, Chris. (1992) Dynamic Kanban Semiconductor Inventory Management System. IEEE/SEMI Advanced Semiconductor Manufacturing Conference and Workshop (ASMC'92) (Cat. N<sup>o</sup> 92CH3182-3)
- Linnegar, Gary J. (1988) An Investigation into the Management of Change in Cost Accounting System Requirements During the Transition from Traditional Manufacturing to Just In Time Concepts. Mississippi (US): Mississippi State University
- Luciano, Vincent P. (1993, Sep) Display Terminals As You Like Them. IEEE Spectrum 30 (9) 35-37
- Marcam Corporation (1996) Welcome to Marcam Corporation. [on-line] Available : [http:// www. marcam. com/ mapics/ main.html](http://www.marcam.com/mapics/main.html)
- Mathews, M. R., Perera, M. H. B., Ng, L. W., Chua, F. C. (1991) Accounting Theory and Development. South Melbourne, VIC: Thomas Nelson Australia
- McDonough, Brian. (1995) Considerations for Manufacturing Execution System Implementation. [on-line] Available: [http:// www. smartdocs. com/ ~bmcd/ accufacts9000/ art3.html](http://www.smartdocs.com/~bmcd/accufacts9000/art3.html)
- Meredith, Paul H., Ristroph, John H., Lee, Jim. (October 27-31, 1991) Implementing JIT: The Dimensions of Culture, Management, and Human Resources, Technology Management - The New International Language
- Messina, William S. (1987) Statistical Quality Control for Manufacturing Managers. New York, NY (USA): John Wiley and Sons, Inc.
- Mirams, Mike, McElheron, Paul (1994) The Quality Tool Kit : Gaining and Maintaining BS 5750 / London, ISO 9000. London (UK): Pitman Publishing
- Mitchell, Geoffrey B., Granof, Michael H. (1981) Principles of Accounting. Sydney, NSW: Prentice-Hall of Australia
- Moser, Kenneth S. (1996) Theory of Constraints. [on line] Available : [http:// www.industry.net/ c/ organpro/ apics/ theory-c](http://www.industry.net/c/organpro/apics/theory-c)
- Murrill, P.W. (1988) Application Concepts of Process Control. North Carolina (US): Instrument Society of America
- National Institute of Standards and Technology (USA), (1994) NIST. [on line] Available : [http:// www. hpcc. gov/ blue94/ section.4.7.html](http://www.hpcc.gov/blue94/section.4.7.html)
-

- 
- Orlicky, Joseph. (1975) Material Requirements Planning: The New Way of Life in Production and Inventory Management. New York, NY (USA): McGraw-Hill, Inc.
- Popovic, Dobrivoje, Bhatkar, Vijay P. (1990) Distributed Computer Control for Industrial Automation. New York, NY (USA): Marcel Dekker Inc.
- Portera, M., Cole, David G., Miyagawa, Ichiro. (1991) Taiichi Ohno. [on line]: Available [http:// bama. elecom. nitech. ac. jp /honor.html](http://bama.elecom.nitech.ac.jp/honor.html)
- Prett, D. M., Garcia, C. E. (1988) Fundamental Process Control. London (UK): Butterworths
- Ranky, Paul G. (1986) Computer Integrated Manufacturing. London (UK): Prentice Hall International, UK, Ltd
- Ranky, Paul G. (1990) Flexible Manufacturing Cells and Systems in CIM. Guildford, Surrey (UK): CIMWare Limited
- Rehg, James A. (1992) Introduction to Robotics in CIM Systems. Englewood Cliffs, NJ (USA): Prentice-Hall, Inc.
- Robinson, Alan (ed.). (1991) Continuous Improvement in Operations: A Systematic Approach to Waste Reduction. Cambridge, MT (USA): Productivity Press
- Rodd, Michael G., Deravi, Farzin (1989) Communications Systems for Industrial Automation. London (UK): Prentice Hall
- Rooney, Joe, Steadman, Philip. (1987) Principles of Computer-aided Design. London (UK): Pitman Publishing
- Royer, Ted M. (1994, Jun) Run Your Factory From Your Desktop. Manufacturing Systems 12 (6) 38-40
- Sartori, Luca G. (1988) Manufacturing Information Systems. Wokingham (UK): Addison-Wesley Publishers Ltd
- Shingo, Shigeo. (1985) A Revolution in Manufacturing: The SMED System. Norwalk, CT (USA): Productivity Press
- Shingo, Shigeo. (1986) Zero Quality Control: Source Inspection and the Poka-Yoke System. Norwalk, CT (USA): Productivity Press
- Shingo, Shigeo. (1988) Non-Stock production: The Shingo System for Continuous Improvement. Norwalk, CT (USA): Productivity Press
- Sillince, J. A. A., Sykes, G. M. H. (1993) Integrating MRP II and JIT: A Management Rather Than a Technical Challenge. International Journal of Operations and Production Management 13 (4) 18-31
- Silva, John (February 23-27, 1992) Advanced Manufacturing Technologies. APEC'92: 7th Annual Applied Power Electronics Conference and Exposition (Cat. N<sup>o</sup> 92CH3089-0)
-



- 
- Simons, B., Spector, A. (eds) (1990) Fault-Tolerant Distributed Computing. Berlin (DE): Springer-Verlag
- Sloman, Morris, Kramer, Jeff. (1987) Distributed Systems and Computer Networks. Englewood Cliffs, NJ (USA): Prentice-Hall Inc.
- Smith, Jeffrey J. (1994) Theory of Constraints and MRP II: From Theory To Results. [on line] Available: [http:// www.lm.com/ ~dshu/ toc/ JJSmith.html](http://www.lm.com/~dshu/toc/JJSmith.html)
- Storey, J (ed.). (1994) New Wave Manufacturing Strategies: Organizational and Human Resource Management Dimensions. London (UK): Paul Chapman Publishing
- Talavage, Joseph, Hannam, Roger G. (1988) Flexible Manufacturing Systems in Practice: Applications, Design, and Simulation. New York, NY (USA): Marcel Dekker Inc.
- Tanenbaum, Andrew S. (1989) Computer Networks (2nd ed.). Englewood Cliffs, NJ (USA): Prentice-Hall, Inc.
- Tannock, J. D. T., (1992) Automating Quality Systems. London (UK): Chapman and Hall
- Taylor, Frederick Winslow. (1967) The Principles of Scientific Management. New York, NY (USA): W. W. Norton & Company Inc
- Taylor, Frederick Winslow. (1993) Principles of Scientific and Shop Management. London (UK): Routledge/Thoemmes Press
- The JUSE Problem Solving Research Group (eds). (1991) TQC Solutions: vol. 1, The 14-step Process, Application. Norwalk, CT (USA): Productivity Press, Inc.
- The JUSE Problem Solving Research Group (eds). (1991) TQC Solutions: vol. 2, The 14-step Process, Application. Norwalk, CT (USA): Productivity Press, Inc.
- Time-Life Books (eds). (1986) Robotics. Turnhout, Belgium: Time-Life Books
- Tschammer, V., Eckert, K. P., Henkel, L. (14-16 September, 1988) Concepts for Open Systems Cooperation in Distributed CIM-Structures. Workshop on the Future Trends of Distributed Computing Systems in the 1990s
- Umble, Michael M., Srikanth, M. L. (1990) Synchronous Manufacturing: Principles for World Class Excellence. Cincinnati, OH (USA): South-Western Publishing Co.
- Venner, K. E. (October 27-31, 1991) Manufacturing Strategies: Implementing "Sequencing". Technology Management: The New International Language (Cat N° 91CH3048-6)
- Wenstrup, Robert A., Appleby, David W. Jr. (1995) MES Meets Process Control. [on-line] Available : [http:// tinman. mke. ab. com/ mem/ prodserv/ solutions/ index.html](http://tinman.mke.ab.com/mem/prodserv/solutions/index.html)
- Wentworth, C. E. (1993, Nov) Guidelines Useful for Incorporating DCS in Existing Process Plant. Oil and Gas Journal 91 (48) 74-78

- Wetherill, G. Barrie, Brown, Don W. (1991) Statistical Process Control: Theory and Practice. London (UK): London (UK)
- Wonderware Corporation. (1996) Wonderware InTouch 5.6 Product Data Sheet. [online] Available : <http://www.wonderware.com/products/pdk.html>
- WG15 of ISO TC 176 on Quality Management and Quality Assurance. (1995, Nov) The Quality Management Principles. [online] Available: <http://www.wineasy.se/qmp/about.html>
- Yoshikawa, H., Burbidge, J. L. (eds). (1987) New Technologies for Production Systems. Amsterdam (ND): Elsevier Science Publishers B. V.

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## 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.	Inflo	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 Plng. & 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 Systems Inc.	SBS Manufacturing 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://lonhrtpub.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													
Product	Vendor	Operating Systems				RAM Required	Application					Pricing	
		Windows 95	Windows 3.x	DOS	Objectives Trade-off (1)		Analysis of uncertainty (2)	Probabilistic Dependencies (3)	Risk Aversion	Sequential decision making	All applications-one model(4)	Commercial	Educational
@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
Criterion 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

Product	Vendor	Operating Systems				RAM Required	Application					Pricing	
		Windows 95	Windows 3.x	DOS	Objectives Trade-off (1)		Analysis of uncertainty (2)	Probabilistic Dependencies (3)	Risk Aversion	Sequential decision making	All applications-one model(4)	Commercial	Educational
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/Sup ertree	Strategic Decisions Group - Decision Systems	y	y	y	8 MB	y	y	y	y	y	y	\$1500	\$75

Product	Vendor	Operating Systems			RAM Required	Application						Pricing	
		Windows 95	Windows 3.x	DOS		Objectives Trade-off (1)	Analysis of uncertainty (2)	Probabilistic Dependencies (3)	Risk Aversion	Sequential decision making	All applications-one model(4)	Commercial	Educational
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	The Development Center Inc.	Hewlett-Packard Korea
Adaptable Business Systems	Draves & Barke Systems, Inc.	HK Systems
Advanced Industrial Systems	Effective Management Systems, Inc.	i2 Technologies, Inc.
Allen Bradley Company	Expandable Software, Inc.	Indel Software Corporation
Applied Statistics, Inc.	Expert Choice, Inc.	Industrial Computer Corp.
Automated Technology Associates	FACT, Inc.	Industrial Cybernetics
Automation Resources Corp.	FASTech Integration, Inc.	InfoPower International, Inc.
Behera & Associates	FloStor Engineering, Inc.	Intec Controls
BMS, Inc.	Focused Approach, Inc.	JBA International USA
Camstar Systems, Inc.	FORTUNE Personnel of Sarasota	Lexel Corporation
CIM Vision International	GE Fanuc Automation N.A. Inc.	Lilly Software Associates, Inc.
CNA	The Genesis Group, Inc.	Macatawa Computer Services, Inc.
Consilium, Inc.	Grant Thornton LLP	Made2Manage Systems, Inc.
Crowe Chizek	Greco Systems	MAHAR Management Solutions
Cybernologic Inc.		Managing Automation Software Guides
Datalogix		



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

## 11.2 MRP/MRP II Software

Available : <http://ltonhrtpub.com/apics/apics-2-96/BG/BGPLmrp.html>

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

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Business Forecast Systems, Inc.	Digital Press	Grant Thornton LLP
Business Systems Consultants, Inc.	Draves & Barke Systems, Inc.	Greco Systems
CAMM, Inc.	Effective Management Systems, Inc.	GRMS, Inc.
Carolina Cipher	Enhanced Systems & Services	GWBA, Inc.
CFS, Inc	ENTEK Inc.	Hal Mather Inc.
CIM Bar Code Technology, Inc.	Enterprise Planning Systems Corp.	HarrisData
CIMCASE International Corp.	Escom Inc.	Holland & Davis, Inc.
CIMPAC Inc.	ESI/Technologies	Hunter Consultants
Cincom Systems, Inc.	Expandable Software, Inc.	i2 Technologies, Inc.
CMI-Competitive Solutions, Inc.	Experience In Software	Industrial Data Technologies
CMS Manufacturing Systems	Expert Buying Systems, Inc.	Industrial Technological Associates, Inc.
CNA	Expert Choice, Inc.	InfoPower International, Inc.
Command Line Corp.	EXSYS, Inc.	Integrated Software Design
ComMIT Systems Inc.	Facilities Planning Services	Intelligent Instrumentation
Computer Associates Int'l Inc.	FACT, Inc.	Intelligent Manufacturing Systems, Inc.
Computer Source Inc.	Falcon Software	Intentia International
Crowe Chizek	FastMAN Software Inc.	Inter-Data Systems, Inc.
CTS	Flynn Associates	INTERACTIVE Group, Inc.
Customized Transportation, Inc.	Foreman Solutions	International Purchasing Service
Cybernostic Inc.	Fortune Personnel Consultants of Chapel Hill, Inc.	Intrix Systems Group
Data General Corp.	Fortune Personnel Consultants of Loudoun	Intuitive Manufacturing Systems Inc.
Data Interface	FORTUNE Personnel Consultants of New York City Inc.	IQR International
Data Solutions, Inc.	Fourth Shift Corporation	Edwards & Company
Data Technical Research, Inc.	Friedman Associates	Jack Gips, Inc.
Datalogix	Genesis (J.D. Edwards)	JBA International USA
DataModes, Inc.	The Genesis Group, Inc.	JOBSCOPE
Datasul Inc.	Genzlinger Associates, Inc.	Kingwood Systems, Inc.
DataWorks Corporation	Graha Mitra Solusi	Wechsler, Ltd.
DCD Corporation		Lexel Corporation
Decision Consultants, Inc.		Lilly Software Associates, Inc.
Decision Servcom, Inc.		
The Development Center Inc.		

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

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

## 11.3 Planning & Scheduling

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

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

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

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

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

## 11.4 Product Data Management

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

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

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

## 11.5 Production Control

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

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



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

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

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

## 11.6 Purchasing

<http://lionhrtpub.com/apics/apics-2-96/BG/BGPLpurch.html>

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

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

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INTERACTIVE Group, Inc.	Marcam Corporation	Productivity Concepts Inc.
International Purchasing Service	Material Management Consultants, LLC	Productivity Press Inc.
Intrix Systems Group	McMillan Associates, Inc.	Professionals for Technology, Inc. (Pro-Tech, Inc.)
Intuitive Manufacturing Systems Inc.	MDIS - Chess	ProfitKey International, Inc.
IQR International	Micro Perfect Corporation	PT Publications, Inc.
Irwin Professional Publishing	Micro-MRP, Inc.	QAD Inc.
J.D. Edwards & Company	Microcomputer Specialists, Inc.	Quantel Technologies, Inc.
Jack Gips, Inc.	MicroWest Software Systems, Inc.	QED Information Systems
JBA International USA	MPA	Qube Connections, Inc.
JOBSCOPE	National Association of Purchasing Mgmt. (NAPM)	R. Michael Donovan, Inc.
Josalli Inc.	New Dimension Systems	R.J. Roman & Associates
Kenhar Products Inc.	North American Business Services	Raytheon Engineers & Constructors
Kingwood Systems, Inc.	North Highland Company	Realogic, Inc.
KnowledgeWare Systems Group	NRS Consulting	Relevant Business Systems, Inc.
Least Cost Formulations, Ltd.	OHM Systems, Inc.	Repacorp Label Products
Lilly Software Associates, Inc.	OnBase Technology Inc.	Rinehart Engineering
Lexel Corporation	Online Applications, Inc.	ROI Systems Inc.
Luman Consultants	Online Software Labs	Ross Systems
Macola Software	Oracle Corporation	Royal 4 Systems, Inc.
Made2Manage Systems, Inc.	Ormandy, Inc.	SAP
MAHAR Management Solutions	Partners For Excellence	SATCOM
MAN-TRAK	PBBS - Paper Buyers Bulletin Service	Schlueter Business Systems (SBS) Inc.
Managing Automation Software Guides	PEBBS - Print Equipment Buyers Bulletin Service	Scruggs & Associates, Inc.
Manufacturers' Services Ltd.	PeopleSoft	SCS, Inc.
Manufacturing Action Group	Pilot Systems Inc.	Sextant Corporation
Manufacturing And Computer Systems	Power Cerv	Software 2000, Inc.
Manufacturing Control Systems Inc.	Plexus Systems	Software AG of North America
Manufacturing Solutions & Systems	Printronic	Software PM, Inc.
	PRO:MAN Group	Software Solutions, Inc.

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

## 11.7 Quality Control

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

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

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

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## 11.8 Relational Database Software

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

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



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

## 11.9 Shop Floor Control

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

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

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

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

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

## 11.10 Simulation

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

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

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

## 11.11 Supply Chain Management

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

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

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

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

## 11.12 Training

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

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

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

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

## 11.13 Transportation/Distribution

<http://lionhrtpub.com/apics/apics-2-96/BG/BGPLtrans.html>

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

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

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Material Management Consultants, LLC	Productivity Press Inc.	The Summit Group
McMillan Associates, Inc.	Professionals for Technology, Inc. (Pro-Tech, Inc.)	Superior Handling Equipment Inc.
MDIS - Chess	ProMeta Consulting	Symix Computer Systems, Inc.
Micro Analysis & Design Simulation Software, Inc.	PROMODEL Corporation	SyntegraTech, Inc.
Micro Perfect Corporation	QAD Inc.	Sysmark Information Systems, Inc.
MicroAnalytics	QED Information Systems	Systems Modeling Corporation
Mt. Valley Farms & Lumber Products Inc.	Quality Software Systems Inc. (QSSI)	T.L. Ashford & Associates
Munck Automation Technology	The Raymond Corp.	Tangible Vision Inc.
National Technology Services	Recognition Equipment Brokers, Inc.	Tech Conveyor, Inc.
New Dimension Systems	Red Pepper Software Company	TechnoLogix Decision Sciences Inc.
Norel Systems, Inc.	Repacorp Label Products	Teklogix
North American Business Services	Resource Optimization Inc.	Telxon Corporation
North Highland Company	REYcomp Incorporated	Tompkins Associates
NRS Consulting	RF Link Systems	Trigesta Americas, Inc.
Numetrix Ltd.	Roberts Express, Inc.	Trillium Software, Inc.
OHM Systems, Inc.	ROI Systems Inc.	United Barcode Industries, Inc.
Oliver Wight Companies	ROLS	Verbex Voice Systems Inc.
Online Applications, Inc.	Ross Systems	W5 Associates, Inc.
Online Software Labs	Royal 4 Systems, Inc.	Wolverine Software Corporation
Oracle Corporation	SAITECH, Inc.	
Ormandy, Inc.	SAP	
P-E International	SAS Institute Inc.	
Package Research Laboratory	SATCOM	
Paragon Decision Technology B.V.	ScanData Systems, Inc.	
Partners For Excellence	Scruggs & Associates, Inc.	
The Peak Technologies Group, Inc.	Sedlak Management Consultants, Inc.	
Power Cerv	Smurfit Pallet Systems	
Printronic	Software Solutions, Inc.	
	Spalding Software, Inc.	
	SSA	
	SSA Southeast	
	Strandware, Inc.	

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## 11.14 Warehousing Systems

<http://l1onhrtpub.com/apics/apics-2-96/BG/BGPLware.html>

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

The Development Center Inc.	Gateway Data Sciences Corp.	Interlink Technologies, Inc.
Diamond Phoenix	Genesis (J.D. Edwards)	International Technologies & Systems
Draves & Barke Systems, Inc.	Grand Rapids Label Co.	INTERROLL CORP.
Entron Industrial Computers	Grant Thornton LLP	J.D. Edwards & Company
Equipto	GSI Logistics and Distribution	JBA International USA
Eric C. Baum & Associates	Hand Held Products	JEKA USA Services
ESI/Technologies	Haushahn Systems & Engineers	K-RAM Corporation
ESKAY Corporation	The Hayo Consultants	Kardex Systems, Inc.
Exeter Software Ltd.	Helmco Consulting Assoc.	Kearney Systems, Inc.
Expandable Software, Inc.	Hi-Line Storage Systems	King Computer Services, Inc.
Expert Buying Systems, Inc.	HK Systems	KnowledgeWare Systems Group
EXSYS, Inc.	Howard Way & Associates	Kraft Technologies, Inc.
F&H Simulations, Inc.	Hunter Consultants	Lambert Material Handling
Facilities Planning Services	IHE	LDS, Inc.
FACT, Inc.	IKG Industries	Lexington Engineering Associates
FASCOR	Industri-Matematik International	Lowry
FloStor Engineering, Inc.	Industrial Data Technologies	LXE
FoodPro International, Inc.	Industrial Kinetics Inc.	MAN-TRAK
Footlik & Associatesv	Industrial Technological Associates, Inc.	Managing Automation Software Guides
Forté Technology Inc.	InfoPower International, Inc.	Manhattan Associates
Fortune Personnel Consultants of Chapel Hill, Inc.	Information Strategies Inc.	Manufacturers' Services Ltd.
Fortune Personnel Consultants of Loudoun	Infoscan, Inc.	Manufacturing Control Systems Inc.
FORTUNE Personnel Consultants of New York City Inc.	Infrapak, Inc.	Manufacturing Systems Associates, Inc.
Foxware	Integrated Software Design	Marcam Corporation
Fred Fenster Associates	Integrating Data Systems	Marprint, Inc.
Friedman Associates	Intek Integration Technologies	Material Management Consultants, LLC
Frog Navigation Systems, Inc.	Intelligent Manufacturing Systems, Inc.	Mathews Conveyor Division
G/S Data Solutions	Intentia International	McMillan Associates, Inc.
Gardner Denver Machinery Inc.	Interlake Material Handling	Micro Analysis & Design Simulation Software, Inc.

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