CIM—still the solution for manufacturing industry

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Abstract

In today’s economic environment, enterprises that solely rely on traditional technologies cannot meet dynamic customer demands. Hence, proactive enterprises seek the application of intelligent and integrated manufacturing systems in order to meet the customer’s demands and be the winners in the competitive market. Although, with available technologies and systems in Computer Integrated Manufacturing (CIM) and its related technologies, the application of CIM in manufacturing enterprises is a reality and can meet the need of the enterprises; today mangers in many enterprises are confused with varying technologies and new terminologies that prevail in the public domain. To make adoption and implementation issues complicated, there are many researchers pursing similar concepts but in different names to solve part of the issues that are or can be addressed by a CIM system. Therefore, this paper summarises the evolution of manufacturing technologies that are associated with developments towards a CIM system, and reviewed some of the new terminologies and technologies, which were proposed during the last four decades. This review is aimed at overcoming the confusion with the new terminologies that have been generated in the past four decades. Further, this paper articulates that all these new proposals are in deed the sub-system or sub-solutions of CIM. Finally, this article focuses on latest research developments in CIM and provides a stepwise justification methodology towards a CIM system for a small or a medium enterprise.

Keywords: CIM; Virtual CIM; Virtual enterprises; Step-by-step integration; Manufacturing concepts

1. Introduction

Manufacturing enterprises face diverse challenges induced by technological changes, geo political and economical environment they operate in, and most importantly by the sophisticated and demanding customers. In today’s open market, customers can reach manufactures across the world and choose their preferred ones, due to the advancements in Information and Communication Technology (ICT) and modern ICT tools that are available at affordable price and with increased reliability. Similarly, in this same environment, manufacturing enterprises face competitions across the globe, encounter many emerging challenges, and struggle to extend their businesses to reach customers in every part of the world. However, an enterprise that relies on traditional manufacturing systems cannot satisfy the needs of globally distributed customers and match the capability of the competitors, since these traditional systems are only deployed within an enterprise and this enterprise does not have the capability to maximise the potential and strength that are available in different parts of the world. Therefore, a more flexible and comprehensive methodology is necessary to overcome the distance barriers, facility sharing problems and communication obstacles. This need has lead to the concept of Virtual Computer Integrated Manufacturing (VCIM) [1], which is a network of interconnected and globally distributed Computer Integrated Manufacturing (CIM) systems across geographical boundaries, whereas CIM is an integration of localised manufacturing facilities.

In today’s information age, the customers are sophisticated and demand high-quality products at reduced cost and with shorter delivery times. In addition, in today’s market non-price factors such as quality, product design, innovation and delivery services are the primary determinants of product success in the global arena [2]. In 1998, National Science Foundation of United States of America
(USA) commissioned a study to create a vision of the competitive environment for manufacturing and the nature of the manufacturing enterprise in time to come and published the “Visionary Manufacturing Challenges For 2020” [3]. The committee of experts identified the most important technical, political, and economic forces for manufacturing as follows [3]:

- sophisticated customers will demand products that are customised to meet their needs,
- rapid responses to market forces are required to survive in the competitive climate, enhanced by communication and knowledge sharing,
- creativity and innovation are required in all aspects of the manufacturing enterprise to be competitive,
- developments in innovative process technologies will change both the scope and scale of manufacturing,
- environmental issues will be predominant as the global ecosystem get strained by growing populations and the emergence of new high-technology economies,
- information and knowledge will be shared by manufacturing enterprises and the marketplace for effective decision making, and
- global distribution of highly competitive production resources will be a critical factor in the organisation of manufacturing enterprises to be successful in this changing technical, political, and economic climate.

Even today, in order to win the confidence of the customers and be the market leaders, manufacturers should have the capability to be flexible, adaptable, proactive, responsive to changes, and be able to produce variety of high-quality and innovative products quickly at a lower cost. In addition, they should be able to address new environmental requirements, complex social issues and capable of operating within dynamic geo-political boundaries. Hence, manufacturing companies were compelled to seek advanced technologies as a solution for the last five decades or more. The most significant outcome of this search resulted in the concept of CIM, which was initially proposed by Dr. Joseph Harrington in 1973 in a book published by the name “Computer integrated manufacturing” [4]. Although, he avoided coining a new acronym by carefully not capitalising the words, the acronym CIM has become a commonly known one in early 1980s and still it prevails among many other three letter abbreviations or acronyms. Although, recently some computer science and electrical engineering researchers are using acronym CIM to denote a common information model [5,6], still CIM is regarded as computer integrated manufacturing by many others. Most interestingly, to achieve a true CIM system in a manufacturing enterprise a common information model for manufacturing systems is complimentary.

Although in his earlier descriptions, Harrington considered CIM as a control and communication structure to integrate a manufacturing system, which was over compartmentalised and over specialised [4], CIM is a process of using computers and communication networks to transform islands of enabling technologies into a highly interconnected manufacturing system. Harrington stated that CIM did not mean an automated factory and asserted that people are very much involved at all leaves [4]. However, the interpretation of CIM has changed from computerised work-cells, large-scale automation, CAD/CAM, interfacing and communication concepts to a mature definition where CIM is an integration effort that embraces the whole organisation across all functional units [7]. CIM in an enterprise is achieved by effectively integrating advanced technologies in various functional units to achieve the corporate objectives. In order to have an effective integration, an in-depth understanding of all the technologies and comprehensive knowledge of all activities across all functional units in an enterprise is required. Having successful application of CIM requires that the integration of functional units and software applications/systems are properly achieved first, since computers are merely tools that facilitate processing and exchanging information across and by the sub-systems.

CIM is a fundamental management and manufacturing strategy of integrating manufacturing facilities and systems in an enterprise through computers and its peripherals. Although, Harrington’s proposal of CIM in early 1970s was appeared to be overly futuristic to many, but today with the sophisticated manufacturing equipment and advanced ICT tools that are available in the market, it is possible to reach the objectives of CIM with ease. Today, many organisations have already achieved CIM and some successes are reported in Section 4 of this article. About three decades ago, having studied the productivity problems that plague the manufacturing industries, Lin [8] stated that the future of engineering is inextricably bound with the application of computer-integrated technology. He suggested that implementing advanced and integrated technologies would be an effective approach in solving problems such as decreased productivity, relative labour costs and consequent rise in unit costs, which are still plaguing present day manufacturers.

While the concept of CIM is broadening its application in manufacturing and other industries, it is interesting to note that new manufacturing and management strategies have also begun to surface during this last five decades. Lean Manufacturing (LM), Just-In-Time (JIT), Concurrent Engineering (CE), Cellular Manufacturing (CM), agile manufacturing, responsive manufacturing, holonic manufacturing, distributed manufacturing, and collaborative manufacturing are some of the new terms evolved over the last four decades to reflect the dynamic nature of improvements in manufacturing applications. The induction of these new terms, by various academia might have resulted due to the result of CIM being an intricate concept to understood by manufacturing managers in order to be successfully implemented. In addition, these new terminologies might have resulted due to the need to create new buzz words every few years to show the world that the
researchers/consultants are seen as innovative [9]. Although, these new terms are being generated every few years, the concept of CIM is far broader than these new terms. In addition, CIM is still able to embrace all these new terms and provide the required features offered by these concepts or strategies. Therefore, CIM still stands as the innovative application for yesterday’s issues, and the newer application required today and for the future.

Today, many CIM researches and managers consider implementation of Advanced Manufacturing Technologies (AMTs) will provide opportunities for manufacturers to achieve a competitive advantage with financial viability for medium to long-term period. However, some researchers/consultants often misinterpreted CIM by focusing only on the letter C, which stands for Computers, however, CIM does not assign its entire focus on computers, but on the other two letters I and M, which stands for integrated manufacturing. Nevertheless, without computers, an enterprise wide integration cannot be effective and efficient, since computers help organise, retrieve and store information in an orderly manner with high accuracy and speed. However, without the holistic integration of a manufacturing enterprise, present day customers’ sophisticated demands cannot be met. In order to meet these demands, the manufacturing industry also has significantly evolved from the state of cottage industry in last few centuries to today’s globally focussed, customer oriented and distributed enterprises.

2. Evolution of manufacturing

Mechanisation facilitated mass production to meet the consumers’ demands for improved products to a certain extent. However, to achieve mass production, transfer lines and fixed automation were needed. This need resulted in the development of programmable automation [7]. The prime objective of the automation was to accelerate the production process throughout the plant and have quality products. Therefore, automation provided the ability to respond to the customers’ demands quickly with high-quality products. With the developments in commercially available ICT tools and equipment, the application of computers in manufacturing started due to the emergence of various new manufacturing technologies, all of which are collectively named as AMTs [10]. In today’s industrialised world, the enormous growth in manufacturing automation has brought a plethora of AMTs with diverse features. These AMTs consist of semi to fully automated systems or equipment that can be used in various functional units of an enterprise.

2.1. Need for integration

The need for a holistic and systematic integration has evolved due to the problems in individual automation solutions adopted by the manufacturers. Individual automation in functional units produced many islands of automation in an enterprise and these automation units could not facilitate communication between functional units. In addition, errors in data sharing and other mismatches with these automation units continually plagued the manufacturing industry. These issues and the complexity of emerging technologies, economics, increasing human limitations, and competition from abroad has forced the initiation of integrated computer aided manufacturing (ICAM) programme by the United States (US) Air force [7]. The ICAM programme conducted in 1983 found that the industrial automation was infested with critical problems [11], such as 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 product of having job shop mindset when deriving automation solutions in an enterprise. This mindset produced individual automation units with lack of proper planning for enterprise-wide issues. Therefore, these individual units became standalone, which could not be connected together for information sharing and streamlined manufacturing. With this unplanned implementation of integration, the full benefits of automation in an enterprise were not obtained. Although, these individual automation units improved local productivity, they were insufficient in providing necessary logistical support to improve the productivity, efficiency and quality throughout an enterprise [12].

Although in 1980s, the prime element of the integration was to have a common or an interconnected database to facilitate automatic data transfer among various units and user groups, many argued that by introducing an integrated manufacturing concept, many potential benefits could eventuate. Some of the identified benefits include:

1. enable a functional unit of an enterprise to communicate easily with other relevant functional units,
2. accurate data transfer among the manufacturing plant, and/or subcontracting facilities,
3. faster responses to required changes,
4. increased flexibility towards introduction of new products,
5. improved accuracy and quality in manufacturing processes,
6. improved quality of products,
7. effective control of data-flow among various units,
8. reduction of lead-times,
9. streamlined manufacturing flow from order to delivery, and
10. a holistic approach to enterprise-wide issues.

2.2. Developments in integration technologies and systems

The benefits of integrated technologies are very difficult to quantify with simple economic tools. Since, integration provides a competitive advantage by linking new and existing hardware, software and middleware of the
functional units, together with database management systems, data communications systems and other ICT systems into a coordinated and efficiently managed process. These benefits are hard to quantify and the benefits across an integrated manufacturing enterprise will be greater due to synergy than individual and unlinked functional applications in an enterprise [13]. Many additional benefits have been obtained by considering cross-functional approach and integrating various technologies across functional units [13,14]. However, along with the direct and tangible benefits when intangible and indirect benefits in an effective integration were taken to consideration by proper justification methodologies, the investment in CIM can be fully justified [15]. In order to appreciate the historical developments that had taken place during the last four centuries, the evolutions in manufacturing technology towards integrated systems are summarised in Fig. 1. However, the precise time span for the evolutionary stages cannot be determined and not given in this figure.

In 1990, Ranky [16] summarised the typical evolution of shop floor automation with respect to manufacturing management automation with some of the technologies and systems that were available at that time. His work depicted the stages of shop floor automation from the level of manually controlled machines towards integrated cells, respectively, automation for manufacturing management improved from paper-based control to flexible or agile systems. In the mean time, integration of manufacturing systems has evolved from physical systems integration to application integration, and then to business process integration [17]. Physical systems integration involves interconnection of manufacturing facilities and data exchange among various units through computer networks that rely on standard communication protocols. This integration considers low levels manufacturing resources. Application integration considers integration and interoperability of systems on heterogeneous platforms. This stage involves sharing data and information among all facilities, distributed processing environments, and common services for execution environments. Today, this information sharing aspect includes both wired and wireless connections across various systems. Finally, the business integration concerns integration of all functions, business processes and systems at an enterprise level (within an enterprise and beyond to business partners and customers) which include e-commerce, customer relationship management, global logistics, supply-chain related applications and many others. Fig. 2 illustrates the evolution of these integration stages towards CIM. Similar to Fig. 1, the precise time span for these three integration stages cannot be determined from the literature and not given in Fig. 2. In addition, various application technologies and systems that help facilitate this evolution are also not identified in this figure, since there are numerous technologies and systems that are available in the market.

In 1997, to represent the evolving process of CIM, and to reflect the need for a VCIM to meet the current global market and environmental conditions, a new CIM wheel

![Fig. 1. Evolution in manufacturing technology.](image)

![Fig. 2. Evolution of manufacturing system integration towards CIM (adopted and modified from [17]).](image)
was developed by the authors from the Centre for Advanced Manufacturing Research (CAMR) of University of South Australia [1]. As illustrated and explained in our earlier article [1], that new CIM wheel stressed the importance in strategic and integrated management in implementing CIM across globally distributed enterprises in present world situation while enhancing the CIM wheel (also known as CASA/SME Manufacturing enterprise wheel) developed by the Society of Manufacturing Engineers (SME) in 1992. The Computers and Automation System Association (CASA), an affiliated association of SME, has been studying and developing descriptive models of manufacturing enterprise over two decades. The historical developments of these models and associated models have been summarised by Estrem et al. [18]. The evolution of these models was the result of global competition, which still exists today and 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 and to encounter the emerging technical, geo-political and economical challenges. Implementation of AMTs could help manufacturing enterprises achieve their competitive goals to survive in the global market environment as long as the technologies chosen are appropriate and justified to meet the enterprise’s objectives. However, a truly integrated enterprise in the form of CIM system will bring immense benefits to an organisation, which has adopted these AMTs in different functional units.

3. New terminologies

To satisfy the conflicting and competitive demands of today’s market, research trends focusing on the application of CIM in manufacturing industries have begun to emerge. The realisation of CIM requires effective integration of a number of available AMTs. At the same time, many variations in manufacturing methodologies were developed and proposed by researchers to revitalise the manufacturing industries. These new terminologies are summarised according to the historical perspective.

3.1. New terminologies on management and manufacturing strategies

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 [19]. This realisation resulted in the formation of the Lean Manufacturing (LM) concept. 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. However, the authors of this paper believe that by having an effective CIM system in an enterprise, LM can be easily achieved and the associated issues resolved.

Just-In-Time, or JIT as a commonly known acronym, is a management philosophy aimed for producing only the right amount and right combination of parts at the right place at the right time. JIT has been a part of the Toyota production system as production and inventory control approach for eliminating manufacturing wastes. Taiichi Ohno at Toyota developed and perfected JIT concept during early 1970s in Japan, and he is now referred to as the father of JIT [20]. In mid 1970s, this concept was widely accepted and used in many companies in Japan. Later, in 1980s, JIT was adopted in USA, one of the early adopters being the General Electric [21]. Nevertheless, implementing CIM in an organisation will help achieve JIT principles easily and effectively, as once implemented, CIM will be an effective control and communication structure in an enterprise across all functional boundaries.

Similarly, Kaizen, which is a Japanese term for achieving continual improvement by cooperatively involving everyone concerned, is still part of the Japanese manufacturing system to date. Kaizen, which became a way of life in Japan when industries start to revive after the World War II, has been helped by the support government and management on adopting quality related tools introduced by Deming and Juran [22]. Implementation of the Kaizen concept has been enormously contributed to the success of manufacturing in Japan to date [23]. As Kaizen involves all employees in an organisation for continuous refinement and improvement of existing activities, and CIM relates to integration of manufacturing activities, both concepts are complimentary to each other.

The concept of Concurrent Engineering (CE) has been around the manufacturing circles from early 1960s in various forms requesting the use of multi-disciplinary teams to accelerate product introduction. CE involves a systematic and simultaneous approach to the integrated design of products and their related processes including marketing, manufacturing, sales and purchasing [24]. Further, it involves formation of multi-disciplinary 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.

Cellular Manufacturing (CM) system, which combines the advantages of process and product layout to optimise the job shop arrangement, is an alternative production system to the conventional conveyor line and batch production systems. CM systems, which are derived from the application of Group Technology (GT), is a major building block of LM system that helps companies manufacture variety of products with less waste compared to conventional ways [25,26]. Applying CM in an
enterprise will result in lower unit cost of production, shorter lead-time to market, higher inventory turnover, and work-in-process control without sacrificing the flexibility. Although, some researchers considered that CM, which was promoted to west by Professor J.L. Burbidge in 1960s, was based on the concept of GT developed by the Russian engineer S.P. Mitronofanow [27,28], CM had many parallel and independent developments in Germany, UK, USA, Italy and other countries. Furthermore, the history of CM is long and complex than the linear developments prompted by others [29]. However, the authors of this paper have a view that by having a fully functional CIM system in an enterprise will provide the flexibilities and benefits of CM in an efficient and cost effective manner.

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 incorporation of highly adaptive, flexible and efficient manufacturing practices in the product development and manufacturing cycle [30]. The initial coining of the term agile manufacturing was the result of a 1991 study initiated by inter-agency task force appointed by the US department of defence [31]. This department was asked by the US congress to take some appropriate actions in relation to concern of declining US manufacturing industry and reduced manufacturing competitiveness, and was asked to investigate what would be the actions required for the US industry to regain global manufacturing competitiveness by the early 21st century [32]. This industry-led study suggested that computer-based information and production technologies that were available could be utilised in industry in the form of agile systems by effective integration of technology, business activities, enterprise and people [31,32]. Similar to LM, the outcomes required by an agile manufacturing system can be simply fulfilled by an effective CIM system in an organisation.

Business process re-engineering (BPR) is the term coined by Hammer and Champy in early 1990s [33]. 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. BPR method eliminates unproductive and unnecessary business activities and operations in an enterprise and actuate process simplification and if necessary out-sourcing. The concept of BPR was popular in the 1990s, but when organisations tried to implement BPR they found that to accomplish the goals of the BPR vast resources in terms of ICT, training, materials and facilities were required. In addition, due to the huge complexity involved in this BPR method, an integrated and holistic approach was required. Therefore, the adoption of BPR failed in many organisations, although there were a few notable successes [34]. However, a CIM system in an enterprise will be an enabler for BPR method, as CIM is a holistic approach.

Agent-based systems are being developed by researchers from late 1980s. These systems utilise intelligent agents, which are derived from Artificial Intelligence (AI). Developments in distributed AI and distributed computing technology has propelled this research on agent-based systems and enabled these systems to be applied in manufacturing enterprises. Many researchers tried to define the agents and their capabilities in various ways. One of the comparisons of definition of agents and the classification of agents has been found in Ref. [35], however, Wooldridge and Jenning’s [36] definition of intelligent agents has received wider acceptance among agent-based researchers (this article has been cited by more than 450 researchers). In the meantime, Shen and Norri [37] in their extensive review of agent-based systems for manufacturing and related applications stated that the intelligent agent technology has been applied in many areas including manufacturing enterprise integration, supply chain management, manufacturing planning, scheduling and control, materials handling, and holonic manufacturing systems. Because of the applicability and efficacy of an agent-based system, Wang et al. [38,39] have applied this concept to their developed VCIM framework.

The concept of Holonic Manufacturing System (HMS), which is a kind of agent-based system that facilitates autonomous and cooperative units of production, was derived from the term ‘holon’ coined by Arthur Koestler in late 1960s [40]. Then this term ‘holon’ was utilised to represent manufacturing systems that require autonomous, cooperative and self-reliant activities and later HMS project was initiated as one of the five IMS (intelligent manufacturing system) projects in 1993 to explore the feasibility of low-volume, high variety production system with agility [40]. During its 10-year programme, the HMS Project has developed specifications for holonic architectures, methodologies to reuse and integrate holonic systems technologies, and demonstrated the applicability of holonic manufacturing systems to derive agility, flexibility and re-configurability in-order to create next generation production systems [41]. Although the concept of HMS tried to solve the issues that arose out of hierarchical structures and rigid implementation architectures wrongly perceived as a result of CIM implementation [42], the CIM concept itself did not enforce the rigidity and master–slave relationships among the manufacturing systems. The CIM implementation projects utilised the technologies available at that time and resulted in some limitations in providing flexibility. However, with the new technologies and tools that are available today, the CIM concept is alive as it was in early 1970s. In order to invigorate the CIM and the reach the organisations beyond the geographical boundaries, Nagalingam and Lin [1] proposed the concept of VCIM and have developed an architecture to make this system a reality [39].
3.2. New terminologies on software applications

While the concepts are being developed, tested and applied, various ICT vendors produced software applications with plethora of acronyms such as Materials Requirement Planning (MRP), Manufacturing Resource Planning (MRPII), Enterprise Resource Planning (ERP), Manufacturing Execution System (MES), Advanced Planning & Scheduling System (APS), Supply Chain Execution (SCE), Customer Relationship Management (CRM), Advanced Order Management (AOM), Warehouse Management Systems (WMS), Transport Management System (TMS) and others.

MRP software was developed in late 1960s early 1970s and was well known through a book published with a title ‘Material requirements planning: the new way of life in production and inventory management’ written by Dr. Joseph Orlicky [43]. MRP software helped automate the planning and controlling of production and related inventory functions of an enterprise from raw materials to finished goods [44]. MRP later evolved to Manufacturing resource planning (MRPII)—a term which was coined by Oliver Wight in 1974 [45]. MRPII expanded the capability and scope of the MRP systems by linking related support functions such as marketing, finance, engineering, purchasing and human resources [44].

The ERP systems, a term originally coined by the Gartner Group in early 1990s to describe the extension of the concept the next generation MRPII software [46], linked the databases of an enterprise to execute the business operations seamlessly and helped in avoiding multiple and redundant entry of the same information and processes. ERP describes a suite of multi-modular software applications that are integrated to serve and support multiple business functions and the suite of applications in ERP package are expanded to include modules such as finance, administration, manufacturing, project management, transportation, human resources and other modules which help automate the business administration functions of an enterprise. Depending on the capability of the ERP software and the proprietary software of the organisations, ERP modules may able to interface with an organisation’s proprietary software in varying degrees. However, many of the issues such as inherent complexity, high cost, large timelines to implement, inadequate in-house expertise and training, overly customised software, unrealistic expectations on the capability and overly relying on ICT to solve the problems, corporate culture and management’s adaptability to the issues are some of the known issues, which made these software applications to fail [46].

Although, the concept of MES represents a new and practical approach to link information with action on the shop floor to help the managers in improving quality, response, and profitability in the operation, the term MES have never reached consensus of all practitioners and might have been overtaken by the popular acronym APS [45].
4. Status of CIM in organisations

In today’s competitive market, across the globe many companies have adopted the concept of CIM and implemented a partial or a full CIM solution to meet the required effectiveness and efficiency in all operations. Attaran [48] reviewed the adoption of CIM among manufacturers in USA and has given a few case applications including Motorola, Allen Bradley Texas Instruments and Tandem computers. He [48] stated that although CIM technology was evolving rapidly and many CIM successes were reported as many companies could afford implementation of CIM within their financial reach, still there were a few failures when it was implemented without a proper strategic plan. In the same year, Milling [49] conducted an analysis of CIM implementations in German industry. He reported that among 115 organisations, which have responded to the survey stating that CIM components have been implemented in their organisations, only around 5% of the organisations had achieved full integration using some of the potential CIM components. These CIM components include: Computer-aided design (CAD), Computer-aided planning (CAP), Computer-aided manufacturing (CAM), Computer-aided quality assurance (CAQ), and Production planning and control (PPC). Among these firms, 101 have some of the CIM components integrated and the remainder using these components as stand-alone. However, he argued that survey does not represent a true status of CIM implementation in Germany, as many as 79% of the firms have not responded to his survey.

Similarly, in China, during 1996–1997 there were more than 100 CIM applications were reported among state owned enterprises [50]. These enterprises invested in CIM systems using government financial subsidies and government-directed technical support from universities and research institutes; therefore, they have had success and progress in CIM implementation. However, most of the CIM enterprises in China did not realise the higher expectations the companies have had with respect to CIM systems, as in early stages of CIM implementation, most managers and researchers regarded CIM as an all-purpose solution rather than an integrated manufacturing strategy [50]. The failures on CIM implementations were mainly due to the reluctance to change management practices and organisational structures in state-owned organisations to match the requirements for an effective use of CIM philosophy and methodology [50].

In the mean time Anjard [51] argued that in today’s need for profitable organisations and with an expectation that automation can increase profitability of an organisation, CIM has even become a vital and strategic approach for many industries that includes pharmaceuticals, electronics, clothing and food. These industries with CIM implementations have achieved lowered costs, reduced processing times and improved productivity [51]. In addition, recent trend suggests that many SMMEs are migrating to CIM to have improved quality, business speed, competitiveness, and profit while lowering the cost as true CIM installations are emerging [51,52].

Although, the authors of this paper could not get a detailed implementation status of CIM across the globe, many publications suggest with availability of mature technology and knowledge, many enterprises either adopted CIM or are in the process of adopting this methodology. These enterprises range from small companies to larger enterprises, as CIM implementations, if properly installed with necessary organisational changes and commitments can deliver many benefits some of which were outlined in Section 2. These benefits include lower costs, reduced work-in-process, reduced lead-time, reduced inventories, improved quality, improved production and management control, improved flexibility and ability to timely respond to the market, and many other tangible and intangible benefits.

5. 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 using age-old technologies or operating their systems in islands of automation to combat the threat from less developed countries, which have the benefit of low paid, but highly literate staff and less regulated economy. This trend of clinging to the past to face the growing competition in the global market will not help the manufacturing industries to be successful.

Furthermore, the vision for 2020 [3] suggests considerable changes in the nature and operations of manufacturing enterprises due to many challenges that will be generated by the social and political environment, the needs of the marketplace, and opportunities created by technological breakthroughs. This vision for 2020 identified six grand challenges for manufacturing such as:

1. the need to achieve concurrency in all operations in an enterprise,
2. challenges in integrating human and technical resources to enhance workforce performance and satisfaction,
3. challenges in dynamically transforming information from many sources into useful knowledge that would help making effective decisions,
4. the need to have zero production waste and environmental impact to be competitive,
5. challenges in having reconfigure manufacturing enterprises in order to rapidly respond to changing needs and opportunities, and
6. challenges in developing innovative manufacturing processes and products to meet the technological breakthroughs in science.

However, even today, to be successful in this emerging competitive market, many companies are relocating offshore to gain the advantage those developing nations offer in terms of reduced labour costs and other economical/ regulatory benefits. This phenomenon of shifting locations can be avoided if manufacturing companies invest in CIM and related technologies to become globally competitive. The efficient application of CIM 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. To facilitate the investment in CIM and to help manufacturing industries, many researchers are seeking solutions in application of CIM, one of which is a VCIM system.

Authors have done extensive research on VCIM systems with other research colleagues and have published more than a dozen research articles on various aspects of this system. Recently, a prototype of an agent-based architecture that can enable Small and Medium Manufacturing Enterprises (SMMEs) to collaborate with each other through the VCIM system has been developed [53]. In this latest work, our approach towards the development of an agent-based architecture for a VCIM system, implementation issues towards distributed manufacturing resource integration, and scheduling in an SMME network are discussed. In our developed framework [39,53], three categories of agents, which include Facilitator agents to coordinate the agent community, Customer agents to provide GUI (graphical user interface) for users to participate in VCIM, and Resource agents to provide manufacturing functionalities are identified. With these agents, an agent-based architecture with a three-layered structure, which can accommodate all these agents no matter where the agents are located and which enterprise the agents belong to, is developed. Further, this architecture permits new agents, whichever the category is, to be connected when and where necessary. This feature enables the VCIM system to have a flexible information processing capability, manufacturing capability to SMMEs, and convenience to customers.

This latest research result on VCIM system provides a simple approach for distributed manufacturing resource scheduling among a network of SMMEs to meet the customers’ product requests. This VCIM system uses agent negotiation in real time with the current working status of the agents to generate work proposals, and a backward network algorithm for shortest-path to reach an optimised schedule that has the lowest cost as the primary criteria and the shortest production time as the secondary criteria. The test results of prototype system have demonstrated that our approaches for resource integration and scheduling with the agent-based VCIM architecture are feasible. Based on the previous work, we are now working on extending the prototype system and investigating more potential issues for a VCIM system implementation in a real industrial application. However, in order to improve the system to be practical and be easily adoptable by SMMEs, and to overcome the firewall and accessibility limitations of SMMEs’ ICT network through an agent-based system, the authors are evaluating the viability and performance of using web services approach for the VCIM systems.

This research on VCIM systems consist a rich research diversity, which includes architectures and modelling formalisms for enterprise integration, evaluation methodologies for enterprise integration, and international collaboration for VCIM implementation through integration of subsystems. In addition, to facilitate a VCIM system, network communications for VCIM should include application of wide-area networks, Internet and intranet-based applications, information enhancement by data integration across various system boundaries. Furthermore, issues related to integration of client and server for manufacturing shop-floor automation, application of multimedia and hypermedia for VCIM environment, data management for VCIM systems, and others are to be investigated and integrated.

6. Step by step in implementing CIM

The step-by-step integration towards CIM is a methodology developed at CAMR for assisting SMMEs achieve the goal of a fully integrated enterprise despite limited resources and expertise [54]. This methodology was perceived by the authors, as it was difficult for this cluster of enterprises to become fully integrated in a short period due to the limited resources these companies have in their disposal, and to give confidence of achieving the implementation results to the decision makers of those enterprises. Although, a justification and optimisation methodology for an integrated system, such as CIM, had been developed at CAMR with the capability to quantify intangibles [55,56], that methodology was not applicable fully to a small or medium enterprise, as a company in this category often do not anticipate a holistic system approach at the beginning of the automation process.

Therefore, a need for a step-by-step integration approach was introduced to enable the SMMEs systematically accumulate sufficient capability and cohesiveness towards a fully integrated system. Interestingly, when analysing implementation issues of CIM in German industries, Milling [49] had found that almost all companies, which had given feedback to his survey, had started their implementation with a singly type of equipment and added other CIM components sequentially. Based on his findings he stated that since CIM implementation requires considerable time and resources, a stepwise implementation strategy is feasible and appropriate to handle
the complexities involved in achieving a CIM system. However, he has not given a solution on how to adopt this step-by-step implantation process and only considered the CIM components such as CAD, CAP, CAM, CAQ and PPC in his analysis. In addition, he found that more than two thirds of organisations had started their CIM implementation with PPC. Similarly, Gunasekaran et al. [57] suggested that SMMEs should be adopting a step-by-step approach or an incremental approach when investing in CIM modules. However, they have only given a brief framework for implementation of CIM in SMMEs, as of other CIM implementation suggestions that are available from many other similar publications, which focus on CIM implementation issues.

As true CIM systems encompass all enterprise wide applications and systems, our stepwise integration methodology has been designed to be flexible for many organisations and be a simple approach to select the implementation sequence. Since, many of the SMMEs implement AMTs on ad hoc basis depending on the critical need without a cohesive action plan, this suggestive methodology will encourage decision-makers of SMMEs to consider a long-term planning for their organisation to achieve a true CIM system. An organisation, which prefers to adopt this methodology, is provided with a list of subsystems, which has individual AMT components as a subset. The components and the subsets are to be selected according to the four critical attributes: nature of the company, opportunities, existing resources and capabilities and special needs [54].

Nature of the company: By identifying the nature of its operation and the business they are in, the company would be able to select the best initial subsystem that will be more applicable to them. For instance, if the business were dealing with import/export, selection of inventory or shipping subsystem prior to selecting a system that enables either marketing or project scheduling would be more appropriate.

Opportunities: The opportunities the organisation has in the marketplace and the SWOT (strength, weakness, opportunities, threats) analysis will help identify the strategies the company needs to implement. In addition, this will enable the company to identify some particular strength they may need during different seasons and in a different market.

Existing resources: By identifying existing resources that are in the company’s disposal and by selecting a subsystem (or the subset components) that can be easily implemented, the organisation can reap the benefits of integration (or the use of AMT) quickly and reliably. In addition, this attribute will require the company to identify the AMTs that already exist in the company and that can be used as CIM modules towards an integrated system. For instance, if the accounting department has a computer with the basic office related software, by complimenting the computer with the necessary accounting software, many of the accounting related tasks can be automated.

Special needs: In some special circumstances, a company may need to have extra capabilities and functionalities to fulfill customer satisfaction. If this need is identified, the company can choose a subsystem that is relevant in satisfying this special need (Fig. 3).

Based on the above methodology, a systematic integration flow chart for a typical small or medium manufacturing company has been identified as shown in Fig. 4. This methodology and the typical integration flow chart have received favourable feedback from five south Australian manufacturing companies [54].

According to our proposed methodology, it is recommended that a small company initiate the systematic integration from an office subsystem. Once the necessary components of the office subsystem has been installed, the

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**Fig. 3.** A decision module for subsystem sequence identification.
company by using an AHP or a simple scoring method can determine the paths 1A or 1B or 1C and the order of implementation among 1A, 1B and 1C by carefully evaluating the issues related to all four attributes. For example, if path 1A is chosen the company can decide again between the Scheduling and the Marketing subsystems by using an appropriate selection mechanism. It is recommended that each block, which is identified as 1A, 1B, 1C, 2A, 2B and 2C, be individually completed before undertaking the next implementation. This implementation suggestion will enable the company in reaching a fully integrated system. As a future work, this decision framework is planned to be integrated with the necessary elements from the previously developed justification and optimisation methodology for CIM at CAMR [13] for the stepwise justification of individual CIM modules. By integrating both these approaches, decision-makers could confidently justify their stepwise implementation of CIM modules by considering both tangible and intangible benefits towards an optimised investment for a CIM system. It is expected this justification methodology for the systematic implementation will enable the company to realise the benefits and financial returns to invest in the next CIM module with confidence.

7. Conclusion

CIM is an innovative and expansive concept to provide the solutions manufacturing industries are seeking to survive in the current competitive global market with sophisticated and demanding customers. Today, we are at the threshold of utilising innovative and improved computer-related technologies and ICT tools 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 authors argue, although a plethora of terminologies for manufacturing technologies has been proposed by various researchers during last four decades to overcome many of the industry issues that were the result of the new global market conditions, still a CIM system or appropriate CIM modules can provide the features suggested by those new methodologies. CIM is an overarching

Fig. 4. A systematic integration flow chart for a typical small or medium manufacturing company (adopted from [54]).
methodology and philosophy compared to the new terminologies such as LM, JIT, CM, agile manufacturing, responsive manufacturing, holonic manufacturing, distributed manufacturing, collaborative manufacturing and others. Similarly, CIM is a complimentary methodology for the concept of CE, Kaizen and others. Therefore, research on CIM and applicability of CIM modules with available ICT tools to manufacturing industry to overcome the current economic climate should be pursued with vigour. The need for a CIM in an enterprise is still alive as of 1970s when Dr. Harrington articulated the need for an integrated solution in a manufacturing industry in the form of CIM.

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 and to meet the current competitive and agility requirements. 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. As such, the latest research on VCIM, which is being conducted at CAMR is briefly discussed in this paper. Currently VCIM research is reaching the mature stage and implementation of this system with commercial available technologies will strengthen the application and applicability of the CIM system to industries, especially SMMEs.

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

References


[56] Nagalingam SV, Lin GCI. Optimising the resources for CIM implementation. In: Fourth international conference on manufacturing technology; 1997 December; Hong Kong; 1997. CD ROM.