Chapter 2

LITERATURE REVIEW

2.1 EVOLUTION OF AGILE MANUFACTURING

In the late 1950s and early 1960s, scholars began to deal specifically with operations management as opposed to industrial engineering or operations research. Writers such as Edward Bowman and Robert Fetter, Elwood S. Buffa noted the commonality of the problems faced by all production systems and emphasized the importance of viewing production operations as a system (Chase *et al.,* 2005). They also stressed the useful application of wasting-line theory, simulation, and linear programming, which are now standard topics in the field. The summary for evolution of agile manufacturing is shown in Figure 2.1.

JIT and TQC

The 1980s saw a revolution in the management philosophies and the technologies by which production is carried out. Just-in-time (JIT) production is the major breakthrough in manufacturing philosophy. Pioneered by the Japanese, JIT is an integrated set of activities designed to achieve high-volume production using minimal inventories of parts that arrive at the workstation exactly when they are needed. The philosophy – coupled with total quality control (TQC), which aggressively seeks to eliminate causes of production defects – is now a cornerstone in many manufacturers' production practices.

Of course, the Japanese were not the first to develop a highly integrated, efficient production system. In 1913 Henry Ford developed an assembly line to make the Model-T automobile. Ford developed a system for making the Model-T that was constrained only by the capabilities of the workforce and existing technology. Quality was a critical prerequisite for Ford: The line could not run steadily at speed without consistently good component. On-time delivery was also critical for Ford; the desire to keep workers and machines busy with materials flowing constantly made scheduling critical. Product, processes, material, logistics, and people were well integrated and balanced in the design and operation of the plant.

Manufacturing Strategy Paradigm

The late 1970s and early 1980 saw the development of the manufacturing strategy paradigm by researchers at the Harvard Business School. This work by Professor William Abernathy, Kim Clark, Robert Hayes, and Steven Wheelwright (built on earlier efforts by Wickham Skinner) emphasized how manufacturing executives could use their factories' capabilities as strategic competitive weapons. Central to their thinking was the notion of factory focus and manufacturing trade-offs. They argued that because a factory cannot excel on all performance measures, its management must devise a focused strategy, creating a focused factory that performs a limited setoff tasks extremely well. This required trade-offs among such performance measures as low cost, high quality, and high flexibility in designing and managing factories. Ford seems to have realizes this about 60 years before the Harvard professors.

Services Quality and Productivity

The great diversity of services industries – ranging from airlines to zoos, with many different types in between – precludes identifying any singles pioneer or developed that has made a major impact in theses areas. However, McDonald's unique approach to quality and productivity has been so successful that in stands as a reference point about how to deliver high-volume standardizes services

Total Quality Management and Quality Certification

Another major development was the focus on total quality management (TQM) in the late 1980s and 1990s. All operations executives are aware of the quality message put forth by the so-called quality – W. Edwards Deming, Joseph M. Jurans, and Philip Crosby. It's interesting that these individuals were students of Shewhart, Dodge, and Roming in the 1930s (sometimes it takes a generation for things to catch on). Helping the quality movement along is the Baldridge National Quality Award, which was started in 1987 under the direction of the National Institute of Standards and Technology. The Baldrige Award recognizes companies each year for outstanding quality management systems.

The ISO 9000 certification standards, created by the International Organization for Standardization, now play a major role in setting quality standards for global manufacturers. Many European companies require that their vendors meet these standards as a condition for obtaining contracts.

Business process reengineering

The need to become lean to remain competitive in the global economic recession in the 1990s pushed companies to seek innovations in the processes by which they run their operations. The flavor of business process reengineering (BPR) is conveyed in the title of Michael Hammer's influential article in Harvard Business Review:" Reengineering Work: Don't Automate, Obliterate." The approach seeks to make revolutionary changes as opposed to evolutionary changes (which are commonly advocated in TQM). It does this by taking a fresh look at what the organization is trying to do in all its business processes, and then eliminate non-value-added steps and computerizing the remaining ones to achieve the desired outcome.

Hammer actually was not the first consultant to advocate eliminating non-value-added steps and reengineering processes. In the early 1900s, Frederick W. Taylor developed principles of scientific management that applied scientific analysis to eliminate wasted effort from manual labor. Around the same time, Frank and Lillian Gilbreth used the new technology of the time, motion pictures, to analyze such operations as bricklaying and medical surgery procedures. Many of the innovations that this husband-and-wife team developed, such as time and motion study, are widely used today.

Supply Chain Management

The Central idea of supply chain management is to apply a total approach to managing the flow of information, materials, and services from raw material suppliers through factories and warehouses to the end customer. Recent trends such as outsourcing and mass customization are forcing companies to find flexible ways to meet customer demand. The focus is on optimizing core activities to maximize the speed of response to changes in customer expectations.

Electronic Commerce

The quick adoption of the Internet and the World Wide Web during the late 1990s was remarkable. The term electronic commerce refers to the use of the internet as an essential element of the business activity. The internet is an outgrowth of a government network called ARPANET, which was crested in 1969 by the Defense Department of the U.S. government. The use of Web Pages, forms, and interactive search engines has changed the way people collect information, shop, and communicate. It has changed the way operations managers coordinate and execute production and distribution functions. This new mode of operations is what we refer to as E-Ops.

Agile Manufacturing

The concept of agile manufacturing was originally introduced in the report entitled "21st Century Manufacturing Enterprise Strategy" and published by the Iacocca Institute of Lehigh University (Nagel *et al.*, 1991) as an option for managing firms in a dynamic world. Since then, it has been adopted by researchers, managers and consultants as the last stage in the evolution of manufacturing models or systems, such as Gunasekaran (1999). There are lots of definitions of agile manufacturing, but the final goals of agile manufacturing are to operate profitably, and sensing and responding effectively to changing demand trends.

Table 2.1 Evolution of Agile Manufacturing (source: Chase *et al*., 2005)

Year	Concept	Tool	Originator
1910s	-Principles of scientific management -Industrial psychology -Moving assembly line -Economic lot size	-Formalized time-study and work-study concepts -Motion study -Activity scheduling chart -EOQ applied to inventory control	-Frederick W. Taylor (U.S.) -Frank and Lillian Gilbreth (U.S.) -Henry Ford and Henry L. Gantt (U.S.) -F. W. Harris (U.S.)
1930s	-Quality control -Hawthorne studies of worker motivation	-Sampling inspection and statistical tables for quality control -Activity sampling for work analysis	-Walter Shewhart, H. F. Dodge, and H. G. Romig (U.S.) -Elton Mayo (U.S.) and L. H. C. Tippett (England)
1940s	-Multidisciplinary team approaches to complex system problems	-Simplex method for linear programming	-Operation research groups (England) and George B. Dantzig (U.S.)
1950s-60s	-Extensive development of operations research tools	-Simulation, waiting-line theory, decision theory, mathematical programming, project scheduling techniques of PERT and CPM	-Researches in U.S. and Western Europe
1970s	-Widespread use of computer in business -Service quality and productivity	-Shop scheduling, inventory control, forecasting, project management, MRP -Mass production in the service sector	-Led by computer manufacturers, in particular, IBM; Joseph Orlicky and Oliver Wight were the major MRP innovators (U.S.) -McDonald's restaurants
1980s	-Manufacturing strategy paradigm -JIT, TQC, and factory automation -Synchronous manufacturing	-Manufacturing as a competitive weapon -Kanban, poka-yokes, CIM, FMS, CAD/CAM, robots, etc. -Bottleneck analysis, OPT, theory of constraints	-Harvard Business School faculty (U.S.) -Tai-Ichi Ohno of Toyota Motors (Japan), W. E. Deming and J. M. Juran (U.S.), and engineering disciplines (U.S., Germany and Japan) -Eliyahu M. Goldratt (Israel)

Table 2.1, continued

1990s	-Total quality management -Business process reengineering -Electronic enterprise -Supply chain management	-Baldrige quality award, ISO 9000, quality function development, value and concurrent engineering, continuous improvement paradigm -Radical change paradigm -Internet, World Wide Web -SAP/R3, client/server software	-National Institute of Standard and Technology, American Society of Quality Control (U.S.), and International Organization for Standardization (Europe) -Michael Hammer and major consulting firms (U.S.) -U.S. government, Netscape Communication Corporation and Microsoft Corporation -SAP (Germany), Oracle (U.S.)
2000s	-E-commerce -Agile manufacturing	-Internet, World Wide Web -Concurrency, re-engineering, total cycle-time management	-Amazon, ebay, America Online, Yahoo! - Iacocca Institute of Lehigh University, Gunasekaran A.

2.2 IMPLICATION OF AGILITY IN MANUFACTURING

Agility, as a concept in manufacturing, was coined by a group of researchers at Iaccoca Institute, Lehigh University, in 1991 to describe the practices observed and considered as important aspects of manufacturing during their investigation (Nagel *et al.,* 1991) .Since the publication of the Iacocca report, many publications on agility have appeared, in book forms, trade magazines and academic journals. AM can be defined as, “The capability of surviving and prospering in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer-designed products and services in the business world.’’ (Cho and Hachtel, 1996). To be ‘agile’ is to master change and uncertainty and to integrate the business employees and information tools in all aspects of production. As a mark of the newness of the concept, every publication attempts to define and explain agility (Ayyappan and Jayadev, 2010). Agile manufacturing has been defined with respect to the agile enterprise, products, workforce, capabilities and the environment that gives impetus to the development of agile paradigm. The main points of the definition of various authors may be summarized as follow (Gunasekaran, 1999):

- High quality and highly customized products
- Products and services with high information and value-adding content
- Mobilization of core competencies
- Responsiveness to social and environmental issues
- Synthesis of diverse technologies
- Response to change and uncertainty
- Intra-enterprise and inter-enterprise integration

2.3 ENABLING TECHNOLOGY OF AGILE MANUFACTURING

Agile manufacturing has been approached from a variety of perspectives using a wide range of tools. In order to achieve agility in manufacturing, physically distributed firms need to be integrated and managed effectively so that the system is able to adapt to changing markets (Ayyappan and Jayadev, 2010). It can be understood from the conceptual model, how all the enablers or tools should be integrated to achieve an effective integration and management of firm in a virtual enterprise. The enablers of agile manufacturing are (Goldman *et al*., 1995):

Virtual Manufacturing and Information Technology

Virtual enterprise environment facilitate the reconfiguration of the organization in order to respond quickly to changing market needs. An individual organization is often not able to respond effectively within a short period of time due to lack of internal capabilities. In virtual enterprise, each functional aspect of the manufacturing design, production and marketing of a product may be performed by different organizations.

Coordination and integration seems very much complicated under such kind of arrangement. Successful attainment of the business goals of virtual enterprise therefore depends on its ability to align the business processes and practices of partner firms.

The virtual enterprise environment places a number of special requirements on the process design activity. Virtual or distributed enterprise is a temporary alliance of partner enterprises located all over the world, where each contributes their core competencies to take advantage of a specific business opportunity or fend off a market threat.

Concurrent Engineering

Concurrent Engineering (CE) is very much part of the other enablers in an agile environment. CE is the answer to the need for shorter product development cycles and quick response to changing markets. The application of CE in product development indicates that new products are designed with inputs from all concerned. The methods of Quality Function Deployment (QFD) are designed to listen to the voice of the customer, especially for evolutionary products, where the customer is well aware of the current choices and capabilities of available products.

Web-based Engineering

To become agile, manufacturers have to distribute intelligence and decision making authority as close to the points of delivery, sale and even after-sale service as possible. To improve their ability to respond, they have to integrate the design and production information with their business partners. To stay in business, they have to be prepared to change the very definition of their core business if business goals and market conditions dictate. Internet technology is a promising enabled technology to achieve such agility in the changing manufacturing business.

Reverse Engineering (RE) and Rapid Prototyping.

RE was once considered as something practiced by those who lack an original concept, but it has now become an engineering science in its own right. The Japanese success in new products development has led to RE being considered as a design process. Even the automobile industry uses a variant design methodology, referred to as 'direct engineering', to replace more general original design methods. Originally, the Japanese used RE to improve on competitors' products and thus avoid original design effort. The 'redesign' process was initiated by observing and testing a product. Thereafter, the product was disassembled and the individual components were analyzed in terms of their form, function, assembly tolerance and manufacturing process. In recent years, the Europeans and the Americans have 'reverse engineered' the RE process and developed powerful tools to further compress product development cycles.

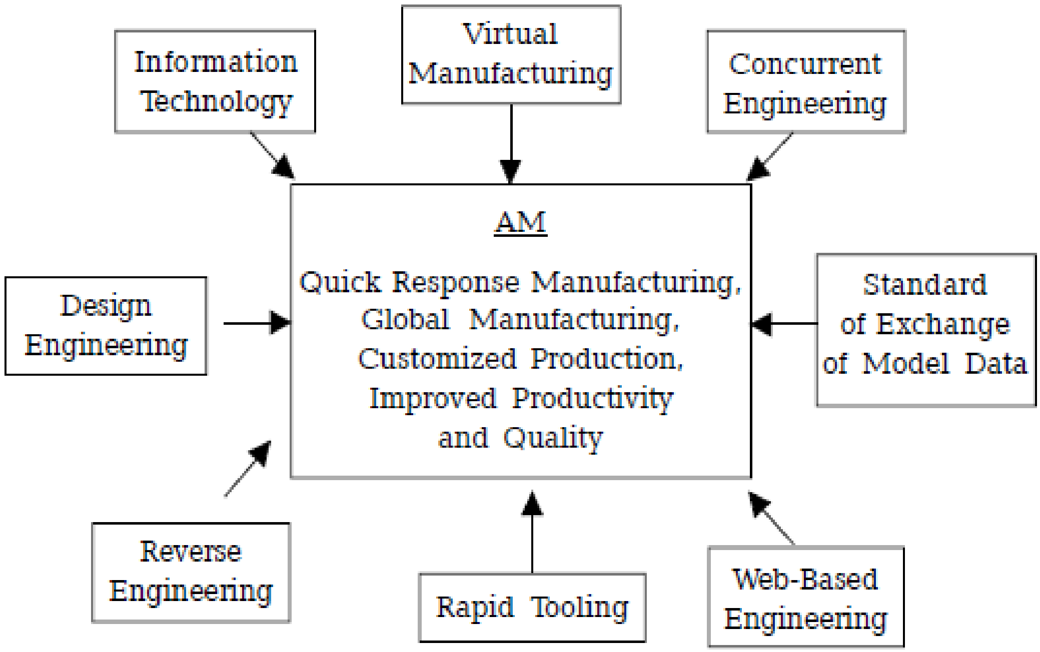

Figure 2.1 A conceptual model to illustrate the concept and enabler of AM (source: Ayyappan and Jayadev, 2010)

2.4 DEFINITION OF QUALITY

The philosophical leaders of the quality movement, notably Philip Crosby, W. Edwards Deming, and Joseph M. Juran – the so-called Quality Gurus – had slightly different definitions of what quality is and how to achieve it, but they all had the same general message: To achieve outstanding quality requires quality leadership from senior management, a customer focus, total involvement of workforce, and continuous improvement based upon rigorous analysis of processes (Chase *et al.*, 2005).

Table 2.2 Comparison in the Quality Gurus (source: Chase et al., 2005)

	Quality Gurus		
	Crosby	**Deming**	**Juran**
Definition of quality	Conformance to requirements	A predictable degree of uniformity and dependability at low cost and suited to the market	Fitness for use (satisfies customer's needs)
Degree of senior management responsibility	Responsible for quality	Responsible for 94% of quality problems	Less than 20% of quality problems are due to workers
Performance standard/ motivation	Zero defects	Quality has many "scales"; use statistics to measure performance in all areas; critical of zero defects	Avoid campaigns to do perfect work
General approach	Prevention, not inspection	Reduce variability by continuous improvement; cease mass inspection	General management approach to quality; especially human elements
Structure	14 steps to quality improvement	14 points for management	10 steps to quality improvement
Statistical process control (SPC)	Rejects statistically acceptable levels of quality (wants 100% perfect quality)	Statistical methods of quality control must be used	Recommends SPC but warns that it can lead to tool-driven approach
Improvement basis	A process, not a program; improvement goals	Continuous to reduce variation; eliminate goals without methods	Project-by-project team approach; set goals
Teamwork	Quality improvement teams; quality councils	Employee participation in decision making; break down barriers between departments	Team and quality circle approach
Costs of quality	Cost of nonconformance; quality is free	No optimum; continuous improvement	Quality is not free; there is not an optimum
Purchasing and goods received	State requirements; supplier is extension of business; most faults due to purchasers themselves	Inspection too late; sampling allows defects to enter systems; statistical evidence and control charts required	Problems are complex; carry out formal surveys
Vendor rating	Yes; quality audits useless	No, critical of most systems	Yes, but help supplier improve

Table 2.3 The Dimensions of Quality (source: Chase et al., 2005)

Dimension	Meaning
Performance	Primary product or service characteristics
Features	Added touches, bells and whistle, secondary characteristics
Reliability	Consistency of performance over time, probability of failing
Durability	Useful life
Serviceability	Ease of repair
Response	Characteristic of the human-to-human interface (speed, courtesy, competence)
Aesthetics	Sensory characteristics (sound, feel, look, and so on)
Reputation	Past performance and other intangibles (perceived quality)

2.5 FLEXIBLE MANUFACTURING SYSTEM (FMS)

A FMS is a highly automated group technology (GT) machine cell, consisting of a group of processing workstations, interconnected by an automated material handling and storage system, and controlled by a distributed computer system (Ranky, 1983). The reason the FMS is called flexible is that it is capable of processing a variety of different part styles simultaneously at the various workstations, and the mix of part styles and quantities of production can be adjusted in response to changing demand patterns (Lefly F., 1994). The components and characteristics of an FMS as described in are as follows (Davis et al, 1989):

- ♦ Potentially independent numerical control machine tool.
- ♦ An automated material-handling system.
- ♦ An overall method of control that coordinates the functions of both the machine tools and materials handling system so as to achieve flexibility.

A FMS relies on the principles of group technology. No manufacturing system can be completely flexible. There are limits to the range of parts or products that can be made in FMS (Boer H. *et al.*, 1990). Flexibility means:

- A ability to identify and distinguish among the different part or product styles processed by the system
- Quick changeover of operating instructions
- Quick changeover of physical

Types of FMS

Each FMS is designed for a specific application, that is, a specific family of parts and processes. Therefore, each FMS is custom engineered and unique (Belassi W. and Fadlalla A., 1998). Given these circumstances, one would expect to find a great variety of system designs to satisfy a wide variety of application requirements. The types of flexibility in manufacturing are (Boer H. *et al*., 1990):

- Machine flexibility: Capability to adapt a given machine in the system to a wide range of production operations and part styles. The greater the range of operations and part styles, the greater the machine flexibility.
- Production flexibility: The range or universe of part styles that can be produced on the system.
- Mix flexibility: Ability to change the product mix while maintaining the same total production quantity, which is, producing the same parts only in different proportions.
- Product flexibility: Ease with which design changes can be accommodated. Ease with which new products can be introduced.
- Routing flexibility: Capacity to produce parts through alternative workstation sequences in response to equipment breakdowns, tool failures, and other

interruptions at individual stations.

- Volume flexibility: Ability to economically produce parts in high and low total quantities of production, given the fixed investment in the system.
- Expansion flexibility: Ease with which the system can be expanded to increase total production quantities.

2.6 TOTAL PRODUCTIVE MAINTENANCE (TPM)

Cost reduction, in all its forms, is a critical element of the equation that spells ongoing profitability in manufacturing management (*Hutchins, 1998*). Among the many tools that have emerged over the past two decades to support this goal is TPM.

The goals of TPM are measured using overall equipment effectiveness (OEE).

$$\text{OEE} = \text{availability x performance x quality rate}$$

where availability is the proportion of the total time during which the equipment is available, performance is a measure of how close the average cycle time is to the theoretical minimum, and quality rate is the proportion of the processed quantity that is of acceptable quality (*Konopka and Fowler, 1994*).

Various elements that are likely to come into the calculation include: downtime, which can be calculated by adding together the amounts of time lost due to equipment failures, set-up and adjustment, and idling and minor stoppages. Speed losses are a combination of time lost due to idling and minor stoppages and time lost due to reductions in speed. Defective products may be caused by defects in process start-up as well as the bare figure of reduced yield.

The exact definition of OEE differs between applications and authors. Nakajima

(1988) was the original author of OEE and De Groote (1995) is one of several authors afterward.

Table 2.4 Definition of OEE variables (Source: Jonsson and Lesshammar, 1999)

	Nakajima (1988)	De Groote (1995)
Availability (A)	$\frac{\text{Loading time – downtime}}{\text{Loading time}}$	$\frac{\text{Planned production time-unplanned downtime}}{\text{Planned production time}}$
Performance (P)	$\frac{\text{Ideal cycle time x output}}{\text{Operating time}}$	$\frac{\text{Actual amount of production}}{\text{Planned amount of production}}$
Quality (Q)	$\frac{\text{Input – volume of quality defects}}{\text{Input}}$	$\frac{\text{Actual amount of production – non-accepted amount}}{\text{Actual amount}}$
OEE	(A) x (P) x (Q)	(A) x (P) x (Q)

Calculations of OEE

Effectiveness is “doing the right things right at the first time”. This is to get the best possible return by each capital asset.

Percent availability

= 100 x actual use of a machine / planned operation time

$$= 100 \times \frac{\text{[Planned operation time (or loading time) – breakdown \& setup loss time]}}{\text{Planned operation time}}$$

Loading time is based on machinery required for production. If it requires for a few hours in a week and is scheduled as such, then its percentage availability is based on those few hours. One definition of loading time is:

Loading time

= Planned production time – breaks – planned maintenance time

Percentage performance

= 100 x actual quantity produced in a given time / expected production quantity

= 100 x quantity produced / {time run x capacity or given time}

This definition is suitable where bulk quantities are produced in a given (short time). That is, standard time and throughput rates are available, but where a few parts are produced per day or week or month.

Percentage performance

= 100 x [time run – minor stoppages – reduced speed] / time run

For bulk quantities are produced in a given (short time):

Percentage quality

= 100 x <u>[quantity produced – defective quantities – amount re-processed]</u>

Quantity produced

For few parts are produced per day or week or month:

Percentage quality

= 100 x [time run – time for producing defective units – re-processing time] / time run

Finally, overall equipment effectiveness is:

OEE

= **Percent availability** x **Percentage performance** x **Percentage quality**

TPM and financial analysis

- Remember identification of big losses and finding OEE
- OEE is a direct measure of earning capacity of facilities and can be used to measure financial benefits arising from application of TPM
- TPM activities are carried out to add values. Calculate the 'added value' after taking any action.

Added value per unit

= value of taking an action – cost of not taking that action.

Added value/ hour

= Added value per unit x number of units produced per hour.

Expected throughput is based on theoretical cycle time for the process without considering the losses. OEE considers losses, so:

Actual added value/hour

= [Added value per unit x number of units produced per hour] x OEE

Loss of added value/hour

= Added value/hour (without taking account of losses) - Actual added value/hour

Average loading hour/year

= hours of work per week x no. of working weeks per year

Annual loss (in monetary unit)

= Loss of added value/hour x Average loading hour/year

Loss in effectiveness (%) = 100 – OEE

Loss in effectiveness (in monetary unit) for (100 – OEE)%

= loss in earning capacity

1% improvement (or additional earning of 1% improvement)

= loss in earning capacity / (100 – OEE)%

Philosophy of TPM – 5S'

The philosophies of TPM in 5S' are:

Seiri: Systemizing and standardizing

Seiri is concerned with the use of equipment: classification, tool selection, material and suitable equipment for each task or activity, information selection and recording of that required to perform the task.

Seiton: Sorting

Seiton means tidying up: finding the right place to save objects, and maintaining general organization of the place of work.

Seisou: Sweeping

Seisou emphasizes cleaning: keeping the work area clean, and retaining only the information and items needed to work on the specific tasks.

Seiketsu: Sanitizing

Seiketshu requires creating good conditions of health and hygiene: checking, illumination, atmospheric pollution, sound and temperature, keeping visible records allowing for easy evaluation and comprehension.

Shitsuke: Self Discipline

Self discipline refers to the habit of looking at procedures and rules, self-control and self-direction.

2.7 Just in Time

Just in time (JIT) is an integrated set of activities designed to achieve high volume production using minimal inventories of raw materials, work-in-process, and finished goods (Chase *et al.,* 2005). Parts arrive at the next workstation "just in time" and are completed and move through the operation quickly. JIT is also based on the logic that nothing will be produced until it is needed. Need is created by actual demand for the product. JIT is also a manufacturing philosophy of eliminating waste in the total manufacturing process, from purchasing through distribution. The long term result of eliminating waste is a manufacturing process that is so streamlined, cost efficient, quality oriented, and responsive to the customer that becomes a strategic weapon (Dyck *et al.*, 1991) to enable this full process to work smoothly, JIT demands high levels of quality at each stage of process, strong vendor relations, and a fairly predictable demand for the end product. The end results of JIT system is higher quality, less rework, and faster throughput, all of which are essential for JIT to operate successfully (Niven & Werner, 1991).

The Toyota production system

The philosophy and elements of JIT production was developed and embodied in the Toyota Production System – the benchmark for lean manufacturing. The Toyota Production System was developed to improve quality and productivity and is predicted upon two philosophies that are central to the Japanese culture: elimination of waste and respect for people.

Elimination of waste

Waste, as defined by Toyota's president, Fujio Cho, is "anything other than the minimum amount of equipment, materials, parts and workers (working time) which are absolutely essential to production." An expanded JIT definition advanced by Fujio Cho identifies seven prominent types of waste to be eliminated:

- waste from overproduction
- waste of waiting time
- transportation waste

- inventory waste
- processing waste
- waste of motion
- waste from product defects

The first basic component of waste elimination is establishing balance and synchronization and flow in the manufacturing process, either where it does not exist or where it can be enhanced (Hay, 1988). This definition of JIT leaves no room for surplus or safety stock. No safety stocks are allowed because if it is not used now, it is not needed to be made: that would be waste. Hidden inventory in storage areas, transit systems, carousels, and conveyors is a key target for inventory reduction. The seven elements that address elimination of waste are (Chase *et al.*, 2005):

- focused factory networks
- group technology
- quality at the source
- JIT production
- uniform plant loading
- Kanban production control system
- minimized setup times

Focused factory networks

The Japanese build small specialized plants rather than large vertically integrated manufacturing facilities. For example, Toyota has 12 plants located in and around Toyota City and other areas of Aichi Prefecture. They find large operations and their bureaucracies difficult to manage and not in line with their management styles. Plants designed for one purpose can be constructed and operated more economically. The bulk of Japanese plants, some 60000, have between 30 and 1000 workers.

Group technology

Group technology (GT) is a philosophy in which similar parts are grouped into families, and the processes required to make the parts are arranged in a specialized work cell. Instead of transferring jobs from one department to other specialized workers, GT considers all operations required to make a part and groups those machines together. The group technology cells eliminate movement and queue (waiting) time between operations, reduce inventory, and reduce the number of employees required. Workers, however, must be flexible to run several machines and processes. Due to their advanced skill level, these workers have increased job security.

Quality at the source

Quality at the source means do it right at the first time and, when something goes wrong, stop the process or assembly line immediately. Factory workers become their own inspectors, personally responsible for the quality of their output. Workers concentrate on one part of the job at a time so quality problems are uncovered. If the pace is too fast, if the worker finds a quality problem, or if a safety issue is discovered, the worker is obligated to push a button to stop the line and turn on a visual signal. People from other areas respond to the alarm and the problem. Workers are empowered to do their own maintenance and housekeeping until the problem is fixed.

JIT production

JIT means producing what is needed when needed and no more. Anything over the minimum amount necessary is viewed as waste, because effort and material expended for something not needed now cannot be utilized now. This is in contrast to relying on extra material just in case something goes wrong (also termed as safety stock or buffering). JIT is typically applied to repetitive manufacturing, which is when the same or similar items are made one after another. JIT does not require large volumes and can be applied to any repetitive segments of a business regardless of where they appear. Under JIT the ideal lot size is one. Although workstations may be geographically dispersed, the Japanese minimize transit time and keep transfer quantities small – typically one-tenth of a day's production. Vendor even ship several times a day to their customers to keep lot sizes small and inventory low. The goal is to drive all inventory queues to zero, thus minimizing inventory investment and shortening lead times.

When inventory levels are low, quality problems become very visible. Referring to Figure 2.3, if the water in a pond represents inventory, the rocks represent problems that could occur in a firm. A high level of water hides the problem (rocks). Management assumes everything is fine, but as water level drops in an economic downturn, problems are presented. If management deliberately force the water level down (particularly in good economic time), management can expose and correct problems before they cause worse problems. JIT manufacturing exposes problems otherwise hidden by excess inventories and staff.

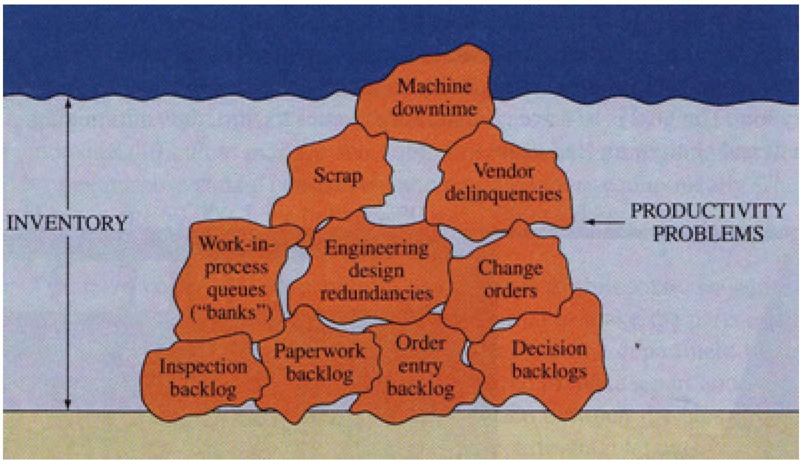

Figure 2.2 Inventory Hides Problems (source: Chase *et al*., 2005)

JIT layouts and design flows

JIT requires that plant layout to be designed to ensure balanced work flow with a minimum of work-in-process inventory. Each workstation is part of production line, whether or not a physical line actually exists (Chase *et al.*, 2005). Capacity is balanced using the same logic for an assembly line, and operations are linked through a pull system. In addition, the system designer must visualize how all aspect of the internal and external logistics system tie to the layout (Hay, 1988).

Preventive maintenance is emphasized to ensure that flows are not interrupted by down time or malfunctioning equipment. Preventive maintenance involves periodic inspection and repair designed to keep a machine reliable. Operators perform much of the maintenance because they are most familiar with their machines and because machines are easier to repair, as JIT operations favor several simple machines rather than one large complex one.

The reductions in setup and changeover times are necessary to achieve a smooth flow. Figure 2.4 shows the relationship between lot size and setup costs. Under a traditional approach, setup cost is treated as a constant, and the optimal order quantity is shown. Under the kanban approach of JIT, setup cost is treated as a variable and the optimal order quantity is reduced.

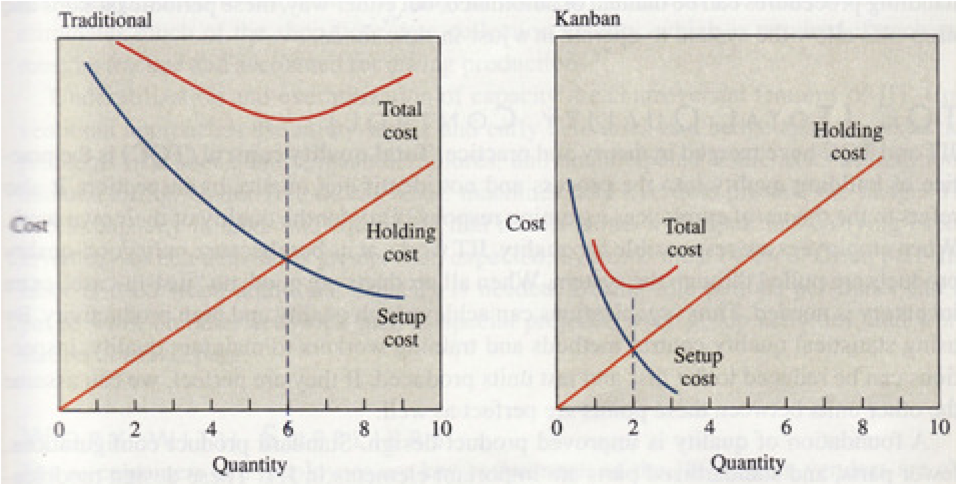

Figure 2.3 Relationship between Lot Size and Setup Cost (source: Chase *et al*., 2005)

2.8 PDCA CYCLE

The PDCA cycle is a checklist of the four stages which must go through to get from `problem-faced' to `problem solved' (Deming, 1989). The four stages are Plan-Do-Check-Act, and they are carried out in the cycle illustrated below.

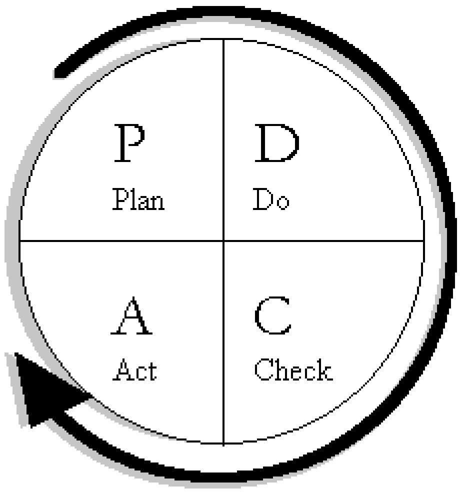

Figure 2.4 PDCA cycle (source: Deming, 1989)

The concept of the PDCA Cycle was originally developed by Walter Shewhart, the pioneering statistician who developed statistical process control in the Bell Laboratories in the US during the 1930's. It is often referred to as `the Shewhart Cycle'. It was taken up and promoted very effectively from the 1950s on by the famous Quality Management authority, W. Edwards Deming, and is consequently known by many as `the Deming Wheel' (Verheggen, 2006).

The PDCA cycle coordinates continuous improvement efforts (Shewhart, 1986). It both emphasizes and demonstrates that improvement programs must start with careful planning, must result in effective action, and must move on again to careful planning in a continuous cycle. Also, the PDCA cycle diagram is used in team meetings to take stock of what stage improvement initiatives are at, and to choose the appropriate tools to see each stage through to successful completion (Cecelia and Kim, 2005).

Plan-Do-Check-Act

For each stage of the cycle, tasks done are (Deming, 1989):

- **Plan** to improve operations first by finding out what things are going wrong (that is identify the problems faced), and come up with ideas for solving these problems.
- **Do** changes designed to solve the problems on a small or experimental scale first. This minimizes disruption to routine activity while testing whether the changes will work or not.
- **Check** whether the small scale or experimental changes are achieving the desired result or not. Also, continuously check nominated key activities (regardless of any experimentation going on) to ensure that user know what the

quality of the output is at all times to identify any new problems when they crop up.

- **Act** to implement changes on a larger scale if the experiment is successful. This means making the changes a routine part of your activity. Also, act to involve other persons (other departments, suppliers, or customers) affected by the changes and whose cooperation you need to implement them on a larger scale, or those who may simply benefit from what you have learned (you may, of course, already have involved these people in the Do or trial stage).

After the cycle is completed and arrived at `problem solved', go back to the Plan stage to identify the next `problem faced'. If the experiment was not successful, skip the Act stage and go back to the Plan stage to come up with some new ideas for solving the problem and go through the cycle again (Cecelia and Kim, 2005). Plan-Do-Check-Act describes the overall stages of improvement activity, but how is each stage carried out? This is where other specific quality management, or continuous improvement, tools and techniques come into play (Shewhart, 1986). The diagram below lists the tools and techniques which can be used to complete each stage of the PDCA cycle. This classification of tools into sections of the PDCA Cycle is not meant to be strictly applied, but it is a useful prompt to help user choose what to do at each critical stage of improvement efforts.

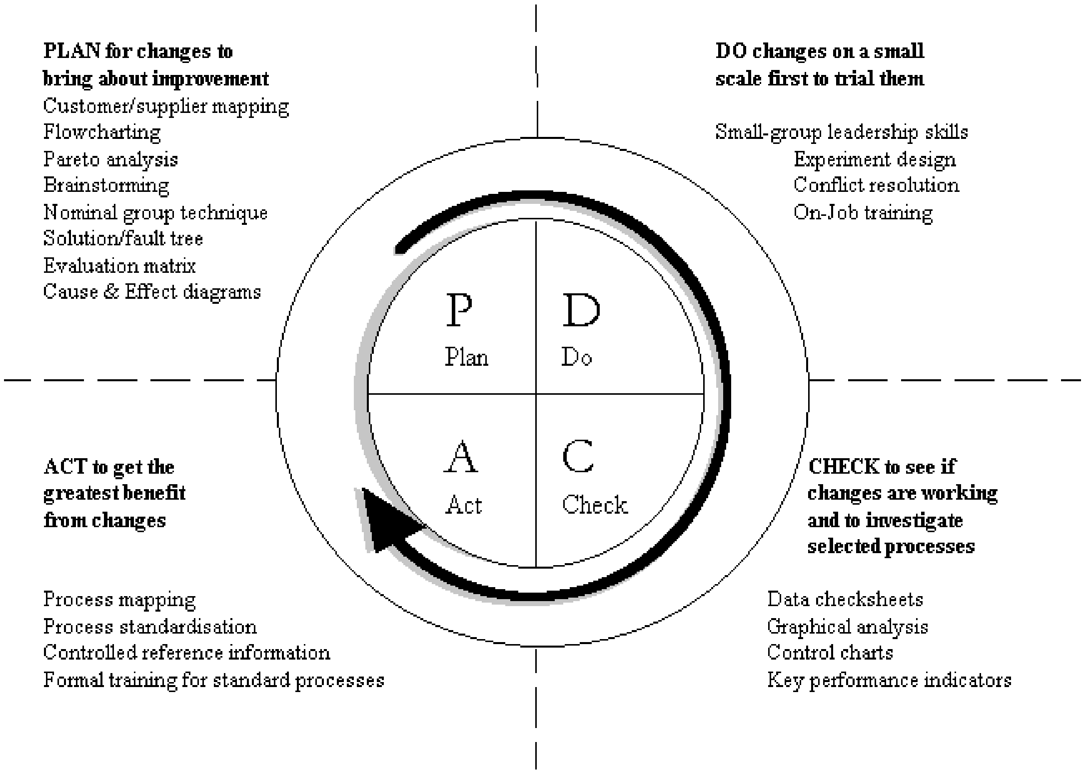

Figure 2.5 Classification of tools in each section (source: Deming, 1989)

2.8.1 PDSA Cycle

In 1987 Moen and Nolan presented an overall strategy for process improvement with a modified version of Deming's cycle of 1989. The planning step of the improvement cycle required prediction and associated theory. The third step compared the observed data to the prediction as a basis for learning (Deming, 1993). Langley, Nolan, and Nolan refined the improvement cycle and called it the PDSA cycle. The use of the word "study" in the third phase of the cycle emphasizes that the purpose of this phase is to build new knowledge (Langley *et al.,* 1994, 1996, 2009). It is not enough to determine that a change resulted in improvement during a particular test.

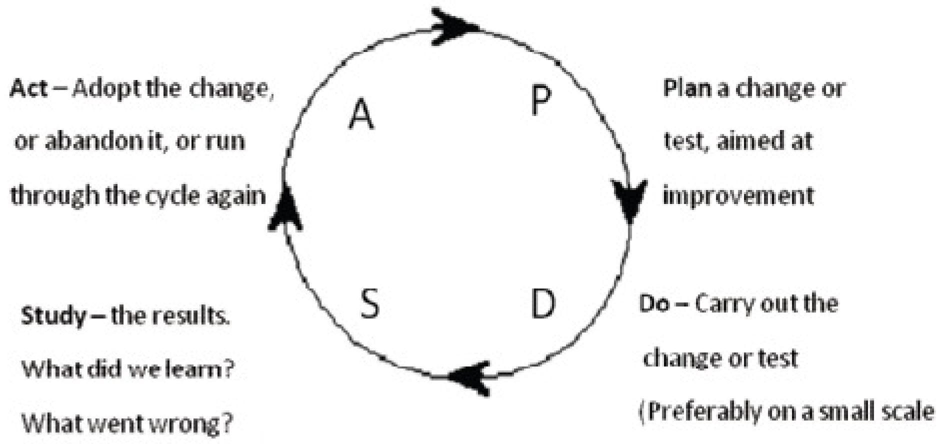

Figure 2.6 PDSA cycle and functions of each phase (source: Deming, 1993)

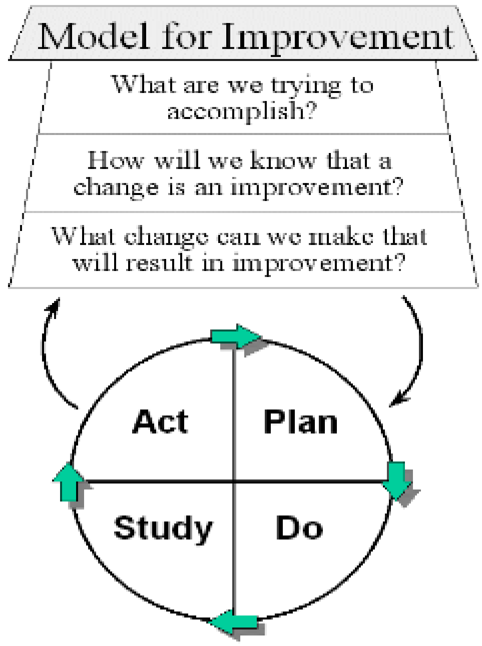

Figure 2.7 Model for improvement and its 3 question (source: Langley et al., 1996, 2009)

2.9 DEVELOPING A MANUFACTURING STRATEGY

The main objectives of manufacturing strategy development are (Chase *et al.*, 2005):

- To translate required competitive dimensions (typically obtained from marketing) into specific performance requirement for operations

- To make the necessary plans to ensure that operations and enterprise capabilities are sufficient to accomplish them.

The steps for prioritizing these dimensions are:

1. Segment the market according to the product group.
2. Identify the product requirement, demand patterns, and profit margins of each group.
3. Determine the order winners and order qualifier for each group.
4. Convert order winner into specific performance requirement.

The process of achieving a satisfactory manufacturing segmentation that maintains focus is often a matter of deciding which products or products groups fits together in the sense that they have similar market performance characteristics or place similar demands on the manufacturing systems. The purpose of analysis is to differentiate their market competitive characteristics. Therefore, different external performance objectives are required from the manufacturing operation. Each product group also has different priorities for its internal performance objectives. The flow of developing manufacturing strategy is shown in Figure 2.8.The criteria of manufacturing requirements are (Chase *et al.*, 2005):

- Products
- Customers
- Product specs
- Product range
- Design changes
- Delivery

- Quality
- Demands variation
- Volume/line
- Margins
- Order winners
- Qualifiers
- Main operations performance dimensions

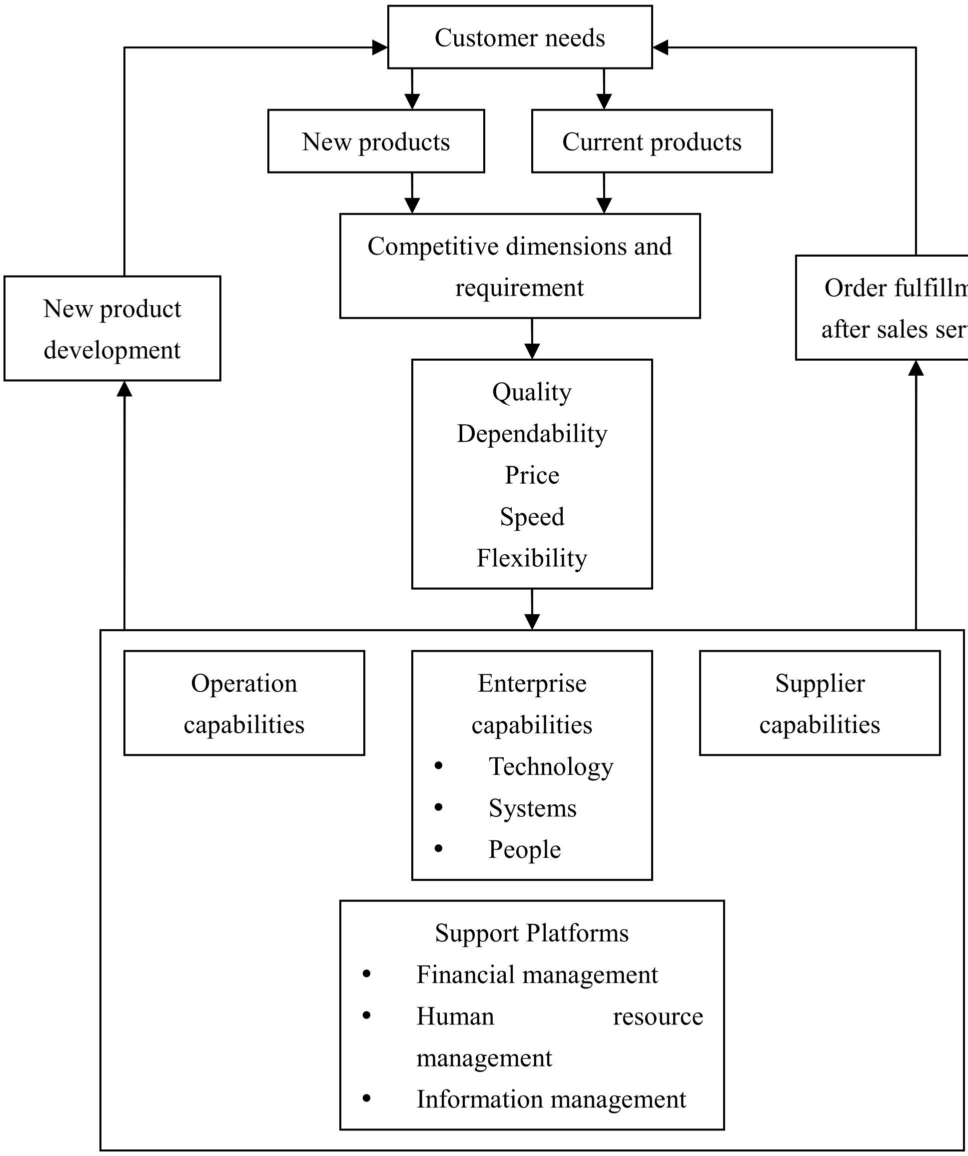

Figure 2.8 Operations Strategy Framework: From Customer Needs to Order Fulfillment (source: Chase *et al*., 2005)

2.10 METHOD AND TECHNIQUE SELECTED

The method chosen to become the framework of the study is PDSA cycle. Engineering tools chosen to be used in the analysis are TPM, OEE and FMS.