CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

The field of manufacturing emerged in the world during ancient days when humankind began to shape the naturally available components to fulfil specific needs. Particularly, the humankind lived during ancient days would have sharpened the stones for killing animals. Thus, the manufacturing field has ancient day roots. On further development, the manufacturing field expanded to produce little more sophisticated products like utensils and furniture (Devadasan et al. 2012). In order to manufacture these kinds of sophisticated products, the humankind began to adopt manufacturing paradigms. The first manufacturing paradigm that was adopted by the humankind is craft production (Stump & Badurdeen, 2012; Meade & Sarkis, 1999; Krishnamurthy & Yauch, 2007). By following this paradigm, individual humans or group of them adopted manual methods to produce products in low volume. This paradigm was adopted by the humankind till the world experienced industrial revolution. After the emergence of industrial revolution, many manufacturing activities were mechanized (Poesche, 2002). This mechanization increased the volume of production significantly. Hence, the humankind was compelled to adopt another manufacturing paradigm. Today, this paradigm is called as mass production (Sreenivasa & Devadasan, 2011).
According to mass production paradigm, hundreds of humans have to assemble in companies under one roof and use machines to produce products in large volume. After the occurrence of industrial revolution, this mass production paradigm made the humans to ponder over the way of managing the companies. In order to face this situation, humans adopted Taylor’s management model (Montgomery, 2010; Vaszkun & Tsutsui, 2012; Santos et al. 2002). According to this model, the companies are divided into a few segments under the name ‘departments’. The humans with different capabilities are assigned responsibilities under these departments. This approach triggers different segments of the companies to function as islands. Different activities required for manufacturing the products are carried out by the humans working in these departments. Thus, the manufacturing of products is carried out throughout the working hours without ensuring whether the volume of production matches with that of the customer demand. When excess quantity of products is produced by following the mass production paradigm, the same (excess quantity) is pushed into the market by following various marketing methods. When less quantity than it is demanded by the customer is produced by following the mass production paradigm, the customers have to wait to get the delivery of the products.

When the mass production paradigm is adopted, several wastes like overproduction, delay in manufacturing and production of defective products occur as the departments and humans working in the companies are not intensively networked through communication networks. The utilization of additional resources to manufacture the products and the resources lost due to the occurrences of wastes have to be absorbed by the customers by paying higher price while buying the products. This kind of scenario existed in the world till 1950s (Zandin, 2001). During this time, quality gurus like Deming (Jacobs & ‘Ted’ Weston, 2007; Watson & DeYong, 2010) began to point out that, in mass production paradigm, there was no provision for achieving
continuous improvement which made the manufacturing of products ineffective (Yeung, 2008). Even before the world began to realize the value of the principles pronounced by the quality gurus like Deming, Japanese products began to invade the global market (Lagrosen & Lagrosen, 2003). These Japanese products were superior in quality but were priced less. This invasion was sensed in the world from 1970s and is called as Japanese miracle (Sreenivasa & Devadasan, 2011).

On sensing the Japanese miracle, the human community looked at the various practices which were carried out in Japanese companies. Particularly, humans began to look at the practices followed in Toyota Motor Company, Japan. In this company, a signboard called Kanban is used to communicate the quantity of the components to be processed at the each workstation (Towill, 2010; Al-Baik & Miller, 2014). Later on, American professionals called the entire practices adopted in Toyota Motor Company as Just in Time (JIT) manufacturing (Yavuz & Akcali, 2007). These practices were studied further by many researchers to incorporate the facilities that would reduce the resources required for manufacturing the products. J.Krafcik introduced the term lean manufacturing in the year 1988 to indicate this kind of facilities (Arlbjørn & Freytag, 2013). Then this lean manufacturing term was popularized by James P. Womack, Daniel T. Jones, & Daniel Roos through the publication of their book titled “The machine that changed the world” (Womack et al. 1991; Stone, 2012; Shetty et al. 2010). In this book, James Womack and his coauthors described lean manufacturing paradigm by combining JIT manufacturing and waste elimination concepts (Yusuf & Adeleye, 2002).

According to lean manufacturing paradigm, the quality and productivity of manufacturing products and offering of services must be improved to eliminate wastes (Shahin & Jaberi, 2011; Chauhan & Singh,
2012; Elmoselhy, 2013; Karim & Arif-Uz-Zaman, 2013) occurring during the execution of the processes in the organisation. Such wastes listed by James Womack and his co-authors are overproduction, delay, processing, transportation, unnecessary motion, unnecessary inventory and defective parts (Shahin & Jaberi, 2011; Browaeys & Fisser, 2012). After gathering preliminary knowledge, both theorists and practitioners began to work in the direction of implementing and examining the lean manufacturing paradigm. These theorists and practitioners utilized several techniques and approaches like Total Quality Management (TQM), Total Productive Maintenance (TPM), 5S, single piece flow and Single Minute Exchange of Die (SMED) to implement lean manufacturing paradigm (Vinodh et al. 2010 c; Shetty, 2010; Pepper & Spedding, 2008). Many case studies reporting the nourishing of several benefits like reducing the cost of manufacturing, garnering higher profit and delivery of products on time to the customers on implementing lean manufacturing paradigm in several types of companies have appeared in literature arena (Shahin & Jaberi, 2011). These reports have revealed that the lean manufacturing paradigm has enabled the organizations to produce the right quantity and quality of the existing and available products and services (Hallgren & Olhager, 2009). Because of reaping this ultimate benefit, companies which implemented lean manufacturing paradigm began to produce products and offer services by consuming least resources and thereby, garner higher profit (Narasimhan et al. 2006).

By the time lean manufacturing paradigm was implemented in several companies, the world began to experience globalization (Sanchez & Nagi, 2001). In response to globalization, the governments of several countries allowed the entry of products produced by different countries into their markets. This enabled the companies situated in various parts of the world to compete globally. These developments fuelled the intensification of competition. This intensified competition enabled the customers to demand...
innovative products rather than the traditionally used products at low price with high degree of quality (Stump & Badurdeen, 2012). On realizing this kind of implicit expectations of the customers, few companies in the world acquired appropriate capabilities to produce innovative products within a short period of time to compete globally with the competitors (Sreenivasa and Devadasan 2011; Mishra et al. 2013). A very apt example to be cited to support this claim is the capabilities being demonstrated in contemporary days by the mobile phone manufacturing companies. The modern mobile phone manufacturing companies have been manufacturing and selling several models of mobile phones with amazing innovative features (Sreenivasa et al. 2012a).

In the early period, mobile phone manufacturers produced large sized mobile phones with the provision for telephoning and utilizing other few facilities like calculator and calendar. Today, those manufacturers have brought out mobile phones under different names like tablet and iPad, which are incorporated with facilities like high resolution camera and high speed internet. Thus, the mobile phone manufacturers are capable of quickly responding to the dynamic demands of the customers (Dobrota et al. 2012). This is due to the fact that mobile phone manufacturing companies are incorporated with a type of production paradigm that is agile in nature. On seeing this kind of development, during 1990s, a group of researchers named this advanced paradigm as ‘Agile manufacturing’ (AM) (Putnik & Putnik, 2012; Bottani, 2010; Dubey & Gunasekaran, 2014). These researchers triggered the formal way of pursuing researches in this direction by forming an association called agile forum at Iacocca Institute in Leigh University, USA.

After the formation of agile forum at Iacocca Institute, a considerable number of researchers began to work in the direction of effecting agile manufacturing in companies. In the beginning period, these researchers began to work in the direction of exploring the meaning of agile
manufacturing. The collective meaning of agile manufacturing, as recognized by these researchers is that, it is the manufacturing paradigm that enables companies to react quickly in accordance with the dynamic demands of the customers (Devadasan et al. 2005; Vinodh et al. 2011 c). These researchers mentioned that agility is the characteristic that is created through the implementation of agile manufacturing. Later on, the researchers working on agile manufacturing began to explore the enablers of agile manufacturing. Some of the enablers of agile manufacturing identified by these researchers are team based management, multi-skilled and multi-knowledgeable employees, CAD, Computer Aided Manufacturing (CAM), Rapid Prototyping Technology (RPT) and Computer Numerical Control (CNC) (Vinodh et al. 2011 a). In the recent years, researchers have been striving to implement the agile manufacturing implementation procedures developed by them in different manufacturing sectors. These efforts have not been fruitful in all cases due to certain impediments. Some of the impediments include high cost of implementation, rigid nature of the product and lack of sufficient multi-skills and multi-knowledge among the employees.

While mobile phone manufacturing sector is prospering in today’s world by either implicitly or explicitly adopting agile manufacturing paradigm, many manufacturing sectors are yet to implement the same and flourish in in today’s competitive world (Sreenivasa & Devadasan 2011). However, even those manufacturing sectors in which agile manufacturing is yet to be implemented intensively, spontaneous implementation of certain agile manufacturing concepts has occurred (Vinodh et al. 2010 c; Ramesh & Devadasan, 2007). The automobile sector in which numerous models of cars have appeared during the recent two decades to fulfil the requirements of the numerous customers, can be cited as an example of the sector in which agile manufacturing concepts are imbibed spontaneously (Sreenivasa & Devadasan 2011; Kirk & Tebaldi,1997). Because of the spontaneous adoption of agile
manufacturing concepts, companies belonging to these manufacturing sectors have implemented agile manufacturing to different levels of depth. Thus the voyage of agile manufacturing began at Iacocca Institute and progresses today through several sectors. This situation has revealed the need of studying the degree of implementation of agile manufacturing in these sectors. In this context, the literature survey reported in this chapter was carried out with the intention of studying the voyage of agile manufacturing from its birth at Iacocca Institute in Leigh University in the year 1990 and the progression that occurs in the pump manufacturing industry.

The pump manufacturing industry was chosen to study the degree of implementation of agile manufacturing due to two reasons. The first reason is that pump is one of the products used in several industries like those are involved in mineral water production, oil extraction and chemical distillation. Besides pumps are used for pumping water in domestic houses. The second reason is that the author of this thesis resides at Coimbatore, a city of India located in Tamil Nadu state, in which numerous pump manufacturing companies are operated. These pump manufacturing companies have not been able to flourish well due to the slackness in implementing agile manufacturing concepts in them. In this background, the literature survey being reported in this chapter was carried out from four perspectives. In the first perspective, the papers were surveyed to study the voyaging of agile manufacturing concepts and their potentials of implementing them in pump manufacturing industry. In the second perspective, the pace of implementing agile manufacturing concepts in pump manufacturing industry was surveyed. In this perspective, the impediments that would cause slow implementation of agile manufacturing concepts in the pump industry were examined. From the third perspective, the research agenda for implementing agile manufacturing in pump manufacturing industry and thereby enabling this industry to flourish well were drawn critically by examining the researches reported in these papers.
2.2 SURVEY METHODOLOGY

After deciding to explore the voyaging agile manufacturing from its origin at Iacocca Institute to its application in pump manufacturing industry, the literature survey was carried out to locate any such kind of researches that have been carried out in either pump manufacturing or agile manufacturing domains. In order to explore in this direction, this literature survey was carried out by following a systematic methodology. This methodology is shown in Figure 2.1. As shown, this literature survey was begun by gathering peer reviewed papers reporting researches on agile manufacturing and manufacturing of pumps. Subsequently the papers reporting agile manufacturing researches were studied. From these studies, the meaning, definition and origin of agile manufacturing as reported in these papers were gathered. Then, the areas in which agile manufacturing concepts have been applied while conducting these researches were identified by studying the contents of these papers. Subsequently, the search was made to identify the papers reporting the application of agile manufacturing concepts in pump manufacturing industry. This search resulted in the identification of four papers. These papers were critically studied. Meanwhile, the papers reporting the pursuance of researches on the manufacturing of pumps were studied. From these studies, the historical development of pumps was studied. Further, the different types of pumps and different types of customers who use them were identified by studying these peer reviewed papers. This information was critically studied to identify the gaps that need to be filled by applying agile manufacturing concepts in pump industry. After identifying these gaps, the research agenda was drawn to enable pump manufacturing companies to adopt agile manufacturing concepts and prosper in the competitive market.
2.3 STATISTICS

The statistics of the papers on agile manufacturing that were reviewed during the conduct of the literature survey being reported here is depicted in Figure 2.2. As shown, in total 124 papers were reporting agile manufacturing.
manufacturing researches. These papers were extracted from the journal databases namely emeraldinsight, sciencedirect and springerlink. After reading the contents, these papers were grouped under three categories. As shown in Figure 2.2, almost equal number of papers were found to deal with the history and applications of agile manufacturing. Almost half the number of papers were found to deal with both history and applications of agile manufacturing. This statistics reveals that researchers have been striving hard to explore the meaning of agile manufacturing as well as the issues involved in implementing the same. The information drawn by reviewing these papers is presented in the following sections of this chapter.

Figure 2.2  Statistics of papers reporting agile manufacturing issues

2.4  HISTORY, ORIGIN AND MEANING OF AGILE MANUFACTURING

As shown in Figure 2.2, during the doctoral work being reported here, 26 papers dealing with history, origin and meaning of agile
manufacturing were reviewed. The information drawn by reading these papers are presented in the following three subsections.

2.4.1 History and origin of agile manufacturing paradigm

Some authors have reported the emanation of agile manufacturing paradigm by tracing the history of the germination of three paradigms namely craft production, mass production and lean production in the world (Jin-Hai et al. 2003). The information gathered from the papers authored by them is presented in this subsection.

Hormozi (2001) has traced the development of production paradigms in the world. The first paradigm that the world witnessed was craft production in which the activities were carried out by following the job-by-job basis. The requirements of the customers varied from job to job which were fulfilled by employing the craft production. At one point of time, the world began to adopt Henry Ford’s principles for carrying out production activities in a different way. From the nineteenth century, this way of carrying out the production activities was called as mass production paradigm. Under mass production paradigm, the production volume was higher than that was achieved by employing craft production. Though in the beginning years of its development, the varieties of products developed were less, in the later years, the number of varieties of products produced increased marginally. Subsequent to the mass production paradigm, the world witnessed the emergence of lean production. Lean production encompasses the principles of mass production paradigm and JIT manufacturing. The core aspect of lean manufacturing is achieving continuous improvement in the production of products through the elimination of wastes.
The preciseness of the information contained in Hormozi (2001) can be improved by referring to the information presented in few other papers. For example, Duguay et al. (1997) have pointed out that the mass production paradigm emerged after the industrial revolution between the years 1770 and 1800. These authors have also mentioned that mass production paradigm effectively spread its roots in the USA by absorbing the tenets of F.W. Taylor and Henry Ford. These authors have also mentioned that the mass production paradigm worked well till 1960s. After that, the productivity of the US industries declined and in order to prevent this decline, concepts like TQM and JIT emerged in the world in the late 1980s and early 1990s. As the extension to this development, the world witnessed the emergence of lean production. Similar preciseness is also indicated by Brown & Bessant (2003). According to these authors, lean manufacturing emerged in 1980s as the extension of mass production paradigm.

All the authors of the above papers have mentioned that agile manufacturing has appeared as a paradigm to provide solution for facing the intensified competition that has been happening currently in the world. During the last two decades, approaches like world class manufacturing, virtual manufacturing and flexible manufacturing have appeared in the world. To cap all, agile manufacturing has emerged as the paradigm that would encompass all these approaches under its umbrella and would support the modern organizations to face the intensified completion (Gunasekaran & Yusuf, 2002; Hallgreen & Olhager, 2009). Besides these authors, many other authors who have reported their researches carried out in agile manufacturing arena have mentioned that the formal beginning of the agile manufacturing research occurred when a group of researchers formed agility forum at Iacocca Institute of Leigh University in 1991. The formation of this forum was also the sequel to the placing of agile manufacturing report in the Iacocca Institute (Ali et al. 2013; Vinodh et al. 2012; Hasan et al. 2012; Sreenivasa et al. 2012a).
2.4.2 Definitions and meaning of agile manufacturing

The formation of agility forum in 1991 at Iacocca Institute in Leigh University marked the beginning of the voyage of agile manufacturing researches. Thus beginning of the voyage stimulated several researchers to carry out researches in agile manufacturing arena (Vinodh et al. 2008 c). In the beginning, these researchers strove to define agile manufacturing. As a result, several researchers brought out their own definition on agile manufacturing. Some authors have summarized the definitions of agile manufacturing as defined by many other authors. Particularly Gunasekaran & Yusuf (2002) and Jin-Hai et al. (2003) have listed the definitions contributed by different researchers. On seeing these lists, it is understood that from the year 1995, as many as 14 definitions of agile manufacturing have appeared in literature arena. Amidst the emergence of these many definitions, agile manufacturing is uniquely viewed as a post-mass production concept which focusses on mass customization (MC) of products and services with the ability to respond quickly in response to the dynamic changes in customer demands (Mishra et al. 2013). Agile manufacturing paradigm necessarily encompasses a manufacturing system to produce varieties of products, which is flexible enough to make changes in the product design quickly. The critical characteristics of agile manufacturing are ‘manufacturing system re-configurability’ and ‘flexibility to produce varieties of products’. In other words, agile manufacturing is the paradigm that enables an organization to be flexible enough to quickly respond to the dynamic changes in customer demands and to manufacture different varieties of products and offer varieties of services (Elmosethy 2013).
2.4.3 Confusions and comparison of lean and agile manufacturing paradigms

While the world is spontaneously moving towards adopting agile manufacturing paradigm, a section of the theorists are confused with the two terms ‘lean’ and ‘agile manufacturing’ (Narasimhan et al. 2006). For example, Putnik & Putnik (2012) have mentioned that it is pondering to examine whether lean and agile manufacturing are exclusive or supportive or complementary to each other. These authors have mentioned that this confusion arises because, both these paradigms are applied in the same domain. After examining these confusions, these authors have mentioned that lean manufacturing needs to be implemented when the market conditions are stable and predictable while agile manufacturing is required to be implemented when the market conditions are highly dynamic and unpredictable. In this research paper itself, these authors have mentioned that in today’s highly intensified competitive situation, the companies are required to implement agile manufacturing paradigm and not lean or mass production paradigms. Despite arriving at these findings, these authors have mentioned that, the relationship between lean and agile manufacturing paradigms is not clear. This unclear relationship is clarified by Flumerfelt et al. (2012) by stating that agile manufacturing is the next higher paradigm of lean manufacturing. These authors have also mentioned that the scope of the application of the lean manufacturing is restricted to the production of existing products by making use of the resources efficiently. The application of agile manufacturing goes beyond this scope by enabling the production of new innovative and customized products to face the intensified competition. Another difference between the lean and agile manufacturing paradigms is pointed out by Gunasekaran (1999) from the point of view of carrying out manufacturing activities in organizations. According to this distinction, lean
manufacturing is oriented towards cost cutting approach, while agile manufacturing stipulates higher degree of responsiveness and flexibility.

While carrying out the literature survey being reported here, two papers which address the different nature of lean and agile manufacturing paradigms were reviewed. One of the papers is authored by Hallgreen & Olhager (2009). According to these authors, lean stipulates producing the products without incurring wastes, while agile manufacturing enunciates the creation of the capabilities to react in response to the dynamic changes that occur in the markets. These authors have cited many references to claim that, lean manufacturing is dominated by repetitive production, whereas agile manufacturing facilitates to bring out new and customized products. Like these authors, Katayama & Bennett (1999) have also addressed the differences between lean and agile manufacturing paradigms. These authors have mentioned that leanness, adaptability and agility are not mutually exclusive to each other. Rather these principles facilitate the modern organizations to enhance their responsiveness to the customer requirements and facilitate the organizations to meet the volatile and highly competitive market situations.

On the whole, researchers have established that there is distinct difference in the concepts of lean and agile manufacturing. Particularly, agile manufacturing paradigm is required to be implemented in modern organizations to thrive in today’s competitive and dynamic markets. While implementing agile manufacturing, many lean manufacturing tools and techniques may also be adopted to enhance the quality, productivity and profitability of producing products and offering service. These aspects are depicted in Figure 2.3. As indicated in this Figure, one important distinctive feature of agile manufacturing in comparison to that of lean manufacturing is its ability to achieve MC (Vinodh et al. 2010 b). In fact, the goal of implementing agile manufacturing paradigm in organizations can be attained
only if MC is achieved quickly. In essence, agile manufacturing paradigm is the next advanced paradigm of lean manufacturing paradigm (White et al. 2014).

**Figure 2.3   Distinguishing principles of lean and agile manufacturing paradigms**

2.5 **ENABLERS OF AGILE MANUFACTURING**

After evolving the definitions of agile manufacturing, researchers began to carry out researches for determining the enablers that would enable the companies to implement agile manufacturing concepts. These researches have been frequently reported in literature arena. In order to indicate these enablers, besides using the term ‘enabler’, the authors of these papers use slightly different terms like ‘criteria’ and ‘drivers’. The number of agility enablers pinpointed by the authors using these slightly different terms in these research papers have varied from 2 to 53. The details of this observation are enumerated in Table 2.1.
Table 2.1 Agility enablers reported in literature arena

<table>
<thead>
<tr>
<th>Paper Number</th>
<th>Papers reporting agility enablers</th>
<th>Number of agility enablers identified</th>
<th>Agility enablers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vinodh et al. 2010 b</td>
<td>2</td>
<td>Computer-Aided Design (CAD), Rapid Prototyping Technology (RPT).</td>
</tr>
<tr>
<td>2</td>
<td>Yusuf et al. 1999</td>
<td>4</td>
<td>Core competence management, Virtual Enterprise (VE) formation, capability for reconfiguration, knowledge driven enterprise.</td>
</tr>
<tr>
<td>3</td>
<td>Narasimhan et al. 2006</td>
<td>4</td>
<td>Partnership arrangement, close relationships with suppliers, JIT production, advanced technologies.</td>
</tr>
<tr>
<td>4</td>
<td>Vinodh et al. 2008 c</td>
<td>5</td>
<td>Organizational structure enabler, manufacturing management enabler, employee agility enabler, technology enabler, manufacturing strategy enabler.</td>
</tr>
<tr>
<td>5</td>
<td>Gunasekaran, 1998</td>
<td>7</td>
<td>VE formation tools/metrics, physically distributed teams and manufacturing, rapid partnership formation tools/metrics, Concurrent Engineering (CE), integrated product/production, business information system, Rapid prototyping tools, Electronic commerce (EC).</td>
</tr>
<tr>
<td></td>
<td>Bottani 2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gunasekaran &amp; Yusuf 2002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Vinodh et al. 2011 c</td>
<td>9</td>
<td>CAD, CAM, Computer Numerical Control (CNC), Computer-integrated manufacturing (CIM), Rapid Prototyping (RP), Rapid Tooling (RT), Reverse Engineering (RE), VE, Information Technology (IT).</td>
</tr>
<tr>
<td></td>
<td>Authors</td>
<td>Page</td>
<td>Topics</td>
</tr>
<tr>
<td>----</td>
<td>------------------------------------------</td>
<td>------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>7</td>
<td>Dowlatshahi and Cao 2006</td>
<td>10</td>
<td>Core competencies, VE, RPT, CE, multi-skilled and flexible people, continuous improvement, team working, change and risk management, IT, empowering.</td>
</tr>
<tr>
<td>8</td>
<td>Sreenivasa &amp; Devadasan, 2011</td>
<td>25</td>
<td>Artificial Intelligence (AI), internet, inter and intra enterprise activities, Standard for Exchange of Products (STEP), CE, virtual manufacturing, component based distributed shop floor control system, tabu-enhanced genetic algorithm approach, customization, RPT, IT, web technology, Innovative Total Quality Function Deployment (ITQFD), management responsibility, manufacturing management, employee status, technology and manufacturing strategy, RPT, Computer-Aided Design of Experiments (CADOE), Activity Based Costing (ABC), CAD/CAM, CAD.</td>
</tr>
<tr>
<td>9</td>
<td>Eshlaghy et al., 2010</td>
<td>25</td>
<td>VE, EC, RPT, improvement, multi-skill and flexible people, team working, CE, change and risk management, integrated information system, continuous improvement, flexible infrastructure, supply chain, improved manufacturing technology, core competence, capability for reconfiguration, knowledge management, innovation, agile strategy, agility process, reward system, culture, re-engineering, leadership, collaborative relationships, uncertainty and essential changes, people leverage and IT.</td>
</tr>
<tr>
<td>10</td>
<td>Vazques-Bustelo et al., 2007</td>
<td>53</td>
<td>Top management support, employee involvement and empowerment, team working, job rotation (multifunctional workforce), training and education, knowledge workers, decentralized decision making, entrepreneurial firm culture, reward schemes to encourage innovation and based on both financial and non-financial measures, Enterprise Resource Planning (ERP), Materials Requirement Planning (MRP), Robotics, Automated guided vehicle (AGV), automated storage and retrieval systems, CNC machines, CAD/CAM, RPT tools, intranet internet and world wide web, Electronic Data Interchange (EDI), EC, visual inspection, manufacturing cells, virtual reality software, Flexible Manufacturing Systems</td>
</tr>
</tbody>
</table>
(FMS), Computer-aided Process planning (CAPP), Group technology (GT), Point of Sales (POS) data collection, bar codes, automatic data collection, real time communication/execution systems, Design For Manufacture/Assembly (DFM/A), strategic alliance/based on core/complementary competencies, virtual firm/organization, rapid partnership formation, integration of functions from purchasing to sales, global supply chain management, customer integrated processes for designing, manufacturing, marketing and support, strategic relationship with customers and suppliers, internal and external cooperation, Business Process Re-engineering (BPR), formation of cross-function product development teams, concurrent design of products and processes, multi-disciplinary team working environment, intelligent engineering design support system, customer and supplier integrated multi-discipline teams, global access to databases and information, Knowledge Based Systems (KBS), knowledge management systems, sensitive information protection, organization structure that promotes innovation, training and education, learning organization, knowledge acquisition from internal and external resources, core competence management
An overview of the contents of Table 2.1 would indicate that RPT and Virtual manufacturing are found to be the frequently mentioned enablers of agile manufacturing. RPT facilitates the rapid production of prototypes which enables the companies to reconfigure the products to suit the customers’ preferences before actually the product is manufactured in the shop floor. Furthermore, virtual manufacturing enables the viewing of manufacturing procedure in the computer screens before the product is actually manufactured. This capability of virtual manufacturing enables the reconfiguration of manufacturing facilities to suit the manufacturing of the products according to the customers’ dynamic demands. Next to RPT and virtual manufacturing, CAD is frequently referred by the researchers as agile enabler. A critical thinking would indicate that without the aid of CAD, the production of prototypes quickly using RPT and reconfiguring the manufacturing facilities by using virtual manufacturing is not achievable. Thus CAD enables the reconfiguration of products and manufacturing facilities. Hence, the foundational enabler of agile manufacturing is the application of CAD in the case of manufacturing products.

2.6 IMPLEMENTATION OF AGILE MANUFACTURING IN INDUSTRIES

Since the conceptualization of agile manufacturing paradigm, several researchers attempted to implement the same in different industries. As a result, during the last two decades, many research papers reporting the efforts made to implement agile manufacturing in various industrial sectors have appeared in literature arena. During the conduct of the literature survey being reported here, a total of 48 such research papers were found. The industries and products around which the implementation aspects of agile manufacturing reported in these papers are enumerated in Table 2.2. As shown, the researchers have made efforts to implement agile manufacturing in
as many as 10 industries. Among them, the researches on implementing agile manufacturing have been found to be maximum in electronics industry. The researches reported in these papers are briefly described in the following subsections.

2.6.1 Agile manufacturing in electronics industry

The implementation aspects of agile manufacturing have been reported in literature arena under five categories of electronics industry. The researches reported in the papers which are grouped under these five categories are described in the following subsections.

2.6.1.1 Agile manufacturing in an electronics switches manufacturing company

Vinodh et al. (2007, (2008 - a, b, c), (2009 - a,b,c,d,e), (2010 - a,c,d,e,f,g), 2011-a,d) have carried out extensive researches on implementing agile manufacturing in an electronic switches manufacturing company. During the conduct of the researches reported in these papers, the implementation of agile manufacturing in the manufacturing of electronics switches was examined from several perspectives. The candidate product chosen during these researches was cam operated electronic switch. These researches were carried out in a company by name Salzer Electronics Limited (hereafter referred to as Salzer). Salzer is situated in Coimbatore city of India. The activities carried out and the outcomes of these researches are briefly described in this subsection.
Table 2.2 Papers reporting the implementation oriented researches on agile manufacturing

<table>
<thead>
<tr>
<th>Serial Number</th>
<th>Industry</th>
<th>Product</th>
<th>Papers reporting the implementation oriented researches on agile manufacturing domain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Printed Circuit Boards</td>
<td>Deif &amp; ElMaraghy 2007, Hooper et al. 2001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Computers</td>
<td>Khoo &amp; Loi 2002, Mondragon et al. 2004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electronic components and devices</td>
<td>Sharifi &amp; Zhang 2001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Semiconductors</td>
<td>Zandi &amp; Tawana 2011</td>
</tr>
<tr>
<td>2</td>
<td>Aerospace Industry</td>
<td>Aircraft components</td>
<td>Gunasekaran et al. 2002, Mondragon et al. 2004</td>
</tr>
<tr>
<td>3</td>
<td>Air dryer Industry</td>
<td>Regenerative air dryer</td>
<td>Sreenivasa et al. 2012b,2013 (a,b)</td>
</tr>
<tr>
<td>4</td>
<td>Automotive industry</td>
<td>Engine and transmission parts</td>
<td>Mondragon et al. 2004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-</td>
<td>Coronado 2003</td>
</tr>
<tr>
<td></td>
<td>Industry Type</td>
<td>Component</td>
<td>Reference</td>
</tr>
<tr>
<td>---</td>
<td>--------------------------------------------</td>
<td>-------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>5</td>
<td>Machine tool industry</td>
<td>Sprocket</td>
<td>Vinodh et al. 2011c</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frayret et al. 2001</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Chemical Industry</td>
<td>Rolling bearings</td>
<td>Cheng et al. 2000, Pan et al. 2003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Journal bearings</td>
<td>Cheng et al. 1998</td>
</tr>
<tr>
<td>7</td>
<td>Casting industry</td>
<td></td>
<td>Guisinger &amp; Ghorashi 2004</td>
</tr>
<tr>
<td>8</td>
<td>Household products manufacturing industry</td>
<td>Domestic cookers</td>
<td>Sharifi &amp; Zhang 2001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Fabrication industry</td>
<td>Steel frames</td>
<td>Jiang &amp; Fung 2003</td>
</tr>
<tr>
<td>10</td>
<td>Pump industry</td>
<td>Submersible pumps</td>
<td>Devadasan et al. 2005</td>
</tr>
</tbody>
</table>
Vinodh et al. 2010 (a) have reported a case study on integrating agility and sustainability in the manufacturing of electronic switches to gain business benefits. Initially, these authors created a CAD model of the knob of an electronic switch by using the data obtained from Salzer. Then, by keeping the actual design as base and by referring to the customer preferences, new knobs were designed by using Pro/E package. After that, sustainability analysis was carried out by using sustainability Xpress software. While carrying out this exercise, inputs like CAD model, material, manufacturing process, and location of manufacture were fed into this software. The outputs obtained from this software included carbon footprint and air acidification. By referring to these outputs, these authors have claimed that the proposed models which were developed based on customer preferences in an agile manner have minimal impact on the environment.

The need for amalgamation of agile manufacturing and MC was reported by Vinodh et al. 2010 (b). The results of the literature review conducted in this regard have indicated that both agile manufacturing and MC principles have few commonalities and differences between them. The MC paradigm was conceptualized in parallel with agile manufacturing in 1990s and was successfully implemented in manufacturing and service arenas and in mobile phone manufacturing industry. These authors have combined MC and agile manufacturing concepts to conceptualize a new concept under the title ‘agile customization program’ (ACP). In order to implement ACP in Salzer, these authors developed a website by using adobe Dreamweaver CS3. This website contains the list of products that are manufactured at Salzer. Customers visiting this website can browse and choose their products from which the features can be customized based on their preferences. After choosing the preferred switch, the exploded view of the same will appear in the computer screen. During this exercise, customer can choose combination of different features as preferences. A separate coding will be allotted against
each preference. On choosing these preferences, a table called agile customization sheet will be developed. It will aid the CAD engineer to refine the design changes required by the customers. After completing this implementation oriented research, these authors gathered the feedback of the top executives of Salzer about the utilities developed during their research work using a questionnaire. Based on the feedback of these top executives, the feasibility of these utilities was assessed. These authors have mentioned that the response of these top executives revealed that they are appreciative of the utilities developed during this research and also, indicated the feasibility of adopting these utilities that would enhance the agility of Salzer’s performance.

Vinodh et al. (2010 c) reported the designing of a model under the name ‘total agile design system’ (TADS) to facilitate the systematic implementation of agile manufacturing paradigm in organizations. After designing TADS, the same was subjected to implementation study in Salzer. During the conduct of this implementation study, the acquirement of agility in Salzer on applying TADS was measured by using an index called ‘agility index’. The TADS model was designed to facilitate the acquirement of agility through the infusing of the CAD/CAM technologies in organizations. According to TADS, initially the customers’ requirements are to be collected from various regions by using ‘data technology’. Then, these data are to be translated into design requirements using agile innovative total quality function deployment technique. Then, these design requirements are to be used to design the model of the switch by using CAD packages like Pro/E. The manufacturing feasibilities are to be analysed by using CAM package. Thus, the TADS model works based on the requirements of customers. The agility index of the Salzer before and after implementing TADS model was measured. The results of this measurement indicated that before the implementation of TADS, the agility index of Salzer was 6.7. After the implementation of TADS, the agility index of Salzer was expected to increase.
to 9.5 (out of 10). This anticipation indicated that the level of acquiring agility will significantly increase in Salzer on applying TADS model.

Vinodh et al. (2010d) reported a research in which fuzzy logic and AHP technique were integrated to identify a group of concepts that are required to impart agility in specific companies. The combining of fuzzy logic and AHP technique has been addressed under the name fuzzy AHP process. This fuzzy AHP process was applied in Salzer pertaining to the development of the handle of a switch in agile manner. First, using TADS model, five agile concepts were chosen. Each concept encompassed certain agile criteria. For example, under concept A, three agile criteria namely ‘Organizational structure’, ‘Devolution of Authorities’ and ‘Nature of Management’ were encapsulated. By applying Fuzzy AHP process, the best one of the five agile concepts was chosen. By referring to these best agile concepts, the CAD model of the handle was developed. Subsequently, a prototype of this handle was developed. The manufacturing feasibility of this handle was also analysed.

Vinodh et al. (2010e) have reported a research on assessing agility of an organization by using multi-grade fuzzy approach. Modern organizations are required to imbibe agile characteristics for facing global competition. Before implementing agile manufacturing paradigm, the agility level in the traditional organizations need to be assessed (Cornado, 2003). Then, the actions required to enhance the agility level can be proposed and implemented. This assessment was carried out by using a multi-grade fuzzy logic approach in Salzer. These authors designed an agility evaluation system based on a 20 criteria agile model presented in Ramesh & Devadasan (2007). This agility evaluation system consists of three levels. Under level 1, agility enablers are listed. In level 2, 20 criteria are accommodated. The agile attributes are encapsulated in level 3. By making use of this system, agility
index of the Salzer was measured. This value was found to be 7.36 (out of 10) which indicated that Salzer was in the journey of agile manufacturing. Using this system, the criteria which were found to be weak from the point of view of implementing agile manufacturing paradigm in Salzer were identified. Improvement proposals were suggested to strengthen these weak criteria.

A research on achieving agility in Salzer by carrying out finite element mould analysis was reported in Vinod et al. (2010f). These authors considered a component called ‘top’ of the electronic switches as the candidate component. The finite element mould analysis on this component was carried out by using Mold flow Plastics Insight (MPI) package. The CAD model of the mould ‘top’ was designed and imported into this MPI package. This MPI package was used to analyse the mould model and by keeping the actual mould as reference, five more mould models were developed. The fill and flow analysis was conducted on these five mould designs and the data were gathered and tabulated. These data indicated the anticipated fill time, total packing time, pressure and volumetric shrinkage when each mould design was employed. By referring to the experiences of carrying out this research, these authors have reported that the integration of CAD/CAM with Finite Element Analysis (FEA) would facilitate organisations to acquire agility characteristics. These authors have also developed a roadmap to overcome the hindrances that would be encountered while carrying out FEA for infusing agility in the organizations.

Vinodh et al. (2010 g) have reported a research in which the possibilities of acquiring design agility characteristics with the aid of CAD were examined. The candidate product chosen in this research is knob of the electronic switch. A 3D model of the knob was created by using the Pro/E package. Then, a brainstorming session was conducted among the executives of Salzer and their ideas regarding the new model designs were gathered.
Based on the gathered ideas, the authors generated ten new CAD models of the knob. Aesthetics, ergonomics and functional improvement were the design criteria based on which the CAD models were designed. Then, these developed CAD models were submitted to the top executives of the Salzer and their responses were gathered by using a questionnaire. These responses were tabulated and compared, which showed the feasibility of developing the new knob models at Salzer. Thus, these authors established the feasibility of employing CAD to achieve agility in designing new products within a short period of time.

The research on using IT as an enabler for implementing agile manufacturing was reported by Vinodh et al. (2011a). These authors developed a digital product catalogue (DPC) incorporated with the electronic switch designs. DPC is an internet based system which facilitates the loading of the products and components in a company’s webpage. The customers can view the products and specify their preferences by visiting this webpage. The DPC was designed by using Hypertext pre-processor (PHP), Hypertext mark-up language (HTML) and cascading style sheets which were supported by MySQL. The customers can see the 3D view of the products and components with their variants and features in DPC. Based on the customers’ preferences, the design department will develop the feasible design of the product and analyse its manufacturing feasibility. These authors supplied a questionnaire to assess the response of the top executives of Salzer about the DPC. The responses of these top executives indicated the possibility of using DPC as an aid to achieve agility in Salzer.

Vinodh et al. (2007) have designed a model named by them as ‘agile innovative total quality function deployment’ (agile ITQFD) and a financial accounting system to account it. This model was designed by carrying out a detailed study on QFD and TQFD. The agile ITQFD model is
incorporated with five matrices namely ‘agile innovative customer requirement matrix’, ‘agile innovative cross-functional matrix’, ‘agile innovative product development matrix’, ‘agile innovative component deployment matrix’ and ‘agile innovative planning and control chart’. These agile ITQFD matrices are required to be developed by integrating agile manufacturing elements namely ‘design reuse’, ‘virtual teams’ and ‘IT for manufacturing’. During the implementation of these agile ITQFD matrices, the customer voices will be translated into technical languages. These technical languages will be communicated using ‘agile innovative work instructions’. The working of agile ITQFD was examined in Salzer by conducting an implementation study. While conducting this implementation study, ‘Touch proof’ (TP) and ‘Rear access Terminal’ (RT) switches were chosen as the candidate products. The conduct of this implementation study was begun by conducting a meeting. During this meeting, the features of the agile ITQFD were explained in detail to the team members. Subsequently, the first three matrices namely ‘agile innovative customer requirement matrix’, ‘agile innovative cross-functional matrix’ and ‘agile innovative product development matrix’ were developed. Later, the ‘agile innovative component deployment matrix’ and ‘agile innovative planning and control chart’ were developed. The feedback of the team members about the implementation study were gathered by using a questionnaire. The responses of these team members were in favour of implementing agile ITQFD at Salzer. These authors also designed a financial accounting system of agile ITQFD. The data required for substituting in this system were obtained from the reactions of the agile ITQFD team members. The points against the reactions on agility characteristics namely technological advancement, the solutions which lead to evolution of simple technology, product superiority, meeting customer needs and lowering of life cycle cost were gathered. The gathered points were converted into financial values. Using these financial values, ‘profit and loss account’ and ‘balance sheet’ were developed. Then, the values obtained in the financial accounting
system were shown to all the agile ITQFD team members and their responses were recorded. These authors have reported that the responses of the team members indicated that the financial accounting system of agile ITQFD is practically compatible.

Vinodh et al. (2008b) have reported a research on agile ITQFD which is similar to that is presented in Vinodh et al. (2007). Two pilot projects on implementing agile ITQFD were carried out in Salzer. The team members of these pilot projects suggested the consideration of three types of switches to study the implementation aspects of agile ITQFD. Those are known as ‘phase selection’ (PS), ‘touch proof’ (TP) and ‘rear access terminal’ (RT) switches at Salzer. The two pilot projects were carried out under the code numbers ‘Agile ITQFD1’ and ‘Agile ITQFD2’. The team members explored the implementation of ‘Agile ITQFD1’ by considering a customer voice titled ‘Development of new switch’ and that of ‘Agile ITQFD2’ by considering a customer voice titled ‘Evolution of new product’. Initially, a meeting was conducted among the team member to explain about the agile manufacturing concepts and the different development stages of agile ITQFD. Then as stated in Vinodh et al. (2007), the matrices of agile ITQFD were developed. A feedback on agile ITQFD exploration was gathered from the team members after the conduct of pilot projects by using a questionnaire. The responses of the team members indicated that agile ITQFD can be successfully implemented in Salzer. Then the application of agile ITQFD was financially accounted. The data required for financial conversion of agile ITQFD activities was gathered by interviewing the fourth author of this paper and two team members. The financial accounting system of agile ITQFD was used to foresee the gains and losses on implementing agile ITQFD in Salzer. Then, the responses of the team members were gathered by using a questionnaire which indicated that the financial accounting system of agile ITQFD can be successfully implemented in Salzer.
Vinodh et al. (2008a) have designed a tool for quantifying agility in organisations and test its practical compatibility. Initially, these authors designed the agile quantification tool by referring to the 20 criteria agile model presented in Ramesh & Devadasan (2007). Then, this model was subjected to implementation study in Salzer. While carrying out this exercise, these authors chose five executives who possess sufficient knowledge on agile manufacturing. Then the authors supplied to them a questionnaire to assess the extent of implementing agile criteria in the Salzer. The data filled in these questionnaires were used to compute the agility index of Salzer. After this computation, it was found that the agility index of the Salzer was 0.846 (out of 1). This value clearly indicated that Salzer had the potential to become an agile manufacturing company. The data gathered to determine agility index were also used to carry out the gap analysis. The results of this analysis indicated that, huge gap in the ‘cost management’ criterion was prevailing in Salzer with regard to the implementation of agile manufacturing. These authors suggested to employ activity based costing practice instead of employing conventional cost management practices in Salzer to fill this gap. These authors conducted a feedback session among the executives to assess the practical feasibility of employing agile quantification tool in a company. The responses of these executives indicated that agile quantification tool is a simple and portable tool which can be used by a company to assess its agility level.

Vinodh et al. (2009e) have reported a research on infusing agility by implementing CAD and RPT. These authors investigated the practical implications of adopting 3D printing technology in Salzer. Initially, the three dimensional CAD model of cam operated rotary electronic switch was developed by using the two dimensional drawings provided by the design engineer of Salzer. The three dimensional CAD model of the actual product was developed by using Pro/E software package. Then, these authors developed six new models of the knob. The feedback of the executives on the
new CAD models of the knob were gathered by using a questionnaire. Then, five of them were subjected to investigation for exploring the application of 3D printing technology to infuse agility. The model name of the 3D printer used during this research was SD300. The prototypes of the five new knob models of the switch were developed by using SD300. The model developed by using RPT could not be subjected to testing since it was not made of the same material of the switch. Hence, the CAD models of both the existing and new models were subjected to analysis by using ANSYS package. Subsequently these authors gathered the feedback of the executives on the 3D model and corresponding prototype by using a questionnaire. The reactions of the executives that were derived from the completed questionnaires indicated the practical feasibility of making use of 3D printer to achieve the goals of agile manufacturing in the Salzer. As a result of this observation, these authors have recommended the adoption of CAD and RPT to enable the implementation of agile manufacturing in companies.

Vinodh et al. (2008 c) developed a decision support system which was named by these authors as Decision Support System for quantifying Agile Criteria (DESSAC). Initially, these authors refined the 20 criteria based agile quantification model contributed in Ramesh and Devadasan (2007). Then, incorporating this refined agile quantification model, these authors developed the DESSAC using Visual Basic 6.0 and Microsoft Access. The DESSAC model was introduced in Salzer to examine its practicality. The screens of DESSAC will display the questions against the 20 agile criteria and the users should respond to the same. After responding to all the questions, the DESSAC may be consulted to quantify and analyse the agility level of the company. The overall agility score and the agility index of the company will be displayed on the screen. Thus, the DESSAC enables the personnel to quantify and analyse the agility level achievable by the company in an easier, faster and accurate manner.
Vinodh et al. (2009 a) proposed an approach named by them as computer-aided design of experiments (CADOE) to enable the companies to implement agile manufacturing. The CADOE approach was developed by integrating the CAD and Design of Experiments (DOE), which are the major enablers of agile manufacturing. The features of the products can be electronically captured by using CAD. The DOE approach allows the conduct of minimum number of experiments to determine the best parameters and levels to carry out to evolve the best design of the product. As CAD and DOE are incorporated in it, the CADOE approach enables the conduct of experiments virtually and not physically. The practical implications of adopting CADOE were investigated in Salzer. Initially, these authors modelled an electronic switch by using Pro/E software package. Then, the mold of the model was subjected to analysis by using MPI package. The DOE module incorporated in this package aids to carry out the analysis. Then, the reactions of the executives of Salzer on CADOE were obtained by using the questionnaire based approach. The virtual results displayed by the MPI package were compared with the actual results. This comparison was carried out from the points of view of three parameters. The three parameters are cycle time, fill time and injection pressure. The results of the virtual and practical experimentations showed that CADOE will enable an organization to achieve agility by compressing time and enhancing accuracy.

Vinodh et al. (2009b) have reported a research on integrating CAD and CAM to achieve agility in Salzer. The candidate product chosen while pursuing this research is knob of the cam operated rotary switch. Initially the CAD model of the knob being currently manufactured in Salzer was developed. Then these authors gathered creative ideas by conducting brainstorming sessions among the executives. Subsequently, the new CAD models of the knob were generated by using Pro/E by referring to the existing model as reference. Then the mold of the respective CAD model was
developed by using Unigraphics package. This package was used to generate the Numerical Control (NC) codes for making the die. These NC codes can be loaded in a CNC machine to carry out the required machining operations. Thus, by carrying out this research, these authors derived an inference that CAD and CAM can be employed to develop a new product in an agile manner. Then, these authors conducted a feedback session to gather the opinions of the executives about the outcomes and practical feasibility of this research which involved the application of CAD and CAM for infusing agility in Salzer. The results of this feedback indicated that CAD and CAM can be used in companies producing products to achieve the goals of agile manufacturing.

Vinodh et al. (2009c) have reported a research on exploring the interfacing of CAD and CAM to infuse agility in organizations. The candidate product chosen while pursuing this research was the cam operated rotary switch. Initially, considering the TADS model as the reference line (Vinodh et al. 2010c), a CAD model of this component was developed. Since this component is made of plastic material, the die and its mold play important role in achieving quality and productivity of manufacturing this component. Usually, the manufacturers use the trial and error method to produce a die and its mold. This method will consume large amount of money and time. In order to overcome this deficiency, these authors developed the mold virtually by using mold advisor software. Then, ten different types of mold of this component were developed using this package and subjected to analysis. Then, the feedback of the executives on the molds was obtained by using a questionnaire. The collective response of the executives was in favour of applying CAD and CAM technologies to infuse agility in Salzer.

Vinodh et al. (2009d) proposed a model named by them as Total agile design system-Activity based costing model (TADS-ABC). These authors carried out a detailed literature survey on agile manufacturing and
costing methods before designing TADS-ABC. In order to carry out the first stage of TADS model, the customers' reactions were gathered. Then these data were converted into technically understandable languages by using Quality Function Deployment (QFD) technique. Then, the data were summarized and the CAD engineers developed the CAD models by using CAD packages. The CAD models which fulfilled the customers' requirements were selected and their manufacturing features were developed by using CAM packages. Then, these authors focused on designing the TADS-ABC system. The TADS-ABC process progresses through four phases. The overhead expenses and drivers are identified in the first phase. After inputting the necessary costs, the activity costs, agile criteria costs and the costs of products evolved by adopting TADS were identified. The results showed that ‘tooling expenses’ was the highest among all and ‘depreciation expenses’ consumed the least cost. The management’s interests in implementing the TADS-ABC model were assessed by using a questionnaire. While concluding this article, these authors have pointed out that TADS-ABC has a wider scope of costing than Activity Based Costing (ABC) by mapping TADS from the three perspectives namely ‘mapping of overhead expenses’, ‘mapping of TADS activities’ and ‘mapping of agile criteria and product series’.

The information presented above, would indicate that significant number of researches on applying agile manufacturing concepts in electronic industry have been reported in literature arena. Particularly, Vinodh et al. (2007, (2008 - a, b, c), (2009 -a, b, c, d, e), (2010 - a, b, c, d, e, f, g), 2011) have described the application of agile manufacturing concepts in Salzer. While pursuing most of these researches, the impact of applying CAD, CAM and RPT on enhancing the agility of Salzar was studied. A deficient aspect of these researches is that entire products were not considered during the conduct of these studies. Rather, in majority of these researches, only the individual
components were considered as the candidate components for studying the method of infusing agility in Salzer.

2.6.1.2 Agile manufacturing in a semiconductor manufacturing company

During the conduct of the literature survey being reported here, it was found that a research on evaluating the best electronic-customer relationship management (e-CRM) network for achieving agility in a semiconductor manufacturing company has been described in Zandi & Tavana (2011). The integration of internet and electronic commerce in the applications of manufacturing companies resulted in the development of e-CRM networks. The e-CRM network enhances the interaction between the customers and aid the organization to achieve agility by producing customized products and offering service at low price. These authors have evaluated the best e-CRM network to attain manufacturing agility by considering financial and customer related features. Three main e-CRM frameworks presented by three different authors were analysed to explore their capabilities in facilitating to acquire agility from three perspectives. These criteria are titled as strategic, operational and functional agility. These agile perspectives were ranked based on their financial characteristics and customer related characteristics by using a four phase QFD model. The evaluation of the best e-CRM network suitable for application in a semiconductor industry was carried out by involving managers like capital budgeting manager, e-quality manager and e-customer relations manager. The best e-CRM network which covers all the manufacturing operations like sales, marketing, customer service, new product development, procurement, supplier relationships, logistics, supply chain management and strategy development was chosen by using this approach. These authors report that the selected e-CRM network was recommended to the top management by the top managers and the feasibility of implementation
was discussed. Altogether, the experience of conducting this research has indicated that the e-CRM networks will enable companies to acquire agility characteristics.

2.6.1.3 Agile manufacturing in PCB manufacturing companies

During the conduct of the literature survey being reported here, two papers reporting researches on applying agile manufacturing concepts in Printed Circuit Board (PCB) manufacturing companies were found. The researches reported in these papers are briefly described in this subsection.

Hooper et al. (2001) have explored the operational issues of agile costing systems by conducting a case study in a PCB manufacturing company. These authors carried out a detailed literature review on costing systems employed in traditional mass and lean production enterprises. These authors have emphasised that the costing system should be forward looking, outward looking, dynamic and able to control the activities in agile manufacturing environment. Then, the costing techniques such as throughput accounting, standard costing and activity based costing have been compared with the agile costing system characteristics. After this comparison, these authors have stated that no specific costing technique is available for adoption in agile enterprises, but the ABC system is adaptable for the implementation in the agile enterprise. These authors have carried out a case study on applying ABC to focus on the strategic elements of agile manufacturing. The company chosen for the case study manufactures PCB for supplying to companies belonging to the aerospace, automotive, telecommunication and research industries in UK. This company manufactures three types of PCB which consists of single-sided, double-sided and multi-layered boards. The costing system was implemented by using a simple generic method. These authors analysed the manufacturing and supporting activities of each type of PCB.
Since there were variations in the activities, these authors decided that the activity centre approach of activity based cost management would be beneficial for quantifying the value provided by each activity. Hence, a spreadsheet solution with the cost information was developed. Then, these activities were grouped under 16 main activity centres. Again these main activity centres were grouped under six cost drivers. This costing system was then evaluated, which indicated that there has been an immediate need to focus on reducing process waste in the company. This costing system has also revealed that in comparison to that is expended on single and double-sided PCBs, the cost expended on obtaining and servicing orders for multilayer PCBs was higher. Additionally, this costing system has facilitated to explore the intra and inter enterprise cost structure of the company.

Deif & ElMaraghy (2007) have developed a system called agile manufacturing planning and control (agile MPC) system. This system aids to link manufacturing strategy with market strategy. The Manufacturing Planning and Control (MPC) systems are generally classified as inventory based MPC system and capacity based MPC system. These authors proposed a dynamic MPC module by using distributed controllers which have the ability to control the inventory, capacity and Work in Process (WIP) parameters. The control of these parameters is achieved through a supervisory controller known as Decision Logic Unit (DLU). The high-level market strategy, its constraints and feedback of the current manufacturing system will be taken as the input by the DLU. The DLU is composed of three hierarchical layers, in which the first two layers function off-line and the third layer is an online control layer. These authors have applied the agile MPC system in an automatic PCB assembly factory. The candidate product chosen during this application is the random access memory (RAM) unit. The proposed DLU facilitated the alignment of the assembly line with the marketing strategy. Then, a cost analysis was carried out to examine the performance of the agile MPC system. This
comparative cost analysis indicated that the agile MPC system can efficiently react to different anticipated demand patterns through different distributed controllers.

2.6.1.4 Agile manufacturing in a computer manufacturing company

While carrying out the literature survey being reported here, it was found that a research on examining the way of enhancing agility in the manufacturing computers has been reported in Khoo & Loi (2002). These authors have identified ‘product modularity’ approach as one of the ways of achieving agility in manufacturing companies. These authors state that while implementing agile manufacturing in companies, the assembly line of a product which is incorporated with modularity can be divided into two different subassembly lines. In the first subassembly line, the basic components shall be assembled. In the second subassembly line, the components which create variations in the product are assembled to infuse agility in the manufacturing of products. These authors state that the agility in manufacturing can be achieved by focusing on line-balancing and optimising scheduling of variant operation assembly line. These authors state that an optimal solution can be derived through the application of AI techniques such as simulated annealing, neural networks, and genetic algorithm. These authors have carried out a case study to examine this aspect. While pursuing this case study, these authors have considered a company in which computer towers are produced. In this company, the computers with different product variants with mixed configurations are produced. This kind of production is achieved by assembling different main assemblies such as motherboards and casing based on the customer preferences to create product variants. This task is complex with voluminous activities. It is difficult to identify the assembly steps that would reduce the cost of manufacturing. In order to identify the assembly segment that does not violate any constraints, these authors first applied
genetic algorithm and then tabu search. These authors found that the manufacturing cost was found to be lesser in the case of the assembly sequence identified by applying tabu search than that was obtained by applying genetic algorithm. Further, these authors explored the possibility of solving this assembly line problem by adopting a novel tabu-enhanced genetic algorithm approach. This approach was incorporated with the positive aspects of both genetic algorithm and tabu search. Then, these authors investigated the assembly sequence evolved by applying this new approach and found out that the cost of manufacturing is going to be lesser by applying this approach than that was obtained by applying genetic algorithm and tabu search. Moreover, these authors found out that the results obtained by using this genetic algorithm enhanced tabu search were robust.

2.6.1.5 Agile manufacturing in ‘domestic cooker’, ‘high-technology electronic components and devices’ manufacturing companies

While carrying the literature survey being reported here, it was found that a research on enhancing the agility in manufacturing companies has been reported in Sharifi & Zhang (2001). These authors designed a conceptual model of agility which consisted of three elements namely agility drivers, agility capabilities and agility providers. Then, based on this conceptual model, a methodology was developed to aid manufacturing companies to formulate strategic policies for achieving agility. The methodology developed by these authors encompassed three major stages. In the first stage, the company’s agility needs and the current agility level are determined. In the second stage, the capabilities required by the company in order to become agile are determined. In the third and final stage, the agility providers are identified and the level of agility achieved is determined. Based on this conceptual model, an assessment model of agility was developed. This assessment model consisted of two tools. The first tool was used to assess the
agility needs of the company. The second tool was used to assess the level at which agility was practiced in the company. These authors validated the practical applicability of this methodology by conducting implementation studies in two companies. The first company in which this implementation study was carried out was a leading manufacturer of domestic cookers. The second company was a manufacturer of high-technology electronic components and devices. On using the assessment model of agility, it was found that the average score of all factors was 5.2 (out of 10). According to this assessment model, this score indicates that this company has acquired a moderate level of agility. The second tool was used to assess the level of agility practiced in the company. The result of using this tool indicated that the company scored a score of 5.6 (out of 10). Further, these authors have used this methodology to enhance the agility of a company which manufactures domestic cookers. These authors have concluded that different companies tend to react differently to implement changes. Hence, their requirements will be unique and different combination of practices and methodological approaches are required to be followed for implementing agile manufacturing.

2.6.2 Agile manufacturing in aerospace industry

While carrying out the literature survey being reported here, two papers reporting researches on applying agile manufacturing paradigm in aerospace industry were identified. The researches reported in these papers are briefly described in this subsection.

Gunasekaran et al. (2002) have reported a research which was carried out to examine the application of agile manufacturing in an aerospace company by name GEC-Marconi Aerospace Company (GECMAe). GECMAe, formerly known as Marconi aerospace, is a part of General Electric company/PLC of UK. GECMAe is leading in designing and producing a wide
range of critical systems which maximise the performance, safety and integrity of the aircraft and air/land systems. The GECMAe is a specialist company involved in designing, developing and producing components and systems for civil and defence applications. These authors developed and used an agility audit questionnaire for assessing the agility level of this company. The responses against the questions were obtained from ‘change team’ members of GECMAe. These responses were converted into scores by using a predetermined scale. Using this score, the agility index of the company was calculated. By refereeing to the agility index, these authors suggested few changes to improve the agility level of GECMAe. For instance, GECMAe has incorporated process layout in the shop floor. This facility was found to be the cause of ‘late delivery’. These authors have stated that by adopting group (cellular) technology layout in this company, agile characteristics can be improved dramatically. Further, these authors found that, cost is a crucial parameter in infusing agility in GECMAe. Hence, these authors recommended GECMAe to adopt lean principles to reduce costs by employing concepts and technologies such as Business Process Reengineering (BPR), JIT, Kanban, concurrent engineering, RPT and QFD. Thus, these authors have investigated the application of agile manufacturing in GECMAe by using agility audit questionnaire. By referring to the results of this investigation, these authors brought out a number of recommendations with the objective of increasing the value of the agility index of GECMAe.

Mondragon et al. (2004) have studied the impact of information systems in achieving agility in four companies. These authors have cited the research papers in which the favourable role played by the information systems incorporated with IT infrastructure in achieving agility is mentioned. Subsequently, these authors have presented their research, which was conducted in four stages. In the first stage, the background of the four companies in which the impact of information systems on enhancing agility
was examined. During the second stage, the information system requirements and performance levels were identified. In the third stage, the nature of manufacturing operations carried out in the companies was studied. In the fourth stage, the impact of information systems on enhancing agility level in these companies was studied. While carrying out these studies, the competent personnel of these companies were interviewed by using a questionnaire. In order to quantify the qualitative responses, a Likert’s scale of range 1-5 was used. Using this approach, the agility levels of the four companies and the impact of information systems on enhancing agility levels in these companies were assessed and analysed. The first and fourth companies fall under aerospace sector. The second company falls under electronics computer sector. The third company falls under automotive sector. A surprising finding of this study was that information system is not a vital primary enabler of agile manufacturing paradigm. However information systems support the implementation of agile manufacturing paradigm. The results of this study have also shown that poor operation of information system does not impede the process of acquiring agility characteristics. Amidst this finding, these authors have preferred to claim that the role of information systems may become crucial in case agile manufacturing is required to be supported through the incorporation of supply chains and the management of the same. In this case, information systems may facilitate to increase responsiveness by transmitting information to enable ‘supply chains dependant’ companies to acquire agility by responding quickly against the dynamic demands of the customers.

2.6.3 Agile manufacturing in air dryer industry

In literature arena, few authors have reported the researches which were pursued for the purpose of enhancing agility level in the case of
producing air dryers. The experiences of conducting these researches reported in these papers are described here.

Sreenivasa et al. (2012) have developed a 30 criteria agility assessment tool by keeping the 20 criteria model presented in (Vinodh et al. 2010e) as reference. These authors have refined the 20 criteria model and regrouped the 30 agile manufacturing criteria under the agile manufacturing enablers. The mark pattern stipulated in the quality award model called Malcolm Baldrige National Quality Award (MBNQA) was adopted to design this 30 agile manufacturing criteria assessment tool. This tool was designed to measure the agility level of the organization on the basis of the mark obtained out of the total marks of 1000. These marks are distributed under five agile manufacturing enablers namely ‘Management’, ‘Employees’, ‘Technology’, ‘Manufacturing management’ and ‘Manufacturing strategy’. Since an organization can become agile only with the involvement of the management, half of the marks (that is, 500) are allotted against the management enabler. Thus, based on the guidelines of 30 agile manufacturing criteria, the companies scoring marks less than 500 will not be encouraged to proceed further towards implementing agile manufacturing. A total of 125 marks are allotted against each other agile manufacturing enablers. These marks allotted are in turn distributed among the agile manufacturing criteria encapsulated under each agile manufacturing enabler. Based on these 30 agile manufacturing criteria, a questionnaire was developed. In order to convert the responses of the responder against the questions of the questionnaire into marks, a reckoner matrix was developed. For example, when a responder responds ‘Yes’ against a question, the marks to be allotted against this response are to be chosen from this reckoner matrix. These authors have assessed the agility level of a company by name ‘Trident Pneumatics Private limited’ (hereafter referred to as Trident) by using this 30 criteria agile manufacturing assessment model.
Trident is situated in Coimbatore city of India. Trident is a company in which the products like compressed air dryer, drain valves and filters are designed and manufactured. This exercise was started by explaining the 30 agile manufacturing criteria to the top executives of the Trident. Their responses were gathered by using the questionnaire. Then, these responses were converted into marks by referring to the reckoner matrix. The total marks scored by the Trident was 682.625 out of 1000. As this score is more than 500, it was construed that Trident could be driven towards acquiring agility characteristics. Then, the gap analysis was carried out by referring to total agility level (TAL). The drag factors and mitigation actions were identified by analysing the responses. The factor associated with a question is considered as drag factor, if the score of the response of one respondent against that question is zero. The factor associated with a question will be identified as ‘failure factor’, if the score against response of the two or more respondents against a question is zero. This analysis showed that Trident had 25 drag factors and 15 failure factors. Then, the mitigation actions to overpower the drag factors and the success elements to engulf the failure factors were proposed and explained to the Managing Director of Trident. These proposals were partially accepted by the management personnel of Trident.

Sreenivasa et al. (2013a) have reported a research on theoretically mapping air dryer capabilities from agile manufacturing perspectives. An air dryer is used to remove the moisture from the compressed air. The moisture free dry air is used in pneumatic applications in the fields like construction, mining, military, medical, telecommunication, marine, power generation, automotive and robotics. The performance of an air dryer is assessed based on a parameter called ‘dew point’. Dew point is the temperature below which the moisture contained in the compressed air begins to condense and become water. The function of the air dryer is to lower down the dew point of the compressed air. The characteristics and working principles of four types of air
Dryers are described in this paper. By theoretically mapping, the type of air dryer that is susceptible for applying agile manufacturing in Trident was identified. Based on the dew point temperature requirements, the specifications of the air dryers to be manufactured for suiting the particular applications may differ. The increase in global competition has made the modern customers to demand customized products and therefore, the air dryer manufacturing companies should also acquire agility characteristics so as to produce air dryers with the specifications based on the customer requirements. In order to study this aspect, these authors mapped the capabilities of two air dryers from the four perspectives namely market, cost, environment and time. The results of this mapping revealed that in Trident, a type of air dryer called ‘regenerative air dryer’ possesses more agile manufacturing capabilities than the other types.

Sreenivasa et al. (2013b) report a research that was carried out in Trident for investigating to enhance the TAL in the production of regenerative air dryer. While pursuing this research, a model named as ‘Model for Enhancing the Total agility level’ (METAL) was developed. The METAL was implemented in five stages. The first stage of METAL was employed to assess the TAL value of the Trident by using 30 agile manufacturing criteria agility assessment tool. The TAL value of Trident was found to be 68.37%. Then the agile manufacturing criteria namely ‘time management’, ‘global optimization’ and ‘production methodology’ were found to be weak in Trident. In the third stage, the characteristics of the products manufactured were mapped from the agile manufacturing perspectives namely environment, cost, market and time. Then, in the fourth stage, appropriate activities or operations had to be carried out to strengthen the weak criteria pertaining to the production of the regenerative air dryer in Trident. As mentioned earlier, ‘time management’, ‘global optimization’ and ‘production methodology’ were found to be the weak criteria in Trident. In order to strengthen ‘time management’ criterion,
the non-value added activities carried out in Trident were observed and a proposal was submitted. In this proposal, it was suggested to remove the two non-value added activities and thereby, reduce the time consumption.

While investigating the strengthening of ‘global optimization’ criterion, it was found that there was no effective utilization of IT infrastructure in Trident. In order to rectify this deficiency, these authors designed a web portal to integrate and share information among customers, suppliers and employees. In order to strengthen the weak criterion namely ‘production methodology’, electronic leak detection inspection was recommended in place of manual inspection. During the fifth stage of the METAL, the TAL value was reassessed to compare the agility index before and after the anticipated implementation of these proposals. In the end, the authors used a questionnaire to gather the responses from the executives to estimate the TAL value on implementing agile manufacturing in the production of regenerative air dryers in Trident. Then, the authors compared the TAL values before and after the anticipated implementation of the proposals. This comparison indicated the possibility of improving agility level of Trident by 1.91% on implementing the suggestions mentioned in the proposal.

The experience of carrying out the researches reported in the above three papers have indicated that high potential exists to improve the agility level of the companies in which air dryers are designed and manufactured. The implementation of agile manufacturing by using the model ‘METAL’ will facilitate to enhance the agility level of those organizations.
2.6.4 **Agile manufacturing in automobile industry**

Due to the intensification of competition, automobile industry has been absorbing agile characteristics. Frequent appearance of new models of cars with amazing features vouches this claim. In coincidence to this development which has been occurring in global markets, some authors have reported researches on applying agile manufacturing concepts in the automobile field. The highlights of the contents of the papers authored by these authors are described in this subsection.

Vinodh et al. (2011c) reported a research on investigating the application of CAD and Computer Aided Engineering (CAE) as enablers of agile manufacturing in an automotive sprocket manufacturing company. These authors have assessed the practical feasibility of developing new products through the integration CAD and CAE technologies. A 3D model of the existing sprocket design was created by using the 2D drawings obtained from the company. Then, the 3D model was subjected to stress analysis by using the ANSYS software package. These authors used the results of this analysis to carry out design optimization process (DO). The DO was carried out by using DO module of ANSYS to obtain the optimized design parameters. These authors optimized the design of the sprocket by using first order and factorial methods. Then, these authors generated two new sprocket designs by using the two different methods. The feasibility of these designs was validated by examining the responses of the executives of this company by making use of a questionnaire. The responses of these executives which were presented in the filled-in questionnaire indicated that infusing CAD and CAE would improve the agility level of this company.

Frayret et al. (2001) have demonstrated the effectiveness of a method called ‘NetMan approach’ in acquiring agility characteristics in
organisations. NetMan approach refers to the formation of autonomous business units called ‘NetMan centres’ which are dependent on each other to achieve the ultimate objective of running the company. Each NetMan center functions according to its own mission. Here NetMan strategic framework is used to connect NetMan centers for attaining the goals of implementing agile manufacturing. These authors have mentioned that NetMan approach is the extension of Fractal factory and holonic manufacturing. Besides these two concepts, these authors have compared the NetMan strategic approach with bionic manufacturing from the perspectives of four system parameters. After explaining thoroughly the NetMan strategic framework, these authors have described its application in acquiring agility characteristics in Prevost car manufacturing company which is managed by Volvo group. According to this approach, three plants are operated to manufacture Prevost car. In the first plant, buses are assembled. In the other two plants, bus frames and substructures are built and assembled. Besides a facilitating center called ‘bus sales center’ is created. The responsibility of this center is to match the customer requirements and manufacturing activities. The strategic NetMan framework enables the implementation of agile manufacturing in the Prevost car manufacturing company by creating collaborative competencies among the NetMan centers. Some of the techniques used during this process are Kanban management, assembly line planning and vendor management inventory. While concluding, these authors have mentioned that creation of collaborative competencies by employing NetMan strategic framework enables the organisations to achieve the goals of implementing agile manufacturing.

The researches reported in the above papers have given rise to an impression that automobile industry is in the initial stage of imbibing agile characteristics. More researches are required to be carried out to identify the ways and means of infusing agility characteristics in automobile industry for
enabling the automobile and accessories manufacturing companies to acquire competitive strength.

2.6.5 Agile manufacturing in machine tool manufacturing industry

Although machine tools can serve as catalysts of infusing agile characteristics in manufacturing companies, quite a few researches on infusing agility characteristics in the manufacturing of machine tools have so far been carried out. As a result, during the conduct of the literature survey being reported here, only one paper reporting such research could be identified. The research reported in this paper is briefly described here. Wang et al. (2003) have proposed a multi-agent and distributed ruler based approach to carry out production scheduling in agile manufacturing systems. These authors state that a multi-agent system (MAS) has the capabilities such as modifiability, extensibility, re-configurability and adaptability. These authors have developed a multi-agent and distributed based agile scheduling system based on the hierarchical agent-based scheduling system. These authors have carried out an experiment to evaluate the developed system in the workshop of a machine tool manufacturing company in Shenyang, China. Three kinds of machine tools namely lathes, mills and drills are manufactured in this company. This experimental study considered the dispatching of four different kinds of parts associated with different technical process plans. Totally five simulation runs with different scheduling strategies were made. The results obtained by conducting the simulation runs proved that agent-based scheduling system can finish scheduling tasks in a near optimal manner and MAS can rapidly respond to the requirements. The conducting of these experiments has also indicated that those approaches facilitate the adaptability and configurability to acquire agility characteristics in machine tool manufacturing companies.
2.6.6 Agile manufacturing in journal bearings manufacturing industry

Agility can also be infused in the products that are assembled in other major products. In line to this claim, two papers by Cheng et.al. (1998, 2000) were identified during the conduct of the literature survey being reported here. The researches reported in these papers are briefly described in this subsection. Cheng et al. (1998, 2000) have proposed an architecture for implementing agile manufacturing concepts through the integration of AI and internet technology with particular reference to the selection and design of journal bearings. These authors have stated that the selection and design procedures of a journal bearing are complicated and those procedures rely heavily on the knowledge and experience of the designer. The architecture proposed by these authors would enable the customers to access the details pertaining to the selection of journal bearings at globally any time through internet. The customers can input the application requirements and the architecture will quickly respond to provide an optimal selection or design solution. This internet supported intelligent architecture was implemented in Glasgow Caledonian University, United Kingdom. This architecture was incorporated with seven modules namely electronic catalogue, intelligent selection, mounting details, sealing devices, lubrication, manufacturing database and design modules. These authors developed these modules by integrating AI with the conventional ‘bearing design’ and ‘manufacturing techniques’. This internet technology integrated architecture can enable collaborative product development by involving designers, suppliers, customers and manufacturer who are stationed globally. Further, this architecture can support activities like designing products, developing information systems, carrying out collaborative design and running simulations in virtual environment. The seven modules mentioned above were developed by using HTML, Java script, Java and C++ programming. The
‘mounting details’ module of this architecture incorporates 2D and 3D animations. This module also contains simulations of different mounting techniques which will provide the designer or customer with the detailed design information on the mounting methods. The designer or a customer can access these modules through internet and interactively input the application requirements. The search engine of the ‘intelligent selection’ module of this architecture aids the customers to select the appropriate bearing type with associated configurations. This search engine was developed by integrating artificial neural networks (ANN) and fuzzy logic systems (FLS). Thus, the proposed AI-Internet based architecture will infuse agility in selecting and designing journal bearings. While concluding, these authors have mentioned that this internet based architecture has great potential in terms of providing design knowledge and solutions based on the customer requirements. These authors have also discussed the issues associated with implementing this internet based intelligent architecture in organisations. The trial results indicated that this architecture has great potential to improve the agility of the organisation manufacturing journal bearings by enabling to quickly select and design the journal bearings in accordance with the dynamic requirements of the customers.

2.6.7 Agile manufacturing in chemical manufacturing industry

One paper reporting a research on infusing agility in chemical manufacturing industry was studied during the conduct of the literature survey being reported here. The information and knowledge gathered by studying this paper are highlighted here. Gusinger & Ghorashi (2004) have described the increasing application of agile manufacturing practices in the specialty chemical industry. The capabilities that indicate that the speciality chemical firms are becoming agile are, i) Entering into niche markets through custom chemicals manufacturing, ii) Improving relationships with suppliers, iii)
Forming strategic partnerships, iv) Adopting advanced technology and research and v) Emergence of virtual firms. These authors have cited many examples to indicate that several speciality chemicals manufacturing companies have acquired these characteristics and hence, these companies are becoming agile. In order to further explore in this direction, these authors have carried out an agility gap assessment analysis in a small size chemicals manufacturing company by using a questionnaire. The questions in this questionnaire were listed under three sections namely production, engineering and management. The responses against these questions were obtained from the appropriate personnel of this company by conducting one-on-one interviews.

Then, these observations were recorded and a comparative analysis with an ideal agile manufacturer was carried out. The results of the gap assessment analysis indicated that this company was on the right track in adopting many agile manufacturing criteria. It is presumed that this company was found to be more agile than large commodity producers. This is due to the reason that the size of this company is relatively small with few managerial levels which has been conducive to implement agile manufacturing criteria easily in it. It was suggested that this company shall stress on the ‘customer focus’ philosophy in its mission statement and shall incorporate a system to award the employees who suggest improvements. Further, it was suggested to establish a continuous training and retraining system for imparting rigorous training to each employee of this company. The results of these analyses reveal that in comparison to large size companies, small and intermediate sized manufacturing companies can implement easily the agile manufacturing practices and grow to stay competitive in the global market.
2.6.8 Agile manufacturing in casting industry

During the conduct of the literature survey being reported here, a paper reporting a research on infusing agility in the casting industry was studied. The information and knowledge gathered by studying this paper are briefly presented here. Yang & Li (2002) have reported a research on evaluating the agility of a company by using the multi-grade fuzzy assessment method. First, these authors have described the characteristics of MC. MC refers to the capability of an organization in meeting the individual requirements of large number of customers within a short period of time without compromising the quality and economy of production. In order to effect MC, other words, the outcome of agile manufacturing is MC. These authors have mentioned about the need to assess the agility level of a company in achieving MC. In the model proposed by these authors, the information on the customers’ demands, the speed of product design and the flexibility of product design were used as principles to assess the product design agility which will facilitate to achieve MC in companies. Under these principles, ten indices were incorporated. Based on these indices, these authors developed multi-grade fuzzy assessment method to evaluate the agility level of companies. Using this model, these authors evaluated the agility level of a company by name XiDian casting limited company. This model is designed to indicate the grades A, B, C, D and E to specify the agility level of the company as ‘extremely agile’, ‘agile’, ‘generally agile’, ‘not agile’ and ‘extremely in-agile’ respectively. When evaluated by using this model, the agility grade of the XiDian casting limited company was found to be B (meaning that this company is ‘agile’).
2.6.9 Agile manufacturing in the manufacturing of steel frames

During the conduct of the literature survey being reported here, a paper reporting the research on applying agile manufacturing concepts in steel frames manufacturing company was encountered. The information and knowledge gathered by studying this paper are briefly described here. Jiang and Fung (2003) have proposed an infrastructure for exercising adaptive production control in an agile manufacturing environment. Initially, an infrastructure called virtual production systems (VPS) is introduced. A VPS is constructed by incorporating the relevant job shop to meet the requirements of one customer. Several such VPS can be constructed to meet the requirements of many customers in an agile manner. These authors proposed the incorporation of the architecture of adaptive controllers in a VPS, which consists of a resource planner, a temporised object-oriented Petri Nets with changeable structure (TOPNS-CS), a real time–scheduler, a dispatcher, a system analyser and a monitor. These authors carried out a case study in a job shop in which customer specified steel frames are produced. The four adaptive control mechanisms introduced by these authors were alternative production resources, alternative process, increase in production capacity and change of task priority. The case study involving the manufacturing of various steel frames based on customer specifications has been described to illustrate the way of applying adaptive production control in VPS to cope with dynamic demand and thereby, achieving the goals of implementing agile manufacturing.

2.6.10 Agile manufacturing in pump industry

Few authors have examined the implementation of agile manufacturing in pump industry. The researches reported in the literature arena by these authors are described here. Vinodh et al. (2010h) presented a
research which was carried out to examine the impact of applying CAD and RPT in achieving agility in a pump manufacturing company. During this research, the new designs of a component called impeller of the centrifugal pump were created by using CAD. While creating these designs, Microsoft visual basic 6.0 was utilized to create the front end support. The impeller designs were subjected to analysis by using two software packages namely Gambit and Fluent. Using these packages, the flow analyses of employing the newly created impeller designs were carried out. After conducting these analyses, the prototype of one of its designs was created by using a rapid prototyping machine. The execution of these steps indicated that new products and components can be brought out in agile manufacturing environment by employing appropriate CAD, CAE and RPT. In this research, the ABC methodology was followed to determine the actual cost of manufacturing each design of the impeller. The finding of this research is that, the cost of manufacturing the new designs created using CAD is lesser than that of the impeller currently being produced. Thus, it is also shown that, activity based costing can be used to specifically cost the new products to be manufactured in an agile manner and choosing the one in which case, the production cost is minimum. This implementation study was conducted in a traditional pump manufacturing company in which agile manufacturing practices are yet to be implemented.

Vinodh et al. (2011 b) have reported a research which was begun by analysing the linkages between the CAD, CAM and agile manufacturing characteristics. Then, these authors developed a methodology and designed a conceptual model for carrying out the implementation studies. In the initial phase of implementing the conceptual model, the data on customer requirements were gathered and the solid models of the existing design of two components namely casing and impeller were developed. Based on the data gathered from the customers, the improvements and modifications were made
in the existing design of these two components. Thus, four improved models of these components were designed. Then, these improved models were validated by using two computer aided analysing packages namely GAMBIT and FLUENT. In the last phase of study, the feasibility of manufacturing these improved CAD models was investigated. Then the study of manufacturing feasibility of these models was carried out by using ‘cast cavity’ module of Pro/E wildfire. The experiences gained by pursuing this research have indicated that agile characteristics can be developed in a traditional manufacturing company by infusing CAD and CAM technologies.

Vinodh et al. (2012) have carried out a case study on assessing the agility level of a traditional pump manufacturing company by using a 30 agile manufacturing criteria quantification tool. These authors distributed the questionnaires encapsulated in this 30 agile manufacturing criteria quantification tool to the executives of this company and the agility index was calculated based on their responses. The total score obtained by using this 30 agile manufacturing criteria quantification tool was 529 out of 1000. Since this score is above 500, it was construed that agile manufacturing could be implemented in this company. Then, by referring to these scores, the gap analysis was carried out. Based on the results obtained by conducting this gap analysis, proposals were drawn to enable this company to acquire agile characteristics.

Devadasan et al. (2005) have reported a research on exploiting Taguchi’s off-line model in the agile manufacturing environment. These authors have carried out a detailed literature survey on agile manufacturing and Taguchi’s offline model. The results of conducting this literature survey have indicated that all the experiments comprising Taguchi’s off-line models have been conducted by considering quantitative features. However, in agile manufacturing environment, the criteria involving qualitative features should
also be considered for carrying out experiments. Here, the challenge to be faced is the actual conduct of the experiments. In this case, real time experimentation was not encouraged because of the large amount of time and money involved. Thus, these authors suggested the conducting of interviews instead of conducting experiments. These interviews may be conducted by employing Delphi approach. In order to assess the success rate of the experiments, the executives and employees are to be interviewed. In order to examine this approach, these authors carried out a case study in a pump manufacturing company and the candidate product was the submersible pump. In the first phase, seven factors which would aid in imparting agility while designing a new model of a submersible pump were identified. These seven factors that would impart agility in the design of a submersible pump in this company were impeller diameter, impeller thickness, speed, impeller material, and hardness of shaft, incorporation of remote control and provision of sump level controller. Then, the experiments containing qualitative and quantitative factors and levels were designed by using Taguchi’s orthogonal array based approach. These experiments were shown to two executives and their opinions were obtained. These executives anticipated that on choosing a particular design with best combination of factors and levels, there will be 75 percentage increase in discharge volume and delivery head. In the second phase, Devadasan et al. 2005 authors examined the possibilities of adopting 20 agility criteria in this company and found that, 11 criteria were critical and feasible for adoption in this company. Experiments were designed to examine the implementation feasibility of these 11 critical criteria. Under each criterion, level 1 was chosen as traditional practice and level 2 was choose as agile practice. The experiments thus designed were not actually conducted. Instead, a questionnaire was supplied to two executives for assessing the success rate of implementing each experiment. The responses of these executives indicated that the journey of attaining agility in the pump manufacturing company will be smooth and quick.
Altogether, the researches reported in the above papers indicated that, as the pump manufacturing companies are instilled with traditional mass production characteristics, several agile criteria need to be strengthened in several stages. The study of the above papers has indicated that an assessment tool that is based on agility criteria is very useful in identifying the gaps to be filled in pump manufacturing companies to acquire agile characteristics.

2.7 VOYAGE OF AGILE MANUFACTURING

The information and knowledge described in the previous section indicate that agile manufacturing concepts are applied in several industries. In fact, there are very few industries in which, agile manufacturing concepts have not been applied at all. However, the level of implementing agile manufacturing concepts in different industries has been varying from minimum to maximum. For example, the level of applying agile manufacturing concepts in mobile phone industry is maximum. This level is varying from moderate to minimum in several other industries like chemical industry, machine tool industry and pump manufacturing industry. A careful study of the history of these industries would reveal that, mobile phone industry has been existing only for the past three decades, while other industries had been existing in the world for the past few centuries. The industries that have been existing in the world for more than a century are regarded here as traditional industries. As the application of agile manufacturing concepts has enabled the mobile phone industry to acquire competitive strength, the same principles need to be applied in traditional industries for acquiring the same. Currently some efforts are made by both academicians and practitioners to apply agile manufacturing concepts in these traditional industries. This voyage of agile manufacturing is shown in Figure 2.4. As shown, In order to make this voyage effective, research on applying agile manufacturing concepts need to be theoretically and practically
examined with reference to the specific industries. In this background, while pursuing the doctoral work being presented here, the pump industry was chosen as the domain for investigating the voyage of agile manufacturing concepts so as to instil competitiveness in this industry.

![Diagram of Agile Manufacturing Journey](image.png)

- Voyage of Agile Manufacturing (AM) that has fallen within the scope of this paper

**Figure 2.4  Voyage of agile manufacturing**

## 2.8  HISTORY AND DEVELOPMENT OF PUMP INDUSTRY

Pump is one of the earliest inventions of mankind which makes use of several types of energy to pump liquids from one place to another place. Since pumps are used for pumping several liquids to achieve several purposes, right from their origin, several types of pumps have emerged in the world. In this background, it is required to study the history, development and types of pumps. Although many papers reporting researches on designing and selecting pumps have appeared in literature arena (Meng et al. 2016), no research papers
and books describing the history and developments of pump industry are available. However, the books on pumps describe different types of pumps, their working principles and applications (Karassik et al. 2001). In this background, while conducting the literature survey being reported here, the web site ‘www.pumpzone.com’ was visited to gather relevant information on the history and development of pump industry. In this website, two articles authored by Michelle Segrest narrating the history of pumps are posted. The information gathered by reading these articles are briefly presented in this section.

The first pump was invented by Egyptians in 2000 BC under the name ‘shadoof’. This pump had a long suspend rod with heavy weight on one end and a bucket in the opposite end. It was used to draw water from wells. Archimedes invented screw pump in the year 200 BC, which is considered as a greatest invention. It is being used even today for lifting liquids and granulated solids in several companies. In the year 1738, Bernoulli’s equation modeling the flow of different types of fluid was published in “hydrodynamics” book. The modern screw pump was invented by Revillion. Gouls started casting and assembling the world’s first all metal pumps. In the year 1851, the first patent of the centrifugal pump was filed by John Cryne. Then, in the year 1905, the multistage pumps and internal gear pumps were introduced.

The submersible pump was first introduced by Armais Sergeevich Aruntanoff in Russia during the year 1916. Initially it was used in Germany for dewatering in underground constructions which were carried out to construct railway under-bridges and subways. A positive displacement pump for pumping Liquefied Petroleum Gas (LPG) was developed in the year 1954 by Blackmer. The world’s first high speed boiler feed pumps whose impellers were run at 9000 rpm was produced by Worthington. In the 1980s,
the electronic controls were introduced to make pumps more energy efficient. Thereafter, many technological innovations and advanced materials were infused in the development of pumps. The advanced materials like composites were introduced by the company Sims. In this company, structural composite vertical in-line pumps were developed. Thus, right from ancient days, many advancements were introduced in the pump industry.

2.8.1 Working principles and classification of pumps

The working principle and classification of pumps are presented in Karassik et al. (2001). The information and knowledge gathered from this book are briefly described in this sub-section. Pump is a mechanical device normally used for raising liquids from a lower level to a higher level. Using the pump, a low pressure at the inlet and high pressure at the outlet are created. The pressure at the inlet becomes low resulting in the liquid to rise and the high outlet pressure forces it to flow towards the required place. During this process, an electrical motor is used to convert the electrical energy into mechanical energy. Pumps can be classified on the basis of their applications, the materials from which they are made, the liquids they handle, and their location of installation. The basic system of classification defines the principle by which energy is added to the fluid, identifies the means by which this principle is implemented and finally describes specific geometries commonly employed. Based on the system, all pumps are divided into the following two major categories:

i) Dynamic pumps, in which energy is continuously added to increase the fluid velocity within the pumping chamber to the value greater than that is occurring at the discharge.
ii) Displacement pumps, in which energy is periodically added by the application of force to one or more movable elements, causing to create the pressure required to move the fluid through valves into the discharge point. A summary of the classifications and sub-classifications within this category is depicted in Figure 2.5.

**Figure 2.5**  Classification of Pumps (Pump handbook, 2015)
As shown in Figure 2.5, dynamic pumps can be further subdivided into several varieties of pumps which are called as centrifugal and other special-effect pumps. Depending upon the nature of movement of the pressure-producing members, displacement pumps are basically divided into reciprocating and rotary types. As shown in Figure 2.5, based on their application, each of these major classifications are be further subdivided into several specific types of pumps.

2.9 AGILE MANUFACTURING IN PUMP MANUFACTURING: THE PRACTICAL SCENARIO

As mentioned earlier, agile manufacturing paradigm has been implemented in few modern industries like mobile phone manufacturing industry and automobile industry. However, the research on implementing agile manufacturing in traditional manufacturing industries like pump manufacturing industry has been scant. The observations made during the preliminary phase of conducting the literature survey being reported here has revealed that the agility level of pump manufacturing companies has been very low. These traditional pump manufacturing companies produce only few models of pumps. Besides the companies that produce water pumps are not producing the pumps used for pumping other liquids. Likewise, the companies which produce pumps that are required for pumping other liquids do not produce water pumps. Over the past three decades, the improvements in the design of the pumps have been carried out by the engineers only few times and hence, varieties of pumps suiting varied requirements and tastes of customers are minimum.

In order to face the tough competition, the modern manufacturing companies are introducing innovative features like products with
multifunctioning capabilities purpose and products incorporated with automation elements like those facilitate remote operations. Today, such innovations are lacking in pump manufacturing industry. In the pump manufacturing industry, researches have taken place for improving the efficiency of pumps but improving the speed of its performance is rarely investigated. The pumps can be designed ergonomically for facilitating their easy handling and easy assembling of pipes. The pump manufacturing industry is also yet to use intensively the materials like plastics in order to ease and speed up the manufacturing processes. In the modern days, the customers attach ample importance to the aesthetic aspects of a product and are delighted to use aesthetically appealing products like mobile phone and cars. Amidst this situation, traditional manufacturing companies like those manufacturing pumps do not focus on the aesthetic aspects of the products produced by them. Hence, today, many opportunities exist to apply agile manufacturing concepts in pump manufacturing companies to overcome these deficiencies.

2.9.1 Proposed ways of imparting agility in pump manufacturing industry

As hinted in the previous section, the study carried out while conducting the literature survey being reported in this chapter has revealed that high propensity exists towards imparting agility in the designing and producing of pumps along three directions. In the first direction, the agility can be imparted from the functional perspective. For example, a pump can be designed to discharge high volume of the liquid in a given period of time at a fast rate. Likewise, a pump many be incorporated with the facility to operate by using the mobile phones with timer facility. A pump may also be designed to operate in the absence of electrical power by making use of battery and solar power. A pump may also be made by highly corrosion resistant materials
which will prevent the clogging throughout its life. In the second direction, a pump may be designed to exhibit agility by adopting ergonomical features. In order to impart agility in this direction, a pump may be designed by making use of light weight components so that the pump may be handled by hand easily. The pump may also be incorporated with the facility to easily install and uninstall it from its work place. A pump may also be provided with the easy to install capabilities so that it can be made portable. The noise level of the pump during its operation may also be reduced to minimum.

In the third direction, the agility may be imparted on pumps by applying aesthetic aspects. For example, a pump may be painted using different colour paints. Besides pictures may be painted on the pump, so that it is very attractive to the customer. Quite interestingly many pump manufacturers in the world have started to produce such type of pumps which are painted by using different colours. The reader can visit site ‘http://www.tolexo.com/pumps/centrifugal-pumps.html’ to have a glimpse of such pumps. However, pictures are not painted on the outer surface of the pumps. The pumps may also be covered by using attractive casings. The pumps may also be made in different shapes.

Besides carrying out functional, ergonomic and aesthetic design, the agility can be imparted by offering customized service. For example, when a pump is sold, it can be informed to a service engineer who will approach the customer to install and demonstrate the working of the pump. The manufacturing company may also support the customer while carrying out the piping activities while installing the pumps. Besides the noise level may be transmitted by making use of wireless communication and the company may alert the service engineer to attend to the service requirement of the pump in case its operational noise level increases beyond the specified limit. Thus, high
amount of propensity exists towards imparting agility in the case of designing, manufacturing and operating the pumps. As mentioned earlier, a few researches have been pursued to examine the imparting of agility in certain components of pumps. However, the efforts on imparting agility on the assembled pumps have been scant.

2.10 CONCLUSION

During the past two decades, the world has been witnessing the intensification of competition. In order to face this intensified competition, the world has been slowly adopting the concepts of agile manufacturing (Adamson et al. 2015; Ali et al. 2013). While the research community has been explicitly addressing the phenomenon of agile manufacturing, agile capabilities are implicitly infused in certain industries. As mentioned in certain sections of this chapter, the mobile phone manufacturing industry has been exhibiting agile characteristics in the form of manufacturing new products quickly in response to the customers’ dynamic demands (Vinodh et al. 2010g). This capability of mobile phone manufacturers has been enabling them to conquer markets situated throughout the world. By following this kind of development, manufacturers developing many other products like automobile cars and laptops have been acquiring agility characteristics and have been moving ahead in the intensified competitive race. Amidst this progression, the companies manufacturing traditional products have been struggling to imbibe agility characteristics and hence, also struggle to face the intensified competition.

The traditional products were developed in the world before digitization of product development activities occurred in the world. Hence, these traditional products are unfit to a large extent to get digitized.
Digitization of the product development enables the engineers to virtually view the product features using electronic media like computer screen and infuse delightful features in them (Tong et al. 2008). Thus, digitization of the products enables the development of new and innovative features quickly in accordance with the dynamic demands of the customers. In the case of traditional products, such digitization is seldom possible and hence, the manufacturers have been either slow or failing to infuse agility characteristics in the manufacturing of traditional products. Hence, it is the need of the hour that the engineers’ carryout researches to find out the avenues and methods for digitizing the traditional products and thereby enabling the manufacturers to infuse agility characteristics in the production of traditional products. In the context of this observation, the literature was surveyed and studied to find out the researches that have been carried out to infuse agility characteristics in the production of the pump which is a traditional product.

The literature survey reported in this chapter was carried out with the purpose of tracing the voyage of agile manufacturing in the world. This literature survey was first begun by reviewing the researches reported on agile manufacturing in literature arena. It was found out that in the beginning, researchers made efforts to pinpoint the meaning and definition of the term agile manufacturing and its associated terms. After crossing this phase, the researchers worked in the direction of finding out the enablers of agile manufacturing. During the current phase, the researchers are attempting to infuse agility in the production of traditional products.

During the conduct of the literature survey reported in this chapter, it was found that only a few researchers have worked in the direction of infusing agility in the production of pumps. These researches are very primitive. In fact, in the researches reported in these papers, only an inroad has been made to infuse agility in the production of certain components of pumps.
Also no exhaustive methodology of infusing agility while manufacturing pumps has been addressed in those papers. In the context of this observation, the need of infusing agility technologically, ergonomically and aesthetically in the designing and manufacturing of pumps has been pinpointed in this Chapter.

On the whole, the contents of this chapter have provided information and knowledge about the survey of agile manufacturing researches which have crossed the phases in which the meaning and enablers of agile manufacturing were explored. Currently this agile manufacturing voyage proceeds in the direction of imparting agility in the design and manufacturing of traditional products. Out of all, in this chapter, the agile manufacturing voyage occurring in the direction of infusing agility in pump industry was traced. At the end of tracing this agile manufacturing voyage, it is pointed out that, opportunities exist to carry out researches on imparting agility characteristics while designing and manufacturing pumps. This kind of practice oriented research endeavours will support the contemporary pump manufacturers to generate wealth in the world like the way the mobile phone manufactures have accomplished.