Integrated manufacturing strategy for deployment of CAD/CAM methodology in a SMME

Adedeji O Esan, Mohammed K. Khan, and Hong S. Qi
School of Engineering, Design and Technology,
University of Bradford, Bradford, UK

Chris Naylor.
NTR Ltd, Wetherby, UK

Abstract

Purpose – Cost reduction through the use of technology has become the competitive strength of companies. The benefits of technology integration are quite credible and have been effective in business competition. This paper describes an integrated manufacturing strategy for the deployment of a CAD/CAM system in a Small, Medium Manufacturing Enterprise (SMME).

Design/methodology/approach – A case study of a SMME is utilised in deploying an integrated CAD/CAM system for practical application of manufacturing technology for achieving sustainable growth through Lean Systems Design (LSD). The paper presents a techno-economic and technology change management framework, with an application of a holistic set of lean deployment tools that include establishing a strategic and operational plan for implementing CAD/CAM systems as a means to achieving world-class performance.

Findings – The paper shows that the CAD/CAM integration within the case company increased knowledge of CAD/CAM technology, productivity, and flexibility whilst reducing throughput times. Based on the literature review and the current case study, a framework for ideal CAD/CAM implementation has been proposed. The paper also shows that management and organisational structures are key inhibitors for successful implementation of technology integration.

Research limitations/implications – The paper uses a single case study to validate deployment of the integrated manufacturing strategy in SMMEs. Hence there is a limitation to its generality.

Practical implications – The paper provides an opportunity to further understand CAD/CAM system implementation protocols within a well structured framework and its configuration within SMMEs.

Originality/value – The presentation of conceptualisation, development and implementation of an integrated CAD/CAM system in support of organisational wide Lean Manufacturing initiative in SMME is an originality of this paper

Keywords*: CAD/CAM, Change Management, Small Medium Manufacturing Enterprise (SMME), World Class Manufacturing*

Paper type: Case study

Introduction

Cost reduction through the use of technology has become the competitive strength of companies and there has been an increasing application of an integrated manufacturing strategy for Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) policy deployment. For smaller manufacturing facilities, CAD and CNC are major and often the only components of their Advanced Manufacturing Technology (AMT) portfolio (Vinodh et al, 2009; Marri et al, 2007; Small, 2007). Integrated CAD/CAM promises a “competitive edge” through reducing costs, improving quality, enabling variety production, reducing lead times and flexibility (Gouvea da Costa and Pinheiro de Lima, 2009). Today, ? it is perceived? that, a CAD/CAM environment is desirable in terms of quality, productivity and

reduced time to market and is a reachable goal in any company. -Yet the reality in many manufacturing companies is different (Salaheldin and Eid, 2007; Small, 2007; Devadasen et al, 2005). It is limited in its breadth and implementation only by the willingness or ability of management to invest in the tools, training and methods necessary to make it a strategic fit between the organisation's manufacturing and business strategy (Small, 2007). This paper describes a manufacturing strategy for the advancement of an integrated CAD/CAM system in a Small Medium Manufacturing Enterprise (SMME). Through a case study, the paper aims to provide with an in-depth understanding of the strategic intent of SMMEs and the way in which the implementation process is managed. Based on the premise that the implementation of a CAD/CAM strategy is partly dictated by characteristics that are unique to each adopting firm (Vinodh et al, 2009; Arcelus et al, 1994), the paper also presents solutions to key issues identified during the CAD/CAM integration planning and implementation phases in the case company. The findings have been ultilised to develop a conceptual framework for carrying out ideal CAD/CAM implementation in SMMEs.

Case study based research methodology

According to Tantoush et al (2001), better understanding of technology-induced organisational transformation is achieved where research design is longitudinal and grounded in the social "fabric" of the organisation's settings. On this basis, one can build a thorough understanding of the interactions between the cause and effects of change. Consequently the research design for the paper employs a qualitative grounded theory methodology (Binder and Edwards, 2010) and incorporating a case study approach (Yin, 1994). The case study approach has gained considerable recognition over the years and has been used by many researchers. Some examples include a study of the process of using quality function deployment in manufacturing

strategic planning (Crowe et al, 1996); a study of Automated JIT based materials management for lot manufacture (Jina, 1996); a study of manufacturing strategy formation process in small and medium-sized enterprise (Barnes, 2002). The case study method allows for the opportunity to gain more in-depth understanding of the strategic intent of the organisation in focus and the way in which the implementation process is managed.

The data for the research was gathered by interviewing the owner manager, middle and lower managers (team leaders), engineering, production accountants and the personnel working in sales departments. Direct observations, archival records and the case company history were also studied. Meredith (1998) advocates that gathering data, on all the key decisions and actions which make up a firm's manufacturing strategy (in sufficient detail to understand the process by which that strategy forms) requires access to the company. Therefore the information gathering process presented in this research paper involved active participation in the conceptual and technology integration process by the first author of this paper. A holistic set of lean deployment tools was applied, which included a business case that consisted of a comprehensive stakeholder's analysis, risk assessment, investment and scenario planning, financial justification through a return on investment calculator, force field analysis, and labour linearity. Other deployment methods include training, supplier integration, machine configuration and provision of greater understanding of the internal processes within the case company, illustrating ways in which ideas are generated; the approach taken and how the CAD/CAM system changed the organisation's work methods.

The case study company, a SMME in the north east of England, provides many of Europe's leading automotive, aeronautical and high precision sub-contract manufacturers with tooling reclamation. This case company continues to provide manufacturers with substantial cost savings against the price of new tooling, up to

75%. This case company continues to grow as the need to renew and recycle becomes increasingly important, and currently has a 70% share of the UK tooling reclamation market. **Figure 1** shows a cross-section of product offered by this case company. Manual machining processes at the case company is highly skill dependent and reproducibility and repeatability of machined parts are limited. At the same time, the accuracy requirement for its products is paramount, which reinforces the desire of utilising a better CAD/CAM system to achieve high product quality and is one of the main aims/objectives of this case company.

Figure 1: Cross section of the case company's products

Some hurdles of deploying CAD/CAM

Although CAD/CAM integration has became a need and necessity, it faces several hurdles in real time. The hurdles are discussed in the following subsections.

Gap between strategy formulation and process implementation

The concept of "strategic fit" is central to manufacturing strategy theory (Sonntag, 2003). Additionally, Liu and Barrar (2009) suggested that a firm with a higher level of strategy-technology integration has achieved a degree of "fit" between strategy and technology, and thus would make the firm compete more effectively in the marketplace and attain a better operational as well as financial performance. They also stress on the need for consistency between manufacturing strategy and business objectives. In many organisations, there appears to be a want of it (Sonntag, 2003,

Dangayach, and Deshmukh, 2005). This lack of alignment is a common problem that has received significant attention in the literature (Porter, 1996; Tracey et al, 1999). Much of this failure has been pinned on the actual practices of organisations where manufacturing strategy unfolds as a complex dynamic process (Kiridena et al, 2009). According to Sonntag (2003), actual practice frequently differs from strategic intention and often there appears to be two manufacturing strategies at work – the one that identifies the plan and the one that has been implemented. Sonntag (2003) further suggested that many organisations do not have mechanisms, i.e. strategy formulation and implementation processes, to bring about the desired alignment.

Problems on CAD/CAM integration

The National Economic and Development Office (NEDO 1985) in their report examined the ways in which Advanced Manufacturing Technology (AMT) might help manufacturing organisations compete better. They concluded that there were many failures which were due either to sub-standard equipment, or poor planning.

Internal issues: Most of the reasons cited were internal to manufacturing businesses such as poor planning, poor communications, lack of adequate investment and the piece-meal approach to investment and poor employee involvement and training (NEDO 1985). Another reason they mentioned was the lack of involvement of equipment suppliers.

External issues: Similarly, and referring to the implementation of CAD/CAM in the UK, the CAD/CAM User Experiences Report (CAD/CAM Source, 1983) has looked at 81 CAD/CAM projects. Some of the problems reported during the implementation of these systems included lack of vendor implementation back up and support (15 cases), ineffective or insufficient vendor training (15 cases) and lack of system reliability (14 cases).

Change of management/culture

?? It has been recognised that CAD/CAM integration does not just involve technical issues such as hardware, software and database interfacing, data exchange and communications requirements. Such technical problems are perhaps more obvious and therefore more widely recognised than the challenges involved in the process of organisational change that accompanies implementation (Tantoush et al, 2001). Today companies need people to work together in development teams, sharing their hard-earned knowledge, experience and ideas and hence providing the capability of working on production and support from very early on in the design and consequentially the manufacturing phase. However without being able to effectively use all the functional knowledge retained within the company, the team's effectiveness can be limited severely. Technology can aid this activity significantly – helping companies to look at the whole product life cycle from the start and, thus, produce manufactured products more rapidly and with greater confidence in quality. However, too often the available computer-based design and manufacturing support systems work in isolation, severely restricting the effective use of the knowledge they retain hence the need for concurrent engineering (Vinodh et al, 2009). Concurrent engineering to date has focused on those tools which facilitate it (CAD/CAE/CAM and MRP products) and, subsumed in this, a restructuring of the engineering organisation to take advantage of the new functionalities offered by these products.

Development of CAD/CAM integration at Case Company

The CAD/CAM integration were carried out in the case company in two phases. In the first phase, analyses were conducted to understand the company. In the second phase, the CAD/CAM integration was implemented.

Understanding company business for CAD/CAM integration

The need to develop a strategic focus requires a process of creating and sharing goals throughout the organisation in such a way as to enable each individual or problem-solving group to focus efforts on improvements. This will impact on the strategic targets created to meet the need for the company to implement CAD/CAM integration on a lean platform. Four analyses were conducted To understand these and reference to the case company.

Analysis One: The need for CAD/CAM integration on a lean platform has driven the aim to develop a focus that requires a process of creating and sharing strategic goals throughout the organisation in such a way as to enable each individual or problem-solving group to focus efforts on improvements, which will impact on targets. Figure 2 shows the key drivers for CAD/CAM integration at the case company. It is evident that the CAD/CAM strategy was necessary because of changes in cutting tool technology (configuration and complexity) and hence the limitations were found in the company's manufacturing capability which was vastly manual based (about 80% of machining was done manually).

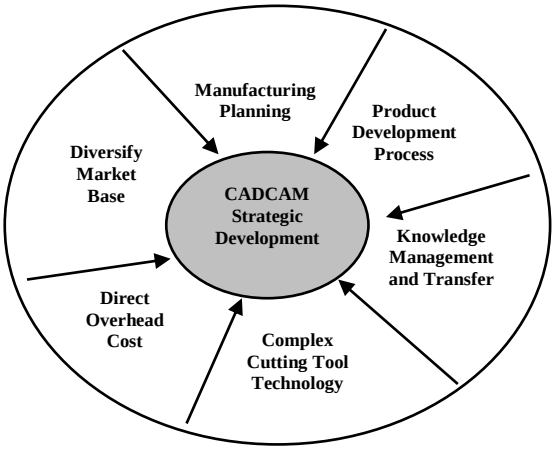


Figure 2: Key CAD/CAM strategic development issues

Analysis Two: A Force Field analysis of the CAD/CAM integration strategy at the case company was carried out, and is summarised in Table 1. The manual

machining process is highly skill dependent and the reproducibility and repeatability of machined parts is limited. The intention however was not to completely alienate the manual operation, but more importantly to retain flexibility in reclamation of parts that have extremely light to medium damage and need the lightest "skim". Therefore this achieves integration into a lean environment that advocates an optimum combination between man, material and machine.

The driving forces for the deployment of the CAD/CAM strategy is based on the fact that the existing manual machining process takes about two years to become proficient and the company desires to be able to quickly and seamlessly transfer and document the organisation's knowledge base. This will result in application of concurrent engineering, manufacturing data management system, productivity increase, product quality improvement, market base diversification and lower manufacturing costs.

For (Driving Forces)	Against (Restraining Forces)
High Product Quality	Measurement System and Machine tool
Lower Manufacturing Cost	Investment Cost and Payback
Rapid Knowledge Transfer	Product Characteristic Documentation
Complex Tooling Geometry	Measurement System and Machine tool configuration
Lower Throughput Time	Machine tool: CNC machine and Rotary Table
Competitive Advantage	Investment Cost and Payback
New Markets	Marketing, and Sales Strategy
Manufacturing/Business Strategy	Investment Cost, Payback and Marketing/Sales Plan
Reduce Operating Cost	Product characteristics, High Skill Requirement and Milling Knowledge

Table 1: CNC/CAD/CAM Integration Force Field analysis

The forces restraining the deployment of the CAD/CAM strategy, on the other hand, are mainly the extent of investment required in achieving a CAD/CAM environment including CAD/CAM acquisition as well as requirements for machine tool technology and/or multi-axis machine tools.

For further understanding of the need for CAD/CAM integration strategy at the case company, a team based continuous improvement framework was used to carry out several studies on various stakeholders' expectations, risks involved, investment scenarios, and expected returns on investment. this involved the incorporation of a production plan with cost estimates for a wider deployment of the CAD/CAM integration strategy. Table 2 and Figure 3 illustrate a Return-On-Investment (ROI) calculator and an incremental investment strategy developed as part of the CAD/CAM integration. Table 2 shows a production plan with expected annual transaction rate of about £275,000 and a gross system's output of 8 parts per day with investment limited to existing machine tools. This shows a drastic increase in parts produced over the manual operation with output of just 3 parts per day on parts needing total refurbishment. With incremental investment in advanced machine tool technology and other ancillaries, an exponential increase in outputs can be achieved as shown in Figure 3.

Operation parameters	Average minutes	Loaded Hourly Rate	Activity Cost	Total Customer Cost	Total Business Cost	Assumptions	
Operation one (OP1)	5.0	£50	£4.17		£4.17		
Operation two (OP2)	5.0	£50	£4.17		£4.17		
Operation three (OP3)	15.0	£50	£12.50		£12.50		
Operation four (OP4)	55.0	£50	£45.83		£45.83		
Operation five (OP5)	5.0	£50	£4.17		£4.17		
Operation six (OP6)	10.0	£50	£8.33		£8.33		
Operation seven (OP7)	5.0	£50	£4.17		£4.17		

Operation eight (OP8)	8.0	£50	£6.67		£6.67		
Operation nine (OP9): Pocket milling ??	5.0	£50	£4.17		£4.17		
Cost Per Transaction				£0.00	£94.17		
Transactions Per day				8	8		
Transaction Cost Per Day				£0	£753		
Rework and Scrap Costs	10.0	£50	£8.33		£8.33		
Transactions reworked/day				0.08	0.08	1.0%	Error Rate
Rework/Scrap Costs Per Day				£0.00	£0.67		
Annual Transaction Cost				£0	£275,210	365	Days/year

Table 2: Calculation of annual transaction cost

Analysis Three: In order to successfully manage and realise the projections, the case company carried out a stake holder's analysis as shown in Table 3. The table uses a matrix structure to identify key stakeholders and the level of their commitment to CAD/CAM integration at the case company. The matrix shows that the management of the case company is helpful whilst the production staff are indifferent about the need for such strategy as it is perceived as an avenue to "de-skilling" their jobs. Some other perceptions of the production staff with regards to CAD/CAM integration include how the integration would be achieved with the current CNC milling machines, and more importantly, what are the benefits over the existing conventional based CNC programming and manual milling methods. In order to gain support for CAD/CAM integration and with any necessary change in organisational culture, staff buy-in is always a pre-requisite.

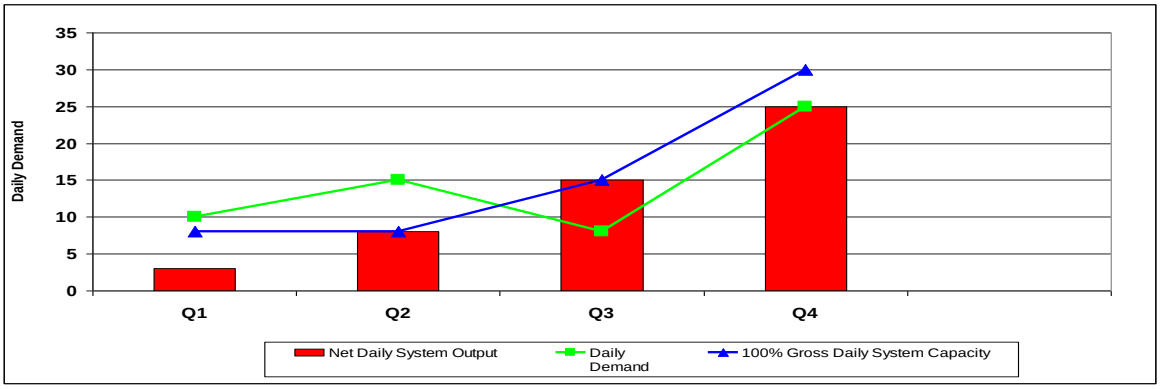


Figure: 3: Incremental investment capacity

Level of Commitment	People or Group			
	Sales	Management	Production	Customer
Enthusiastic		**O**	**O**	
Helpful	**O**	**X**		**OX**
Compliant		**X**	**X**	**OX**
Hesitant	**X**	**X**	**X**	
Indifferent	**X**			

(**Key: O** - Level Necessary for success, **X**-Current level)

Table 3: Stakeholders analysis on CAD/CAM Integration

Analysis Four: A risk assessment framework for CAD/CAM integration was developed and used, as shown in Table 4. This described the nature of the risk, a business impact and probability of occurrence rating thereby providing the organisation with a decision making opportunity. Details of approaches exploited in mitigating some of the risks identified in Table 4 are presented in the next section titled '*Implementation of CAD/CAM integration'*. Besides these risks, the ability to source a reliable vendor for the CAD/CAM system was a significant factor. Reliability in this instance is directed at provision of on-going support for the client and continuous product quality updates.

Risk	Business Impact (1, 3, 5)	Probability of Occurrence (1, 3, 5)	Priority
Poor CTQ definition	5	3	15
Extended product development time	5	3	15
Access to investment finance	3	1	3
Barrier to Entry: Marketing and Sales Strategy	5	5	25
Software and Computer Integration	5	1	5
Hardware: Machine Tools and Measurement System	5	5	25
Production Staff: Communication Plan and Buy-in	5	5	25
Learning Organisation (Time-to-Train, knowledge Mgt& IP)	5	1	5
Highly Skilled Staff Retention	5	1	5
Continuous flow of work to process centre	5	5	25

Table 4: Risk Assessment CADCAM integration (1-Low, 3-Midium, 5-High)

Implementation of CAD/CAM integration

Based on the outputs of the analyses explained in previous sections, some corresponding actions were carried out in the case company.

Change management: Figure 4 illustrates the approach adopted in managing the change process in the case company. The framework involves the establishment of a CAD/CAM integration continuous improvement team centred around production staff members and supporters, education, training and creating awareness of the benefits of CAD/CAM (detailed explanation provided in the following section) to the production staff members.

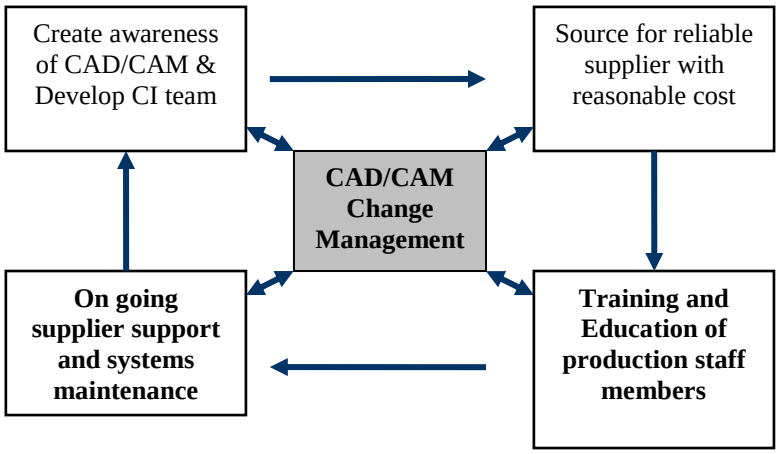


Figure 4: CAD/CAM change management at the case company

Staff training: Staff training was carried out throughout the project, which provided the production staff with the opportunity to witness first-hand the advantages of the system over current methods. More importantly, it provided an avenue for them to share their concern over the deployment of the strategy. To make the training process effective and relevant, an on-site training method was utilised with a combination of practical (hands on machine based training) and software based training. The training focused not only on how to use the CAD/CAM system but also on how to develop a 'Product Data Management' structure that allowed collaborative design for manufacture using a server based technology.

Supplier or vendor partnership changes: The vendor, who supported the CAD/CAM implementation at the case company, was actively involved in staff training and product development. The supplier was collaboratively involved in the product development integration with the concept of remote team working, which allowed working in conjunction with the supplier using internet enabled technology to manage both product development and system's maintenance. This approach allowed the supplier to remotely take control of the manufacturing/design engineer's PC thereby facilitating knowledge transfer and rapid product development.

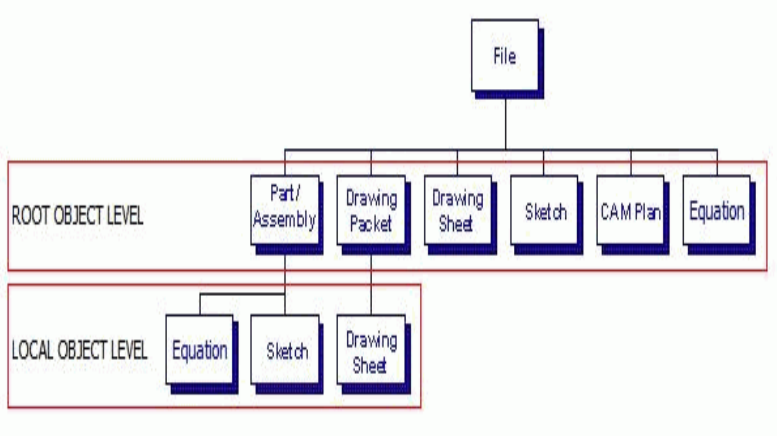


Figure 5: Case company's CAD/CAM system operating levels

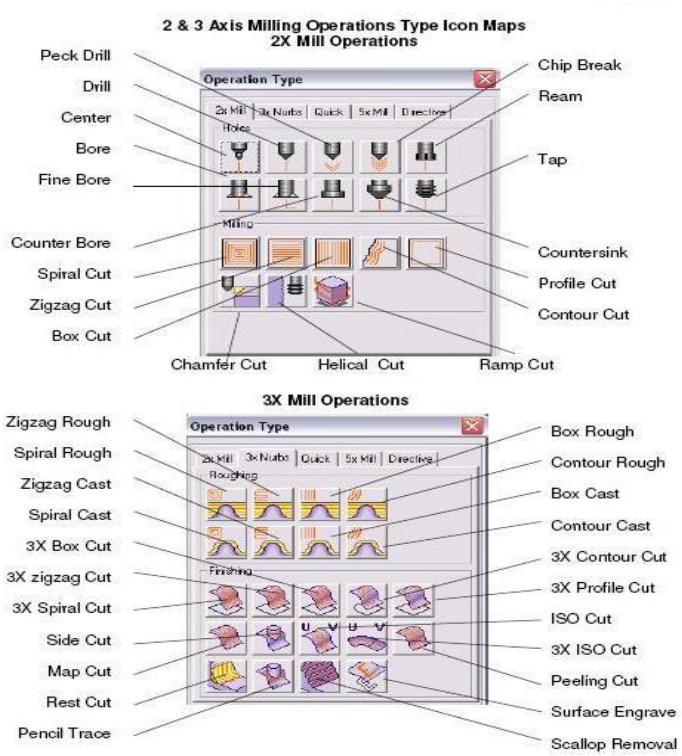


Figure 6: The operation type of the CAD/CAM system

Investment in CAD/CAM software: For improving the quality and efficiency of CNC processes and data management, a CAD/CAM software package was researched and purchased. By using the concept of CAD/CAM part libraries, a parametrically driven feature library associated with design parts, was utilised for efficient change management and the ability to quickly re-use and modify the existing design for manufacturing using a template or library. This can be instantly applied to a vast array of other parts and hence facilitate lean operations. Figure 5 shows the operating levels

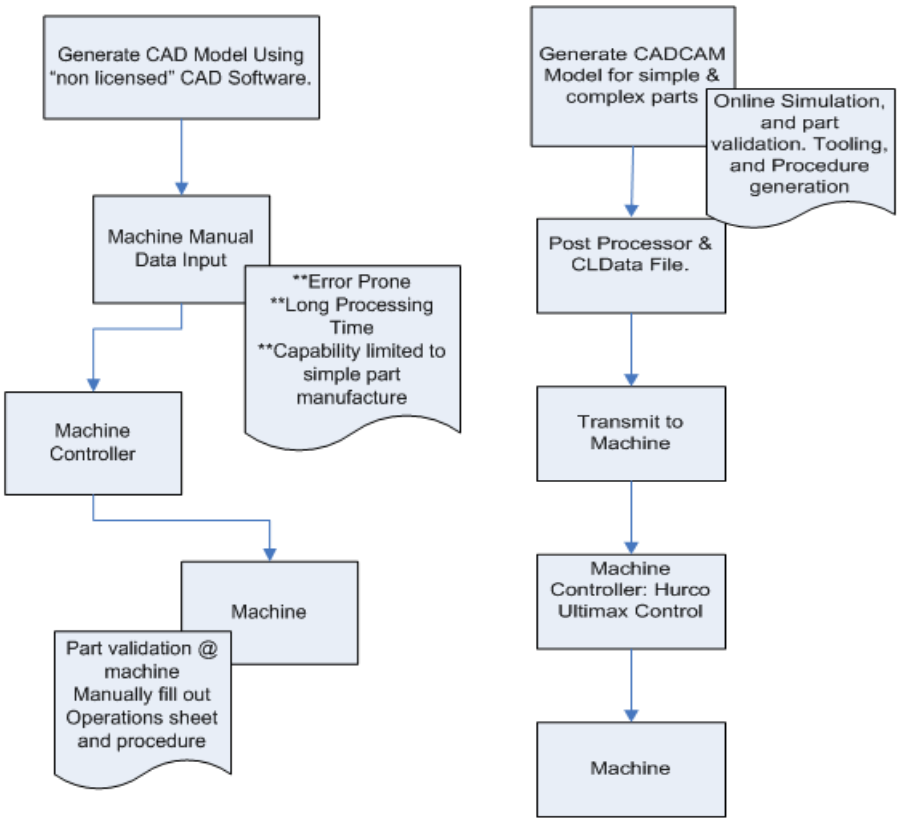
of the CAD/CAM system whilst Figure 6 shows the operating type of the CAD/CAM system.

Discussion

CAD/CAM integration in the case company is discussed in following section from the three sensitive issues.

The CADCAM system

The CAD/CAM system implemented at the case company offers valuable advantages over traditional design/manufacturing methods and can be appreciated by the comparison shown in Figure 7. Figure 7a illustrates the conventional manual data transfer methods. The process begins with generation of a 2D CAD model that includes manual calculation of relevant "pattern location" using trigonometry. The application of this trigonometry calculation is especially limited to calculating compound "pattern locations". Furthermore, on generation and extraction of relevant geometries from the CAD model, the details are then manually transferred into the machine using the conversational part programming interface. This particular process is often long and lends its self to data input error. Other observations from Figure 7a are that tool path validation is always done at the machine, hence the need is rose to continuously adjust programmes to fit (over-processing). On successful validation of the programme, the programmer then needs to develop an operation's sheet (tooling, procedures and other instructions) which often takes long time. In addition, the conventional based programming is limited to one single machine tool type/manufacturer therefore limiting the case company's options in sourcing for other machine tools. However, with the application of CAD/CAM, as shown in Figure 7b, all the highlighted limitations mentioned above are eliminated.



a, Old manual CNC process **b,** New CAD/CAM process

Figures 7a & b: Manual process Vs CAD/CAM process

Furthermore, the user establishes "rules of engagement" to control and contain the tool path. The CAD/CAM system also automates small changes to be needed to individual machining operations. For example, changing a tool size automatically adjusts the XY step-over in a roughing operation. This rules-based approach is extremely effective in rest milling operations where the machinist simply wants to remove the material that the previous operation did not remove. The automation comes from machinists storing their logic and intelligence in a template of operations. The CAD/CAM system allows users to apply their own operating procedures and intelligence to machining, unlike the current conversational based machining that is highly prescriptive and where the manual machining knowledge is stored with the particular operator.

Increasing flexibility in response to market needs

The CAD/CAM system permits the case company to speed their responses to market needs and frees users to focus on creativity, innovation and production at minimum possible cost. It does this by facilitating true collaborative engineering across the multidisciplinary extended enterprise, including mechanical design, tooling, systems engineering, machining analysis, simulation and tool path verification, collision checking and analysis of the in-process part. The system allows for accurate tool path definition through a full set of milling operations from 2.5-axis up to 5-axis for machining operations, with high level of automation and standardisation, thereby enabling faster development and a reduction in time-to-market.

Returns on investment for CAD/CAM

The main advantage that the CAD/CAM system offers is the winning of sales order due to the ability to use continuous 3-axis for machining the radius shown in Figure 8. this is the first order won by the case company due to its new capability. The CAD/CAM system uses its 3-axis spiral cut milling operation and containment strategy to create the profile. The order's worth was about £50,000, hence representing an immediate pay-off and significant return on investment on the CAD/CAM software and associated training costs (with total cost of about £8,500).

In summary the CAD/CAM system offers the case company the following advantages:

- a competitive advantage over competitors who take longer to respond to market changes, customer needs and new technologies;
- premium prices before competitors offer customers a choice;
- a faster return on the development investment and a lower financial risk;
- a longer life cycle for the product;
- a higher return on the total investment.

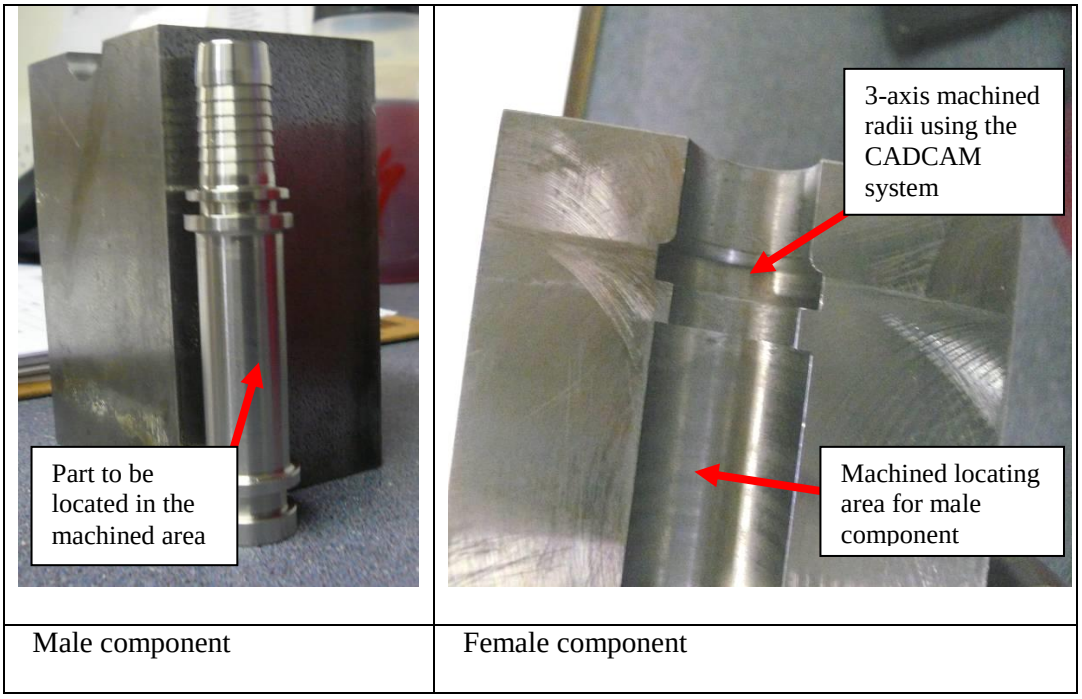


Figure 8: Machined component for first order

Other observations from the CAD/CAM implementation

It is known from the literature cited earlier that management and organisational structures are the key inhibitors of the implementation of successful computer integration (in addition to the lack of technology and finance) for SMMEs. The issue of creating a CAD/CAM environment is truly not dissimilar from that of putting good practice into manual processes. In the manual world, the teaming of expertise and sharing of knowledge produce the best product development process. In the CAD/CAM environment, it is the teaming or integrating of hardware and software solutions, the implementing of company- or user-specific tools, and the training of personnel which produce the best CAD/CAM results. Education of people and staff training is another key investment for achieving optimum CAD/CAM results. Computer integration must have the full support of every employee, from top management down to the work floor.

Right balance between manual system and CAD/CAM system: The goal for CAD/CAM integration as part of a wider manufacturing strategy at the case company

was not to completely eliminate manual operations as a sizeable amount of work was more attuned and cost effective to being machined manually. Hence for the SMMEs like the case company, CAD/CAM system should be used in supporting effective manual production line/operations. Through further training, the staff with high manual skills should be able to familiarise with, and even master, the CAD/CAM skills/knowledge. This is vital for further continuous improvement in terms of manufacturing quality and further CAD/CAM integration in the SMMES like the case company.

Right balance on the level of hardware investment: The output from this study recommended that computer integration in SMMES should be implemented on an incremental basis, due to ease of control, training and financial prudence. As shown in the previous section, the investment on the software and training costing was immediately paid-off within one year by the case company's first sales order.

Conceptual Framework for the CAD/CAM integration in SMMEs

As a summary of the knowledge gained through the literature review and the CAD/CAM integration at the case company, a conceptual framework, shown in Figure 9**,** is proposed as part of the CAD/CAM integration strategy. The framework gives SMME a detailed set of guidelines to follow in deploying CAD/CAM systems as a manufacturing strategy for delivering world-class performance. Key elements of the conceptual framework and the key strategic and operational questions embodied therein are:

- What is the strategic intent in the chosen technology?
- How economically feasible is the chosen strategy?
- How is the integration process for CAD/CAM systems deployment to be achieved?

Furthermore, the framework explores the application of a holistic set of lean deployment tools which include establishing a strategic need, a stakeholder's analysis, risk assessment, investment and scenario planning, financial justification through a return on investment calculator, force field analysis and labour linearity. Other deployment methods that are included in the framework are training, supplier integration, machine configuration and provision of greater understanding of the internal processes. It is believed that the framework and its sub-elements can provide all SMMEs with the detailed guidelines to develop their strategy and thereafter the operational plan for successful implementation of CAD/CAM systems.

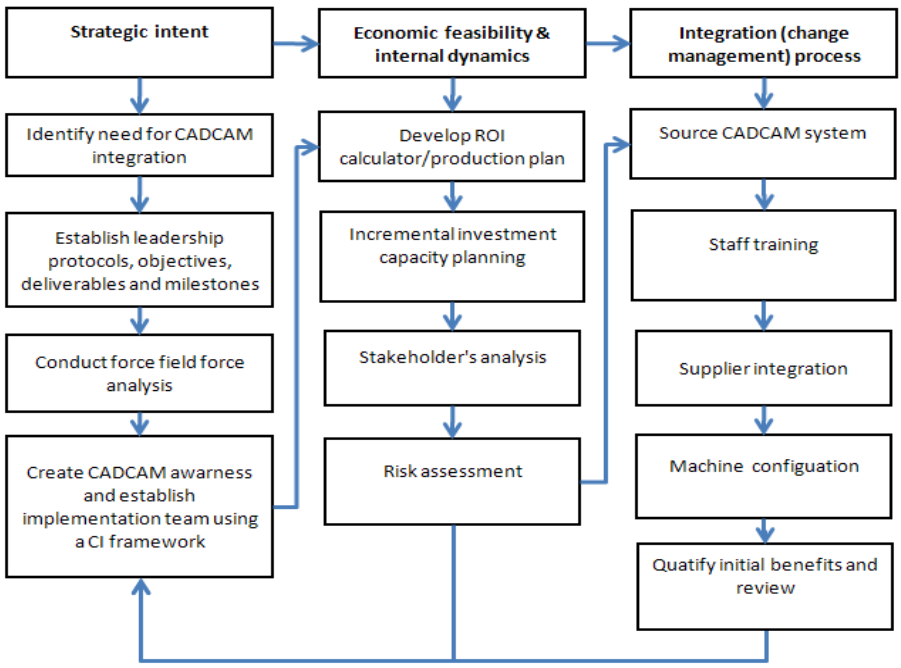


Figure 9: Conceptual model for CAD/CAM integration in SMMEs

Conclusions

To understand the scope of manufacturing strategy in CAD/CAM applications in Small Medium Manufacturing Environment (SMME) the work presented in this paper was conducted as a part of the KTP project at the case company. It was believed that CAD/CAM strategy was necessary due to the changes in cutting tool technology (configuration and complexity) and the limitations in the case company's vastly

manual based manufacturing capability (about 80% of machining was done manually). Several analyses with various approaches were conducted, which included key driver identification for CAD/CAM integration, a Force Field analysis, an expectation analysis on expected returns and risk assessment framework. It was found that the main benefit of the integrated CAD/CAM system was that, it promised a "competitive edge" through improving quality, enabling variety production, reducing costs and reducing lead times. The benefits of computer integration were quite credible and have been effective in enhancing the case company's competitive advantage. At the same time, CAD/CAM integration required (as well as pushed) a change of management framework and a change of the case company's culture as part of organisational evolution, which lead to the seamlessly transferring of the organisation's knowledge base and documentation, improving product quality, diversifying market base and achieving lowering of manufacturing costs. Furthermore, the techno-economic and technology change management conceptual framework for ideal CAD/CAM implementation, developed in the case company, will provide other SMMEs guidelines to follow in deploying CAD/CAM systems as a manufacturing strategy for delivering world class performance.

References

Barnes, D., "The manufacturing strategy formation process in small and medium-sized enterprise", *Journal of Small Business and Enterprise Development*, Vol. 9, No. 2, pp. 130-149, 2002

Binder M, Edwards J. S., "Using grounded theory method for theory building in operations management research", *International Journal of Operations & Production Management*, Vol. 30, No. 3, pp: 232-259, 2010

CADCAM Source, "1983 report on CADCAM user experiences", CAD Source Ltd, Macclesfield, UK, 1983

Crowe, T., Cheng, C., "Using quality function deployment in manufacturing strategic planning", *International Journal of Operations & Production Managemen*t, Vol. 16 No. 4, pp: 35-48, 1996

Dangayach, G.S., Deshmukh, S.G., "Advanced manufacturing technology implementation: evidence from Indian small and medium enterprises (SMEs)", *Journal of Manufacturing Technology Management*, Vol. 16 No.5, pp.483-96, 2005

Devadasan, S. R., Goshteesivaran, S., Gokulachandran, J., "Design for quality in agile manufacturing environment through modified orthogonal array-based experiments", *Journal of Manufacturing Technology Management*, Vol. 16, No. 6, pp576-597, 2005

Gouvea da Costa S.E., Pinheiro de Lima E., "Advanced manufacturing technology adoption: an integrated approach" *Journal of Manufacturing Technology Management*, Vol. 20, No.1, pp. 74-96, 2009

Jina, J., "Automated JIT based materials management for lot manufacture", *International Journal of Operations & Production Management*, Vol. 16, No. 3, pp. 62-75, 1996

Kiridena S., Hasan M., Kerr R., "Exploring deeper structures in manufacturing strategy formation processes: a qualitative inquiry", *International Journal of Operations & Production Management*, Vol: 29, N0: 4, pp: 386-417, 2009

Liu H., Barrar P., "Performance implications of strategy-technology connections: an empirical examination", Journal of Manufacturing Technology Management, Vol. 20, No. 1, pp. 52-73, 2009

Marri, H. B., Irani, Z., "Advance Manufacturing Technology implementation in SMEs: A framework of justification criteria", *International Journal of Electronic Business*, Vol. 5, No. 2, pp124-140, 2007

Meredith, J., "Building operations management theory through case and field research", *Journal of Operations Management*, Vol. 16, pp.441-54, 1998

NEDO, "Advanced Manufacturing Technology - The Impact of New Technology on Engineering Batch Production", *National Economic Development Office (NEDO)*, London, 1985.

Porter, M.E., "What is strategy?" *Harvard Business Review*, Vol. 74, No.6, pp.61-78, 1996

Salaheldin, S. I., Eid, R., "The implementation of world class manufacturing techniques in Egyption manufacturing firms – an empirical study", *Industrial Management and Data Systems*, Vol. 107, No. 4, pp. 551-566, 2007

Sonntag V, "The role of manufacturing strategy in adapting to technological change", *Integrated Manufacturing Systems*, Vol. 14, No. 4, pp. 312-323, 2003

Small M. H., "Planning, justifying and installing advanced manufacturing technology: a managerial framework" *Journal of Manufacturing Technology Management*, Vol. 18, No. 5, pp. 513-537, 2007

Tantoush, T., Clegg, S., and Wilson, F., "CADCAM integration and the practical politics of technology change", *Journal of Organisational Change Management*, Vol. 14, No. 1, pp. 9-27, 2001

Tracey, M., Vonderembse, M., Lim, J., "Manufacturing technology and strategy formulation: keys to enhancing competitiveness and improving performance", *Journal of Operations Management*, Vol. 17, pp.411-28, 1999

Vinodh, S., Sundararaj, G., Devadasan, S. R., Rajanayagam, D., "Agility through CAD/CAM integration – An examination in an Indian electronics switches manufacturing company", *Journal of Manufacturing Technology*, Vol. 20, No. 2, pp. 192-217, 2009

Yin, R.K., *Case Study Research: Design and Methods*, Sage, London, 1994.