Latest developments in CIM

Sev V. Nagalingam*, Grier C.I. Lin

Centre for Advanced Manufacturing Research, University of South Australia, Levels Campus, Mawson Lakes Boulevard, Mawson Lakes, SA 5095, Australia

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Abstract

Manufacturing enterprises play an important role in improving the economic environment of a country. The economic environment of many developed countries is under threat from emerging industrialised countries. Today, the capability of producing high quality products with shorter delivery times and the ability to produce according to the diverse customer requirements have become the characteristics required of order-qualifiers for manufacturing industries. Hence, application of intelligent manufacturing systems and computer integrated manufacturing (CIM) has become the necessity to overcome the above issues while retaining the employment level and revenue of a country in today’s highly competitive global market. With the developments taking place in CIM and its related technologies, the application of CIM in manufacturing enterprises has become a reality. This paper focuses on latest research developments in CIM and a new CIM wheel proposed to satisfy the emerging technological application of virtual enterprises. © 1999 Elsevier Science Ltd. All rights reserved.

1. Introduction

Manufacturing industries have evolved tremendously from cottage industries in the early 16th century to the global force as it stands today. The characteristics of the present world market (see Fig. 1) include higher competition, shorter product life cycles, greater product diversity, fragmented markets, variety and complexity, and smaller batch sizes to satisfy a variety of customer profiles [1]. Furthermore, non-price factors, such as quality, product design, innovation and delivery services are the primary determinants of product success in today’s global arena [2]. To achieve these requirements, manufacturing companies need to be flexible, adaptable, responsive to changes, proactive and be able to produce variety of products in a short time at a lower cost. In addition, they should be able to address new environmental requirements, complex social issues and concerns. Hence, manufacturing companies are compelled to seek advanced technologies as a panacea for all these needs. The most significant outcome of this search resulted in the concept of computer integrated manufacturing (CIM) in the early 1970s. The concept of CIM was initially coined by Dr. Joseph Harrington in 1973 in the book “Computer Integrated manufacturing” [3]. However, until the early 1980s, CIM did not become a commonly known acronym as it exists today.

CIM promulgates a fundamental strategy of integrating manufacturing facilities and systems in an enterprise through computers and its peripherals. The definition of CIM has various connotations depending on the application of it. CIM is a process of using computers and communication networks to transform islands of enabling technologies into a highly interconnected manufacturing system. CIM involves integration of advanced technologies in various functional units of an enterprise in an effective manner to achieve the corporate objective of the manufacturing enterprise. Effective integration requires an in-depth understanding of all the technologies and comprehensive knowledge of all activities in all functional units of an enterprise. To be successful in the application of CIM, first the integration of advanced manufacturing technologies (AMTs) should be achieved, the computers act only as subordinates to the technologies. However, without computers the integration cannot be effective and efficient since computers help organise, retrieve and store information in an orderly manner with high accuracy and speed.
The proposal of CIM in the early 1970s might have appeared to be overly futuristic, but in today’s technologies, it is possible to reach the goal of CIM, without much difficulty. In 1976, Lin [4] stated that the future of engineering is inextricably bound with the application of computer integrated technology. He suggested that implementing integrated advanced technologies is an effective approach towards solving the problems of decreased productivity relative to labour costs and consequent rise in unit costs which are continually plaguing present day manufacturing managers. Even after two decades, Sohal [2] reflected this view as implementation of AMTs provided opportunities to achieve the competitive advantage which is financially viable in an intermediate to long-term time frame.

CIM is a management and manufacturing strategy. While the concept of CIM is broadening its application in manufacturing industries, it is interesting to note that some innovative manufacturing and management strategies have also begun to surface. Concurrent engineering, lean manufacturing, responsive manufacturing and agile manufacturing are some of the new terms evolved in the last decade to reflect the dynamic nature of improvements in manufacturing applications. The induction of new terms, by various academia, may have resulted due to the result of CIM being an intricate concept to be understandable by manufacturing managers and be implemented. Nevertheless, the concept of CIM is far broader than these new terms and it is still able to embrace all the new features of similar strategies. CIM stands as the innovative application for yesterday’s proposals and the newer application required today and for the future.

Today we are witnessing a steady rise in the number of virtual enterprises in many facets of industry. This paper reviews the historical developments in manufacturing and CIM. It also illustrates a new CIM wheel developed to satisfy the emerging technological application of virtual enterprises in the information era and provides suggestions for the future research trends in CIM.

2. Historical developments in advanced manufacturing technologies

Mechanisation facilitated mass production to meet the consumers’ demands for improved products. To achieve mass production transfer lines and fixed automation were created. This resulted in the development of programmable automation [5]. The prime objective of the automation was to accelerate the production process throughout the plant. Automation has provided the ability to respond to the consumers’ demands while ensuring high quality products. Numerical control was developed as an innovative approach to programmable automation in 1952 and gave a tremendous boost to the concept of mechanisation and automation [6]. With the developments in commercially available computer technology, the application of computers in manufacturing started to emerge producing a variety of new technologies, all of which are collectively named as AMTs. AMTs are generally defined as systems providing flexibility as well as data driven computer integration for a manufacturing organisation [7]. AMT illustrates a technological application where the manufacturing technology utilised is intelligent enough to process the activities with less human intervention. In today’s industrialised world, the enormous growth in manufacturing automation has brought a plethora of AMTs with diverse features. These AMTs could consist of semi to fully automated systems or equipment.

The need for integration has evolved in response to the problems faced by the traditional manufacturing process of industrial automation. Individual automation in each functional unit created islands of automation. These islands of automation did not facilitate communication between the functional units. Errors in data sharing and other mismatches with these islands of automation continually plagued the manufacturing industry. The complexity of new manufacturing technologies, economics, increasing human limitations, computer developments, and competition from abroad has forced the initiation of integrated computer aided manufacturing (ICAM) program by the United States of America Air force [5]. The ICAM program conducted in 1983 found the following critical problems in industrial automation [8]:

- information could not be controlled by users,
- changes were too costly and time consuming,
- systems were not integrated, and
- data quality was not suitable for integration.
These problems were the result of the job shop approach to automation. The job shop approach created islands of automation and owing to the lack of planning in integration, these islands were very difficult to integrate. When properly planned integration was not carried out, and only islands of automation were implemented, the full benefits of automation were not obtained. In addition, these islands of automation improved only the local productivity, but they were insufficient in providing necessary logistical support to improve the productivity and quality throughout the company [9]. To overcome these issues the ICAM program was established. The ICAM program was a practical effort to provide compatible techniques and a unified direction to industry. In addition, it served as an integration guide to CAD and CAM [5].

The prime element in an integration concept is having a common or interconnected database, by which the data can be transferred automatically among various units and user groups. By introducing an integrated manufacturing concept, simplified workflow and reduction in the work-in-progress will be the standard and beneficial features.

The integration of the technologies brings the following benefits:

1. Creation of a truly interactive system which enables manufacturing functions to communicate easily with other relevant functional units.
2. Accurate data transferability among the manufacturing plant or subcontracting facilities at in-plant or diverse locations.
4. Increased flexibility towards introduction of new products.
5. Improved accuracy and quality in the manufacturing process.
6. Improved quality of the products.
7. Control of data-flow among various units and maintenance of user-library files for system-wide data.
8. Reduction of lead times which generates a competitive advantage.
9. Streamlined manufacturing flow from order to delivery.
10. Easier training and re-training facilities.

Although the benefits of integrated technologies are very difficult to quantify, integration provides a competitive advantage by linking new and existing hardware and software of the technologies, together with database management systems and data communications systems into a coordinated and efficiently managed process. Voss [10] has stressed the importance of integration by stating that the benefits of the new manufacturing technologies will be greater with cross-functional applications than with unlinked functional applications. Many additional benefits have been obtained by considering cross-functional approach and integrating various technologies across functional units [10, 11].

The necessity to use automated machines has become an indispensable concept with the developments in technology and with the driving force of the demanding and sophisticated consumer market. As Lin [12] has elaborated in his keynote speech in December 1997, with the globalisation of the potential markets and production facilities, CIM has a further potential to propel towards a virtual CIM in today’s perspective. The historical developments made in manufacturing technology throughout the period can be described as in Fig. 2.

The global competition, which exists today, forces manufacturing managers to consider and adopt innovative and advanced technologies. The manufacturing engineer today must understand and be able to plan for these new technologies to survive in the present world condition. They should have a clear concept of automating the manual and semi-automatic machinery to reap the benefits of these emerging technologies. Implementation of AMTs could help companies achieve their competitive goals to survive in the global market environment as long as the technologies chosen are appropriate to meet their objectives.

3. Research trends in CIM and related strategies

To satisfy the conflicting and competitive demands of today’s market, research trends focusing on the
application of CIM in manufacturing industries has begun to emerge. The realisation of CIM requires effective integration of a number of available AMTs. Many variations in manufacturing methodologies were developed and proposed by researchers to revitalise the manufacturing industries. The importance of reducing the product delivery time, thus the necessity to revitalise the manufacturing industries can be understood by Fig. 3. It depicts the trend of increasing product development time due to complexity of a product and the shortening of the product lifetime, due to changes in peoples’ life styles.

The concept of concurrent engineering (CE) has been around the manufacturing circles from early 1960s in various forms requesting the use of multidisciplinary teams to accelerate product introduction. However, in 1987, the concept was given the name “concurrent engineering” with an appropriate definition by the United States Defence Advanced Research Projects Agency. CE involves, a systematic and simultaneous approach to the integrated design of products and their related processes including marketing, manufacturing, sales, and purchasing [13]. Further, it involves formation of multidisciplinary teams for the rapid product development and introduction of the product into the market. CE could be considered as a management strategy rather than the manufacturing strategy.

In late 1950s, Japanese automobile manufacturers realised that the mass production did not fit into the production and management strategy required to satisfy the product differentiation which was evolving as a fundamental market feature [14]. This realisation resulted in the formation of the concept, lean manufacturing (LM). LM involves addressing the product strategy, product development, supply chain, manufacturing and product distributions for the production of diverse products in small batches. It may further consist of out-sourcing and effective integration between the suppliers and subsidiaries. From the early 1980s, the impact of LM on mass producers of North American automobile manufacturers began to unfold and the American companies realised that this concept of LM can be utilised in their workforce as well.

The concept of agile manufacturing is similar to the concept of LM by emphasising on small batch sizes. However, agility requires: reduction in product development time; allowance for considerable customisation of product features; and incorporating highly adaptive, flexible and efficient manufacturing practices in the product development and manufacturing cycle [15]. It further involves effective integration of technology, business activities, enterprise and people.

Business process re-engineering (BPR) involves identifying each business activity, evaluating the importance and relevance of the activities towards achieving the business goal and redesigning all the activities in an efficient and economical manner to achieve the business objectives. BPR achieves these objectives through business modelling and analysing techniques. The use of BPR eliminates unproductive and unnecessary business activities and operations in an enterprise and actuate process simplification and if necessary out-sourcing.

However, the analysis of these explanations for the new manufacturing strategies and terms, which are evolving simultaneously to CIM shows that CIM could still provide all the features of lean, agile and concurrent manufacturing in an integrated manner. The potential for CIM in manufacturing industries is considerably large. Nevertheless, there is often a mismatch between the hypothesis of CIM and the application in a real world. Today, research in CIM is conducted with increased vigour to meet the requirements of industry with the latest facilities and tools available in the market and to reduce the mismatch. In addition, the trend in CIM research is moving towards finding new ways and tools to make the futuristic factory into a realistic factory.

4. Developments in CIM research

Today, we are at the threshold of seeing rapid changes in information- and communication-processing equipment. While the mass production is still needed for certain sectors of manufacturing, it is no longer a competitive weapon in a rapidly changing global economy. The challenge in reviving the manufacturing industry to face the competitive threat depends on the ability to respond to all the requirements of the global market. However, many of the manufacturing industries in the developed world are still operating islands of automation or age old technologies. This trend can be avoided if manufacturing companies invest in CIM and related
technologies and become globally competitive. The efficient application of CIM in a fully integrated manner will help the industries face the global and local competition with a high degree of confidence. With the advent of new network technology and Internet, the application of CIM has transcended geographical boundaries and embraced the global application of CIM [16]. To facilitate the investment in CIM and to help manufacturing industries, many researchers are seeking solutions in application of CIM. Some of the research trends in CIM which are evolving today can be categorised as follows:

- Justification of CIM and management strategies for CIM.
- Enterprise integration for CIM beyond and within geographical boundaries.
- Network communications for the implementation of CIM.
- Advanced tools and technologies for the application of CIM.
- Manufacturing system modelling.
- Application of artificial intelligence (AI) such as fuzzy logic, neural network, genetic algorithms and intelligent agents for fully integrated intelligent manufacturing systems.

Each of these categories is diverse in nature and consists of many subgroupings. In addition, few research directions may overlap in more than one grouping due to the complexity of the research in CIM.

Justification and management strategies for CIM consist of multitude of research directions. This research trend focuses on providing managers with principles and guidelines for the application of CIM in their working environment and approaches to overcome the resistance to change towards integrated manufacturing. Further, this categorisation addresses the organisational and social issues in an enterprise, issues involving benchmarking the features of the manufacturing supply chain and manufacturing strategy implementation through real-time systems, optimised enterprise integration and decision support systems (DSS) and expert systems (ES) for manufacturing managers. DSS and ES may further include ES for quality inspection, ES for production planning and selecting manufacturing parameters, DSS to evaluate designing decisions, financial decisions, and educational and informative systems.

Enterprise integration for CIM beyond and within geographical boundaries consists of a research diversity, which includes architectures and modelling formalisms for enterprise integration, evaluation methodologies for enterprise integration, and international CAD/CAM collaboration for CE and CIM implementation through integration of subsystems. While, network communications for the implementation of CIM category include application of wide-area networks and Internet for CIM, information enhancement by data integration, issues related to integration of client and server for manufacturing shop-floor automation, application of multimedia and hypermedia in CIM environment, and data management in CIM systems.

The categorisation of advanced tools and technologies for the application of CIM is one of the thriving areas in CIM-related research. It consists of robotics and automation for a CIM framework, vision-based manufacturing systems and intelligent AGVS and intelligent and knowledge-based enabling systems for CIM. While, manufacturing system modelling category consists of research variations which include integration of information models with functional models for CIM, object-oriented resource modelling, integrated simulation modelling approaches for CIM, and modelling approaches and methodologies for designing CIM systems.

Application of AI for fully integrated intelligent manufacturing systems consists of research directions, which include the application of neural network on manufacturing automation and technologies, intelligent scheduling systems with genetic algorithms, fuzzy scheduling systems, hybrid systems of CIM components, adaptive models for CIM architectures and embedding AI in CIM software.

5. Future direction of CIM

In today’s competitive global market survival of any industry depends on its ability to communicate and transfer the right information at the right time to the right people. Manufacturing cannot escape from this present requirement. Having an ability to communicate for effective management and manufacturing activities across the geographical boundaries among the globally distributed resources will significantly benefit manufacturing industries. Today a number of global conglomerates are formed in many facets of industry. A virtual enterprise is defined as a network of interconnected global conglomerates in this paper. Predicting the future research direction of CIM and related areas is a difficult task in ever expanding and growing technological development era. However, an attempt is made to foresee the future direction, which will dominate the researchers’ mind for the next decade, based on the current developments in CIM research.

Today’s competitive and agility requirements of the global market can be only met by virtual enterprises. To provide a better future in the present market requirements research in virtual CIM and the application of it in worldwide manufacturing industries are beginning to emerge. Application of virtual CIM has been proposed as a necessary step towards the future in manufacturing to face competitive challenges [12]. However, many development works need to be carried out to face challenges faced by virtual enterprises [17]. Hence, the research...
should be further strengthened towards developing a virtual CIM to satisfy the globalised and distributed manufacturing enterprises of today in order to meet the competitive and agility requirements of present market conditions.

In a virtual enterprise the integration of information is extolled, as only through information can a virtual organisation become meaningful, and only by effecting a new generation of information technology can this vision be realised [18]. To represent the evolving process of CIM and to reflect the present need for a virtual CIM, which stresses the importance in strategic and integrated management in implementing CIM in globally distributed enterprises, a new CIM wheel, as shown in Fig. 4, has been developed at the Centre for Advanced Manufacturing Research of University of South Australia. It was presented by Professor Grier Lin at his keynote speech at the Fourth International Conference of Computer Integrated Manufacturing in Singapore, 21–24 October, 1997.

The concept of the virtual CIM wheel is in parallel with the CIM wheel developed by the Society of Manufacturing Engineers and it can be explained as follows:

- The outer circle represents the present world situation. It depicts characteristics such as global competition, environmental concerns, mass customisation to satisfy the variety of customer requirements, shorter product life cycles of the product, and requirement for innovative products and of faster response.
- The second circle represents global systems and concepts needed to address the situation.
- The third circle explains briefly how the concepts and systems can be realised.
- The fourth circle represents the need for global information and communication links and the need to share data among systems.
- The inner circle represents the final outcome of CIM as a globally integrated enterprise through an integrated architecture.

In the justification of CIM and management strategies for CIM research area, recent developments in the group-based management information systems have strengthened the application of a DSS in a group decision environment. In addition, rapidly changing technology and the increasing reliance on knowledge and communication create significant challenges to static and old economic models of an enterprise [19]. Therefore, in order to justify and optimise investments in a virtual enterprise, a need exists for a group decision support system (GDSS) which has a capacity to consider the effect of AMTs in a global framework. A GDSS can improve decision outcomes by using structured approaches for the unstructured problems in a group decision making endeavour [20]. A GDSS will help decision-makers in a team environment analyse the investment decisions of a company in an interactive manner, either in geographically distributed or a localised manufacturing enterprise with diverse functional units.

The rapid developments in technology provide innovative approaches to manufacturing and the recent trend towards global manufacturing has increased the number of geographically distributed and multi-location enterprises. In the research direction of enterprise integration for CIM beyond and within geographical boundaries, a collaborative framework for remote machining [21] and planning and control systems [17] have been proposed. The prime technology which propels the advances in manufacturing system and international networking is the communication technology [22]. Hence, the research direction of network communications for the implementation of CIM has produced a plethora of research articles. In addition, the use of Internet and the World Wide Web in manufacturing applications is gaining momentum. However, research should be further strengthened towards providing integrated architectures and communication protocols for virtual CIM framework to enable real-time machining, processing, decision-making facilities in geographically dispersed enterprises.

Research in robotics and automatic guided vehicles is predominant in the research direction of advanced tools and technologies for the application of CIM. In today’s technologies the remote manipulation of these machines has already been achieved. Mobile robots and global positioning satellites have played a significant role in remote manipulation of robots [23]. Collaborative robots are being developed to machine complex surface and large components [24]. In addition, vision-based
systems have been developed towards rapid prototyping, part identification and processing. These developments need to be enhanced towards providing practical solutions for a globally dispersed manufacturing enterprise and be tested in a virtual CIM framework.

Today, many manufacturing industries are under pressure to achieve the goal of the objectives within limited capital available for new investments. Optimisation of resource allocation for strategic investments could provide a mechanism to achieve the goal of the enterprise. As Hess [25] has stated, the future of CIM depends on optimised integrated systems. Traditionally, to improve the effectiveness and competitiveness of an organisation, all the efforts are focused on achieving a single goal or achieving the objective within a functional unit. However, the traditional method of single goal seeking mechanism or optimising the results of an individual unit, does not satisfy the overall objective of a manufacturing company. Therefore, a multiple goal seeking or multicriteria optimisation which considers all the relevant factors and overall benefit of a company as a single unit, has been proposed to make CIM an effective application in the present global economic circumstances [26,27]. The existing multicriteria optimisation mechanisms should be further enhanced or new approaches be developed for application in the globally distributed virtual CIM enterprises, so that the benefits of virtual CIM is fully realised. In addition, global integration approaches which regard a globally distributed company as a single entity, should be developed and utilised to make virtual CIM an effective application to meet the present global economic circumstances. Intelligence manufacturing is the path for the future. Therefore, manufacturing technologies should be blended with intelligence, which will help manufacturing enterprises to produce better quality products and manufacturing equipment to solve problems encountered during the normal course of operation itself.

6. Conclusion

CIM is an innovative and expansive concept to provide the solutions manufacturing industries are seeking to survive in the competitive global market. Today, we are at the threshold of utilising innovative and improved computer-related technologies for the betterment of manufacturing industries, compared to the situation prevailed a decade ago. The successful future of manufacturing industry is inextricably involved in the efficient and effective utilisation of CIM and its components. The research in CIM and related technologies and the application of it in manufacturing industries are progressing towards a better future. The research should be further strengthened towards developing optimised CIM systems to control the scarce resources we are having today to meet the current competitive and agility require-
mnts. In addition, various developments in CIM components, which had been achieved, need to be integrated into the CIM system in a cohesive manner to provide a complete and intelligent solution to the manufacturing industries and help them step into the next decade with confidence and competitive ability.

The Centre for Advanced Manufacturing Research at University of South Australia is proud to be a part of an international research team, conducting research on CIM-related technologies to help industries, particularly the manufacturing industries in Australasia and cater to the present and future requirements.

References