2.1 Introduction

The unprecedented surge in free market ideology all around the world is dramatically changing the competitive landscape. Customers expect multi-featured, high quality products at a low cost with speedy delivery. Organizations are responding with new customer initiatives by realigning resource allocation along more friendly, efficient and utilitarian lines. A mass-customization strategy creating an economy of scope through modular product architecture accommodates customer preferences has become more prevalent. Implementing innovative management concepts and harnessing the full potential of new technologies and strategies, like agile manufacturing, can only achieve these goals.

Agile manufacturing and agility were terms initially introduced by the Iacocca Institute study in 1991 and has been defined in a number of ways, but involves being able to respond quickly and effectively to the current and future configurations of market demand, and also to be proactive in developing and retaining markets in the face of extensive competitive forces (Bessant et al., 2001; Yusuf et al., 1999).

2.2 Agile manufacturing – Basis Concepts

Manufacturing systems have gone through major changes during recent years mainly due to two factors: (i) advances in technology, and (ii) advances in management
of the manufacturing systems. The advent of NC / CNC machines, automation, robotics, automated storage and retrieval systems (AS/RS), etc. have led to a greater dominance of technology in the present era of manufacturing. Along side, there had been major interventions during recent years in the areas related to adoption, deployment and management of the new technology. Flexible manufacturing systems (FMS), cellular manufacturing systems (CMS), computer integrated manufacturing systems (CIMS), agile manufacturing systems, quick response manufacturing systems (QRMS) etc. are some of the recent concepts in the design and management of advanced manufacturing systems.

In 1991, an industry-led study was accomplished under the auspices of the lacocca Institute at Lehigh University (USA). The objective of the study was to understand the characteristics that successful manufacturing companies would possess by the year 2006. The report of the study with over 100 US companies was titled “21st Century Manufacturing Enterprise Study”. In this report, the term “agile manufacturing” was coined to describe a new manufacturing paradigm that was recognized as emerging to replace mass production. Yusuf et al. (1999) have defined agility as follows: “Agility is the successful exploration of competitive bases (speed, flexibility, innovation, proactivity, quality, and profitability) through the integration of re-configurable resources, and best practices in a knowledge-rich environment to provide customer-driven products and services in a fast changing market environment.” Proposed research is aimed in the area of agile manufacturing.
As businesses enter the twenty-first century, the manufacturers have to cope up with an increasingly competitive environment. Among other things, the competitive environment is characterized by product proliferation with short and uncertain life cycles, innovative process technologies and, customers who simultaneously demand quick response, lower costs, and greater customization. To survive and prosper in this dynamic and uncertain competitive world, manufacturing systems must be able to react quickly and effectively to unanticipated changes. To accomplish this, manufacturing systems must possess extraordinary capabilities that synergistically include, and go beyond, those one finds in flexible manufacturing systems, lean production systems, and firms with mass customization strategies. The proponents of agility at the Iacocca Institute of Lehigh University, in the early 1990s, touted “agile manufacturing” as a new paradigm that possesses such capabilities (Iacocca Institute, 1991).

The four dimensions of agility as identified in the “21st Century Manufacturing Enterprise Study”, are: (i) organize to master change, (ii) leverage the impact of people and information, (iii) cooperate to enhance competitiveness, and (iv) enrich the customer. These four agility dimensions indicate that agile manufacturing involves more than just manufacturing. It involves the firm’s organizational structure, it involves the way the firm treats its people, it involves partnerships with other organizations, and it involves relationships with customers. Therefore, agile manufacturing 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 (Cho et al., 1996). Agile manufacturing is not about small-scale continuous improvements, but an entirely different way of doing business (Kidd, 1996).

A number of market forces can be identified that are driving the evolution of agility and agile manufacturing in business. These forces include: intensifying competition, fragmentation of mass markets, cooperative business relationships, changing customer expectations, increasing societal pressures etc. Companies seeking to be agile must organize their production operations differently than the traditional organization. To reorganize the production system for agility require changes in three basic areas (Groover, 2002):

(1) **Product Design**: The design department of a company has a crucial role and responsibility in imparting and improving the agility of a company. The design of the products shall be supportive to customization, up-gradation, re-configuration, modularity, frequent model changes, platforms for information and services.

(2) **Marketing**: In an agile manufacturing (AM) environment, the characteristics of the marketing function shall be: aggressive and proactive product marketing, cannibalize successful products, frequent new product introductions, life cycle product support, pricing by customer value, effective niche market competitor.
(3) **Production Operations:** From the production operations perspective, the following procedures work well for agility: (i) be a cost-effective, (ii) low volume producer, (iii) be able to produce to customer order, (iv) master mass customization, (v) use re-configurable and reusable processes, tooling, and resources, (vi) bring customers closer to the production process, (vii) integrate business procedures with production, (viii) treat production as a system that extends from suppliers through to customers, etc.

The general policies and practices that promote cooperation in relationships and, in general, promote agility in an organization include the following: management philosophy that promotes motivation and support among employees, trust-based relationships, empowered workforce, shared responsibility for success or failure, pervasive entrepreneurial spirit.

Yusuf et al. (1999) suggested 32 attributes, in 10 decision domains, of an agile manufacturing enterprise. The suggested attributes of agility are summarized in Table 2.1. The pathways and obstacles to achieving these attributes are important issues for consideration if progress is to be achieved in moving towards agility.
<table>
<thead>
<tr>
<th>S. No.</th>
<th>Decision domain</th>
<th>Related Attributes of Agile Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Integration</td>
<td>- Concurrent execution of activities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Enterprise Integration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Information accessible to employees</td>
</tr>
<tr>
<td>2</td>
<td>Competence</td>
<td>- Multi-venturing capabilities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Developed business practice difficult to copy</td>
</tr>
<tr>
<td>3</td>
<td>Team Building</td>
<td>- Empowered individuals working in teams</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Cross functional teams</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Teams across company borders</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Decentralized decision making</td>
</tr>
<tr>
<td>4</td>
<td>Technology</td>
<td>- Technology awareness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Leadership in the use of current technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Skill and knowledge enhancing technologies</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Flexible production technology</td>
</tr>
<tr>
<td>5</td>
<td>Quality</td>
<td>- Quality over product life</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Products with substantial value-addition</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- First-time right design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Short development cycle times</td>
</tr>
<tr>
<td>6</td>
<td>Change</td>
<td>- Continuous improvement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Culture of change</td>
</tr>
<tr>
<td>7</td>
<td>Partnership</td>
<td>- Rapid partnership formation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Strategic relationship with customers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Close relationship with suppliers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Trust-based relationship with customers/suppliers</td>
</tr>
<tr>
<td>8</td>
<td>Market</td>
<td>- New product introduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Customer-driven innovations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Customer satisfaction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Response to changing market requirements</td>
</tr>
<tr>
<td>9</td>
<td>Education</td>
<td>- Learning organization</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Multi-skilled and flexible people</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Workforce skill upgrade</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Continuous training and development</td>
</tr>
<tr>
<td>10</td>
<td>Welfare</td>
<td>- Employee satisfaction</td>
</tr>
</tbody>
</table>

Table 2.1: The Attributes of an Agile Organization (Source: Yusuf et al., 1999)
The various enabling technologies and management practices for agile manufacturing are provided in Table 2.2 (Source: Groover, 2002):

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Components of Agile Manufacturing Systems</th>
<th>Features of technology/ management system</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Enabling Management Practices</td>
<td>Concurrent Engineering, Manufacturing Resource Planning, Just-in-time Production Systems, Reduced Set-up and Change-over times, Shorter product development times to increase responsiveness and flexibility, Production based on orders rather than forecasts, Lean Production</td>
</tr>
</tbody>
</table>

**Table 2.2:** The enabling technologies and management practices of Agile Manufacturing (Source: Groover, 2002)

The various definitions, concepts and issues related to Agile Manufacturing (AM) as identified by various researchers are summarized in Table 2.3 and Table 2.4:

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Reference</th>
<th>Definitions of Agility and Agile Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Iacocca Institute (1991)</td>
<td>Agility means a manufacturing system with extraordinary capabilities (internal capabilities: hard and soft technologies, human resources, educated management, information) to meet the rapidly changing needs of the marketplace (speed, flexibility, customers, competitors, suppliers, infrastructure, responsiveness) among product models or between product lines (flexibility), ideally in real-time response to customer demand (customer needs and wants).</td>
</tr>
<tr>
<td>2</td>
<td>Goldman (1994)</td>
<td>Agility is a comprehensive strategic response to fundamental and irreversible changes that are taking place in the dominant system of commercial competition in “first world” economies.</td>
</tr>
<tr>
<td></td>
<td>Reference</td>
<td>Description</td>
</tr>
<tr>
<td>---</td>
<td>--------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>3</td>
<td>Goldman et al. (1995)</td>
<td>Agility is defined as means for delivering value to customers, being ready for change, valuing human knowledge and skills, and forming virtual partnership.</td>
</tr>
<tr>
<td>4</td>
<td>Kidd (1994)</td>
<td>Agility is a synthesized use of the developed and well known technologies and methods of manufacturing. That is, it is mutually compatible with lean manufacturing, CIM, TQM, MRP, BPR, and employee empowerment.</td>
</tr>
<tr>
<td>5</td>
<td>Booth (1996)</td>
<td>Agile manufacturing is a vision of manufacturing that is a natural development from the original concept of “lean manufacturing”. In lean manufacturing, the emphasis is on cost cutting. The requirement for organizations and facilities to become more flexible and responsive to customers led to the concept of “agile manufacturing” as a differentiation from the “lean organization”.</td>
</tr>
<tr>
<td>6</td>
<td>Cho et al. (1996)</td>
<td>Agile manufacturing 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.</td>
</tr>
<tr>
<td>7</td>
<td>Kidd (1996)</td>
<td>Agile manufacturing is not about small-scale continuous improvements, but an entirely different way of doing business.</td>
</tr>
<tr>
<td>8</td>
<td>Gould (1997)</td>
<td>Agility is about casting off those old ways of doing things that are no longer appropriate — changing patterns of traditional operation. In a changing competitive environment, there is a need to develop organizations and facilities to be significantly more flexible and responsive than current existing ones.</td>
</tr>
<tr>
<td>9</td>
<td>Devor et al. (1997)</td>
<td>Agile manufacturing is a new expression that is used to represent the ability of a producer of goods and services to thrive in the face of continuous change. These changes can occur in markets, in technologies, in business enterprise. It requires one to meet the changing market requirements by suitable alliances based on core competencies, organizing to manage change and uncertainty, and leveraging people and information.</td>
</tr>
<tr>
<td>10</td>
<td>Fliedner and Vokurka (1997)</td>
<td>Agility is defined as an ability to produce a broad range of low-cost, high quality products with short lead times in varying lot sizes, built to individual customer specification.</td>
</tr>
</tbody>
</table>
| 11| Gunasekaran (1999)             | • Agile manufacturing requires to meet the changing market requirements by suitable alliances based on core-competencies, organizing to manage change and uncertainty, and leveraging people and information.  
• Agile manufacturing is a vision of manufacturing that is a natural development from the original concept of “lean manufacturing”. |
• Agile manufacturing includes rapid product realization, highly flexible manufacturing, and distributed enterprise integration. Technology alone does not make an agile enterprise. Every company must find the right combination of culture, business practices, and technology that are necessary to make itself agile.

<table>
<thead>
<tr>
<th></th>
<th>Bullinger (1999)</th>
<th>Agility means mobility in an organization’s behavior towards the environment and can therefore be understood as an extensive answer to continually changing markets. Agile companies are in a process of constant re-determination, or self-organization, self-configuration, and self-teaming.</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Yusuf et al. (1999)</td>
<td>Agility is the successful exploration of competitive bases (speed, flexibility, innovation, pro-activity, quality and profitability) through the integration of reconfigurable resources and best practices in a knowledge-rich environment to provide customer-driven products and services in a fast-changing market environment.</td>
</tr>
</tbody>
</table>
| 13 | Katayama and Bennett (1999) | • Agility relates to the interface between the company and the market.  
• Agility acts as a pillar to improve competitiveness and the business prospects. |
| 14 | Christopher (2000) | Agility is defined as the ability of an organization to respond rapidly to changes in demand, both in terms of volume and variety. |
| 15 | Mason-Jones et al. (2000b) | Agility means using market knowledge and virtual corporation to exploit profitable opportunities in a volatile market place. |
| 16 | Van Hoek et al. (2001) | Agility is all about customer responsiveness and market turbulence and requires specific capabilities that can be achieved using 'lean thinking'. |
| 17 | Aitken et al. (2002) | Agility is an ability to have visibility of demand, flexible and quick response and synchronized operations. |

Table 2.3: Definitions of Agility and Agile Manufacturing
<table>
<thead>
<tr>
<th>S. No.</th>
<th>Reference</th>
<th>Concepts and Issues related to Agile Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Iacocca Institute (1991)</td>
<td>The four dimensions of AM as identified in the “21st Century Manufacturing Enterprise Study”, are: (i) organize to master change, (ii) leverage the impact of people and information, (iii) cooperate to enhance competitiveness, and (iv) enrich the customer.</td>
</tr>
<tr>
<td>3</td>
<td>Gupta and Nagi (1995)</td>
<td>Partner selection is one of the most important activities in agile enterprise. Selecting manufacturing partners in AM is an endeavour that is worried with the complexity and dynamic of the market driven by customer needs as well as the inherent subjectivity of the selection process. Traditional vendor selection methodologies do not lend themselves as a ready solution to these needs of agile environment.</td>
</tr>
<tr>
<td>4</td>
<td>Abair (1997)</td>
<td>Agile manufacturing requires customer integrated multidisciplinary teams, supply chain partners, flexible manufacturing, computer-integrated information systems, and modular production facilities.</td>
</tr>
</tbody>
</table>
| 5     | Talluri et al. (1999) | • Network organizations (NOs), virtual corporations (VCs), and value-adding partnerships (VAPs) are envisioned by many experts as the solution for rapid introduction of a variety of products while maintaining high quality and low costs.  
• A key factor, emphasized by researchers, in forming the Value Chain Network (VCN) is the selection of agile, competent, and compatible partners. Therefore, not only is there a need for strong compatibility among the participants, but more importantly they need to be very efficient in what they contribute individually and as a group. The partner selection process is therefore critical in the formation of a value chain network (VCN). |
| 6     | Gunasekaran (1999) | • Agility should be in all areas of manufacturing to effectively respond to changing market requirements. Achieving agility therefore requires flexibility and responsiveness in strategies, technologies, people and systems.  
• Agile manufacturing itself is a strategy. To achieve this, several sub-strategies are needed including virtual enterprise, rapid-partnership formation, rapid prototyping, and temporary alliances based on core competencies. Without suitable strategies, technologies and systems alone not sufficient to achieve agility. |
• Partnership formation based on core-competencies and temporary alliances facilitate agility in manufacturing.
• Agility in supply chain can be achieved by integrating organizations, people, and technology into a meaningful unit by deploying advanced information technologies and flexible organizational structures to support highly skilled, knowledgeable, and motivated people.
• A methodology for evaluating potential partners for agile enterprises based on core-competencies and market forces needs to be developed. Criteria for selecting partners of agile enterprise should be identified with the help of suitable conceptual and empirical research.
• In AM environments, prequalifying partners, evaluating a product design with respect to the capabilities of potential partners, and selecting the optimal set of partners for the manufacture of a certain product are important. A decision support system for design evaluation and partner selection in AM needs to be developed.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Gunasekaran and Yusuf (2002)</td>
<td>AM highlights the development of dynamic capabilities, the strategic use of new technologies, the integration of strategies and operations, customer satisfaction through new forms of interfirm cooperation and knowledge management.</td>
</tr>
<tr>
<td>9</td>
<td>Guisinger and Ghorashi (2004)</td>
<td>An agile company can be defined as an enterprise that is capable of operating profitably in a competitive environment of continually, and unpredictably, changing customer opportunities.</td>
</tr>
<tr>
<td>10</td>
<td>Gupta and Gunasekaran (2005)</td>
<td>Organizations are trying to become agile enterprises with the help of strategic alliances of firms and integration using information technologies.</td>
</tr>
<tr>
<td>11</td>
<td>Lau et al. (2005)</td>
<td>Partner selection becomes a major process of business operation. In order to maintain profit in an increasingly complex business environment, it is very important to select a partner/suppliers appropriately.</td>
</tr>
<tr>
<td>12</td>
<td>Va’zquez-Bustelo and Avella (2006)</td>
<td>As the concept of agile manufacturing is at the developmental phase, it has been surrounded by considerable confusion.</td>
</tr>
</tbody>
</table>
A transformation has been observed in “traditional” production models leading to a new production paradigm linked to agility. The interest of agile manufacturing for firms has been widely disseminated, however, its relation with performance has not been empirically validated. Therefore, attempts shall be to analyze the drivers, practices and results of agility in order to offer an initial approach to agile manufacturing.

| 13 | Narasimhan et al. (2006) | Production is agile if it efficiently changes operating states in response to uncertain and changing demands placed upon it. |
| 14 | Baker (2007) | The agility of a firm comes from a number of areas, such as product development, manufacturing and logistics. |

Table 2.4: Concepts and Issues related to Agile Manufacturing

There are two different types of relationships that should be distinguished in the context of agility (Groover, 2002):

1. Internal relationships, and
2. External Relationships i.e. relationships between the company and other organizations (including a concept of virtual enterprise).

The two main reasons to manage these external relationships are:

1. to provide rapid identification and certification of suppliers.
2. to encourage rapid partnership formation for mutual commercial advantage (gives rise to a concept of virtual corporation)

This research work shall mainly concentrate on these external relationships.

2.3 Sphere of Agile Manufacturing

AM emphasizes for agility in operations and business functions of a manufacturing company. As agility could not be successfully achieved in isolation, AM considers:
Although, sometimes the concept of supply chain agility and virtual corporation is regarded interdependent as virtual corporations also forms a means to bring agility in supply chains (Bal, et al., 1999). The main difference between the two is regarding the nature and focus of relationships among the partners / Virtual Constituent Companies (VCCs). The supply chain represents a relatively static relationship whereas virtual corporation represents a dynamic relationship among the partners / VCCs (Cagliano et al., 2004). However, the issue common to both the supply chain and virtual corporation in regard to agility is the selection of agile and competent suppliers (Talluri et al., 1999). The thrust of this research is to develop methodologies / framework for such a selection.

2.3.1 Supply Chain Agility

In order to be competitive, the companies have to align with suppliers, suppliers’ suppliers, customers and customers’ customers. This whirlpool of suppliers and customers has been termed as Supply Chain. For a company to be agile, its supply chain partners must also be agile (van Hoek et al., 2001).

Agile supply chain enables to provide each company in the chain with better and timelier information about orders, new products, and special needs. It helps all members of the chain, to shorten work cycle by removing the obstacles to time compression that
one company often unwillingly impose on another. It synchronizes lead times and capacities among the levels of supply chain so that more work can flow in a coordinated fashion up and down the chain (Lau et al., 2003).

The frameworks for introducing agility in supply chains such as those proposed by Van Hoek et al. (2001), Christopher (1998, 2000) and Harrison et al. (1999) consist of a holistic view through practices and application of concepts such as lean thinking, rapid replenishment and postponed fulfillment, organizational agility, quick response, decoupling and postponement. Sharifi et al. (2006) presented a conceptual framework which addresses the issue of developing agile supply chains. It proposed an approach which integrates aspects relating to product development and supply chain development while interacting with factors such as the market place dynamics, supply chain dynamics, business environment, technology, as well as with each other to support the dynamic characteristics of agile supply chains. Yusuf et al. (2004a) have presented a conceptual model for assessing the capability of an agile supply chain, which consists of four dimensions: value chain practice, competitive objectives, impact of change drivers, and business performance.

The success and failure of supply chains are ultimately determined in the market place by the end consumer. Getting the right product, at right price, at the right time, to the customer is not only the lynch pin to competitive success but also the key to survival. Hence customer satisfaction and market place understanding are crucial elements for consideration when attempting to establish a new supply chain strategy (Helo, 1999).
The rapid and concurrent development of low cost information systems has become key in the management of the supply chain through such technologies like CAD, CAM, EDI (Electronic Data Interchange). Recent developments in telecommunications have further enabled instantaneous and global networks, supporting the notion of real time development, production, marketing and servicing of product (Lau et al., 2003). Agile manufacturing requires a responsive supply chain in order to compress the lead time to ease the flow of material, resources and information. It develops low cost information system and removes obstacles in time and location.

The various definitions, concepts and issues related to supply chain and its agility as identified by various researchers are summarized in Table 2.5:

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Reference</th>
<th>Definitions, Concepts and Issues related to Supply Chain and its Agility</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lee and Billington (1992)</td>
<td>A supply chain is a network of facilities that performs the functions of procurement of material, its transformation to intermediate and finished products, and its distribution to end customers.</td>
</tr>
<tr>
<td>2</td>
<td>Harland (1996)</td>
<td>Supply Chain Management may be defined as managing business activities and relationships (1) internally within an organization (2) with immediate suppliers (3) with first and second tier suppliers and customers along the supply chain, and (4) with the entire supply chain.</td>
</tr>
<tr>
<td>3</td>
<td>Towill (1997)</td>
<td>A seamless supply chain is a lean enterprise, which operates with minimum entropy. All the players think, communicate, and act as one so that the total chain benefits through achieving a high customer service level.</td>
</tr>
<tr>
<td>4</td>
<td>Narasimhan and Das (1999)</td>
<td>A key determinant of the ability of supply chain to make rapid changes is the selection, development and integration of suppliers with appropriate capabilities.</td>
</tr>
</tbody>
</table>
The businesses in the agile supply chain must be able to cope with market demand and they should also be able to exploit its volatility for their strategic advantage.

To be truly agile, a supply chain must possess a number of distinguishing enable-attributes such as marketing / customer sensitivity, cooperative relationships, process integration, and information integration.

Agile supply chain requires minimum total lead-times defined as the time taken from a customer raising a request for a product or service until it is delivered.

The management of agile supply chain uses technology to promote productivity, new product development and customer satisfaction.

The agile chain has a stronger impact on competitiveness because it enables mobilization of global resources to track evolving changes in technology and material development as well as market and customer expectations.

The idea of agility in the context of supply chain management focuses around “responsiveness”.

Alignment between the type of product and the type of supply chain is important, and significant for delivery speed, delivery dependability, and cost performance.

<table>
<thead>
<tr>
<th></th>
<th>Mason-Jones et al. (2000a)</th>
<th>The businesses in the agile supply chain must be able to cope with market demand and they should also be able to exploit its volatility for their strategic advantage.</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Christopher, 2000; Goldman et al., 1995; van Hoek et al., 2001</td>
<td>To be truly agile, a supply chain must possess a number of distinguishing enable-attributes such as marketing / customer sensitivity, cooperative relationships, process integration, and information integration.</td>
</tr>
<tr>
<td>7</td>
<td>Christopher and Towill (2000)</td>
<td>Agile supply chain requires minimum total lead-times defined as the time taken from a customer raising a request for a product or service until it is delivered.</td>
</tr>
<tr>
<td>8</td>
<td>Power et al. (2001)</td>
<td>The management of agile supply chain uses technology to promote productivity, new product development and customer satisfaction.</td>
</tr>
<tr>
<td>9</td>
<td>Yusuf et al. (2004a)</td>
<td>The agile chain has a stronger impact on competitiveness because it enables mobilization of global resources to track evolving changes in technology and material development as well as market and customer expectations.</td>
</tr>
<tr>
<td>10</td>
<td>Christopher et al. (2004)</td>
<td>The idea of agility in the context of supply chain management focuses around “responsiveness”.</td>
</tr>
<tr>
<td>11</td>
<td>Selldin and Olhager (2007)</td>
<td>Alignment between the type of product and the type of supply chain is important, and significant for delivery speed, delivery dependability, and cost performance.</td>
</tr>
</tbody>
</table>

Table 2.5: Definitions, Concepts and Issues related to Supply Chain and its Agility

2.3.2 Virtual Corporation (VC)

Continuing competition and regional economic pressures have forced many industrialists to reconsider the way their manufacturing operations are carried out. Today’s market demands a new kind of product that delivers instant customer satisfaction in a cost-effective way. An isolated facility of production cannot provide such product. It
has to be a VC, a temporary network of companies that come together quickly to exploit fast-changing opportunities (Tsuchiya and Tsuchiya, 1999).

The Intelligent Manufacturing Systems (IMS) project (IMS, 1996) defines the virtual enterprise as the next generation of manufacturing enterprise, which consists of a globally distributed assembly of autonomous work units linked primarily by the goal of profitably serving specific customers and operating in an environment of abrupt and often unanticipated change. The agile company uses virtual enterprise to form temporary alliances in order to make a specific product for a specific period of time, and then dissolve these alliances as the participants move on (Handley, 1997). VCs are suitable for Agile Manufacturing as it requires the development of a system that embraces virtual design, virtual manufacturing, virtual assembly and virtual distribution.

VCs are generally defined as a way of organizing business activities, where different and independent partners, termed in this research as Virtual Constituent Companies (VCCs), exploit business opportunity by establishing a corporation. Business opportunities within the VC may create a new VC comprising a team of partners with the common interest of timely manufacture and delivery of the right quantity product to the customers (Lau and Wong, 2001). In fact the fast growing internet technology does provide the catalyst for the emergence of VCs.

The formation and functioning of a VC involves the following two main issues:
(1) Selection of VCCs / suppliers of the required categories (design / manufacturing / distribution) and capabilities.

(2) Allocation of jobs to different plants in geographically dispersed regions according to the relative strengths and core competencies of each plant.

The other related issues to be taken into account for the proper formation and functioning of a VC are as follows:

(1) Communication flow among clients and partners

(2) Matching customer requirement with supplier capabilities from a supplier/partner database

(3) Agents for identifying and ranking suppliers

(4) Scheduling workflow in different enterprises

(5) Coordinating and monitoring business practices and electronic commerce

To establish such a network system requires the resolution of several technical issues such as communication technology, operational platform and network management as well as data security (Goldman et al., 1995).

The various definitions, concepts and issues related to VC as identified by various researchers are summarized in Table 2.6 and Table 2.7:
### Definitions of Virtual Corporation

<table>
<thead>
<tr>
<th>S. NO.</th>
<th>Reference</th>
<th>Definitions of Virtual Corporation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Abair (1995)</td>
<td>A virtual organization is the integration of core competencies distributed among a number carefully</td>
</tr>
<tr>
<td></td>
<td></td>
<td>chosen but real organizations all with similar supply chain focusing on quick to market, cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>reduction and quality.</td>
</tr>
<tr>
<td>2</td>
<td>Tuma (1998)</td>
<td>Virtual enterprises can be interpreted as a certain kind of an intermediate organizational form</td>
</tr>
<tr>
<td></td>
<td></td>
<td>between the institutional poles: market and hierarchical structured enterprises.</td>
</tr>
<tr>
<td>3</td>
<td>Talluri et al.</td>
<td>Virtual corporations (VCs) are an alliance of independent business processes or enterprises each</td>
</tr>
<tr>
<td>(1999)</td>
<td></td>
<td>contributing “core competencies” in areas such as design, manufacturing, and distribution to the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>corporation.</td>
</tr>
<tr>
<td>4</td>
<td>Nikolenko and</td>
<td>The virtual corporation represents a temporary network of independent companies that “come together</td>
</tr>
<tr>
<td></td>
<td>Kleiner (1999)</td>
<td>quickly to exploit fast changing opportunities”.</td>
</tr>
<tr>
<td>5</td>
<td>Browne and Zhang</td>
<td>A virtual enterprise is a temporary consortium of independent member companies and indeed individuals,</td>
</tr>
<tr>
<td>(1999)</td>
<td></td>
<td>who come together to exploit a particular market opportunity.</td>
</tr>
<tr>
<td>6</td>
<td>Stough et al.,</td>
<td>Virtual organizations are usually a temporary group of independent companies formed to exploit a</td>
</tr>
<tr>
<td></td>
<td>2000</td>
<td>specific opportunity. They may be suppliers, manufacturers, marketers, customers, and even</td>
</tr>
<tr>
<td></td>
<td></td>
<td>competitors.</td>
</tr>
<tr>
<td>7</td>
<td>Presley and Liles</td>
<td>Virtual Enterprise is a temporary alliance of member companies joining together to take advantage</td>
</tr>
<tr>
<td>(2001)</td>
<td></td>
<td>of a market opportunity with each member company provides its own core competencies in areas such as</td>
</tr>
<tr>
<td></td>
<td></td>
<td>marketing, engineering, and manufacturing to the VE.</td>
</tr>
</tbody>
</table>

Table 2.6: Definitions of Virtual Corporation

### Concepts and Issues related to Virtual Corporation

<table>
<thead>
<tr>
<th>S. NO.</th>
<th>Reference</th>
<th>Concepts and Issues related to Virtual Corporation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pant et al. (1994)</td>
<td>Agile manufacturing is considered by many as relating to the vision of virtual corporations</td>
</tr>
<tr>
<td>2</td>
<td>Bloch and Pigneur (1995)</td>
<td>Some of the driving forces that drive companies to adopt the virtual enterprise paradigm as:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• an increased focus on core competences, which means that companies concentrate on what they do best and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>outsource the rest of their activities;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• an increased need for partnering, to cope with the extremely high levels of complexity involved in the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>lifecycle engineering of products in some areas;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• market forces requiring more agile systems owing to the shortening product life cycle.</td>
</tr>
</tbody>
</table>

30
<table>
<thead>
<tr>
<th></th>
<th>Author(s)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Presley et al. (1995)</td>
<td>Identified a major issue in the formation of the virtual enterprise (VE) as the rapid integration of the business processes of the participating companies and the solution to the successful attainment of the business goals of the virtual enterprise often depends on its ability to align the business processes and practices of partner enterprises. A major facilitator to this integration is the use of process models to assist in the design of the VE.</td>
</tr>
<tr>
<td>4</td>
<td>Daniels (1998)</td>
<td>The virtual corporation should naturally be smaller (in terms of permanent employee numbers) than its more traditionally organized competitor. It is also likely to have a flatter organisation structure. This reduction in the layers of management helps communication and improves the flexibility.</td>
</tr>
<tr>
<td>5</td>
<td>Kornelius and Wamelink (1998)</td>
<td>For a virtual corporation, the main problem lies in the fact that many of its participants work in several projects simultaneously, and set their own priorities regarding the use of capacity and/or materials.</td>
</tr>
<tr>
<td>6</td>
<td>Kim (1998)</td>
<td>A virtual organization must have a new vision, a common goal among companies, dependable suppliers, and customers in a trust-based relation.</td>
</tr>
<tr>
<td>7</td>
<td>Tuma (1998)</td>
<td>The objective for establishing “virtual production” or “virtual enterprise” is a certain kind of “Best of everything Organization” by a synergetic combination of core competencies of single partners (centers of competence) in order to perform a given business project to a maximum degree of customer satisfaction.</td>
</tr>
</tbody>
</table>
| 8 | Browne and Zhang (1999)   | - Virtual enterprise companies assemble themselves based on cost-effectiveness and product uniqueness without regard to organisation size, geographic location, computing environments, technologies deployed, or processes implemented.  
- Virtual enterprise companies share cost, skills, and core competences which collectively enable them to access global markets with world class solutions that could not be provided by any one of them individually. |
<p>| 9 | Gunasekaran (1999)        | The agile enterprise requires Virtual Manufacturing (VM) to respond to changing market requirements quickly. VM environments are being proposed to improve their responsiveness, improve product and process design, reduce manufacturing risks, improve manufacturing design and operation, support manufacturing system changes, enhance product service and repair, increase manufacturing understanding, and provide a vehicle for manufacturing training and research. |</p>
<table>
<thead>
<tr>
<th></th>
<th>Author(s)</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Mason-Jones and Towill (1999)</td>
<td>Agility is only enabled by adopting the “information enriched” supply chain in which both information and material flow lead times are slashed. The result is a structural supply chain which uses market knowledge and a virtual corporation to exploit profitable opportunities in a volatile marketplace.</td>
</tr>
<tr>
<td>11</td>
<td>Tsuchiya and Tsuchiya (1999)</td>
<td>Today’s market demands a new kind of product that delivers instant customer satisfaction in a cost-effective way. An isolated facility of production cannot provide such product. It has to be a virtual corporation, a temporary network of companies that come together quickly to exploit fast-changing opportunities.</td>
</tr>
<tr>
<td>12</td>
<td>Nikolenko and Kleiner (1999)</td>
<td>Some of the key attributes of the virtual corporation are technology, opportunism, excellence, and no borders.</td>
</tr>
<tr>
<td>13</td>
<td>Talluri et al. (1999)</td>
<td>VCs are formed in the event of a market opportunity and are dissolved when the opportunity passes and do not own any of the individual business processes that design, produce, and market the product.</td>
</tr>
<tr>
<td>14</td>
<td>Tsuchiya and Tsuchiya (1999)</td>
<td>A virtual corporation has no hierarchy, no vertical integration, and teams of people in different companies routinely work together, concurrently rather than sequentially, via computer networks in real time.</td>
</tr>
</tbody>
</table>
| 15| Nikolenko and Kleiner (1999)                   | • Within a virtual corporation, companies can share costs, skills, and access to global markets with one another, with each contributing to the common goal “what it is best at”.  
• The use of the term “virtual” comes from the computer industry, where “virtual memory” is used to make a computer act as if it has more storage capacity than it really does. Similarly, the virtual corporation appears to be a single firm with vast capacities, when in reality it is a collection of many smaller firms that work together to achieve a specific goal. |
| 16| Stough et al., 2000                            | • Since companies often lack expertise or resources in all areas, the virtual organization (and virtual teams) are formed.  
• Examples of well known corporations that are taking advantage of virtual organizations are Verifone, Hewlett Packard, IBM, AT&T, McDonald’s, Whirlpool, Toyota, Nokia, Nike, Reebok, Intersolve Group, and Apple Computer. |
An emerging organizational form described within agile manufacturing is the virtual enterprise (VE). The VE differs from existing inter-organizational models by the degree of shared accountability and responsibility of the participants and the structure by which companies contribute their competencies through “plug compatible” processes.

- The agility associated with such (virtual organizations) fluid and flexible organisational forms is key to providing efficient and effective response to increasingly sophisticated customer demands.
- Virtual corporations are frequently linked with organisational agility.

Moving from a strategy of full in-house manufacture towards one of virtual manufacturing may offer a means of reducing investment and increasing agility.

- Most definitions of virtual manufacturing incorporate the idea of extensive outsourcing to suppliers and subcontractors in order to achieve a flexible, responsive network-based organisation.

The five most prevalent agile practices in the specialty chemical industry can be summarized as, entering niche markets through custom chemicals manufacturing, improving relationships with suppliers (also, a lean manufacturing practice), formation of strategic partnerships, adaptation of advanced technology/research, and the emergence of “virtual” firms.

The benefits of virtual teams, particularly time savings, are a natural fit for an agile manufacturer.

Table 2.7: Concepts and Issues related to Virtual Corporation

2.4 Agile Manufacturing Enabling Technologies

The right mix of technology can make the organization more flexible in the design and manufacture of products. There are five fundamental reasons to adopt technology to enhance agility (Montgomery and Levine, 1996):
(1) Reduces the product development time to market (2) Reduces the product delivery time to market (3) Improves workforce capabilities and flexibility (4) Enhances the flexibility of the production facilities (5) Improves understanding and control of production processes.

Agile technology is appropriate when it fits within a well-understood operational concept that consistently supports flexibility, level production flow, and short cycle times. Agile manufacturing technology should be adopted only when an organization understands how the technology will be used within its business processes to enhance agility. It should not be purchased simply as a stimulus for becoming agile. Otherwise the organization will run the risk of causing major work disruption within existing production systems.

The various examples of technology that can enhance agility in manufacturing / production systems are (Groover, 2002; Jin-Hai et al., 2003):

2.4.1 Group Technology / Cellular Manufacturing Systems (GT/ CMS)

The wastage of time occurs due to the multiplicity of machines used to do the various operations and the segregation of different machines necessitating transport. While one can reduce the former difficulty by having more general purpose machines, the latter difficulty can be approached through the Group Technology (GT) type of layout and a good material handling system like Automated Guided Vehicle Systems (AGVS), Automated Storage and Retrieval Systems AS/RS. Babu et al., 2000 defined Group technology (GT) as an important technique in the planning and control of manufacturing
systems that allows the advantage of flow production/lean production in the jobbing or batch manufacture. GT uses a family of parts’ concept where parts are grouped according to their commonalities of features such as shape, size, tolerance, finish, material, and the required operations. For a ‘family’, a ‘composite component’ can be envisaged which has all the necessary features of all the members of the family. The machines which together can produce this composite are grouped physically to form a cell. Since this cell or group can produce the composite, the actual parts can be produced by leaving out particular operations not applicable to a part.

This concept of physically dividing the factory into smaller units is certainly appealing to large manufacturing units from the viewpoint of enhancing their agility (Babu et al., 2000).

GT application results in:

(1) reduced item handling/movement times;
(2) reduced change-over times;
(3) reduced idle wait time of items at the machine; and
(4) reduced work-in-progress.

All this results in considerable improvement per unit time and of course reduced in-process inventories. Yazici (2005) empirically investigated the benefits of cellular manufacturing in a dispersed manufacturing environment and made the following observations: As volume flexibility increases, delivery is faster in presence of cellular manufacturing compared to job shop. Furthermore, added routing flexibility results in 70 percent shorter lead time with low volume flexibility, and 85 percent shorter lead time
with high volume flexibility. Additionally, in the two-cell design, assignment of fewer, but more multi-skilled workers shared between cells results in higher utilization and lower lead time. However, CMS have some disadvantages too (Balakrishnan and Cheng, 2007), such as lower machine utilization due to their dedication, requirement of effective training to operate cells effectively. Moreover, when system uncertainty is present and product life cycles are short, cell reconfiguration may be an issue.

Babu et al. (2000) introduced the concept of virtual cellular manufacturing systems (VCMS) which is finding acceptance among researchers and practitioners as an extension to group technology. These virtual cells are in fact conceptual cells formed in the computer software and do not actually exist on the shopfloor. The formation of these cells will be subjected to change as and when required depending on the business, technological and operational environment under which the enterprise functions.

2.4.2 Flexible Manufacturing System (FMS)

Nowadays, there is an increase in the deployment of automated manufacturing equipment and systems that provide the agility and efficiency to cope with the rapidly changing market and customer needs. In general, a modern manufacturing system usually comprises a large amount of specialized equipment, including machine centers, instrumentation, computers, material-handling devices, storage units, communication networks, etc. (Lau and Mak, 2004). Such modern manufacturing systems employing advanced manufacturing technologies (AMTs) are broadly termed as “Flexible Manufacturing Systems” (FMS). However, the literature generally supports the view that
AMT is not the only way to achieve the different types of flexibility. Narain et al. (2000) discussed ways to achieve the various flexibilities.

If the machine tools feature NC or CNC technology, it gives tremendous flexibility to the operations and numerous parts in the ‘family’ using group technology concept can be addressed with no change-overs. For a flexible and efficient manufacturing system which could address a diverse requirement, the availability of a suitable material handling system is very important. When the material handling function between machines in such a GT cell is brought under computer control, we have a Flexible Manufacturing System (Fan and Wong, 2003; Shamsuzzaman et al., 2003; Keung et al., 2001). Thus an FMS generally has the following three components:

1. CNC machine tools;
2. Computer controlled material handling system e.g. AGVS and AS/RS; and
3. Supervisory computer control network.

However, FMS are generally used to market new products, a manufacturer needs to decide on a suitable scheduling strategy due to shorter and shorter product life cycles. This necessitated improving the learning accuracy for FMS scheduling with incomplete and insufficient data sets generally associated with such new and innovative products at an early stage (Li et al., 2007). Production involving an intermediate range of variety and an intermediate amount of volume are suitable through FMS.
2.4.3 Information Technology (IT)

There is a concept known as the IT paradox – where many senior managers in organizations recognize the worth of an effective information systems/services (IS) function but few truly understand its potential role and contribution in enhancing business value (Morgan, 2004). Recent developments in information technology such as the Internet, enterprise resources planning systems and knowledge management systems necessitate the use of these technologies in order for the next generation manufacturers to co-evolve and survive on the new business landscape (Soliman and Youssef, 2001).

The impact of IT not only can improve productivity and quality of production, and service activities, but also enable enterprises to intelligently alter themselves. Through IT the enterprises now collaborate each other to accommodate various customers’ demand, changes in tastes, design, time and quality while keeping the cost at a reasonable level (Lau and Wong, 2001). Such enterprises are hence termed agile enterprises.

Jiao et al. (2007) credited the adoption and success of e-manufacturing to the availability of advanced information systems. An obvious premise is that without information technologies, enterprise agility at all the enterprise levels would be impossible (Barad and Nof, 1997). Consider for instance, how information technologies improve enterprise activities in the following examples:

(1) Design: Powerful computation speeds up activities in enterprises. e.g.: CAD
(2) Decisions: Powerful computation allows many simulation trials to find a better solution in decision making.

(3) Sensing: Input devices can gather and communicate environmental information to computers or humans.

(4) Recovery: Computer system may apply technologies of artificial intelligence to improve quality of activities.

(5) Collaboration: Distributed designers can work together in a common design project through a computer supported collaborative work (CSCW) software system.

(6) Partners: A computer system in an organization may automatically find cooperative partners from the internet to fulfill a customer order, without any increase in the organizational capacity.

(7) Logistics: Logistics flows of products and packages are monitored and maintained by networked computation.

It is clear that design, decisions, sensing, recovery, collaboration, partners and logistics have major role in enhancing agility in organizations (Chin-Yin and Shimon, 1999; Baker, 2007). IT also plays a major role in the new product development process which is characteristic of agile manufacturing (Durmusoglu et al., 2006).

For effective production control in agile manufacturing environment, manufacturing information system must access a number of data sources including number of independent computer packages, preparatory data base system and test equipments. Because of the languages and differences in the skills available there is a need to establish a communication network for exchange of information on various
production/operation achieved through advance information technologies like multimedia, internet, EDI (Jagdev and Browne, 1998). The information system should support the following objectives in an agile environment (Cho et al., 1996; Duffie and Prabhu, 1996):

Openness - reliance on published and widely implemented interface protocols so that any one can use and offer services through agile infra structure for manufacturing systems, including the services that enhance the structure itself.

Scalability – The ability to access services across the shop floor or around the world using the same protocols.

Extendibility and graceful degradation – the services can be added, removed or substituted at any time with incremental changes in performance.

Compatibility – With legacy systems through encapsulation.

2.4.4 Rapid-Prototyping (RP)

In the present competitive environment, the manufacturers are facing immense pressures to provide a greater variety of complex products in shorter period of time. This requires innovative techniques from concept to design to prototyping to manufacture of the products at reduced costs and improved quality. Rapid Prototyping (RP) represents technologies that quickly realize the conceptualization of a product design. The evolution of RP allows obtaining parts representative of mass production products within a very short time (Ferreira et al., 2006). RP process typically involves generating a 3D CAD model of a part in stereolithography (STL) format for using layer manufacturing
technology (LMT). A number of RP processes have been developed and they vary mainly in the forming materials employed (Choi and Samavedam, 2001).

The advantages of rapid prototyping include the following:

(1) Using RP the end product could be manufactured. Otherwise, the prototype developed through RP could be used as a guide for evaluating the operations to be involved in the manufacture of the end-product through conventional manufacturing processes. Thus, RP serves as an important manufacturing technology.

(2) Rapid prototyping serves as an important tool for visualization and for concept verification with the development of physical models of parts produced from CAD data files. Using RP such physical models could be manufactured in a matter of hours and could be used for a quick evaluation of the design effectiveness and manufacturability of the end-product.

(3) Rapid prototyping operations can be used in some applications to produce tooling for manufacturing operations. In this way, one can obtain tooling in a matter of a few days.

Hopkinson and Dickens (2001) made a cost-benefit analysis of: (1) Using RP for developing prototypes only, and manufacturing the end-use products using conventional methods, or (2) Using RP for manufacturing the end-use products, and observed that despite high cycle times, materials costs and capital equipment for RP compared to general processes such as injection moulding, use of RP could be justified for
manufacturing end-use products in high or medium volumes through zero tool costs, reduced lead times and considerable gains in terms of freedom in product design and production schedules associated with RP.

2.4.5 Virtual Prototyping (VP)

Virtual Prototyping (VP) attempts to replace the user’s perception of the surrounding world with an artificially generated 3D environment using virtual reality (VR) techniques. By adopting VP, the duration and cost of prototyping are reduced greatly and the modification of the design can be performed in a very fast, economic and efficient manner. VP is generally used for preliminary analysis of functionality, assembly design and ergonomics of the end-product without investing into the manufacture of a physical prototype (Pang et al., 2006; Ferreira et al., 2006).

The simplest forms of such systems use complex software and 3-D graphics routines to allow viewers to change the view of parts on a computer screen. More complicated versions will use virtual-reality headgear and gloves with appropriate sensors, to let the user observe a computer-generated prototype of the desired part in a completely virtual environment.

In a way, this technology is used by CAD packages to render a part, so that the designer can observe and evaluate the part as it is drawn. However, virtual prototyping systems should be recognized as extreme cases of rendering detail.
2.4.6 Design for Manufacture, Assembly, Disassembly, and Serviceability

Design and manufacturing are regarded as the two most important and crucial activities of any organization. In order to agile manufacture the products, these two disciplines shall be regarded as intimately interrelated. It’s the design of the product that defines the ease or difficulty in manufacturing a product. The more the compatibility of the product design to manufacturing the better it is for producing the products economically and efficiently. This broad view has been recognized as the area of design for manufacture (DFM).

Design for manufacture (DFM) specifies a set of design rules to meet or improve production conditions, with the objective of increasing a product’s manufacturability. DFM endeavours to create decision-making methods to incorporate manufacturing issues into product design choices (Hayes et al., 2005). It is a comprehensive approach to production of goods, and it integrates the design process with materials, manufacturing methods, process planning, assembly, testing, and quality assurance.

Traditionally the product realisation process has been treated as having a single design-manufacturing interface, which is imprecise. Instead, two interfaces (product design – process design; process design – process execution) should be investigated (Lu and Wood (2006). Effectively implementing design for manufacture requires that designers have a fundamental understanding of the characteristics, capabilities, and limitations of materials, manufacturing process and related operations, machinery, and equipment. This knowledge includes such characteristics as: variability in machine
performance, in dimensional accuracy, and in surface finish of the workpiece; processing
time; and the effect of processing method on part quality. In the new dynamic
manufacturing environment, DFM has a significant positive effect on time-to-market, and
frequency of introducing new products and processes, and the higher the “intensity” of
DFM (e.g. duration of use), the better (Youssef, 1994b, 1995).

Design for Assembly (DFA) (as well as design for disassembly) is now a well
established technique for cost reduction at the design-manufacture interface. Typically, a
product that is easy to assemble is also easy to disassemble. A number of rules of thumb
have been found useful in bringing about the improvement of a design from an assembly
perspective (Appleton and Garside, 2000). Boothroyd et al. (1994) suggested that two
parts should be combined into a single part unless they followed the rules: (1) It is
necessary for parts to be made from different materials (2) Parts move relative to each
other (3) Parts must be disassembled for manufacture or for maintenance.

Design for Serviceability (DFS) is another area that is gaining importance due to
the time required and hence cost incurred in servicing a product. A lot of inconvenience
could be avoided in servicing a product / parts / sub-assemblies if it is properly designed
for service requirements. DFS strives to enable the ease of performing service operations,
including maintenance, malfunction diagnosis and repair (Gershenson and Ishii, 1993). In
order to understand the dynamics involved in the design for manufacture and design for
assembly, these are sometimes combined into the more comprehensive design for
manufacture and assembly (DFMA).
2.4.7 Computer-Aided Design (CAD) / Computer-Aided Manufacturing (CAM)

Computer-aided design is defined as any design activity that involves the effective use of the computer to create, modify, analyze, or document an engineering design. CAD is most commonly associated with the use of an interactive computer graphics system, referred to as a CAD system. The term CAD/CAM is also used if it supports manufacturing as well as design applications. CAM is defined as the effective use of computer technology in manufacturing planning and control. It is most closely associated with functions in manufacturing engineering, such as process planning and numerical control (NC) part programming (Groover, 2002).

Boubekri et al. (1995) discussed the Standards for computer-aided design (CAD) systems and viewed that as the internal representation of geometric elements differs between the various CAD systems, the direct exchange of data between CAD systems is problematic. However, Standard interfaces have now been developed (Scheer, 1988), which first transform the data of a CAD model into “standard format”, in order for the data to be used by another system. The initial graphics exchange standard (IGES) and standard for the exchange of product model data (STEP) are such standard formats which are used for the exchange and archiving of data between CAD/CAM systems (Yang, 2004; Carter and Baker, 1992), was developed by 1981 as an ANSI standard.

The applications of CAM can be divided into two broad categories: (1) Manufacturing Planning: It includes computer-aided process planning (CAPP); computer-assisted NC part programming; computerized machinability data systems;
development of work standards; cost estimating; production and inventory planning; computer-aided line balancing (2) Manufacturing Control: It includes process monitoring and control, quality control, shop floor control, inventory control, just-in-time production systems (Groover, 2002).

With the use of 3D CAD systems like Pro/Engineer, the designs can be shared and prototypes developed in very short period of time. If these 3D CAD systems properly implemented and leveraged offers several advantages in the overall development cycle of a product, such as: 3D visualization, improved sales presentations, rapid prototypes, rapid castings, rapid tooling, tool path creation, Finite Element Analysis (FEA), kinematics' studies, and assembly interference checks (Lin and Uhler, 2002).

2.4.8 Computer-Integrated Manufacturing (CIM)

Computer Integrated Manufacturing (CIM) is a manufacturing concept which emphasises integration and co-ordination of information and effort throughout all the functional areas of an organisation. CIM combines systems and technologies designed to integrate the data and information of a company's business, engineering, manufacturing and management functions i.e. it spans much more than manufacturing (Hannam, 1997). Computer integrated manufacturing (CIM) was also defined by Krajewski and Ritzman (1987) as an umbrella term that means a total integration of product design, engineering, process planning and manufacturing through complex computer systems. According to Lefebvre et al. (1996), CIM is concerned with providing computer assistance, control and high levels of integrated automation at all levels of manufacturing (and other) industries,
by linking islands of automation into a distributed processing system. Manufacturing industry has recognised CIM as vital for success in today’s competitive climate. Anjard (1995) highlighted that improved product quality and cycle time, lower cost, and increased competitiveness and profitability as driving forces for CIM implementation in the manufacturing sector. However, Attaran (1997) noted that to realise these benefits requires rigorous planning at all organisational levels to develop an appropriate and long-term CIM strategy, taking into consideration the pros and cons of CIM with respect to organisational goals.

One of the primary benefits of CIM is the ability to combine economies of scale and scope in an effort to achieve both flexibility and efficiency. Economies of scope was defined by Goldhar and Jelenik (1983,) as “efficiencies wrought by variety, not volume”. Such advantages allow extreme flexibility, rapid response to changes in demand and product design, greater control and repeatability of processes, reduced waste, faster throughput and distributed processing capacity (Boyer et al., 1996). Benefits associated with CIM working practice could also be achieved in small manufacturing companies (Caputo et al., 1998, Marri et al., 2002). To improve productivity gains, CIM has been implemented in combination with concurrent engineering and knowledge management technologies (Prasad, 2000). Effective and efficient information exchange and complete understanding of the processes are the foundation for a successful CIM implementation (Agbasi et al., 2004). CIM also provides the opportunity to eliminate waste and inconsistent human input, ensuring variability in products can be eliminated. Whilst CIM offers promising benefits, being able to realise these has proved to be very difficult
Zammuto and O'Connor (1992) found that whilst companies had enjoyed "technical" success with CIM they had not translated this into organization wide benefit. Often operational advantages were achieved in areas such as productivity, however, few appeared to have achieved greater flexibility and leverage the new system for strategic advantage.

CIM implementation frequently involves changing existing systems at great risk and requires the adoption of sophisticated technology, requiring extensive planning, training and a large commitment on behalf of top management. Successful implementation has also been shown to be only a component of the successful utilisation of CIM (Sohal, 2000). In the process of CIM implementation, new standards for communications and data exchange for computers used in manufacturing, and new standards for the design and automation of manufacturing processes have been developed. However, these standards are difficult to achieve by all manufacturing organizations as a large number of small and medium-size companies today possess a significant number of machines and equipment incompatible with the new standards. The amount of investment required to replace or retrofit existing equipment is one of the reasons why companies are hesitant to adopt a CIM environment (Boubekri et al., 1995). Wang et al. (2007) developed the architecture of virtual CIM that is a concept towards integrating globally distributed manufacturing resources across enterprise boundaries.
2.5 Agile Manufacturing Enabling Management Practices

This section discusses some of the well-recognized management rules and practices that enhances or supports or leads to agile manufacturing environment (Groover, 2002; Jin-Hai et al., 2003):

2.5.1 Lean Manufacturing

The lean manufacturing concept was born on the Japanese manufacturing shop floor and the focus was on eliminating waste and represented an alternative to the traditional mass production system (Kollberg and Dahlgaard, 2007). Agile manufacturing is generally regarded as a post-lean paradigm incorporating the well-known lean principles and practices. Whilst leanness may be an element of agility in certain circumstances, by itself it will not enable the organization to meet the precise needs of the customer more rapidly (Christopher and Towill, 2000). Agility incorporates almost all the elements of lean production and thus lean and agile organizations have commonality of characteristics. Agility ascribes to additional principles and practices, which enhance its capability to balance both predictable and unpredictable changes in demand (Womack et al., 1990). Thus, agile is often lean but lean is rarely agile.

According to studies that were initially performed in the automobile industry by Womack et al. (1990), Lean has several characteristics:

1. Lean is a dynamic process of change driven by a systematic set of principles and best practices aimed at continuous improvement.
2. Lean refers to the total enterprise: from the shop floor to the executive suite, and from the supplier to customer value chain.

3. Lean requires rooting out everything that is non-value-added.

4. Becoming Lean is a complex enterprise. There is no single principle or method that will make an organisation Lean.

Following are the six indicators of Lean Manufacturing as identified by Sanchez and Perez (2001):

1. Elimination of zero-value adding activities
2. Continuous improvement
3. Multifunctional teams
4. Just-in-time production and delivery
5. Integration of suppliers
6. Flexible information system

2.5.1.1 Agile Vs. Lean Manufacturing

In this section, we shall explore the commonalities and differences between these two paradigms:

The two important requirements for both lean and agile paradigms are high levels of product quality and minimum total lead times. Total lead time is defined as the time taken from a customer's order for a product or service until it is delivered. The lead time is required to be minimized in both lean and agile paradigms but their context is different
in both the cases. Lean manufacturing requires the reduction of lead time so as to eliminate or minimize the wastage of time in tune with its objective of waste removal.

However, agile manufacturing requires the reduction of lead time so as to provide a quick response to the variability in demand and thus to enhance the agility of a system. Moreover, the reduction of lead time shall always lead to reduction in cost of the product or the saved time shall lead to enhanced productivity (Towell, 1996). However, whereas the Total Cycle Time Compression Paradigm (Towell, 1996), when properly implemented, is a sufficient condition for achieving lean manufacturing but for agile manufacturing it is only one necessary condition (Christopher and Towill, 2000). To further understand these two paradigms need an understanding of the concept of “order qualifiers” and “order winners”. Hill (1993) developed these concepts as a criteria for establishing a sound manufacturing/corporate strategy for a business. Order Qualifiers are defined as the minimum capabilities required of a business to enter into a competitive arena, whereas Order Winners are those capabilities that could win an order in that competition. The critical differences in focus between the lean and agile paradigm (Figure 2.1) could be studied through this concept of “order qualifiers” and “order winners” based upon the work of Mason-Jones et al. (2000a). The matrix shown in Figure 2.1 defines market qualifiers for Lean paradigm as Quality, Lead Time and Service level, whereas for agile paradigm as Quality, Cost and Lead Time; the market winner for Lean paradigm as “Cost” whereas for agile paradigm it is “Service Level”. Thus, when order winning criteria is cost, Lean paradigm has an edge over agile paradigm, whereas if the
order winning criteria is service & customer value enhancement then agile paradigm has an edge over lean paradigm.

<table>
<thead>
<tr>
<th>QUALITY</th>
<th>SERVICE LEVEL</th>
<th>AGILE</th>
</tr>
</thead>
<tbody>
<tr>
<td>COST</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEAD TIME</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>QUALITY</th>
<th>SERVICE LEVEL</th>
<th>LEAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>COST</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEAD TIME</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MARKET QUALIFIERS</th>
<th>MARKET WINNERS</th>
</tr>
</thead>
</table>

Figure 2.1: Market winners-market qualifiers matrix for agile versus lean paradigm

(Source: Mason-Jones et al., 2000a)

2.5.1.2 Leagility – Agility with Lean Capabilities

Leagility is the combination of the lean and agile paradigms within a total supply chain strategy by positioning the de-coupling point so as to best suit the need for responding to a volatile demand downstream yet providing level scheduling upstream from the de-coupling point (Mason-Jones et al., 2000a). Thus, it is possible to operate the supply chain on Lean principles till decoupling point and agile onwards toward customers (Figure 2.2). The decoupling point is the position in the material flow streams at which the customer orders penetrate. Both postponement and information decoupling have been considered as relevant initiatives in making the leagile supply chain a reality (Naylor et al., 1999).
Postponement helps to achieve leagility (Su et al., 2005):

1. Through customization of products and services.
2. By making use of the customer order information throughout the supply chain.
3. Through assembly of the products at a stage in the supply chain which is close to the customer.
4. Through mass customization i.e. development of generic modules and parts before customized assembly, etc.

Information decoupling is the integration of upstream and downstream information about the status and demand of the product at the decoupling point. Integrating the flow of information might facilitate customer responsiveness, process and network integration. Thus adopting push type of manufacturing till decoupling point and pull type of manufacturing onwards toward customers (Childerhouse and Towill, 2000).
2.5.2 Just in Time Technology

Just in Time (JIT) is defined as a system popularized by the productivity of Japanese industry that attempts to reduce costs and improve workflows by scheduling materials to arrive at a workstation or facility “just in time” to be used. (Schmerhorn, 1996). It is a concept and philosophy rather than a technique, and as this concept has developed a number of specific techniques and approaches have been absorbed into the general philosophy. These include: reduction of setup time, lot size reduction, buffer stock removal, multifunctional workers, dedicated production line, standardization of process and product, JIT purchase of raw materials, autonomous inspection, automation, waste removal, etc. (Ramaswamy et al., 2002). Setup time reduction that is at the core of JIT production techniques leads to reduction of work in process (WIP) and improved cycle time (Samaddar and Hill, 2007).

Zhu et al. (1994) made the observation that the JIT implementation process is contingent and a kind of “do-it-yourself-procedure”, and concluded that the quality-related, the vendor related, and the production related practices seem to play an important role in JIT implementation.

As the product life cycle is becoming shorter and shorter because of the diversification of customers’ needs, and the duration with a stationary demand also getting shorter, there is a need to realize agile control in just-in-time ordering systems for multi-stage production inventory systems. The JIT ordering systems based on the JIT production concept is a concept to produce a necessary item with a necessary volume at the necessary point of time. For this agile environment, Takahashi and Nakamura (2000)
proposed reactive JIT ordering systems which can react to unstable changes in demand by adjusting the buffer size.

In the JIT system parts are ordered and work is done when there is both a requirement for work and the facility for doing it. In the ideal JIT system there should be no queuing of material at work centers and no stock of parts. Thus, JIT is a ‘pull’ system.

2.5.3 Material Requirements Planning (MRP)

Materials requirement planning (MRP) systems help manufacturers determine precisely when and how much material to purchase and process based upon a time-phased analysis of sales orders, production orders, current inventory, and forecasts (Petroni and Rizzi, 2001). It is defined as a set of techniques that uses a Bill of Material (BOM), inventory data and a Master Production Schedule (MPS) to calculate requirements for materials (Koh et al., 2000).

MRP is a technique that is based around the concept of dependent demand. The concept of dependent demand states that the demand for one item is dependent on the demand for another item (Aghazadeh, 2003). This ensures that firms will always have sufficient inventory to meet production demands, but not more than necessary at any given time. MRP will even schedule purchase orders and/or production orders for just-in-time receipt (Petroni and Rizzi, 2001).

The three main advantages associated with MRP are (Aghazadeh, 2003):
(1) It involves statistical forecasting for components with “lumpy” demand. “Lumpy” demand means that the demand for a product, while being continuous and uniform, occurs sporadically and usually in relatively large quantities. MRP provides a better demand forecast by calculating the dependent demand of components from the production schedules of their parents.

(2) It provides managers with better information about production schedules, production capacities, financial requirements, material requirements, order and completion times, etc. This helps to maintain an optimum inventory level and minimize capacity shortages and delivery delays.

(3) It helps to update dependent demand and replenishment schedules of components as the schedules of the parent items change. MRP systems alert planners when a change in production levels is needed.

MRP assumes fixed lead-time, infinite resource availability, fixed routing, constant scrap rate, and 100 per cent adherence of schedule receipt and schedule release. In order to respond to uncertainties, various buffering and dampening approaches are employed. The most used approaches were identified to be overtime, subcontract, safety stock for parts and multiskilling labour (Koh et al., 2000).

Caridi and Cigolini (2002) proposed a model for uncertainty dampening to improve materials management effectiveness in MRP environments. The proposed model provides guidelines for approaching the problem of sizing, positioning and managing
safety stocks against demand uncertainty. It considered appropriate MRP parameters setting as a prerequisite for achieving agility in the manufacturing management area.

2.5.3.1 Manufacturing Resource Planning (MRP II)

MRP II has been termed or referred to as “Closed Loop MRP”. MRP II is an extremely powerful technique, and is an integrated information system that step beyond first-generation MRP to synchronize all aspects (not just manufacturing) of the business. Through this holistic approach MRPII has become the focal plan for manufacturing, marketing, technical support and finance; and as such the whole company now is able to generate and use one set of data (Wong and Kleiner, 2001). MRP II has evolved to include order entry, purchasing and direct interfaces with customers and suppliers such as electronic data interchange (EDI) and advanced shipping notice. These advanced MRP systems that tie customers and suppliers to MRP are now referred to as Enterprise Resource Planning (ERP) systems (Aghazadeh, 2003).

MRP leads to improved productivity through efficient resource utilisation. Some of the benefits associated with MRP are: Reduced Inventory, Improved Customer Service, Improved Direct Labour Productivity, Reduced Purchased Costs, Reduced Traffic Costs, Reduced Obsolescence and Reduce overtime (Wong and Kleiner, 2001).

2.5.4 Concurrent Engineering (CE)

Concurrent Engineering (CE), sometimes called simultaneous engineering or parallel engineering, has been defined in several ways by different authors:

57
Concurrent Engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support (Winner et al., 1988). It attempts to optimise the design of the product and manufacturing process to achieve reduced lead times and improved quality and cost by the integration of design and manufacturing activities, and by maximising parallelism in working practices (Broughton, 1990). It is an organisational strategy. The idea is to shorten the time of product design by simultaneous planning of product and production (Eversheim, 1990).

The concurrent engineering concept as practised by manufacturing organisations implies the almost simultaneous design of a product, its development, and preparation for production, whether one-of-a-kind (e.g. ships) or volume (e.g. automobiles) (Anumba et al., 2000). This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements (Khalfan et al., 2001).

CE is primarily concerned with two activities: parallelism or overlapping of different but hitherto sequential activities and early involvement of all enterprise functions that contribute to a successful product (Bergring and Andersin, 1994). These activities require a high degree of "integration" among different business functions. In achieving this integration, the main barrier is the degree to which companies are able to adapt their organisational structures and organizational processes to suite the demands created by this approach (Haque and Pawar, 2003). According to a survey by Ainscough and Yazdani, 2000, Concurrent Engineering is gradually becoming the norm for
developing and introducing new products, which is a key characteristic of agile manufacturing.

2.5.5 Synchronous Manufacturing

The idea of synchronous manufacturing is to balance the flow of material through a system, not the capacity of the system. As there are bottlenecks in any manufacturing flow, there are variations in the capacity of the resources in a manufacturing line. The main causes of such bottlenecks are: raw materials shortage, lack of skilled labor and absenteeism, queue of jobs waiting for processing, priority rules. In synchronous manufacturing, the bottlenecks are identified and managed effectively to maximize the rate of flow through the system. The examples of bottlenecks are workcentres, materials, market, behavior of workers, etc.

Synchronous manufacturing results in materials moving smoothly and continuously from one operation to the next, resulting in the reduction of both lead times and inventory waiting in queues. Improved use of equipment and reduced inventories can reduce total cost and can speed customer delivery, allowing a company to compete more effectively. Shorter lead times improve customer service and provide company a competitive edge (Sivasubramanian et al., 2003).

2.5.6 World-Class Manufacturing

The term world-class manufacturing was coined by Hayes and Wheelwright (Giffi et al., 1990). This manufacturing philosophy got prominence with the publication of a
book "World-Class Manufacturing: The lessons of simplicity applied" by Schonberger (1986). In order to judge the status of a company for World Class Manufacturer, there are three criteria (Gunn, 1987):

1. Work-in-Process (WIP) inventory turns:
   (a) A company that can turn WIP inventory 25-30 times per year is a class C world-class manufacturer.
   (b) A company that can turn WIP inventory 50-60 times per year is a class B world-class manufacturer.
   (c) A company that can turn WIP inventory 80-100 times per year is a class A world-class manufacturer.

2. the level of quality: A world class manufacturer should have fewer than 200 defective parts per million of any product it manufactures

3. manufacturing cycle time: considers the reduction in cycle time as a necessary, but might not be sufficient, criterion for achieving the world-class manufacturer status.

World Class manufacturing forms the foundation for agile manufacturing (Jin-Hai et al., 2003; Maskell, 2001).

2.5.7 Benchmarking

Benchmarking is a strategy that can demonstrate to managers what is possible through transformation (Underdown and Talluri, 2002). From a managerial perspective, benchmarking has been defined as a continuous, systematic process for evaluating the products, services, and work processes of organizations that are recognized as
representing best practices, for the purpose of organizational improvement (Sarkis, 2001). Benchmarking is a process that determines best practices, which can be utilized as a guide for improving an organization’s practices. Upon the identification of a target or benchmark, firms indulge in reengineering efforts in order to reconfigure their processes to improve agility. Thus, it is critical for firms to focus on benchmarking in transforming their operations in order to become agile (Underdown and Talluri, 2002).

Camp (1989) defined the following three levels of benchmarking process:

1. Internal benchmarking - benchmarking against internal operations or standards, usually in a multi-division or multinational enterprise.
2. Industry (or competitive) benchmarking - benchmarking against other companies in the same industry, whether they are direct competitors or not.
3. Process (or generic) benchmarking - benchmarking generic processes (e.g. order receipt and dispatch process) against best operations or leaders in any industry.

“Futures benchmarking” (von Stackelberg, 1993), is a process benchmarking approach that finds application in the analysis of breakthrough advancements. The futures benchmarking technique is primarily focused on technology benchmarking, but analysis and forecasting of advanced processes may be added to this technique. Pozos (1995), presents another category, strategic benchmarking, which is defined as, proactive analysis of emerging trends, options in markets, processes, technology and distribution that could affect strategic direction and deployment. The process of benchmarking may need some adjustment for agile environments. The more proactive use of strategic and futures benchmarking should be considered for adoption in agile environments (Sarkis, 2001).
McGaughy (2002) has proposed a framework for benchmarking B2B e-commerce. This framework describes five levels of benchmarking in B2B e-commerce. Seol et al. (2007) developed a systematic approach for benchmarking service process using integrated form of DEA and decision tree as benchmarking method.

2.5.8 Business Process Reengineering (BPR)

Business Process Reengineering (BPR) has been defined by various authors as:

Business process reengineering (BPR) is a management technique to radically transform organizations for dramatic improvement (Akhavan et al., 2006); The fundamental philosophy of business process reengineering (BPR) is an innovative approach to change management, resulting in best practices (Yung and Chan, 2003); BPR is the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures in performance, such as cost, quality, service and speed (Hammer and Champy, 1993); BPR is defined as a radical redesign of business processes to achieve dramatic improvements in critical areas of performance, such as cost, quality, delivery and flexibility. This definition treats the TQM and the BPR concepts separately since BPR’s focus is on large scale “radical redesign” or “dramatic improvements” whereas the TQM focus on small incremental “continuous improvement” (Andersen, 1999).

If BPR is to be applied successfully, either its usage needs to be restricted to change situations where process dominates, or a holistic approach is needed to help address adequately change situations where different types of organizational change are
surfaced. BPR failure, however, can frequently be traced to ineffective communication, ineffective management of organizational resistance to change, or the failure to create the new organizational culture and structure needed to support it (Cao et al., 2001).

The various steps involved in BPR are (Gunasekaran et al., 2000):

1. Teach employees about BPR
2. Choose team
3. Identify processes
4. Determine measures for each process
5. Analyze and reengineer each process
6. Train staff
7. Simulate, and
8. Implement

Activities 1 & 2; and 6 & 7 could be done in parallel. The activity which takes the longest time is “Analyze and reengineer each process” i.e. to analyze and see how each process can be reengineered and fitted together. Each process could be judged on the three main criteria, viz. Cost, Quality and Time, after assigning a suitable priority to these criteria.

Yung and Chan (2003) introduced a model of performance benchmarking used in the newly introduced concept of flexible business process reengineering (FBPR). The model can be used with any parameter, including quality, flexibility, agility, profitability
or market share. The concept of FBPR is based on three management tools: positioning, continuous improvement and business process reengineering (PIR). As the concept of FBPR is based on the management methodology of PIR, the organization’s performances can continuously be improved both linearly and non-linearly, since it utilizes both ceaseless improvement and fundamental rethinking. PIR delivers the best of both the evolutionary and revolutionary change tactics.

2.5.9 Total Quality Management (TQM)

The concept of quality has migrated from being considered as a non-price factor on which imperfect competition in the markets is based, to being considered as a strategic resource of firms leading to the dynamic capability of the firms (Perdomo-Ortiz et al., article in press). There are four indicators of quality performance (Prajogo and Sohal, 2006): (1) reliability (2) performance (3) durability, and (4) conformance to specification. Managing quality has quickly moved from quality control (QC) to quality assurance (QA) to total quality management (TQM). This is a progression in which new developments do not negate their predecessors, but rather build on them (Youssef et al., 2006). When quality is assimilated to a set of management practices, this becomes a philosophy of integral management based on the continuous improvement of products and processes, known as TQM. Thus, TQM is a multi-dimensional concept that goes beyond quality standards, techniques and instruments for controlling quality (SPC) (Perdomo-Ortiz et al., article in press). The various dimensions of TQM are: Management support and leadership; Organizational design, communication and strategies; Training, instruction and learning; Product design process; Relationship with suppliers; Process
flow management; Information and evaluation for quality; Management and integration of human resources; Continual improvement/Kaizen; Empowerment and workers’ fulfillment; Relationships with customers; Benchmarking; Flexible manufacturing; Availability and use of technology; Consumer satisfaction; Product quality; Financial, operational and social results (Perdomo-Ortiz et al., article in press; Sañchez-Rodrígue et al., 2006). These dimensions provide a measure of the degree of implementation of TQM in firms. TQM leads to benefits such as lower costs, improved reputation and market share, increased employee motivation and satisfaction, and improved profitability, improved internal efficiencies and competitiveness of the firm (Brah and Lim, 2006; Sohail and Hoong, 2003). TQM and ISO 9000 certification leads to enhance organizational performance but organizations already adopting TQM philosophy can have their performance further enhanced indirectly through ISO 9000 certification (Prabhu et al., 2000; Sohail and Hoong, 2003).

2.6 Traditional Methods of Production

Irrespective of specific processes, traditionally, there are three production methods used in manufacturing: Job, Batch, and Mass. Each of these is appropriate to a particular set of circumstances according to the demand for the product, the production volume required, the range of product to be produced in a single facility, and the degree of standardization of the product. The characteristics of these three methods are described below (Groover, 2002):

(1) Job Shop
• Produce low quantities (approx. 1-100 units per year) of specialized and customized products

• Utilize general purpose machinery and the labor force is highly skilled

• Possesses maximum flexibility to accommodate various types of products

• For small/medium jobs, the job shop utilizes a process layout in which the machinery is arranged according to functions or type

• For large and heavy products such as ships, aircrafts etc., the workers and machinery are brought to the product rather than moving the product to the machinery. This type of layout is known as fixed-position layout

• Mechanization and division of labor is not economical

• Prior planning becomes difficult

• Product design takes a lot of time

(2) Batch production

• Articles are manufactured in batches of different products as per the specific order procured

• Division of labor is possible

• Process and product planning is done for each batch

• Layout is either process type (for hard product variety) or cellular layout (for soft product variety) based on group technology

• Automation of processes and mechanization of material handling may be resorted to

• Allows for variable demand

• Allows processing of a variety of products
(3) Mass Production

- This type of production is made when there is a high demand for the product, and the production facility is dedicated to the manufacture of that product
- There is scope for considerable division of labor
- There are two categories of mass production: (a) quantity production and (2) flow line production
- Quantity production involves the mass production of single parts on single pieces of equipment dedicated to the production of one part type. The typical layout used for it is the process layout
- Flow line production involves multiple workstations arranged in sequence, and the parts or assemblies are physically moved through the sequence to complete the product. The layout used is called a product layout
- Very little time is spent on the resetting of machines
- Requires standardized product

2.7 Manufacturing Strategy

According to Skinner (1969) manufacturing strategy refers to exploiting certain properties of the manufacturing function as a competitive weapon. He argued that no technologically-based system can perform equally well on every performance criterion, and need to choose which few criteria are strategically the most important and design the system accordingly. Suggested that the following need to be traded off against each other: cost, quality, delivery and flexibility. Cox and Blackstone (1998) defined manufacturing strategy as a collective pattern of decisions that acts upon the formulation and
deployment of manufacturing resources. To be most effective, the manufacturing strategy should act in support of the overall strategic directions of the business and provide for competitive advantages. Manufacturing strategy of the firms is significantly influenced by factors such as mass customization, shortening product life cycles, increasing technological change, and the entry of international competitors into their markets (Prajogo et al., 2007).

2.8 Agile Manufacturing - a Paradigm

The concept of the paradigm is that of a development, a search, even a plan, for a meta-model. The paradigm is a management system that is not a collection of techniques, methods and approaches, but rather a coherent body of inter dependent criteria and logic in the spheres of organisation, management, decision making and motivation (Zeleny, 1995). Consolidation of a paradigm leads to the identification of a coherent set of basic management principles for manufacturing / production systems, which are to be seen as guidelines and general criteria and certainly not as operational constraints (Bartezzaghi, 1999). Thus, agile manufacturing being an evolving manufacturing paradigm does not impose any operational constraints on the production systems rather suggests strategies and approaches to be followed by a company to face the present competition marked with abrupt and unanticipated changes in the product/market (Gunasekeran, 1999).

2.9 Supplier Selection

In the present competitive environment, companies are increasingly looking for competitive success not only through the integration of internal business processes and
strategic alignment of internal functions but also through the integration and alignment of inter-company processes (Frohlich and Westbrook, 2001). This integration and alignment of inter-company processes is made through the selection of suppliers conducive to the company’s competitive environment. Cagliano et al. (2004) empirically investigated the various supply strategies, including lean and agile supply, defined on the basis of both supplier selection criteria and integration mechanisms, and their impact on manufacturing performance, in terms of conformance, flexibility, delivery, lead time and costs, and concluded that a company shall adopt a suitable supply strategy along with a procedure for supplier selection commensurate with the company’s operational environment.

Supplier selection is defined as a multicriteria problem, which includes both qualitative and quantitative factors. In order to select the best suppliers it is necessary to make a trade-off between these tangible and intangible factors, some of which may conflict (Braglia and Petroni, 2000; Xia and Wu, 2007).

Agile supply is characterized by high volatility and uncertainty of demand, focuses on achieving high responsiveness to the market through the management of a dynamic supply network. The main goals are speed of delivery, flexibility and quality, which can be achieved through dynamic partnerships, rich information sharing and the coordination of physical flows without rigid investments, in order to allow rapid reconfiguration (Cagliano et al., 2004). This concept of dynamic partnerships gives rise to VCs.

Two situations are faced in the selection process of suppliers: (1) selection of suppliers from a ‘homogeneous’ set of potential suppliers, and (2) selection of suppliers /
VCCs from a ‘heterogeneous’ set of potential suppliers / VCCs (a situation often faced in the formation of virtual corporation). This research work shall develop supplier selection models for both the situations.

2.10 Literature Review on Research Methods

Literature covering various methodologies used in the present study is included in this section. The methodologies included are, Analytical Hierarchy Process (AHP) /Analytical Network Process (ANP), Interpretive Structural Modeling (ISM), Data Envelopment Analysis (DEA), Goal Programming (GP) and Case Study.

2.10.1 Analytical Hierarchy Process (AHP) and Analytical Network Process (ANP)

The logic of Analytical Hierarchy Process (AHP) is similar to ANP but cannot capture interdependencies (Meade et al., 1997; Meade and Sarkis, 1999). The ANP technique allows for more complex relationships among the decision levels and attributes (Saaty, 1996).

Analytical hierarchy process (AHP) is used for selecting the most suitable alternative, which fulfills the entire set of objectives in multi-attribute decision making problem (Wasil and Golden, 2003). AHP allows a set of complex issues, to be compared with the importance of each issue relative to its impact on the solution to the problem. Since the introduction of AHP, numerous applications have been published in the literature (Zahedi, 1986; Shim, 1989; Kleindorfer and Partovi, 1990; Corner and Corner, 1991, 1995; Ghodsypour and O’Brien, 1998). The AHP has been extensively applied and
sometimes combined with mathematical programming (Xia and Wu, 2007; Abdel-Kader and Dugdale, 2001; Chiadamrong and O’Brien, 1999; Luong, 1999; Rangone, 1996; Lee et. al., 1995).

ANP is a more general form of the analytical hierarchy process (AHP). Whereas, AHP models a decision making framework using a unidirectional hierarchical relationship among decision levels, ANP allows for more complex interrelationships among the decision levels and attributes (Sarkis, 1999). This provides a more accurate approach for modeling complex decision environment (Meade and Sarkis, 1999; Lee and Kim, 2000; Agarwal and Shankar, 2002 and 2003; Yurdakul, 2003; Agarwal et al., 2005). ANP finds its application for various purposes (Chen et al., 2004; Agarwal and Shankar, 2002; Meade and Sarkis, 2002; Meade et al., 1997). ANP has also been used in conjunction with other techniques (Sarkis, 1999; Lee and Kim, 2000; Karsak et al., 2002; Ravi et al., 2005b; Thakkar et al., 2007).

2.10.2 Interpretive Structural Modeling (ISM)

Interpretive Structural Modeling (ISM) is a well-established methodology for identifying relationships among specific items, which define a problem or an issue (Warfield, 1974; Sage, 1977). It provides us a means by which order can be imposed on the complexity of such items (Mandal and Deshmukh, 1994; Jharkaria and Shankar, 2005). In the literature, ISM methodology has been applied to various areas. For example, Faisal et al., 2006 applied ISM to present an approach to effective supply chain risk mitigation by understanding the dynamics between various enablers that help to
mitigate risk in a supply chain. Bolanos et al., 2005 applied ISM in the clarification of the perceptions of different individuals in a managerial group in order to improve group decision making. Jharkaria and Shankar (2005) have analyzed the barriers of IT-enabled supply chain using ISM methodology. Singh et al. (2003) have used ISM to categorize variables for implementing Knowledge Management (KM) in manufacturing industries. Sharma et al. (1995) have carried out ISM to develop a hierarchy of actions required to achieve the future objective of waste management in India. The important vendor selection criteria have been analyzed (Mandal and Deshmukh, 1994) to obtain an ISM that shows the interrelationship of the criteria and their levels. These criteria have also been categorized depending on their driver power and dependence. Saxena et al. (1990) and Saxena et al. (1992) have presented the results of the application of ISM methodology to a case of “Energy conservation in Indian Cement Industry”. In their work, they have developed direct relationship matrices of key actors, objectives, and activities for energy conservation in the Indian cement industry. Thakkar et al., 2007 developed an integrated approach of ISM and ANP for the performance measurement of companies under the balanced scorecard approach. In the literature, there is hardly any work using ISM methodology to analyze the variables of agile manufacturing.

2.10.3 Data Envelopment Analysis (DEA)

DEA utilizes techniques such as mathematical programming, which can handle large numbers of variables and relations (constraints). DEA is a useful technique because of the nature of the relations between the multiple inputs and multiple outputs involved in many activities. It is used for assessing the relative efficiency of a set of comparable
(homogeneous) processing units (decision making units, DMUs). The characteristic of DEA is that it is non-parametric in character, which means that only the observed inputs consumption values and outputs production amounts are needed in order to properly assess the relative efficiencies of the DMU (Lozano and Villa, 2006).

The other characteristics of DEA are that it does not require limiting assumptions of many parametric methods such as normality and equal variance, and also does not require a priori factor weights to be specified in the evaluation process, and it is based on best practice, not average (mean) practice (Swink et al., 2006).

The efficiency of a DMU having a single input and a single output is defined as the ratio of output to input. However, the efficiency of a DMU having multiple inputs and outputs may be defined as the ratio of the weighted sum of its outputs to the weighted sum of its inputs (De Boer et al., 2001):

\[
\text{Efficiency} = \frac{\text{Weighted sum of outputs}}{\text{Weighted sum of inputs}}
\]

This definition requires a set of weights to be defined and this can be difficult, particularly if a common set of weights to be applied across the set of organizational units is sought. The problem can be solved by arguing that individual units may have their own particular value systems and therefore may legitimately define their own particular set of weights (Charnes et al., 1978).
Through DEA the relative efficiency of each DMU is evaluated which is a measure of the maximum proportion of the inputs the DMU should have been using, if efficient, in order to secure at least its current output levels. Alternatively, the inverse of the efficiency score is the minimum factor by which the current output levels of the unit can be multiplied for the unit to be efficient while its inputs remain at their current levels. Thus, DEA not only leads to an identification of the most and least efficient units but also a measure of the conservation of resources and/or augmentation of outputs possible (Boussohane et al., 1991).

DEA has also been applied to a variety of applications for choice and selection modeling (Leachman et al., 2005; Sofianopoulou, 2006), including its utilization for supplier evaluation from a pre- and post-selection perspective, and negotiation (Weber, 1996; Weber, et al., 1998; Seydel, 2006). Use of DEA with other techniques and in phases has also been recommended for supplier selection in a dynamic environment (e.g. Weber and Current, 1993; Braglia and Petroni, 2000; Barros, 2006; Seth et al., 2006; Korpela et al., in press).

2.10.4 Goal Programming (GP)

Goal programming, introduced by Charnes and Cooper (1961), deals with the problem of achieving a set of multiple and may be conflicting goals. This technique uses the simple method for finding satisfactory solution of one dimensional or multi-dimensional objective function with a given set of constraints, which are expressed in linear form. In goal programming technique, all management goals, whether one or
many, are incorporated in to the objective functions and only the environmental conditions i.e., those outside the management’s control are treated as constraints. Moreover, each goal is set at a satisfying level which may not necessarily be the best obtainable, but one that management would be satisfied to achieve given multiple and sometimes conflicting goals.

Goal programming can be solved in two ways: (i) using of the simplex algorithm directly if weights given for goals are precisely defined and (ii) using of the preemptive goal programming if weights given for goals are not precisely defined, but are ordered $P_1 > P_2 > \ldots > P_n$. In a preemptive goal programming model, the upper level goals are first optimized before lower level goals are considered. In a non-preemptive model, the goals are given some weights and considered simultaneously (Go'keen, H. and Erel, E., 1997; Gokeen, H. and Agpak, K., 2006). GP has also been applied to a variety of applications for prioritisation and selection modeling (Abdelaziz et al., 2007; Ahern and Anandarajah, 2007; Sarkis and Talluri, 2004).

2.10.5 Case Study

Lohman et al. (2004) state that case study research has small but consistent tradition in the Operation Management. Case study provides an in-depth and relatively unstructured approach to develop theories and frameworks. The case method is suited to the situations where the researcher is attempting to answer a “how” question (Yin, 1989). It is also suited to the situations where the phenomena and the context in which they exist
are difficult to separate. Case study has a number of advantages such as (Dangayach, 2001):

- It enables the researchers to develop grounded theories that are practical and relevant.
- Inferences on causal relationships can be made with more validity due to the availability of long-term observations.
- It provides broad holistic pattern of phenomena in real world settings.

Va’zquez-Bustelo and Avella (2006) presented an initial approach to agile manufacturing based on case studies on four factories in Spain, and confirms the suitability of case study methodology in the early stages of research, especially for drawing up hypotheses in an exploratory work. With the help of a case study, Lin et al. (2005) have addressed the question of how to measure and improve agility in the context of supply chain. Through two different case studies, Al-Mudimigh et al. (2004) have analyzed the merits and limitations of SCM and proposed a model, which covers key elements supported by a drive on agility and speed. Their case studies provide broader awareness of value chain management, and its critical factors. Yusuf et al. (2004b) in their paper, take an in-depth look at the issues backing the process of ERP implementation through a case study methodology. Their case study also looks at the implementation of time scales and assesses the benefits from the project which are both tangible and intangible. Siemieniuch et al. (1999) report in their paper a case study investigation, which sets out to identify critical and human and organizational issues that could enhance or constrain the “partnership sourcing”. Gunasekaran et al. (2002)
presented a case study conducted on agile manufacturing in the GEC-Marconi Aerospace (GECMAe) company for assessing the agility level of the company.

Keeping in view the advantage of case study approach, case studies of three Indian companies have been presented primarily:

(1) To have an understanding of agile manufacturing in Indian manufacturing industry.

(2) To validate the models developed in this research work.

2.11 Gaps in Contemporary Research

The identified gaps in literature provide opportunity for research in the area of agility and Agile Manufacturing. There is vast scope of research in this area due to the fact that agile manufacturing encompasses a wide range of activities. The main gaps identified are:

- There have been no practical models or frameworks developed in regard to agile manufacturing and validated in Indian industry. Thus the models developed in this research work are simple, easy to use and validated in Indian industry.

- There is no systematic study of the various variables that could lead to or obstruct the path leading towards the newly defined manufacturing paradigm known as agile manufacturing. Thus, an ISM based model is developed for each enablers and barriers of agile manufacturing.

- There has been no recommendation for an ordinary production system that could achieve the goals of agile manufacturing. Thus an ANP based model is developed
for the selection of a production system that could approximate the agile manufacturing.

- There has been no model for the selection of suppliers in an agile manufacturing environment using ANP and DEA incorporating both the tangible and intangible factors. Thus, an integrated model has been suggested for the same and validated in Indian industry.

- There has been no model for the selection of the constituent companies for the formation of virtual corporation which approximates the agile manufacturing environment using ANP and GP and incorporating both the tangible and intangible factors along with the consideration of other constraints. Thus, an integrated model has been suggested for the formation of virtual corporation in an Indian environment.

2.12 Conclusion

In today’s competitive environment, businesses are undergoing profound changes leading to increased attention being paid to customer satisfaction, of which timely and customized services are the key concepts. Pooling of core competencies with other organizations in order to deliver a world class product has become a way out to the present demand of the business. Competitiveness in the highly diversified and global markets, and the capabilities to thrive in the face of continuous and unexpected changes become the key factors for success. The need for a method of rapidly and cost effectively developing products, production facilities and supporting software, including design, process planning, shop floor control system has led to the concept of agile manufacturing.