CHAPTER 2

LITERATURE REVIEW ON LEAN MANUFACTURING MANAGEMENT

2.0 Introduction

This chapter presents a review of Collaborative Lean Manufacturing Management (CLMM) which includes Just-in-Time (JIT), Manufacturing Resources Planning (MRP II), and Total Quality Management (TQM) approaches. The review also encompasses the roles of these three systems and their integration in the area of CLMM. Further references are cited and reviewed as part of Knowledge-Based CLMM System description, covered in Chapters 4, 5, and 6.

2.1 Review of Just-in-Time (JIT)

A self explanatory term which refers to the concept of everything occurs 'just in time' (JIT), this is a manufacturing operations approach formally devised by Japanese automotive manufacturers more than 40 years ago. Nevertheless, the idea of JIT approach can be traced back as early as 1922 when the founder of Ford Motor Company, Henry Ford's wrote in his book *My Life and Work* [reprinted edition: Ford (1973)]:

"*We have found in buying materials that it is not worthwhile to buy for other than immediate needs. We buy only enough to fit into the plan of production, taking into consideration the state of transportation at the time. If transportation were perfect and an even flow of materials could be assured, it* *would not be necessary to carry any stock whatsoever. The carloads of raw materials would arrive on schedule and in the planned order and amounts, and go from the railway cars into production. That would save a great deal of money, for it would give a very rapid turnover and thus decrease the amount of money tied up in materials. "*

This statement describes the ideal concept of incoming materials from suppliers that are not stored before going into production. Although the idea originated in America, JIT is always cited in literatures [White and Prybutok (2001), Amasaka (2002), Mistry (2005)] as a Japanese approach since the Japanese manufacturers, especially Toyota Motor Corporation, were the first to formally devise and successfully adopt, implement, publicise, and gain benefits from JIT. The Japanese organisations were motivated to this approach due to economical (limited resources after the World War II) and geographical (large amounts of land needed to warehouse parts) reasons [Lee-Mortimer (2006), Shah and Ward (2007)]. Only in the 1980s did the Western organisations realise the power of JIT and started to implement it. A classic example was NUMMI (New United Motor Manufacturing Inc), a joint venture of General Motors and Toyota in 1984, who successfully implemented JIT [Womack and Jones (2003), Liker (2004)]. Since then, a considerable attention to JIT has been paid by both academics and industrialists worldwide [Shingo (1985), Ohno (1988), Womack *et. al.* (1990), Liker and Yu (2000), Chase *et. al.* (2006), Dolcemascolo (2006)].

Based on cited literatures, JIT has been covered in Production and Operations Management (POM), Manufacturing Planning and Control (MPC), and Manufacturing Strategy and thus has been defined in many ways as follows:

- Shingo (1985):

  "A management philosophy aimed at eliminating waste from every aspect of manufacturing and its related activities. The term JIT refers to producing only what is needed, when it is needed, in just the amount needed."

- Monden (1998):

  "*JIT basically means to provide the necessary units in the necessary quantities at the necessary time*"

- Krajewski and Ritzman (2005):

  "The JIT philosophy is to eliminate waste by cutting unnecessary capacity or inventory and removing non-value-added activities in operations. A JIT system is the organisation of resources, information flows, and decision rules that can enable an organisation to realise the benefits of the JIT philosophy."

- Stevenson (2005):

  "*A highly coordinated processing system in which goods move through the system, and services are performed, just as they are needed*"

- Chase *et. al.* (2006):

  "*JIT means producing what is needed when it is needed and no more*"

From these various definitions JIT can be defined as a revolutionary production management system which focuses on producing the highest value product on time. The highest value of products is achieved by identifying and eliminating as much as possible non-value-added activities through continuous improvement which result in greater productivity, shorter delivery times, cost reduction, improved quality, increased customer satisfaction and higher profit [Schroer (2004), Dolcemascolo (2006)].

In this research, the Lean Manufacturing term is considered to be equivalent to Just-In-Time (JIT) approach. As mentioned by Krajewski and Ritzman (2005):

"*One of the most popular systems that incorporate the generic elements of lean systems is the JIT system. The JIT philosophy is to eliminate waste by cutting unnecessary capacity or inventory and removing non-value-added activities in operations. A JIT system is the organisation of resources, information flows, and decision rules that can enable an organisation to realise the benefits of the JIT philosophy*."

Despite many advantages mentioned, there are still drawback aspects of the JIT approach. For example, Young (1992) and Cusumano (1994) highlights the difficulties faced by workers and suppliers. JIT approach was found to be aggravating the workers since they are expected to work continuously due to small amount of work-in-process [Young (1992)]. JIT principle of supplying parts in small lots and delivering frequently to the customers also forces suppliers to simply hold their inventory to meet the demand which results in the increasing of holding costs and limiting their ability to improve quality and productivity [Cusumano (1994)].

However, these claims of JIT were mainly based on the misunderstanding of the concept. Hopp and Spearman (2004) found that many organisations failed to view JIT holistically. The failure was due to the implementation of JIT in isolation without the commitment from management and partners in the supply chain. Another reason was the simplification of JIT definition as make-to-order production [Hopp and Spearman (2004)].

There are a major set of elements which are inter-related in a JIT system which includes continuous improvement (*Kaizen*), *Kanban* system, setup time reduction, uniform plant loading, and cellular manufacturing. Other important elements include focused factory, employee involvement, waste elimination, job standardisation, and total productive maintenance (TPM) [Hokoma (2007)].

2.1.1 Continuous Improvement

In the LMM view, improvement process is never-ending. Also known as *kaizen*, continuous improvement is an ongoing effort to identify and remove wasteful elements in the manufacturing process [Womack *et. al.* (1990)]. Waste in LMM is defined as anything that is not required by customers or any activity which is not adding value to the part produced. There are seven wastes mentioned in many sources [Emiliani (1998), Monden (1998), Womack and Jones (2003), Dolcemascolo (2006)]. These are defect, overproduction, transportation, waiting, inventory, motion, and over processing. Womack and Jones (2003) add underutilisation of employee as the eight waste of manufacturing. In LMM, the focus on elimination of these forms of wastes is one of the most significant parts [Slack *et. al.* (2007)].

It is necessary to have a clear internal and external communication strategy, a system of improvement suggestions should also be in place, and employees must be trained in methods of continuous improvement [Garcia *et. al.* (2006)]. The function of continuous improvement is to eliminate wasteful actions and use the time instead to perform net operations with added value, thus reducing the total standard operations time and the number of workers from time to time [Monden (1998)].

2.1.2 Setup Time Reduction

According to Monden (1998), to shorten the setup time, the most important point is to convert as much as possible of the internal setup to the external setup. Shingo (1985) defines internal setup as the setup that requires the machine to be idle, while external setup is the setup that can be performed while the machine is operating.

As inventory is considered as waste in LMM System, production process is aimed for small batch production. To accommodate this, an element of quick changeover or setup time reduction is required. Developed systematically by Shingo (1985) as Single-Minute Exchange of Dies (SMED), setup time reduction not only reduces time but also reduces setup cost, allows small lot production, reduces batch sizes, and smooths flow. The advantages of a setup time reduction includes minimisation of stocks, job-order oriented production, and prompt adaptability to demand change [Monden (1983)]. The achievement of SMED should then be followed by the challenge to achieve One-Touch Exchange of Die (OTED) which achieves setup changes in less than a minute [Shingo (1985)]. For example, in a recent study by Lee-Mortimer (2006), it is described that an electronic company recorded a time of 58 seconds, representing a 90 per cent reduction in the setup time.

2.1.3 Cellular Manufacturing

Cellular Manufacturing is a manufacturing layout concept that groups various types of machines and equipment into work cells so that a family of similar products can be produced [Singh and Rajamani (1995)]. Every single cell work on the mix of products that have similar processing requirement form and profile [Chase *et. al.* (2006)]. The cells are arranged in an order that maintains smooth flow of parts through the process [Abdullah (2003)], so that line flow type of production is achieved within a batch production environment. As an example of this layout, machines are normally arranged in U-form lines as shown in Figure 2.1.

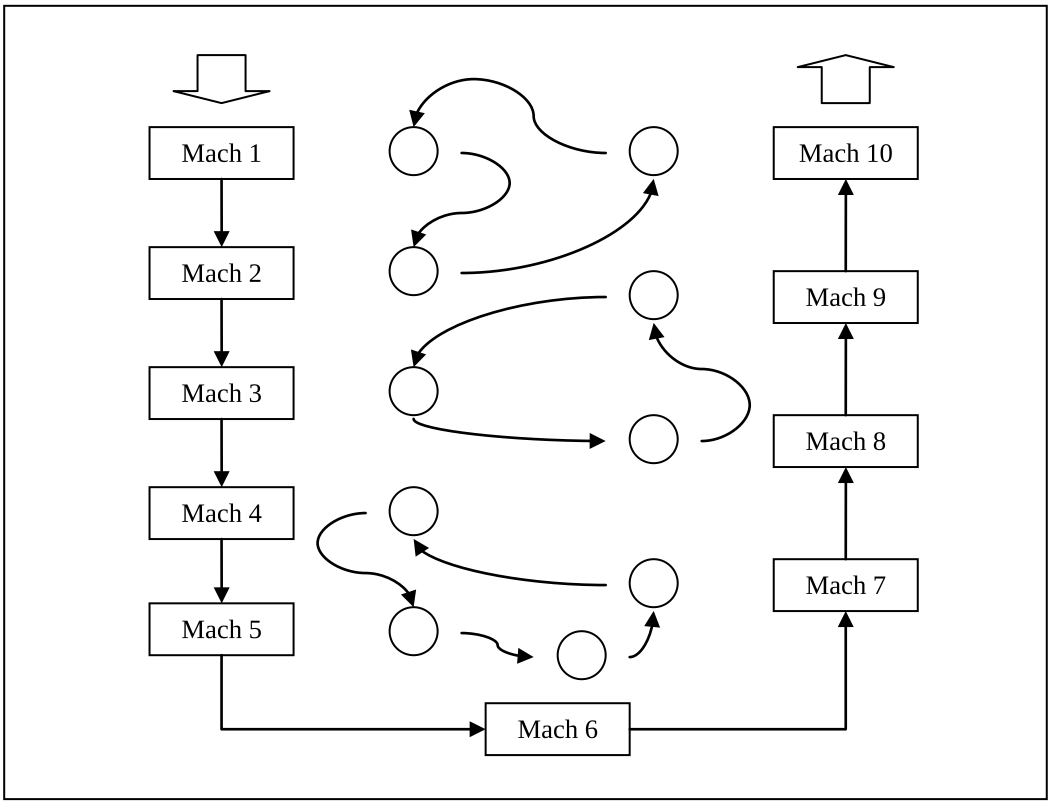

Figure 2.1: U-form Layout of a JIT Cell

The main advantages of cellular manufacturing includes one-piece flow concept which reduce work in process inventory, and also flexibility to cater high variety of products mix [Abdullah (2003)]. For Cellular Manufacturing to work, setup time reduction and batch reduction must also have been achieved.

2.1.4 Uniform and Mixed Loading and Job Standardisation

LMM systems work best if the daily load on individual workstations is relatively uniform [Krajewski and Ritzman (2005)]. The ideal production system assembles the same type and number of units each day, thus creating a uniform daily demand and smooth process at all workstations [Krajewski and Ritzman (2005)]. The techniques are used to make the production smooth includes capacity planning, which recognises capacity constraints at critical workstations, a line balancing, to develop Master Production Schedule (MPS) and a mixed-mode production which generates a steady rate of component requirements for the various models and allows the use of small lot sizes at the feeder workstations [Krajewski and Ritzman (2005)]. However, it is important to note that mixed-mode production requires shorter setup times as a pre-requisite.

At the same time, standardisation of job is a vital principle, with its main goal to shrink production costs by achieving a balanced production and uniform loading. Monden (1998) lists three main goals of job standardisation together with two sub-goals. Figure 2.2 shows the elements of job standardisation.

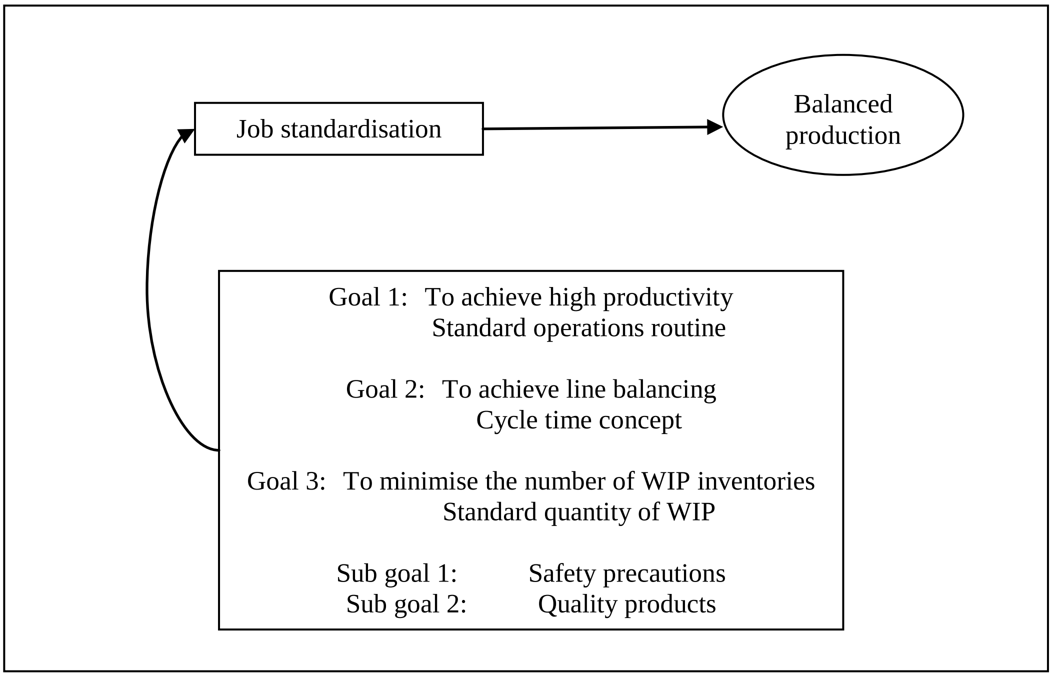

Figure 2.2: Goals and elements of job standardisation

Standardisation of jobs basically ensures that each job is organised and is carried out in the most effective manner [Abdullah (2003)]. Every worker follows the standard operations routine all the time which includes the time needed to complete a particular job, and the order of steps to follow for each job [Abdullah (2003)]. By doing this, goals of achieving line balancing and minimising WIP can be realised.

2.1.5 Kanban

LMM system requires small and frequent lot delivery between processes and shipments. The *Kanban* system manages the JIT production method. *Kanban* is a signal that is used to control the number of parts to be produced in every process [Monden (1998), Hokoma (2007)]. This system depends upon other LMM elements, e.g. batch reduction, one-piece flow, kaizen, uniform plant loading, before it can be implemented.

In one of the recent studies, Lee-Mortimer (2008) found that *Kanban* system provides benefits which include:

- Overproduction is reduced, ensuring that resources are used more efficiently, with reduced inventory and the cost of quality failures kept to a minimum.
- Fewer and more quickly resolved interruptions to the flow with shorter waiting times, means that the *Kanban* has enabled an increase in production using the same resources.
- Capacity constraints and availability very visible and enables team leaders to move operators from areas with excess capacity to areas with capacity shortage.

- Factory is equipped with an increasingly stable production system that will enable it to approach upstream and downstream supply chains to remove additional waste through the use of external *Kanban* systems.

2.1.6 Other Elements

Other elements of JIT include focused factory, employee involvement, supplier development, and total productive maintenance (TPM). A focused factory strives for a narrow range of products, customers and processes [Strategos Inc. (2007)]. The result is a factory that is smaller, simpler and totally focused on one or two key manufacturing tasks; i.e. the task that is most important for competition in the market [Strategos Inc. (2007)]. According to Skinner (1974):

"*The focused factory will out-produce, undersell and quickly gain competitive edge over the complex factory. The focused factory does a better job because repetition and concentration in one area allows its work force and managers to become effective and experienced in the task required for success. The focused factory is manageable and controllable. Its problems are demanding, but limited in scope*."

The Japanese build small specialised plants rather than large vertically integrated manufacturing facilities, e.g. Toyota has 12 plants located in and around Toyota City and other areas of Aichi Prefecture (the centre of Japan's automotive and aerospace industries) [Chase *et. al.* (2006)]. Large operations and bureaucracies found to be difficult to manage and not in-line with their management styles [Chase *et. al.* (2006)]. At the same time, the production system is geared to a small number and small variety of products. For example, in the lattice-space manufacturing model developed by Razmi *et. al.* (2000), they relate this element of low product ranges to "Pull System" methodology which is the heart of JIT.

Employee involvement is recognised as one of the important elements in any improvement initiatives. The involvement stretches from top management commitment to workers empowerment. As all of employees are the key resource of any organisation, it is important to develop a program which measures, benchmarks, evaluates, diagnoses, and improves the employee involvement process in the organisation. The program may includes job specialisation, job enrichment, job enlargement, job rotation, employee empowerment, organisational cultural change and teamwork encouragement [Krajewski and Ritzman (2005), Chase *et. al.* (2006)].

Since JIT systems operate with minimum level of inventory, close relationships with suppliers are critical [Krajewski and Ritzman (2005)]. Suppliers must be able to meet the customers (with JIT system) demand which require frequent shipment, on schedule delivery, and high quality products. Hence, the suppliers must be developed to implement the JIT system parallel to their customer JIT system.

In traditional manufacturing, maintenance is the responsibility under special unit, normally called maintenance department within the organisation. In contrast to this, in LMM System, maintenance is the responsibility of the whole organisation, from top management to shop floor operators [Harrison and Petty (2002)]. This philosophy of maintenance is known as Total Productive Maintenance (TPM). This is in line with argument by Cua *et. al.* (2001) and

Nakajima (1988) who mentioned that TPM optimises machine effectiveness throughout its entire life through the involvement of the entire work force.

Abdullah (2003) divides TPM into three components: preventive maintenance, corrective maintenance and maintenance prevention. Preventive maintenance includes routine check-ups instead of random, as well as planned inspection, lubrication, replacement and performance testing [Salameh and Ghattas (2001)]. Corrective maintenance is about the maintenance when machine break downs and the decision on whether to repair or replace have to be made [Abdullah (2003)]. Maintenance prevention deals with purchasing the right machine, that is easy and cheap to maintain [Abdullah (2003)].

2.2 Review of Manufacturing Resources Planning (MRP II)

In this section, a very powerful planning system, Manufacturing Resources Planning (MRP II) is described and reviewed. MRP II has evolved from Material Requirements Planning (MRP). MRP originated in the early 1960s in the USA as a computerized approach for the planning of materials acquisition and production [Aghazadeh (2003)]. Since then, many organisations have been benefited from using MRP systems and the systems have become one of the most effective and widely used inventory control systems across the world [Aghazadeh (2003), Hopp and Spearman (2004)]. Many operation managers have found the vast knowledge that MRP systems provide is absolutely essential in the current global economy [Aghazadeh (2003)].

Later in 1980s, MRP evolved into MRP II, which combined MRP with all manufacturing resources: machines, people, space and energy, and also tools of Rough Cut Capacity Planning (RCCP), Capacity Resources Planning (CRP) and scheduling. Figure 2.3 shows an overview of MRP II with MRP is at the heart of the process. This process begins with an aggregation of demand from all sources which include firm orders, forecasts, and safety stock requirements. In MRP II, not only production but also marketing and finance personnel work toward developing an MPS. It also includes a simulation capability, enabling decision makers to answer a variety of "what if" questions [Harrison and Petty (2002)].

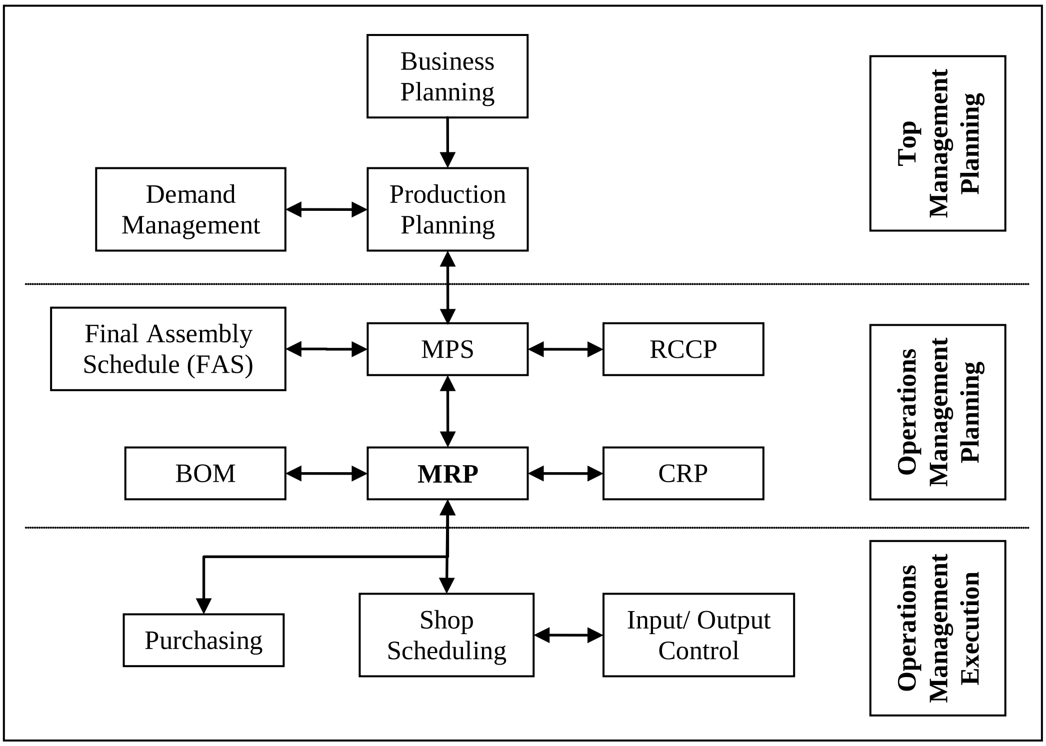

Figure 2.3: An Overview of MRP II

Literature on main elements of MRP II is detailed in the following sub-sections.

2.2.1 Material Requirement Planning (MRP)

Krajewski and Ritzman (2005) define Material Requirement Planning (MRP) as "*a computerized information system developed specifically to aid in managing dependent demand inventory and scheduling replenishment orders*". Dependent demand is a demand of one item which depends on the demand for another item. An example of dependent demand in automotive industry is gearboxes and automobiles. If the demand for automobiles falls, the need for gearboxes will decrease, leading to decreased demand for gearboxes. In this case, demand for automobiles is an independent demand, but the demand for the gearboxes is directly (dependent) related to the demand for automobiles.

MRP systems have been installed almost universally in manufacturing firms, due to its logical and easily understandable approach to the problem of determining the number of components, and materials needed to produce each end item [Chase *et. al.* (2006)]. Moreover, MRP provides the schedule specifying when each of these materials and components should be ordered or produced [Chase *et. al.* (2006)]. It is argued that MRP is most valuable to companies involved in assembly operations, either assemble-to-stock, or assemble-to-order type of industry [Chase *et. al.* (2006)].

There are two main input components of MRP system that must be known, i.e. Master Production Schedule (MPS) and Bill of Materials (BOM), which will be discussed in the following sections. The inter relation between these components is depicted in Figure 2.4.

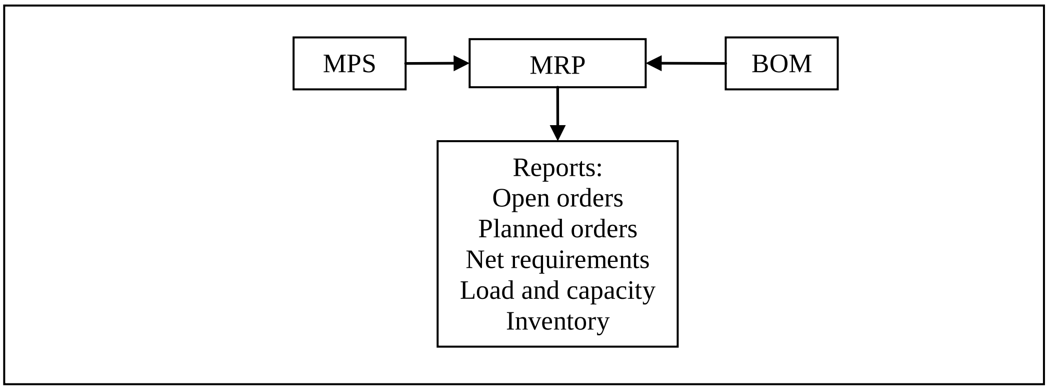

Figure 2.4: Structure of MRP (adapted from Buffa and Sarin 1987))

2.2.2 Master Production Schedule (MPS)

The MPS is a diagram (or a list) of what is to be produced and the time frame in which it will be produced [Aghazadeh (2003)]. It is a statement of planned future output of the production [Vollmann *et. al.* (2005)]. In other words, it states which end items are to be produced, when these are needed, and in what quantities [Stevenson (2005)]. Factors to be included are financial plans, customer demands, engineering capabilities, labour availability, inventory fluctuations, and supplier performance [Aghazadeh (2003)].

2.2.3 Bill of Materials (BOM)

Bill of Materials (BOM) is a record which contains all information on materials, components or sub-assemblies required for each end item, the parent-component relationships and usage quantities derived from engineering and process designs [Aghazadeh (2003)]. The BOM includes three main items, i.e. end, intermediate, and purchased items. An example of BOM structure is shown in Figure 2.5.

End item is the item available to the consumer, an intermediate item is one that has at least one parent item and one component item, and a purchased item has no components because it comes from a supplier, but it has one or more parents [Aghazadeh (2003)].

2.2.4 Rough Cut Capacity Planning (RCCP)

Rough Cut Capacity Planning (RCCP) is used to check the capacity of critical resources to ensure the feasibility of the MPS [Hopp and Spearman (2001)]. The term starts with “rough” due to this check does not consider the work-in-process inventories, existing finished goods, and also the time-phased

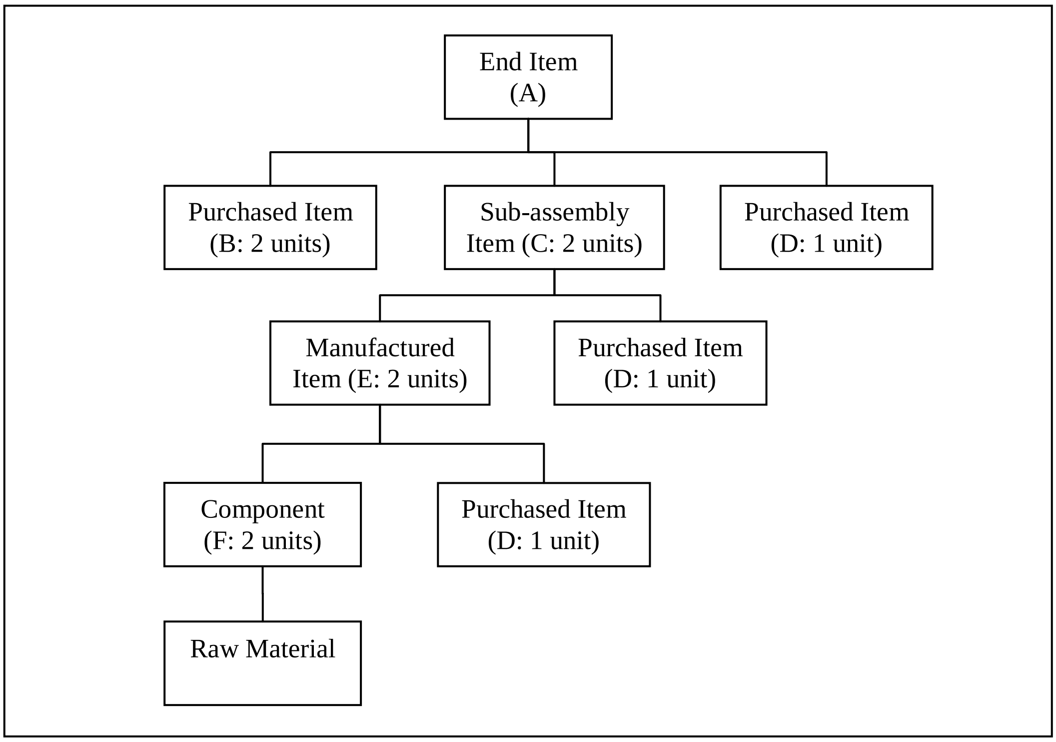

Figure 2.5: An Exam of BOM Structure

requirements of lower level of BOM [Razmi (1998)]. In this sense, RCCP is a gross capacity plan. RCCP is integrated with MPS as part of MRP II to plan and schedule materials and resources within varying degrees of success [Samaranayake *et. al.* (2002)].

2.2.5 Capacity Requirement Planning (CRP)

One of the most important features of MRP II is its ability to aid in capacity planning [Stevenson (2005)]. CRP is the process of determining short-range capacity requirements [Stevenson (2005)]. In a more detail definition, the APICS dictionary [Cox *et. al.* (1995)] defines Capacity Requirement Planning (CRP) as "*the function of establishing, measuring, and adjusting limits or levels of capacity… the process of determining how much labour and machine resources are required to accomplish the tasks of production*". Thus CRP is a net capacity plan (as opposed to RCCP which is a gross capacity plan).

According to Hokoma (2007), CRP adopts the approach of "time-phased-load-over-lead-time" to generate total load over the planning horizon of capacity plan. Based on the time required to carry out various operations the total load time can be calculated. The two methods of capacity loading which can be used in the short term are infinite and finite loading. CRP also functions to check the MRP II output to see if sufficient capacity exists [Harrison and Petty (2002)]. If it does not, feedback to the MRP II indicates that the schedule needs to be modified. Continuing through the MRP II system, orders are released to the production system by executing the capacity and material plans. Moreover, CRP is capable of taking into account demand for service parts, as well as MPS [Vollmann *et. al.* (2005)].

2.3 Review of Total Quality Management (TQM)

This section reviews the literature of TQM and its related elements such as Quality Function Deployment (QFD), Concurrent Engineering (CE), Statistical Process Control (SPC), Quality Systems, and design tools of Failure Mode and Effects Analysis (FMEA), Experimental Design, and Taguchi Method.

TQM is a management integrative philosophy of continuously improving the quality of products and processes with the goal of achieving customer satisfaction [Vuppalapati *et. al.* (1995)]. Quality must be built into its products and processes, and everyone has a responsibility in this effort. The focus of all the efforts to improve the product and process quality is the customer [Babbar and Aspelin (1994), Vuppalapati *et. al.* (1995)]. The basic philosophy of TQM is applicable to all types of organisation: manufacturing and service, public and private [Vuppalapati *et. al.* (1995)].

Krajewski and Ritzman (2005) define TQM as "*a philosophy that stresses three principles for achieving high levels of process performance and quality: customer satisfaction, employee involvement, and continuous improvement in performance*." Another definition Chase *et. al.* (2006) is "*managing the entire organisation so that it excels on all dimensions of products and services that are important to the customer*".

There are so many definitions of quality, among others are from famous Quality Experts such as Edward Deming, Philip Crosby, Joseph Juran, and John Oakland. It is "*a predictable degree of uniformity and dependability at low cost and suited to the market*" [Deming (1986)], "*conformance to requirements*" [Crosby (1999)], "*fitness for use*" [Juran (1999)], or "*exceeding the customer requirements*" [Oakland (2003)].

There are many frameworks developed by various quality experts from around the world, which include American 14-point Deming Framework [Deming (1986)], and Juran's 10-step to quality improvement [Juran (1999)]. Ishikawa (1985) contributed to the development of the cause-and-effect diagram (fishbone diagram), implementation of quality circles, which involve workers in quality improvement, and emphasis not only on external customer but also on internal customer, within the organisation.

In the United Kingdom specially and European generally, Oakland TQM Model [Oakland (2003)] is considered as the latest reliable and acceptable framework since it blends the elements in the previous frameworks. The core of the model, as shown in Figure 2.6, needs to be surrounded by Commitment to quality and meeting the customer requirements, Communication of the quality message, and recognition of the need to change the Culture of most organisations to achieve total quality [Oakland and Porter (2004)]. These 3 Cs are the "soft foundations" which must encase the hard necessities of Planning, People, Processes and Performance [Oakland and Porter (2004)].

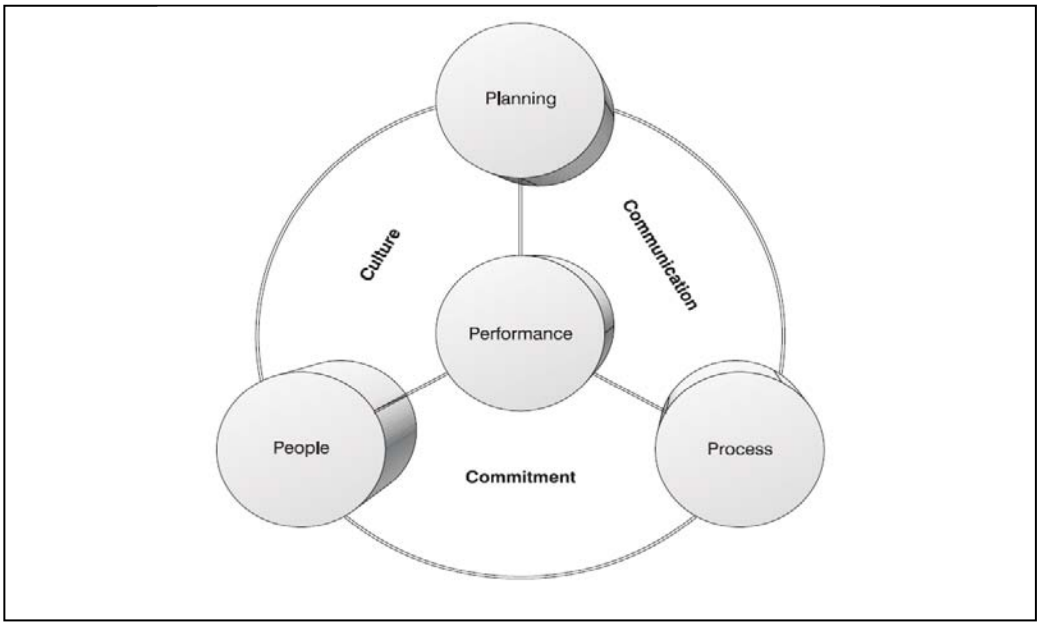

Figure 2.6: The new framework of Oakland TQM (Source: Oakland (2003))

Figure 2.6 shows how Performance may be improved through better Planning, and the management of People and the Processes in which they work [Oakland and Porter (2004)]. According to Oakland (2003), these four Ps are the keys to delivering quality products and services to customers, and form a structure the new TQM model. The elements for each P as described by Oakland (2003) are listed below:

a) Performance: Keys performance results are measured, reviewed and improved. Through performance management system, self assessment, and benchmarking; people know how well they are doing business against customer, competitors and performance goals.

b) Planning: The organisation develops the vision and mission needed for constancy of purpose and for long-term success. Policy, strategy, goal deployment, partnerships, JIT, design for quality, MRP II, FMEA, QFD, and Quality Systems are developed, deployed and updated.

c) Processes: Through personal involvement, organisation ensures that the management system is developed, implemented and continuously improved. Methods for improvement process include BPR, Kaizen, and tools such as SPC, 6-Sigma, Taguchi method, and histogram.

d) People: Teamwork, employee involvement, training, and education are stimulated and encouraged through the 3 Cs:

   i. Culture: Culture played an enormous role in whether organisations were successful or not with their TQM approaches. The values and ethics are developed and implemented to support the creation of a TQM culture. Creativity, innovation, and learning activities are developed and implemented through actions and behaviours.

   ii. Communication: Good communications were seen to be vital to success. Communication and collaboration should be stimulated and encouraged. The vision, values, mission, policies and strategies are personally communicated and accessible.

   iii. Commitment: Commitment not only from the senior management but also from everyone in the organisation, particularly those operating directly at the customer interface.

In the following sub-sections, major elements of TQM are reviewed.

2.3.1 Quality Function Deployment (QFD)

Quality Function Deployment (QFD) is one of the key tools considered as crucial for TQM implementation programme. QFD was first developed by Mitsubishi Heavy Industry at Kobe Shipyards in Japan almost 40 years ago [Yang and El-Haik (2003)]. The technique was later adopted in the automotive industry by Hino Motors and Toyota Auto Body, both of them were under Toyota Group [Akao and Mazur (2003)].

Cohen (1995) mentions that as a systematic tool, QFD translates the customer's requirements into measureable engineering design targets. This is supported by Chakraborty and Dey (2007) who stated that the QFD concept focus on the involvement of customers and marketing needs, relates on how the company lists the target customers group, ranks the customers requirements and so on. A complete QFD involves the House of Quality (HOQ) construction diagram.

An HOQ is a comprehensive matrix used in QFD to translate the customer requirements into measurable and prioritised engineering targets to be met by a new product development [Cohen (1995)]. The structure of an HOQ chart depends on the objective, stage, and scope but there are a set of standard components of an HOQ chart, including customer attributes, customer importance ratings, engineering characteristics, relationship matrix between customer attributes and engineering characteristics, roof matrix among engineering characteristics, and computed absolute/relative importance ratings of engineering characteristic [Shin *et. al.* (2002)] , as shown in Figure 2.7.

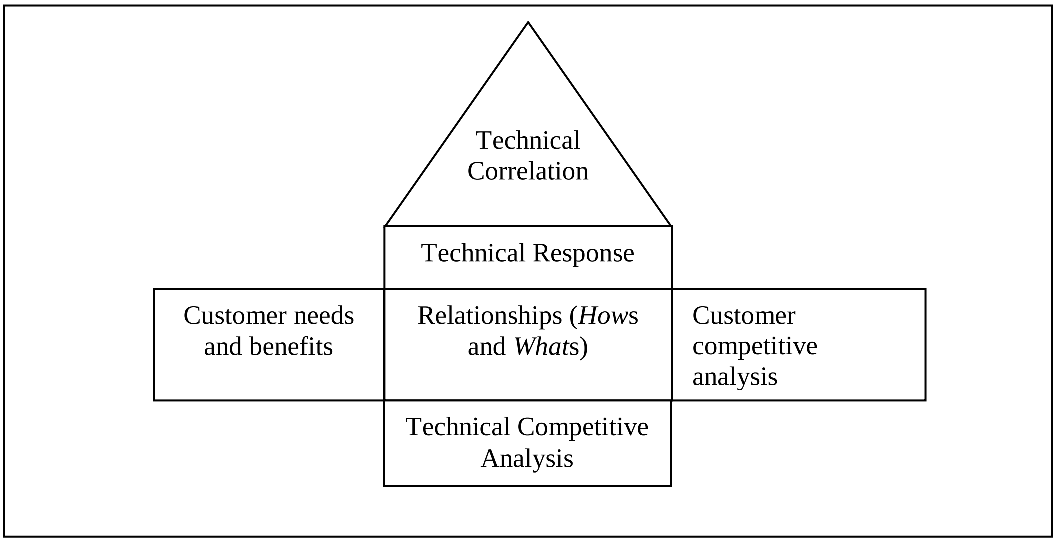

Figure 2.7: House of Quality (Adapted from Shin *et. al.* (2002))

In a recent study, Kumar *et. al.* (2006) showed how QFD and benchmarking methodologies could be effectively combined to improve the design of a product for greater customer satisfaction. QFD and benchmarking, two strategic tools whose integration has a synergistic effect to the extent that greater customer satisfaction which leads to higher market share and greater profitability [Kumar *et. al.* (2006)].

2.3.2 Concurrent Engineering (CE)

Concurrent Engineering (CE) is the process of simultaneously carrying out various product development, design, and manufacturing activities in parallel rather than in sequential [Fowlkes and Creveling (1995)]. CE is realised as the best approach to achieve shorter product development lead times with better quality [Syan (1994)]. In CE concept, a multifunctional team of product engineers, process engineers, marketers, buyers and quality specialists work closely and jointly to avoid mismatches between the design of a new product and the capability of the processes required to produce it [Krajewski and Ritzman (2005)]. The benefit of CE will bring a product development project to a speedy conclusion and improve in areas such as communication, quality, production processes, cash flows and profitability [Syan (1994), Fowlkes and Creveling (1995)].

Jarvis (1999) lists the key components of CE which include a clear understanding of customer needs at the start of the project, stability in the product specification, a systematic approach to product development, the ability to build and support effective teams, a realistic project plan based on application of the defined product development process, the availability of resources inherent in the project plan, and appropriate technological support to minimise time involved in physical prototyping and testing. In automotive industry, CE approaches are widely used in chassis design, body design, engine and transmission design [Sapuan *et. al.* (2006)].

2.3.3 Failure Mode and Effects Analysis (FMEA)

Failure Mode and Effects Analysis (FMEA) is a tool used to determine the effects of the potential failures on the performance within manufacturing system, either the performance of product design or the performance of production process. This leads to two types of FMEA, *Design* FMEA and *Process* FMEA respectively [Teng and Ho (1996)].

Ginn *et. al.* (1998) stated that while QFD is the guardian to the voice of the customer, FMEA is the guardian to the voice of the engineer. According to them, these two quality tools are tackling the same issue of customer satisfaction, but from different perspectives of positive and negative qualities which need to be taken into account equally, and within this product quality can be both exciting, high performing and robust simultaneously. This is agreed by Tan

(2003) who concluded from his modified FMEA which integrated the QFD to reflect the customers' desires in terms of the functional requirements of a product.

Recently, this tool has also attracted attention to the collaborative environment which can be used by all parties in the supply chain [Teng *et. al.* (2006)]. The term Failure Mode Avoidance (FMA) is currently used in place of FMEA. FMA provides a disciplined holistic approach to engineering which employs tools (including FMEA) and practices to ensure that all failure modes are discovered, and countermeasures developed and implemented in a timely and efficient manner [University of Bradford (2008)].

2.3.4 Design of Experiments (DOE) and Taguchi Method (TM)

Design of Experiments (DOE) is a technique introduced in 1920s by an English statistician, Sir R. A. Fisher to determine the optimum water, rain, sunshine, fertiliser, and soil conditions needed to produce the optimum crop [Roy (2001)]. DOE can be defined as a process for generating data that utilises a mathematically derived matrix to methodically gather and evaluate the effect of numerous parameters on a response variable [Fowlkes and Creveling (1995)].

Taguchi Method (TM), developed by a Japanese engineer, Genichi Taguchi is a modified form of DOE utilised in experimental strategy with special application principles [Roy (2001)]. A number of special orthogonal arrays is created in TM, each of which is used for a number of experimental situations, commonly eight, 16 or 18 experimental trials [Antony and Antony (2001)]. In TM, signal-to-noise ratio helps experimenters easily assure a design that is robust to the influence of uncontrollable factors and analyse the results of the experiments for the purpose determining the design solution that produces the best quality [Roy (2001)].

TM has been successfully applied in many areas of engineering, biological science and including physical science to compare the effects of multiple factors, together with their interactions simultaneously [Mohamed *et. al.* (2008)]. In comparison with a traditional DOE, TM provides a significant reduction in the size of experiment, which results in speeding up the experimental process [Mohamed *et. al.* (2008)].

2.3.5 Statistical Process Control (SPC)

Krajewski and Ritzman (2005) define Statistical Process Control (SPC) as a collection of tools used to determine whether a process is delivering parts which meet the specifications. The tools contained in SPC include flow, run and control charts, Pareto analysis, cause-and-effect diagrams, frequency histograms, acceptance sampling plans and scatter diagrams. Considered as a strategy to reduce variability and causes of most problems [Caulcutt (1996)], SPC is also a powerful technique used for continuously improving quality of products and processes [Antony *et. al.* (2000)].

Based on the recent results finding, Elg *et. al.* (2008) emphasise on four main factors: first, the need for top management support with respect to roles such as infrastructural assistance, mentor, critic, financer; second, creating system validity through the involvement of people with experiential knowledge about the applications of SPC; third, keeping a small, highly knowledgeable development team with appropriate expertise together during the whole process from beginning to end; and finally keeping the various end-users in focus but separating and prioritising between their different needs.

2.3.6 Quality Systems

The need for and fundamentals of a Quality System is described in Oakland (2003). A typical Quality System includes planning, management responsibility, policy establishment and implementation, organisation, role and responsibilities, procedures, process, design, communications, control and, documentation [Philpot (1998)]. An example of the most globally accepted Quality System is ISO 9000, which is a series of standards for quality management systems and maintained by the International Organization for Standardization (ISO) [International Organization for Standardization (2009)].

Many organisations are increasingly achieving ISO 9000 accreditation, with the aim of improving the quality of their products and services, and it be seen as crucial in the global business competition [Hallam (2005)]. As a common quality assurance system, ISO 9000 provides a framework in which it is ensured that customer's requirements are met, and periodical audit is performed to maintain the quality assurance.

2.4 Collaborative Lean Manufacturing Management

As reviewed by many researchers [Jones *et. al.* (1997), Bhasin and Burcher (2006), Dolcemascolo (2006), Abdulmalek and Rajgopal (2007)], Lean Manufacturing was conventionally thought of as only referring to manufacturing. Stress on manufacturing is understandable because JIT is an integral approach of automotive manufacturer's Toyota Production System, the foundation of this philosophy [Chase *et. al.* (2006)]. It should now be thought of more widely as collaborative Lean Manufacturing that includes not only the manufacturing process but also the value chain and supply chain from raw material suppliers to the end users [Dolcemascolo (2006), Nawawi *et. al.* (2007)].

Prior to that, MRP II and JIT have been integrated for companies that have a high variation product [Aghazadeh (2003)]. Many firms have integrated MRP II and JIT. While JIT reduces WIP inventory, MRP II provides a good master schedule and an accurate picture of requirement. Therefore, MRP II and JIT systems are not necessarily competing ways for production but can work effectively together [Aghazadeh (2003)].

In a previous study, Lee (1993) differentiates between MRP II and JIT by categorise MRP II as a priority-planning technique and JIT as an execution tool. In JIT system, only those materials that are actually needed on the factory floor are pulled, when they are needed. Lee (1993) describes a hybrid manufacturing system that incorporates the traditional MRP II system and the Japanese JIT system in a single framework, which attempts to integrate both MRP II and JIT production. The integrated hybrid system can provide better production planning, scheduling, and control. It employs the logic of MRP II and JIT, but it eliminates some of the inherent problems and drawbacks in both systems. MRP II and JIT each have benefits, and most major manufacturing firms use MRP II [Chase *et. al.* (2006)]. The integration of JIT and MRP II based planning and control system (MRPII/JIT) creates what might be considered a hybrid manufacturing system [Chase *et. al.* (2006)].

Figure 2.8 shows a hybrid MRPII/JIT production process control. A component of MRP II, an MPS is used at the end of production process to feed a

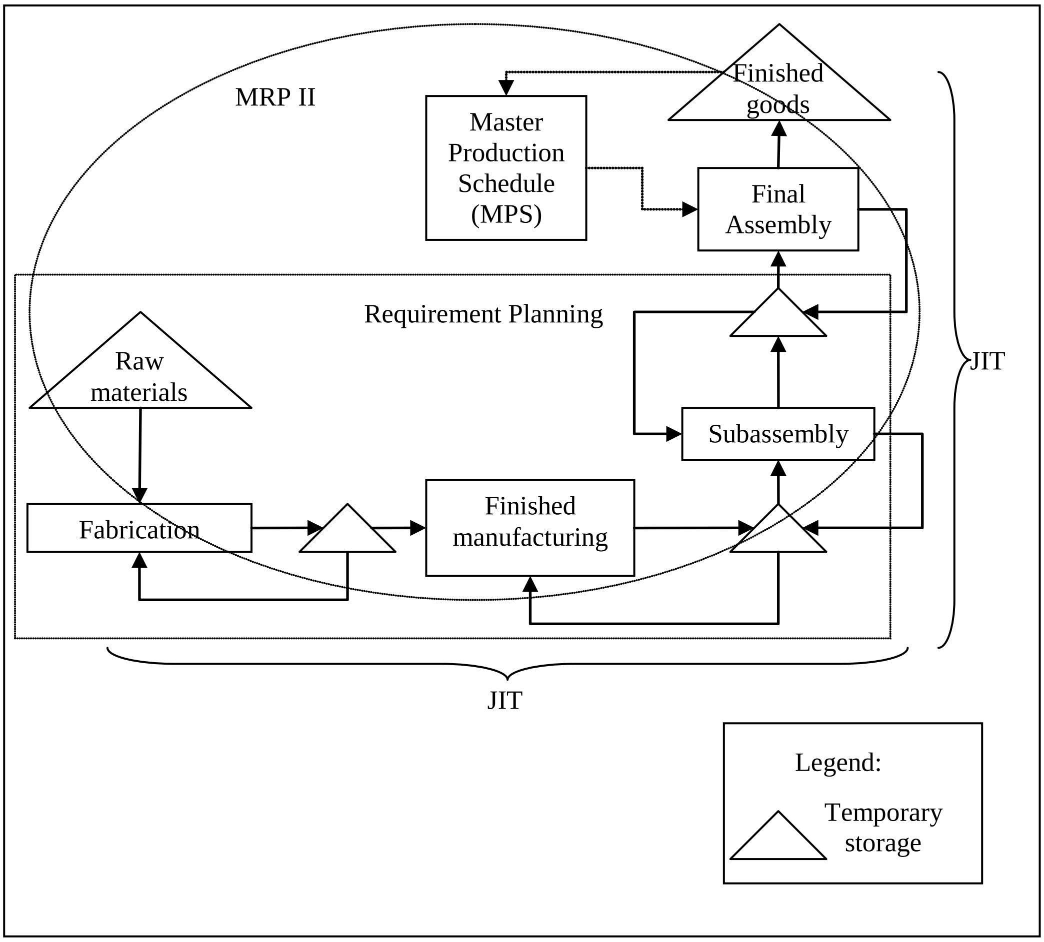

Figure 2.8: Production process control with integrated MRP II/JIT (adapted from Chase *et. al.* (2006))

JIT system. While the MPS feeds the Final Assembly information of items to be produced, the JIT portion operates as its own separate PULL method drawing from preceding stages. For example in this hybrid system, the Final Assembly process pulls materials from the Subassembly process and feeds information of material to be produces at the latter process through *kanban*, an element of JIT system.

Based from substantial research [Vuppalapati *et. al.* (1995), Cua *et. al.* (2001), Hokoma (2007)] on JIT and TQM, various dimensions constituting the planning and implementation of these two approaches were indentified. It can be concluded that JIT and TQM should be integrated and jointly implemented for CLMM to enhance the competitiveness of any organisation.

2.5 Summary

The literature review showed that much has been written on the subject of Lean Manufacturing Management, by many authors, both industrialists and academics, and spanning the globe. Although there are ideological differences between some of the authors, the similarities are much more than these differences. This chapter has provided a literature review of Collaborative Lean Manufacturing Management (CLMM) with its key elements of JIT, MRP II and TQM, the domain knowledge relevant to the work described in this thesis.