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CAD/CAM Revolution for Small and Medium Foundries

Dr. B. Ravi

***Associate Professor* of Mechanical Engineering,**
In-Charge, Casting Simulation Laboratory,
Co-Founder, Rapid Prototyping & Tooling Cell,
Guest Faculty, School of Management.

Abstract

With CAD/CAM technology moving from myth to mainstream applications, most foundries are caught between change and survival. This is especially true in the case of small and medium foundries. This paper attempts to answer the question*: "Is CAD/CAM necessary and economically justifiable for small and medium foundries?*" by focussing on four aspects: key developments, benefits, bottlenecks and strategies.

Key developments in computer-aided product design, casting design, simulation, rapid tooling, intelligent advisory systems and Internet-based collaboration are reviewed, supported by relevant vendor information. Immediate tangible benefits (shorter lead-time, higher productivity and lower rejections), and long-term intangible benefits (better image, higher confidence and stronger partnerships) are illustrated with suitable examples. Various factors hindering small and medium foundries in fully adapting CAD/CAM technologies are examined. These include external factors (price, manpower availability and technical support) as well as internal factors (perceived need, culture clash and integration). Finally, an explore-adopt-adapt-integrate strategy is outlined to spread the risk/investments and allowing more time to assimilate and fully utilize the technology.

Keywords: CAD/CAM, Casting, Design for Manufacture, Die, Mold, Pattern, Rapid Prototyping, Rapid Tooling, Simulation, Technology Management.

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1. Introduction

On the timeline of the metal casting history, CAD/CAM (computer-aided design and manufacture) is a mere dot at the end. However, considering its potential to supplement human intelligence in continuous improvement of quality and productivity, it easily surpasses any other development in the last millennium. Consider the following example:

> A leading ductile iron jobbing foundry in Western India set its competitive edge by assuring the 'lowest total cost' to its customers – on-time supply of castings with high dimensional accuracy and internal soundness. To achieve this goal, the foundry acquired a *solid modeling (3D CAD)* system and *casting simulation* software in 1998 after detailed benchmarking exercises. Within the first six months of integrating both systems, their engineers modeled and analyzed 40 new castings. By increasing the number of trials on the computer (often ten or more in a single day), they reduced the actual number of production trials to one for most cases. For each casting, they confidently maximized the yield while ensuring internal quality. All these meant more castings being shipped (and accepted) without increasing capacity. The part model was reused for *computer-aided tooling design* – the pattern and core box are designed within 1-2 days for most parts. Numerically controlled machining and dimensional inspection of tooling (based on the solid model) ensured geometric fidelity. In one case, their casting was 20% lighter than that from another foundry, both produced from the same part drawing. After assimilating solid modeling and simulation technologies, the company explored new frontiers to further improve its competitive edge. For a particular urgent order, they sent the electronic data of a complex core to a *rapid prototyping* service bureau, and the bureau fabricated a plastic prototype within 4 days. The foundry engineers then replicated the master core into a high fidelity epoxy core box in another 2 days using *rapid tooling* technology. This approach reduced the total lead-time for tooling development from weeks to days. The foundry also strengthens its relationship with

customers by showing them how to *design for castability* – making minor changes to product design to reduce tooling or production costs (while improving the foundry's profitability – a win-win situation). The company is now confidently exporting over 25% of its castings.

None of the technologies mentioned above were commercially available in India 20 years back. Most of them originated in the USA and Europe, and were initially very expensive and difficult to use. Therefore the earliest users were captive foundries of automobile giants and large jobbing foundries. As the success stories spread, and the systems became more reliable, user-friendly and affordable, their penetration increased to other large and even medium size foundries. Today most foundrymen are quite well aware of CAD/CAM systems (particularly casting simulation) and their benefits. Yet, the total number of simulation programs in use is estimated to be about 1000, representing barely 3% penetration of the total 33,000 foundries worldwide. The penetration in small and medium foundries, which comprise the largest proportion in India, China and other developing countries, is close to zero.

Many foundrymen ask: **"***Is CAD/CAM necessary and economically justifiable for small and medium foundries?*" The question itself carries a perception of the dilemma encountered whenever new technology is involved. The most common 'strategy' is to wait and watch. It is akin to the proverbial frog kept in a vessel of water, which is heated gradually. If the frog does not jump out in time, it boils to death. The same frog, if thrown in a vessel of boiling water, does not face a dilemma of when to jump out. It does so immediately, no matter how much it has to struggle… and saves itself. New foundries, including the one mentioned in the previous example, reserve a portion of their capital budget for CAD/CAM technologies without any hesitation.

This paper attempts to answer the above question by breaking it down into four parts:

1. What are the most important developments in CAD/CAM of castings?
2. What are their tangible (immediate) and non-tangible (long-term) benefits?
3. What are the reasons for the low penetration of CAD/CAM technology so far?
4. What are the implementation strategies adopted by progressive companies?

Let us take these one by one.

2. Developments

Key developments in CAD/CAM technology, which are relevant to cast product designers, foundry engineers and pattern makers, are briefly reviewed here. Two new revolutionary advances are also uncovered: intelligent advisory systems and Internet-based engineering, which promise to assist and link all three groups for dramatic improvements in quality and productivity.

2.1 Product Design and Analysis

Engineers in nearly every automobile company today use a range of software tools for design and analysis. The first step is Computer-Aided Design or CAD, in which a solid geometric model of the component is created on a computer. A number of solid modeling systems are available today (Table 1) and these are much more easier to learn and use than those available ten years back. Because of intense competition among the vendors, and also because of a wider market base, the systems have become quite affordable. Indeed, leading engineering OEMs expect and often urge their casting suppliers to acquire a compatible solid modeling system. Here is an interesting example from a study of casting supplier-assembler relationships [1]:

Table 1. Solid Modeling (3D CAD) Systems

SYSTEM	VENDOR	WWW
AUTOCAD MD	AUTODESK INC., 111 MCLNNIS PARKWAY, SAN RAFAEL, CA 94903	autodesk.com
CADCEUS	NIHON UNISYS LTD, TOYOSU, KOTO-KU, TOKYO 135-8560 JAPAN	unisys.co.jp
CADKEY	BAYSTATE TECHNOLOGIES, MARLBOROUGH, MA 01752 USA	cadkey.com
CIMATRON	CIMATRON LTD., 11 GUSH ETZION STREET, GIVAT SHMUEL 54030, ISRAEL	cimatron.com
I-DEAS	SDRC, 2000 EASTMAN DRIVE, MILFORD OH 45150-2740 USA	sdrc.com
IronCAD	VISIONARY DESIGN SYSTEMS, SANTA CLARA, CA 95051-0963 USA	ironcad.com
Pro/ENGINEER	PARAMETRIC TECHNOLOGY CORP., WALTHAM, MA 02453 USA	ptc.com
SOLIDEDGE	EDS UNIGRAPHICS, MARYLAND HEIGHTS, MO 63043 USA	solid-edge.com
SOLIDWORKS	SOLIDWORKS CORP. 300 BAKER AVENUE, CONCORD, MA 01742 USA	solidworks.com

A leading automobile manufacturer in India used a CAD system to create part models in 3D, from which 2D drawings were produced, plotted and sent to the supplier (foundry). The foundry, unknown to the manufacturer, had purchased the same CAD system to create the part model again in 3D, starting from the drawings, for accurate weight calculation and tooling development. Once this situation was brought to the notice of the manufacturer, they started sending the 3D models as well as the drawings on floppies to the foundry. This not only eliminated the overhead of understanding and converting the drawing (from 2D to 3D), but also the chances of misinterpretation of drawings – quite common in the case of complex parts.

Important advancements in CAD systems include parametric and features-based modeling. Parametric modeling enables linking the part shape to its dimensions, so that the shape is automatically updated by specifying new dimensions. This is very useful for generating a new part in a family-of-parts. Features-based modeling allows a user to create a part in terms of holes, bosses, ribs, etc, which is a more intuitive approach compared to earlier solid modeling systems. Most CAD systems are now available on Windows-based computers (familiar interface for most engineers), and they make extensive use of point-click-drag functions to reduce the modeling time (Figure 1).

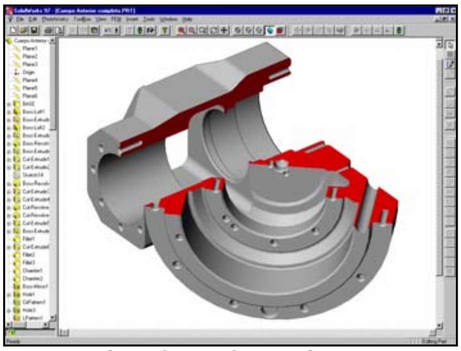

Fig. 1. User interface of a modern CAD system.

Transferring the geometric information from human mind to a computer is perhaps the most involved step, and can often take several days for an intricate shape such as a six-cylinder engine block. However, once the part model is created, it can be used for many different applications. Computer-Aided Engineering or CAE analysis (simulation of stress, strain, heat transfer, vibration, fatigue and fracture) based on Finite Element Method (FEM) is widely used to optimize the functionality and weight of the component. After the part design is finalized, it is sent to a Computer-Aided Manufacturing or CAM program to plan the CNC cutter paths and simulate the machining operation. The part model is also required for accurate and automatic calculation of geometric properties (volume, weight, center of gravity, etc.) and as input for casting design and simulation programs.

A recent trend is to make designers responsible not only for functionality and weight, but also for the manufacturability of the component. Design For Manufacture or DFM involves predicting and preventing potential manufacturability problems at the design stage itself [2]. Examples are thick sections (leading to isolated hot spots, which require chills or additional feeders) and sharp corners (difficulty in molding and turbulence during filling). It is well known that the benefit to cost ratio for modifications early in product life-cycle is several times more than those carried out at tooling or production stage. Yet, most designers are reluctant to take the additional burden of DFM-checking their components because it requires considerable knowledge and experience about the casting processes. One approach is to invite experienced foundry engineers to suggest improvements before freezing the design. This has been partially successful, and only when close personal relations have been established (mainly with captive foundries and long-term suppliers). Intelligent advisory systems and Internet-based engineering, described later, are set to shatter such barriers.

2.2 Casting Design and Simulation

Casting design involves converting the part design to the tooling design: orientation in the mold, parting line, application of draft and allowances, feeding and gating systems, core boxes and other elements. Simulation includes mold filling and casting solidification, useful for optimizing the design of gating and feeding systems respectively. Casting model is the main input for simulation.

Since casting design essentially involves a series of geometric transformations of the part model, the 3D CAD systems described earlier can be used for this purpose. Some of these provide special functions (such as automatic application of draft, after the user selects the faces and specifies the draw direction) and customizing facilities (for example, creating a library of parametric shapes of feeders) to partially automate the tasks. However, general-purpose CAD systems can not take casting design decisions (location and dimensions of feeding and gating systems), since these require an in-depth knowledge of the process. A few programs for deciding the dimensions of feeding and gating systems are available, but these are stand-alone and can not be connected to the 3D casting design systems.

Casting simulation has received good attention of researchers, and several systems are available today [3]. High-end simulation systems handle coupled equations for flow, solidification and eventual cooling to room temperature, and take into account a wide range of boundary conditions and material properties. The results include filling sequence in mold cavity, progress of solidification, position of shrinkage porosity, grain structure, residual stresses and distortion. The results are accurate if the input data (geometry mesh, material properties and boundary conditions) are correct. However, these systems are still quite expensive (US$40,000-120,000), slow (10-40 hours per layout) and difficult to learn (2-4 weeks' initial training, followed by several weeks of on-site customizing). On the other hand, low-end simulation systems are limited to solidification phenomenon for common metals in sand molds. While they are affordable and easier to use, they are mainly useful for verifying the feeder design, important for steel, aluminum and other alloys with positive volumetric shrinkage. A list of casting simulation programs, along with their key features and vendor addresses is provided in Table 2.

Table 2. Casting Design and Analysis Systems

SYSTEM	VENDOR	WWW
AFSOLID	AFS, INC., 505 STATE STREET DES PLAINES, ILLINOIS 60016 USA	afsinc.org
AUTOCAST	ADVANCED REASONING TECHNOLOGIES PVT. LTD., MUMBAI 400 703, INDIA	adva-reason.com
CASTCAE	CT-CASTECH, INC., OY P.B. 524, TEKNIIKANTIE 21 B, FIN-02151 ESPOO, FINLAND	castech.fi
EKK	EKK, INC., 2065 WEST MAPLE, SUITE C309, WALLED LAKE, MI 48390 USA	ic.net/~ekk
FLOW-3D	FLOW SCIENCE, INC., 1257 40TH STREET, LOS ALAMOS, NEW MEXICO 87544 USA	flow3d.com
MAGMASOFT	MAGMA GmbH, KACKERSTRASSE 11, 52072 AACHEN, GERMANY	magmasoft.com
NOVASOLID	NovaCast AB SOFTCENTER, S-RONNEBY, 37225 SWEDEN	novacast.se
PROCAST	UES SOFTWARE, INC., 4401 DATONE-XENIA ROAD, DAYTON, OHIO, 45432 USA	ues-software.com
SIMTEC	RWP GmbH, ALT-HAARENER-STRASSE 251 D-52080 AACHEN, GERMANY	simtec-inc.com
SIMULOR	ALUMINIUM PECHINEY, BP 7-38240 VOREPPE, FRANCE	

Ideally, casting engineers require an integrated, knowledge-based system for combining all the three tasks: casting design decisions, casting model creation and process simulation. This will reduce the overhead of importing and exporting data between the systems for each layout iteration, saving not only valuable time, but also the possibility of errors during data transfer. By using this approach, the AutoCAST system (Figure 2) enables even novice engineers to reach a good first casting design in less than one hour!

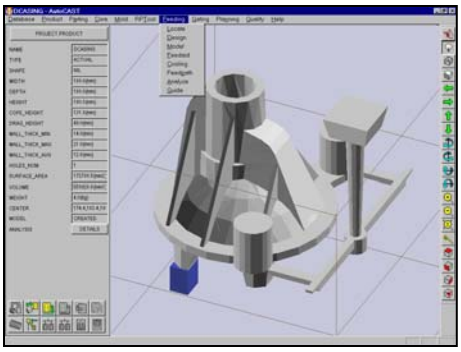

Fig. 2. Integrated casting design and analysis system.

2.3 Rapid Tooling Production

Rapid prototyping and rapid tooling technologies make it possible to produce the tooling for an engine block in six weeks instead of six months. A 3D CAD model is necessary. Rapid prototyping systems automatically decompose the CAD model into a series of layers, and build each layer on top of the previous one to get the physical model – no part-specific tooling is required (Figure 3). The fabrication time mainly depends on the part volume (typically 1-20 cm^3/minute). Most RP systems produce plastic parts, which can be used as patterns for short runs, or used for producing metal patterns through investment casting.

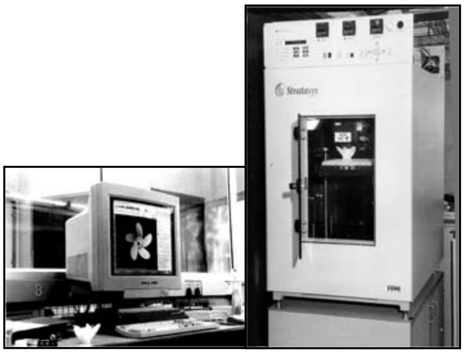

Fig. 3. Rapid Prototyping – from CAD model to part in hours

Rapid tooling technologies involve converting a master model (obtained from rapid prototyping process) into a negative replica, by pouring thermosetting plastic (epoxy or polyurethane) or spraying low melting point metal around the master. The negative replica can then be used to produce a number of positive replicas (in plastic or wax) of the original master. These can be used to create a multi-impression pattern plate or expendable patterns for investment casting. A core box can be produced by fabricating a master core using rapid prototyping and creating its negative replica.

Rapid prototyping and tooling technology has grown at an exponential rate since its evolution ten years ago, and a number of systems are available today (Table3).

Table 3. Rapid Prototyping and Tooling Systems

SYSTEM	VENDOR	WWW
ELECTRO OPTICAL SINTERING	EOS GmbH, ZIESS GROUP, PLANEGG/MUNCHEN, GERMANY	
FUSED DEPOSITION MODELING	STRATASYS INC., EDEN PRARIE, MINNEAPOLIS 55344 USA	stratasys.com
LAMINATED OBJECT	HELISYS INC., OREGON COURT, TORRANCE CA 9503 USA	helisys.com
MODELMAKER	SANDERS PROTOTYPE, INC., WILTON, NEW HAMPSHIRE 03086 USA	sanders-prototype.com
SOLID GROUND CURING	CUBITAL LTD., HA'SADNA ST., IND. ZONE (N), RA'ANANA 43650 ISRAEL	cubital.com
STEREOLITHOGRAPHY	3D SYSTEMS, 26081 AVENUE HALL, VALENCIA, CA 91355 USA	3dsystems.com
SELECTIVE LASER SINTERING	DTM CORPORATION, 1611 HEADWAY CIRCLE, AUSTIN, TX 78754 USA	dtm-corp.com
MCP METAL SPRAY TOOLING	HEK, KANINCHENBORN 28, D-2400 LUBECK 1, POSTFACH 1810	mcp-group.com
SILICON RUBBER TOOLING	GE SILICONE INDIA LTD., HIGH CRESCENT RD, BANGALORE 560 001	
EPOXY/PU TOOLING	CIBA SPECIALTY CHEMICALS (INDIA) LTD., MUMBAI 400 063	ciba-araldite.com

Several organizations in India (including IIT Bombay, IIT Kanpur, IISc Bangalore, PSG Tech Coimbatore and CMERI Durgapur) have initiated R&D projects to demonstrate rapid prototyping and tooling technology to the industry. Here is an example [4]:

> In a benchmarking study, PSG Tech compared the time taken for producing a valve body pattern by conventional and rapid prototyping techniques. The part was modeled using Pro/Engineer system and converted into the pattern model (after splitting across the parting line and applying drafts, etc.). The pattern model was sliced into layers using Quick Slice software and transferred to Stratasys FDM rapid prototyping system. The pattern was produced in ABS P400 material, and coated with Shellac NC-Putty to obtain a smoother surface. The overall tolerance was +0.125 mm. The pattern produces 50-100 castings before its surface starts deteriorating. The rapid prototyping route took 73% less time than conventional machining process. In a similar project with an Indian automobile company, a casting pattern was designed and fabricated in just 30 days.

The number of different rapid prototyping and tooling processes available today provide many routes for rapid production of tooling [5]. Each route is most suitable for a particular range of tooling materials, part size and shape, production lot size and quality requirements. In general, current systems handle a limited range of materials and the life of such tooling models is limited to small production lots (10-1000). Their quality (dimensional tolerance and surface finish) is slightly lower than NC machining. The high initial cost of the rapid prototyping equipment (US$100,000-500,000) makes them unsuitable for purchase by individual companies, and therefore service bureaus are coming up all over the world (including India). Since the cost of fabrication depends mainly on the model volume, rapid prototyping and tooling technology is most suitable for producing the tooling for small intricate parts required urgently. As the technology matures further (better quality and lower cost), it will find increasing favor over conventional processes.

2.4 Intelligent Advisory Systems

A new breed of 'intelligent' CAD/CAM programs based on geometric reasoning and knowledge engineering have started emerging in the last 3 years. Geometric reasoning mainly involves 'understanding' the part model and recognizing relevant features. Knowledge engineering involves storing and linking domain knowledge with a computer program for providing better decision-support to users.

> The FeatureWorks program (marketed by SolidWorks Corp., USA) can automatically recognize machined features such as holes, pockets and slots from a 3D CAD model. The user inputs the solid

model obtained from a conventional (non-features-based) CAD system. The program recognizes and organizes the part features in a tree structure with relevant dimensional data. Using other features-based programs, the user can easily modify the part model (by entering new dimensions), develop the pattern model (by deleting holes) and drive DFM-check routines (based on the limiting values of hole diameter or rib thickness). The program was developed by Geometric Software Services Ltd. Bombay, based on the pioneering work in feature recognition at IISc Bangalore.

Since the type of features and domain knowledge is specific to the manufacturing process, intelligent CAD/CAM programs have to be developed for specific domains to be really useful. An intelligent CAD system for metal casting application (such as AutoCAST) recognizes thick sections, suggests a connection point for feeders, computes section modulus, suggests feeder dimensions and analyzes the results of simulation to provide a 'health-check-index' for the entire casting design [6]. These decisions are supported by relevant knowledge about the casting process (for example, feeder placement: top or side, is influenced by the freezing range of the metal and its dimensions depend on volumetric shrinkage). However, even such intelligent systems can at best be used for double-checking human decisions or trying more alternatives in the same time. Casting is a knowledge and experience-intensive domain, and it is unlikely that a computer program will replace a human engineer in the foreseeable future.

2.5 Internet-Based Engineering

Internet has collapsed distances – a boon for developing countries like India, where engineers spend a significant part of their time in processing, sending or waiting for information through physical channels. Using Internet, a drawing, quotation, order or confirmation (even payments, in near future) can be sent through electronic networks, instantly (Figure 4). Internet is also a convenient source of virtually unlimited information about technologies, products and companies. Here is an example of how Internet can be used to leverage CAD/CAM technologies for dramatic gains in productivity.

A cast iron foundry located in Southern Maharashtra, specializing in automobile parts, received an urgent inquiry for an export order. This required sending a prototype casting immediately. To ensure quality and minimize trials, the foundry contacted a consulting firm located in Western Maharashtra, specializing in computer-aided casting design and analysis. Subsequently, the foundry sent the drawing by courier to a CAD engineer located in another city close by, who created a solid model using AutoCAD Mechanical Desktop and uploaded the file to the consulting company's Internet site on the second day. The consulting company downloaded the solid model, completed the service (casting design, simulation, optimization and defect prediction) and uploaded the results on the third day. The results were verified on-line by a senior consultant of the company located in the USA by next morning. Finally, an email was sent to the foundry customer to download the report (through a special password) for viewing and printing. The complete process, from the time of sending the drawing to receiving the results, took 4 days, which would otherwise have taken at least 3 weeks. The consulting charges were negligible compared to the cost of pattern modification, molding, melting, finishing and inspection, which would have been otherwise required for the same number of conventional trials.

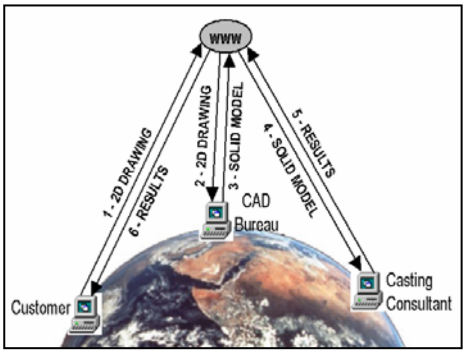

Fig. 4. Internet-based engineering of cast products.

3. Benefits

Proper implementation of CAD/CAM technology in a foundry gives both immediate and long-term benefits. Immediate benefits include shorter lead-time, higher productivity and lower rejections. Long term benefits include better image, higher confidence and stronger partnerships.

3.1 Immediate (Tangible)

The CAD/CAM technologies coupled with Internet have demonstrated that it is possible to develop the tooling and deliver a small lot of medium complexity casting within two weeks. Moreover, engineers can create, store, manage and exchange information in electronic format (which otherwise take up as much as 50% of their time) and focus on more value-added tasks (like optimizing the casting design to improve the yield). Lead-time reduction is important, since it is often said that in future, there will be only two types of companies: fast ones and dead ones.

Computer-aided casting design and tooling production enable achieving high internal quality and dimensional control, lowering the occurrence of defects. This is critical for new orders (especially large castings) and expensive (or difficult to machine) metals where the cost of rejection is high. Also, with increasing use of Just-In-Time (low inventory) philosophy, quality assurance has become a key issue with customers. Defective castings discovered at the machining stage upset their carefully synchronized production and assembly schedules.

> A recent survey of 11 casting simulation software used in 154 foundries in the USA, carried out at the University of Iowa, provided a profile of their use and benefits [7]. About 25% of casting simulation users designed and verified up to 25% of their castings using the software. Casting/tooling design time reduced by over 40%, cost of labor and rework reduced by 30% and the average improvement in casting yield was 25%.

The exact benefits to a particular foundry will depend on the type of foundry, metal, process, capacity, equipment and the current level of automation. Thus programs which perform only solidification simulation may be of more use to steel and aluminum foundries (for optimizing the yield) than cast iron foundries. For the latter, gating design and filling analysis may be more important. Similarly, rapid prototyping and tooling technology may be more valuable to jobbing foundries handling small intricate castings aimed at export market than captive foundries with long production runs of a few standard parts for domestic market.

3.2 Long Term (Intangible)

Long-term or intangible benefits can not be measured easily, but they may far outweigh immediate benefits, by giving a new competitive edge to a foundry – important for continuous growth and increased profitability. The CAD/CAM facilities enhance the image of a foundry, which helps in getting new customers (especially overseas buyers), who prefer such suppliers. Computer-aided design, manufacture and information management enable better control and faster decisions, leading to an increased confidence level in the foundry. The technology also enables foundries to initiate meaningful dialogues with their customers for arriving at a fair pricing or for reducing the costs (by lowering casting weight, tooling development time and production costs; without affecting the profit margins). All these bring more business, enable successful execution of challenging orders and add value to the castings (assured quality and delivery to the customer) – improving the bottom line of the foundry.

> A steel foundry in Iowa, with 320 employees and US$ 33 million turnover per year, purchased a solidification simulation software in 1992. Over the next 4 years, the direct benefits of using the system amounted to US$ 700,000, in terms of reduction of scrap and rework (nearly half the savings), reduction in manufacturing cost and profit on increase in sales revenue. The cost savings 'greatly exceeded' the initial investment in hardware and software. The system is now viewed as a 'technical asset', helping the company move into markets with more complex and technically demanding work [8].

The long term impact of CAD/CAM depends to a large extent on the keenness of the company to exploit the technology to the maximum advantage. Two similar foundries acquiring the same technology at the same time may be able to leverage it differently. This will depend on the knowledge level of new engineers operating the system, continuous support from senior engineers, and how well the new system is integrated with the existing best practices of the foundry.

4. Bottlenecks

Despite proven benefits, and commercial systems being available for more than a decade, the penetration of CAD/CAM technology has been slow in metal casting sector, particularly small and medium foundries in developing countries like India. The main reasons (real and perceived) are outlined below.

4.1 Implementation Cost

The cost of implementation includes initial benchmarking, hardware, software, peripherals, fees for training, technical support and annual maintenance, and salaries of new engineers, if hired for this purpose. A typical low-end set up, including a Pentium computer, color printer, and software for solid modeling, solidification analysis and computer-aided manufacture (for tooling production on NC machines) costs US$40,000-50,000. Annual maintenance costs range between 10-20% of the initial cost. Pay back period is usually 1-2 years, depending on the extent of current problems and the level of production. Most small foundries find it difficult to commit such an investment.

4.2 Qualified Engineers

The difficulty in attracting and retaining young qualified engineers for operating the CAD/CAM systems is a bottleneck. The risk is more in the case of high-end systems, which require considerable training and customization (more than one month). If engineers trained on such systems (at the company's cost) migrate to another company, then the parent company is burdened with the additional cost of finding and training another engineer. The problem is less acute in low-end systems, which require less training (usually one week) and can be learnt even by engineers who are not very familiar with computers.

4.3 Technical Support

This is an important factor and is often ignored during benchmarking exercises for evaluating competing systems. Since CAD/CAM systems are continuously evolving, they must be treated more as service than a one-time acquisition of a fixed asset. Also, most foundries, which are new to computer applications, require a long hand-holding period to assimilate and adapt the technology. This requires a good support mechanism with facilities to contact the vendors at short notice. Physical distance matters, since support engineers may need to visit the foundry to determine the exact nature of a problem and to demonstrate how to overcome it. It is for this reason that most vendors have the biggest market share in their own home countries.

In general, it is advisable to select systems, which require shorter training period (which means more user-friendly), have a good local support network (support engineers must have foundry background) and provide detailed continuously updated information over Internet (virtually free access 24 hours a day, 365 days an year!). All these translate to a lower cost of getting the system up and running if anything goes wrong.

4.4 Internal Factors

In general, most foundries (small as well as large) do not feel an immediate need for implementing CAD/CAM technology. They would rather invest in a new furnace or molding line, which are perceived as revenue earners, rather than CAD/CAM systems, which are at best perceived as revenue savers (at worst as a luxury item to invest in with surplus cash). It is only when the survival is threatened or a competitor gets noticeably far ahead that implementation decisions are taken – possibly in haste, leading to a poor choice of systems and ineffective adaptation.

Another important reason is the lack of support from senior engineers, who feel their jobs will be eclipsed by CAD/CAM systems, and resent the importance given to junior engineers running the systems. They need to realize that CAD/CAM systems are just like any other tools (calculators and faxes) meant for providing decision-support and increasing their productivity. Learning the operation of CAD/CAM systems is a skill, which can be acquired over a short time, but using them effectively requires considerable knowledge and experience in metal casting, which they would have already acquired.

Finally, the ease of integration of a new CAD/CAM system with existing systems and practices is an important factor for gaining a long-term competitive edge over other companies acquiring a similar system. This depends on a systematic organization of the current knowledge base of the foundry and the openness of the new system to incorporate such knowledge. For example, users must be able to change the factors in pouring time and feeder design equations, or link the input and output data of the system with their own programs developed in-house.

5. Strategy

A few enterprising foundries in India have plunged into CAD/CAM technology over the last five years, often with little knowledge of possible bottlenecks. Many of them faced teething problems, including internal resistance, mismatched expectations and loss of newly trained engineers to other jobs. Most problems are often managerial and cultural in nature. Once these are sorted out, foundry engineers have not only enthusiastically adopted the new technology, but also have found ingenious ways to adapt and use it.

The majority of small and medium foundries however, still feel there is considerable risk in terms of investment, internal acceptance and actual returns. To ensure that CAD/CAM technology is successfully implemented, while minimizing cash-outflow and risk, the following four-step approach is proposed (Figure 5).

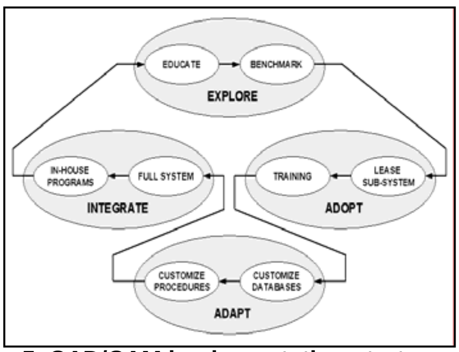

Fig. 5. CAD/CAM implementation strategy.

5.1 Explore

The first step should be to explore the technology and build up an internal consensus. Exploration may begin with collecting relevant information about the technology and vendors. While there are no books on CAD/CAM of casting, several technical papers written on the subject are a good source of information. In a unique experiment, an on-line course on “CAD/CAM of Casting” has been created by the author, and made freely accessible over the Internet. The course includes a rich set of links to other useful sites, including associations, universities, companies and magazines.

After obtaining information about the technologies, the foundry may shortlist the systems matching their requirements. Most vendors offer consulting services, useful for evaluating the systems before purchase. A problematic casting currently in production is the best way to determine if the results match the expectations of the foundry. If possible, the vendor may be requested to install the system in the foundry (assuming adequate hardware is already available) and carry out the consulting service in cooperation with foundry engineers who will be eventually using the system. This approach will ensure that foundry engineers are taken into confidence from the beginning and also highlight the quality of support and service offered by the vendor.

5.2 Adopt

The second step involves actually acquiring and implementing the system in the foundry. To minimize initial costs, the system may be leased for a short period. Most vendors offer an annual lease, which is beneficial to jobbing foundries. If the number of castings to be designed using the systems is low (say, less than 100 per year, assuming that 2 projects will be completed per week), then a project-based lease option will be more economical and may be requested, if available with the vendor.

Instead of acquiring all components of the system at once, it may be more prudent to purchase only basic components first and add others later. Critical components include solid modeling and casting design. Even solid modeling is not necessary if foundries can arrange their customers to send the 3D CAD models along with the inquiry, or if a local solid modeling service bureau is available. Process simulation and computer-aided manufacture software can be added later.

Training is an important part of acquiring a new system. Ideally, more than one person must be trained on the system and senior engineers must participate in the training program to acquaint themselves with all the features available. Training must include a hands-on session, in which the foundry engineers complete a project all by themselves. The cost of retraining (if a key engineer leaves the company) and annual refresher courses must be discussed with the vendor at the time of purchase itself.

5.3 Adapt

Adaptation of the system mainly involves customizing or ‘tuning’ it to the foundry’s best practices. The vendor may do the initial customizing at the time of installation and training itself. This is however, a continuous process, and is best done by foundry engineers in parallel with regular use of the system. A customized system differentiates one foundry from another having a similar system, and defines their competitive edge. Therefore, foundry engineers must learn about various facilities for customization (including data and file structures, and special commands, if any) during the training session, or request an advanced training session for this purpose.

Customization depends on the type of system. A solid modeling system can be adapted to a foundry by creating a parametric library of common features, shapes or even complete castings. This is useful for foundries specializing in a family of parts such as pistons, gear wheels and cylinder liners. Similarly, a casting design system can be standardized in terms of pattern allowances, feeder shapes, gating ratios, pouring rates, etc. used in the foundry. Process simulation systems (which are based on FEM) need to be carefully customized in terms of thermo-physical properties of the cast metal, mold material, core material and feed-aids used in the foundry.

5.4 Integrate

Implementing and using the basic components of a CAD/CAM system provides valuable experience and confidence in technology. After this, other components can be acquired and integrated to get the entire system in operation. At this point, the foundry may decide to switch from an annual lease to a permanent license of the system.

Integration also refers to connecting in-house programs to the CAD/CAM system. Indeed, a good way to retain young engineers (those with programming skills) is to involve them in coding the knowledge base and best practices of the foundry in databases or computer programs. Examples include lead-time and cost estimation, furnace charge calculation, route card generation and defects analysis. In this regard, CAD/CAM systems with an open database structure should be preferred, since they facilitate connecting the in-house databases or programs with them.

A final word on the explore-adopt-adapt-integrate strategy outlined above. Many small and tiny foundries may still hesitate even to explore the technologies mentioned above. Such foundries may consider the option of a consortium or cooperative CAD/CAM facility. The facility may be funded by a group of foundries and set up in a common location, and run by 'neutral' engineers hired for the purpose. A time-sharing arrangement can be worked out and sufficient security measures can be adopted to ensure confidentiality among members. Such cooperatives are already being initiated in a few pockets of India.

6. Conclusions

The CAD/CAM technology has proven benefits, and no foundry can afford to ignore it any longer – growth and profitability are at stake. The technology has become reliable, user-friendly and affordable enough. Many medium-size foundries have already acquired the systems to dramatically improve their competitive edge. Small foundries can take advantage of the lease options and add the modules of a system gradually to minimize risk. Tiny foundries can explore the feasibility of setting up cooperative CAD/CAM facilities. An early acquisition and assimilation will enable the foundries to take maximum advantage of an upsurge in the economy.

That would be just the beginning. Foundries need to continuously adapt the CAD/CAM systems to their existing knowledge-base and best practices. It will enable them to achieve world-class competence in their niche areas of operation. This calls for a high level of confidence building and cooperation among not only senior engineers and junior CAD/CAM engineers in a foundry, but also between the foundry, pattern-makers and customers. At the dawn of the new millenium, the marriage between one of the oldest and youngest industries (metal casting and information technology) is all set to revolutionize the way castings are conceived and produced.

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