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Capabilities and Integration Potential of Current Casting Design Software

(A Preliminary Report)

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Introduction

The production of castings can be a lengthy, cost intensive, iterative procedure. Heavy design dependence is placed on a few, experienced mold and pattern makers, and iterative techniques are often the rule rather than the exception. The best results (e.g., lowest cost, highest yield, best quality, and shortest production cycle) are achieved when the designer has access to information about the casting process in order to tailor design decisions to the most appropriate casting process and process variables. Computer software tools can provide designers with needed information and the capability to evaluate design alternatives before investing in prototype hardware.

Current Practice

Many foundries have begun to implement CAD/CAE/CAM technology to facilitate the exchange of information and engineering data among design and manufacturing engineers. The technologies being applied include: computer-aided drafting of the mold cavity design, electronic transfer of part geometry and engineering information, simulation of the casting process (including solidification) to optimize design parameters, and microprocessor-based monitor and control of critical process variables during production. Though computers are often used to carry out some of these important tasks, they are not coordinated or integrated to take advantage of the full potential of CAD/CAE/CAM procedures, and thus, the total productivity and quality improvements possible are not realized.

The design of a casting must consider many casting variables in addition to part geometry and part material. Engineering design decisions are made in determining: the placement of the pattern's parting line; the assignment of allowances; the location and support of cores (when needed); the design of the gating system and risers; process-specific mold-flow and solidification factors; and other part and process design tradeoffs. How computer technology is currently used, and how it may be used in the future to aid in these decisions is the focus of this project

Project Description

The objective of this project is to determine the capability and availability of casting design software that can create an integrated simulation environment to drastically reduce delivery time and production cost for high quality castings. Consideration is given to the technical features of the software as well as its potential for integration with other state-of-the-market part design software.

The project includes a review of the capabilities of off-the-shelf software packages to support the primary casting design functions and their potential for integration. The casting design functions considered include: pattern design (location of parting line, assignment of allowances, shape constraints and application of draft), design of rigging system, assignment of tolerances, and modeling of the casting process itself (fluid flow, heat transfer, solidification, defects, and microstructure development). Both expendable mold and permanent mold processes are being investigated. The cast materials that are being considered include steel, cast iron, aluminum, and copper/zinc alloys.

The project consists of the following three tasks: (a) a survey of suppliers and users; (b) a functional design of an integrated casting design system; and (c) an assessment of currently available casting software. The purpose of this paper is to report the preliminary findings of the first and third tasks of this project, and to provide the reader with a review of the capabilities and the compatibility of current software for effecting benefits to the foundry industry. The paper discusses the survey procedure and current software capabilities, profiles current industrial uses and users of casting design software, and discusses the integration potential of current software offerings. Recommendations for further efforts are given at the end of the paper.

Survey Procedure

The purposes of the survey activities are: (a) to identify and obtain baseline information on casting software capabilities as described by the software vendors; (b) to identify and obtain information on casting software capabilities and limitations as described by the software users; and (c) to identify and estimate the realized and expected industrial benefits from casting software. Information from the first two activities are expected to help identify barriers to and gaps in integrating currently available casting software into a seamless design environment. Information from the third activity addresses the salience of possible future research and development efforts and the rationale for foundries to use casting software.

Two survey populations were identified: casting software vendors, and casting software users. Survey forms were drafted for both populations; the Product Information Form for the vendors, and a two-part packet for the users (Company Information Form and Software Information Form). Copies of these forms, and the Project Information Sheet, appear in Appendix 1.

Vendor Survey

The vendor survey packets were mailed to North American metal casting software companies and/or those thought to have a significant number of users in the industry. The firms were identified by a review of the industry's trade journals over the past five years, lists of solidification conference attendees, and recommendations from recognized experts. A listing of these vendors appears in Appendix 2. Survey packets included a cover letter, Project Information Sheet, and Product Information Form(s).

User Survey

The user survey packets were sent to industrial North American metal casting software users. The users were identified by the software vendors, some for direct contact by the University, the remainder were contacted through the vendors. All users returns are reported in summary form only, to protect respondent confidentiality.

The packets sent to the users consisted of a cover letter, Project Information Sheet, one copy of the Company Information Form, and three copies of the Software Information Form (and pre-posted return envelope). These forms were developed by project personnel, then forwarded to interested technical societies and industrial foundries for review, comment, and revision. The finalized packets were mailed as vendor mailing arrangements were completed. Follow-up telephone contacts were initiated approximately five weeks after the first mailings. Survey packet recipients were requested to fill out a Company form for their location, and one Software form for each package identified on the Company form,

Survey Response

The sample size and response rates for each survey are given in Table I, below.

Table I. Survey Response Rates

Survey Type	Number Sent	Response Rate
Vendors	11	100%
Users	148	47%

Current Casting Software Profile

As part of the vendor survey, the Product Information Form, was sent to the software vendors. This form provided a baseline for identifying the design functions, materials, and processes supported, and the databases and data transfer capabilities provided for in each of the packages. Eventually, Product forms for 21 casting software modules or packages from 11 vendors were obtained (see Appendix 2). That information, along with follow-up conversations, provides the basis for this section.

Software Package Overview

Casting design software provides an aid or an analytical result to a human designer, enabling him/her to perform the tasks necessary in the production of castings. CAD and geometric modeling programs (such as Pro/ENGINEER, AutoCAD, PATRAN, etc.), and mechanical analysis packages (such as ANSYS, ABAQUS, etc.) may play an important role in the definition, design, and analysis of cast products, but they are typically not what we mean strictly by casting software. Casting software is intended to cover two kinds of programs. The first kind of software performs solidification analysis, mold/die filling simulation, and defect prediction (macro & micro porosity, distortion, shrinkage, residual stress). The second kind of packages are intended to aid in determining gate, sprue, runner, and riser dimensions/location(s); and casting weight, volume, and charging materials calculation/optimization. For convenience, this paper will refer to the former as solidification packages, and the latter as other casting software. Fourteen of the twenty-one packages investigated in this section would be classified as solidification software, the rest as other casting. All of the other casting packages currently available run solely on personal computers.

Many important differences characterize the various casting design software offerings. Among just the solidification packages, such things as model build and simulation time; whether the package uses modulus, heat equation, and/or Navier-Stokes melt flow approaches; meshing issues (FEM, FDM), and the types of defect prediction criteria all may form the basis for comparison. Indeed, authors such as Estrin (1994), Midson (1994), Andresen (1994) and Uicker & Sather (1992) have described and compared the methodological differences among the various solidification packages. The purpose of this paper is not to recap these comparisons; instead it addresses the ways casting software is used, the benefits realized by its use, and the potential for integration of these packages.

Most of the solidification packages come with some form of a geometric modeler, and many provide one or more of the aids ascribed to the other casting software. Overlap of function is, to some degree, typical of the software studied. However, when the intended purpose of the software is to model solidification, one cannot expect the geometric modeler to perform with all the convenience of a major CAD package. In practice, CAD packages generally provide the geometry and topology; aided by the dimensions suggested by the other casting software; and then this information provides input to the solidification software for design analysis. The results output by the solidification packages are then interpreted by a human designer, who may modify the design and iterate as necessary.

The geometric and topologic information may be transferred to the solidification packages by two main methods: (a) using an industry-standard data transfer protocol, such as IGES; or (b) by means of a direct interface - a program intended to interpret the geometric information in the native data format of the CAD package. Other information, such as material and process parameters, can sometimes be transferred from one package to another by database import/export. Most of the other casting software neither transfer data to, nor accepts data from, other programs. These packages may be characterized as stand-alone, special purpose software.

Design Environments

The available operating platforms for the packages form two design environments: PC and workstation (WS). The PC environment requires an MS-DOS/Windows operating system, 200 or more megabytes of disk storage, eight or more megabytes of RAM, a math co-processor and a VGA color display. The WS environment runs on a UNIX or similar operating system, needs over one gigabyte of disk storage, 64 megabytes of RAM, and color display capabilities. Five of the eleven vendors offer versions of the software that can run on either platform, thus there are eight vendors offering products for both the PC and WS environments. Analysis of the returned user surveys, however, revealed that no respondent uses a particular vendor's package in both computing environments.

Materials and Processes

The majority of the 21 casting design software packages and modules offered by the vendors support aluminum, cast iron, steel, copper alloys, magnesium and zinc. No major cast metal was supported by less than 17 of the packages. Focusing on just the solidification packages, the major casting processes are well supported: sand casting, die casting, investment casting, permanent mold, and evaporative pattern casting. Some exception may be taken for evaporative pattern processes, which only six vendors attempt to support.

Integration Potential

Integration requires the ability to link the output of one software package to the input of another. Among the solidification software, there is some support for this linkage. Figures 1a and 1b depict the data import and export formats supported in the two design environments. Few solidification packages currently make provision for data export; and as will be seen, data transfer, as currently practiced in industry, tends to be unidirectional - solely from CAD program to solidification application. Other casting software packages, as stated before, tend to be stand-alone programs; and thus have little integration potential.

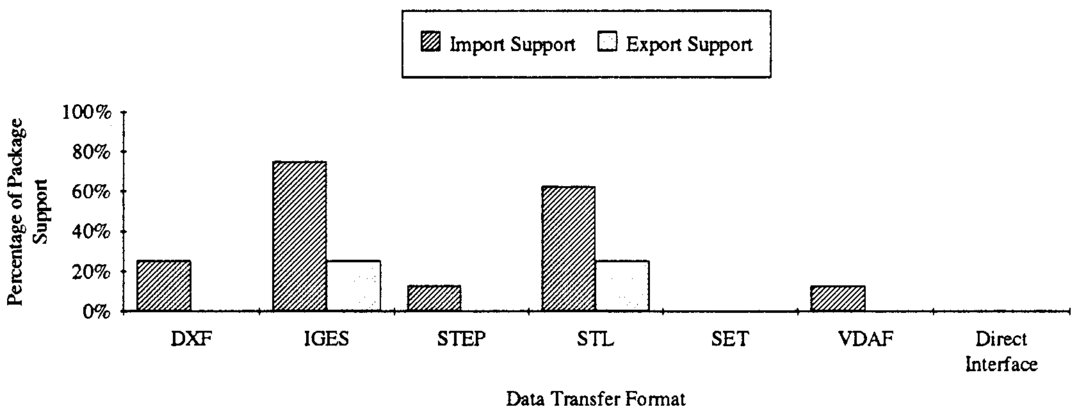

Figure 1a. PC Environment: Solidification Package Support for Data Transfer Formats

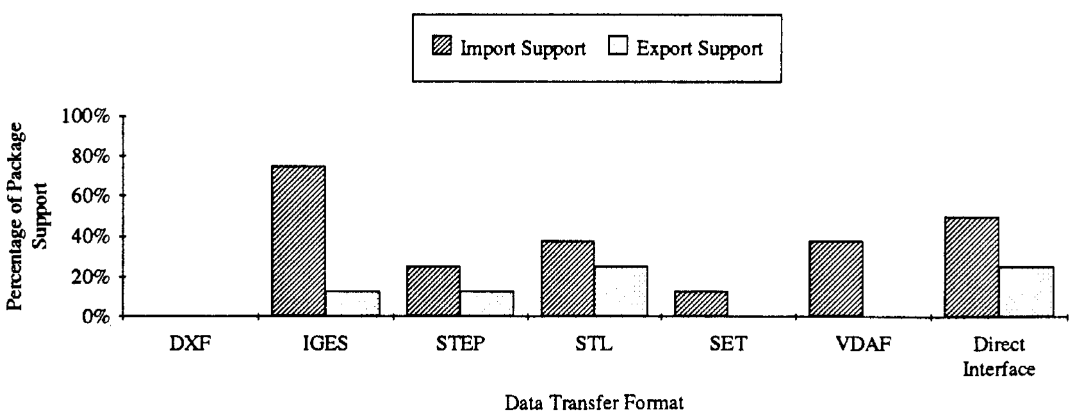

Figure 1b. WS Environment: Solidification Package Support for Data Transfer Formats

Another means of integration would be to share the databases needed between the integrated application programs. The sharing of data in this manner may better fulfill the requirements for full integration than the currently provided data transfer interfaces. As pointed out by Paul and Yu (1995), full integration requires that the same information must be available to subsequent operations. Otherwise, the user must reconcile multiple sets of material properties, geometries, etc.

Observation of the internal databases maintained by each of the solidification packages (shown in Figures 2a and 2b) and the transfer capabilities offered shows that it may be possible to import data, but not to export the information. For example, no vendor in the WS environment reported that they provided a means to export process database information, such as dwell times or mold spray parameters. Slightly better database import access is found for the WS environment, compared to the PC environment; but on the whole, database exportability is lacking.

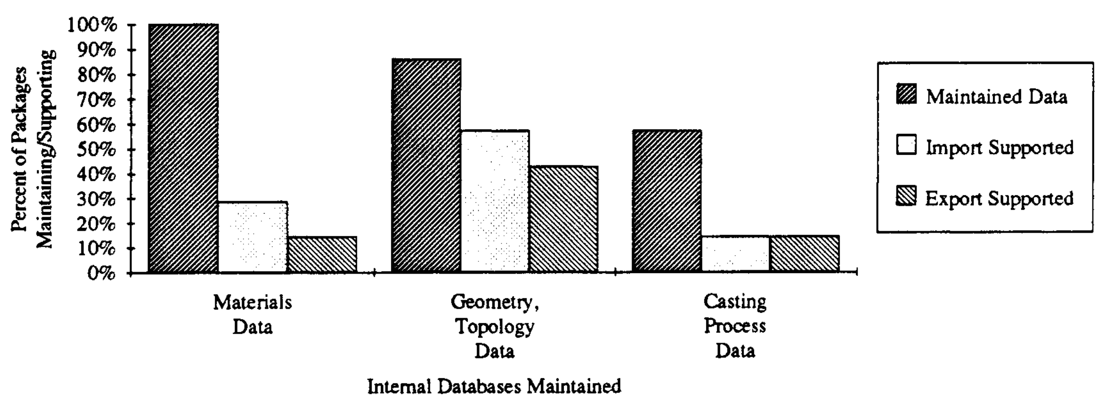

Figure 2a. PC Environment: Internal Data Maintained and Support for Data Import/Export

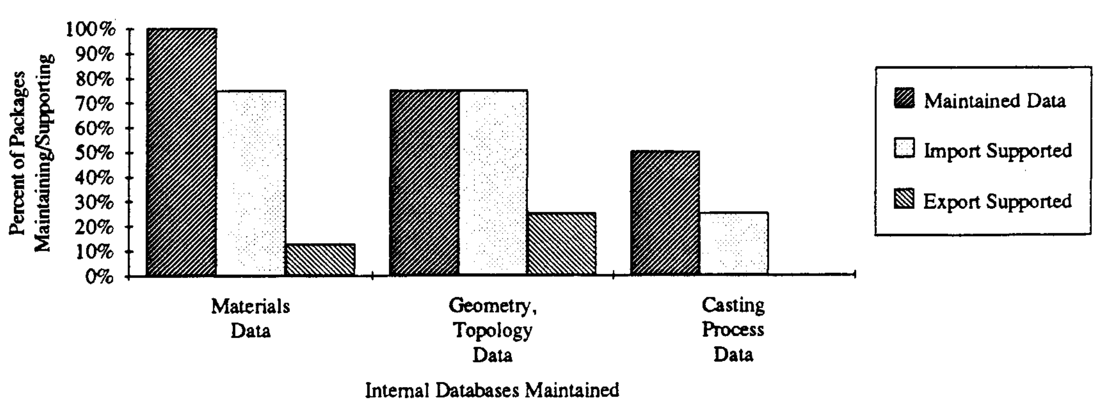

Figure 2b. WS Environment: Internal Data Maintained and Support for Data Import/Export

Industrial Casting Software User Profile

The Company Information Form provided a profile of the types of companies using computer software in the conduct of their business. The profile covers how they perform design functions, the size of the respondent firms, primary products cast, business nature, materials cast, and casting processes used.

Design Function Coverage

Naysmith, Prucha, and Ruff (1992, 1991) and Orogo, Calihan, Sigworth and Kuhn (1993) described many functions that should be possible in an integrated casting design environment, including design optimization. Optimization can really only be addressed after adequate coverage of the design functions has occurred. Part of the project's user survey activity, the Company Information Form queried respondents about how they currently perform their casting design functions.

The design of cast products may be broken into two parts: (a) product design, and (b) casting design. Product design tasks are primarily concerned with defining the geometry and functional attributes of the end product. CAD software is used to perform the tasks of part and tooling design, and of end product dimensional analysis. General purpose finite element codes, such as ANSYS, are used to analyze the product design for mechanical stress, thermal stress, heat transfer and fluid flow performance. Because few of the foundries reported performing this work, the product design tasks deserve consideration primarily in terms of the information that is provided to the foundry for casting design.

Casting design function support is operationally defined, here, as software that provides a generative capability or an analytical result that can be used to perform design a casting. Using this definition and the user survey responses, the following generalizations can be made with respect to the use of casting software among the industrial respondents.

CAD software is predominantly used to generate the pattern design by adding drafts and allowances to the product design geometry. CAD software also provides the geometric models in support of the gating, runner and riser design tasks. A few foundries reported manually carrying over results from stand alone, other casting software to aid in performing the last three tasks.. Currently, software packages providing this support are available only in the PC environment (but WS functions are being developed). Present software coverage of these last three design tasks is characterized as weak.

Solidification packages are available to perform the tasks of mold filling simulation, solidification simulation, casting defect prediction, prediction of casting microstructure and mechanical properties, and casting residual stress analysis. Coverage of the solidification and mold filling simulation functions appears strong, although most PC environment respondents report that their packages do not do filling simulation. The routines to predict porosity defects, microstructure, mechanical properties, and residual stresses are recent developments. Software support for these design functions still needs development.

Other casting software, usually home-grown, sometimes fills in the remaining functional voids: determining process parameters, providing melt control, and production process monitoring. All three of these design functions need development to provide better coverage.

Company Size

Several means can be used to describe the size of a metal casting company. Among these are the number of employees and number of plant locations, capacity for pouring castings, number of different castings poured, and sales generated. Figure 3 portrays the percentage of respondents by employee size. Plotted alongside is the expected percentage if the distribution were to match the casting industry breakdown (AFS, 1995). From this information, it appears that the firms using casting design software usually tend to be medium sized or larger. The smaller foundries are not using casting software in the proportion expected, based on the current size mix in the casting industry.

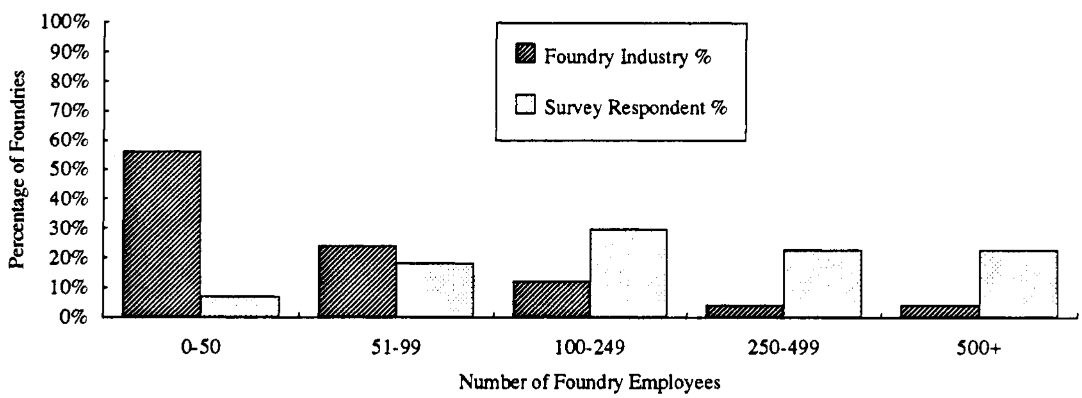

Figure 3. Respondent Profile: Comparison with Industry Size Distribution

Survey participants also responded on the Company form with the thousands of tons of metal poured by their firms. Separating the returns into those pouring the ferrous and non-ferrous alloys, the frequency with which respondents fit into four size categories can be observed (Figure 4). Among the ferrous metal casters, the proportion with small and medium pouring capacities dominate those using casting software. A similar trend may or may not exist with the non-ferrous metal casters, the large number of those not responding to this question masks the true relationship. It does not appear, however, that capacity poured influences use of casting software.

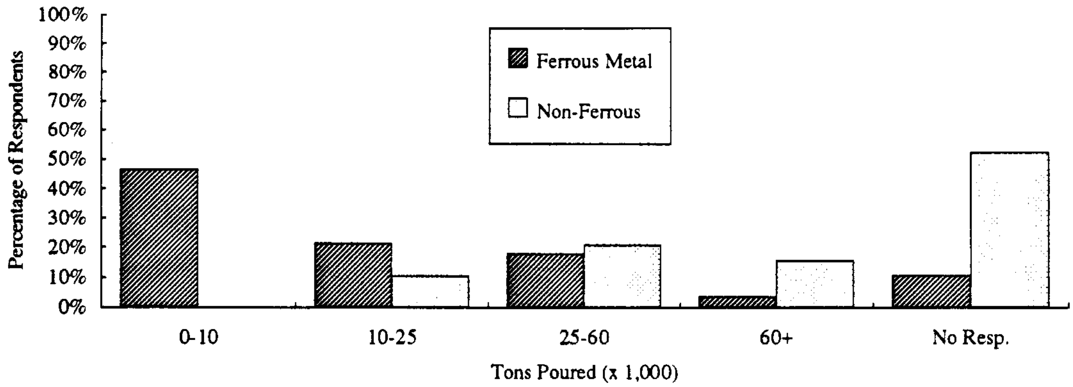

Figure 4. Software Response Profile: Respondent Firm Tons Cast

Each of the survey respondents was asked to estimate the number of different parts (operationally defined as different part numbers) that were cast at his/her location. Figure 5 shows the percentage of responses falling between the four breakpoints. Roughly half of the responses came from firms casting less than 700 different parts. It does not appear that the number of parts available for development with casting software has a large effect on software usage.

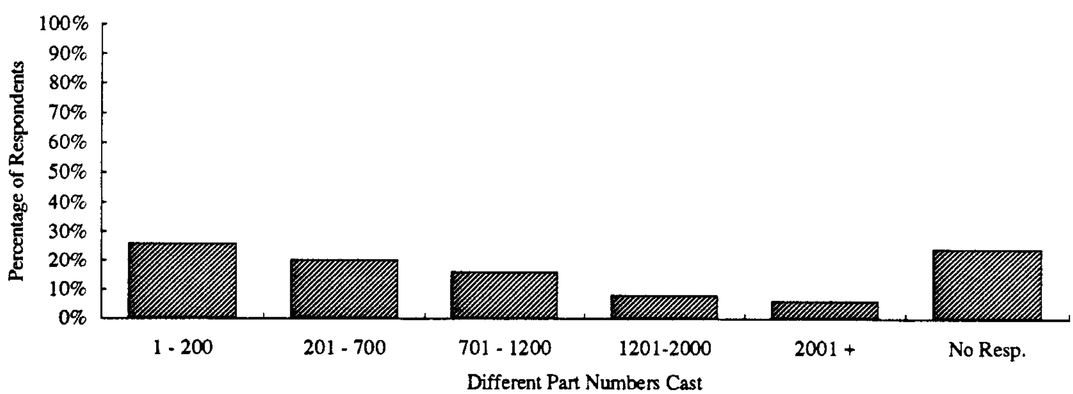

Figure 5. Software Response Profile: Different Parts Cast by Respondents

An estimate of gross sales proved difficult to obtain. Only half of the respondents chose to address this question (see Figure 6). From the data provided, it does not appear that sales volume has any clear relationship with the use of casting software.

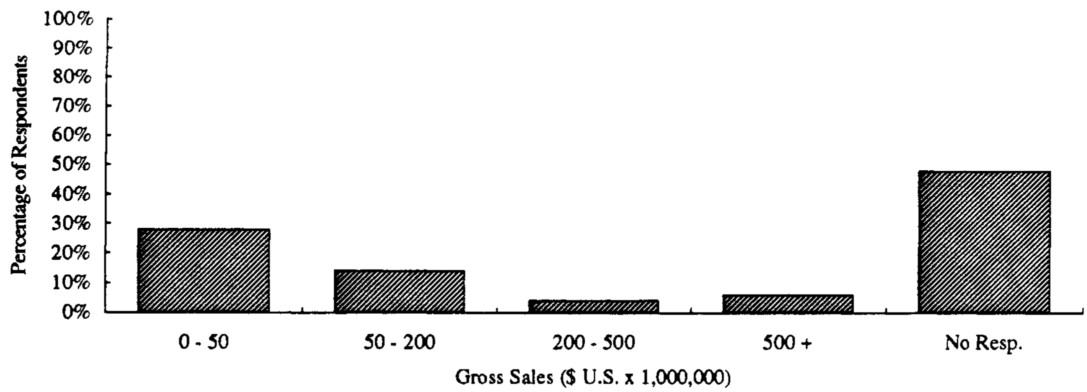

Figure 6. Software Response Profile: Respondent Firm Gross Sales

Figure 7 shows the number of plant locations for the companies responding to the survey. Assuming that the smaller operations have the fewest number of production locations, the smaller firms appear to use the software less frequently than their proportionate industrial distribution, and the larger operations appear more apt to use the packages.

Figure 7. Software Response Profile: Respondent Production Locations

Summarizing: among those casting software users responding to the survey, (a) the smallest firms in terms of employee size apparently do not use the software in proportion to their frequency in the foundry industry (Figure 3), and possibly in terms of number of plant locations (Figure 7); and (b) those using the software do not appear to be the largest firms in terms of pouring capacity (Figure 4), part numbers poured (Figure 5), or gross sales (Figure 6). This implies that a lack of available staff may affect the decision to use casting design software more than the availability of funds.

Primary Products /Industries Served

Figure 8 illustrates the frequency with which the respondent firms are categorized by the products produced, and compared to the distribution found in the foundry industry (AFS, 1995). For the most part, use of solidification software mirrors the overall industry when markets are considered, with the machinery and equipment sector slightly less than expected among the users. Closer inspection of the responses reveals that the bulk of the users cast products such as engine, hydraulic, construction equipment, and aerospace components that require critical attention to the material properties.

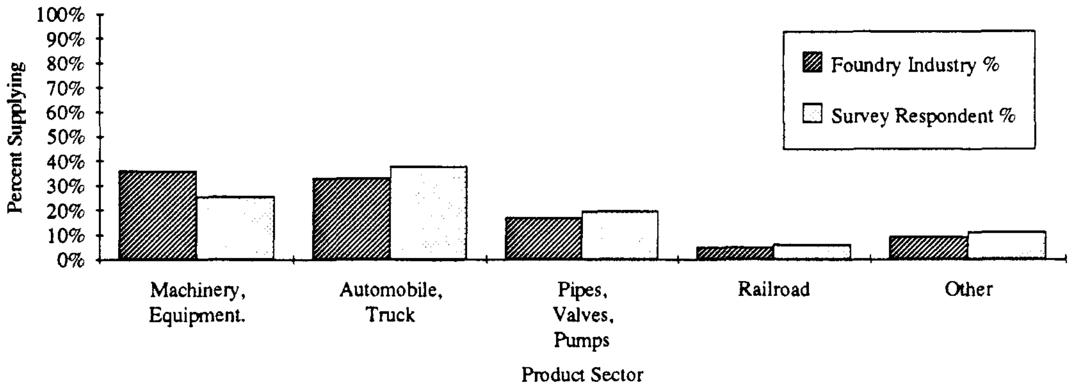

Figure 8. Comparison of Sector Served for Foundry Industry and Respondents

Nature of Business

Figure 9 depicts the frequency with which the responding fms characterized their business as having a job, captive, design service, or other nature. More than one classification was possible for a respondent. Those reporting in the Other category were primarily research laboratories. A large proportion of the industrial casting software users report that jobbing business comprises some portion of their overall casting activity. The fact that the casting software users have to address castings designed from outside their direct control has implications for the ways in which the software is used and the need for easy data transfer between customer and foundry application packages.

Assume, for example, that an outside firm provides a casting design to the foundry in a compatible digital format. (a) If the transfer format employed is .STL, and the design is complete, down to the gating and risers, then the software-using foundry may easily do a solidification analysis. If the design works, then the pattern would usually require re-posting from the original CAD package or be created manually. If not workable, then the design goes all the way back to the originating firm for revision. (b) If the format used is DXF or IGES, and there are no geometry translation problems, then the software-using foundry may both generate the rigging system and perform the solidification analysis. In this case, they may even be able to correct design flaws and send workable designs on for CNC pattern making. (c) If the data is supplied in full STEP format or via direct CAD interface (both firms happen to use the same/compatible CAD systems), then the foundry can easily add rigging, perform the solidification analysis, modify the geometry if necessary, and post the information on to the pattern shop for CNC work. The last data transfer option has the greater opportunity for efficiency from design to part.

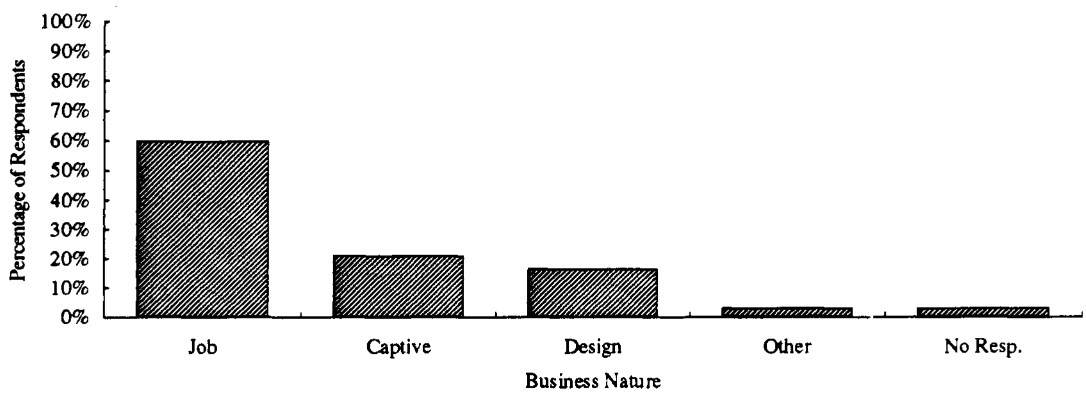

Figure 9. Software User Profile: Respondent Firm Business Nature

Materials Cast

Figure 10 shows the percentage of respondent firms pouring the most common cast metals. It should be noted that some firms cast more than one type of metal. Overall, the results seem to reflect the demographics of the U.S. casting industry, with aluminum, cast iron, and steel being the most frequently cast materials. Casting software usage does not seem to depend on the material poured, among the major metals cast.

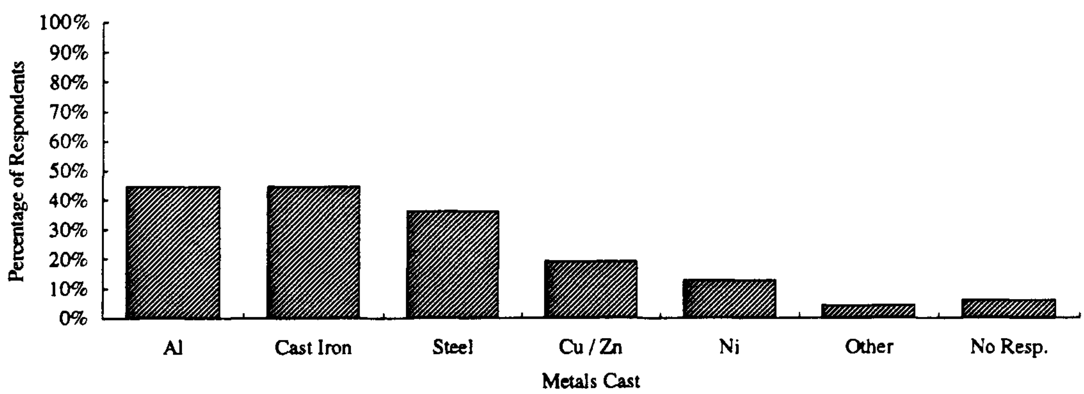

Figure 10. Software User Profile: Respondent Firm Metals Cast

Figure 11 illustrates the frequency with which the respondents report their capability for a particular casting process. The results, again, seem reflective of the overall industry, and serve to demonstrate the applicability of casting software for use with the main casting processes.

Noteworthy, also, is that although only one of the vendors targeted die casting alone, other packages seem to be providing useful results to the die casters.

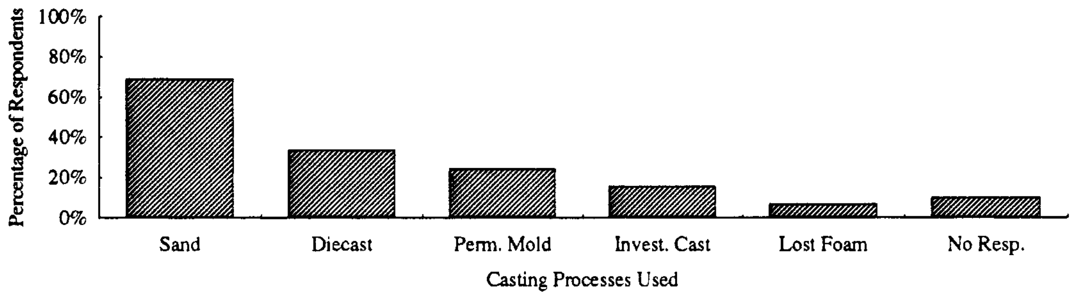

Figure 11. Software User Profile: Respondent Firm Casting Processes

Profile of Current Casting Software Implementation

The Software form sent in the user survey packets provided more detailed information on how each firm uses its casting software packages. This section develops a profile of typical industrial casting software use.

Costs Incurred

Implementation costs for solidfication software are depicted in Figure 12 for both computing environments. The figures are broken down by cost area, and represent the mean cost per software seat. Staffing levels for operating the software packages have a mean value of 0.69 man-years per seat, with a standard deviation of 0.54 for the PC environment; the mean is 1.04 man-years per seat with a standard deviation of 0.67 for the WS platforms. It is possible that the workstation packages take longer for the operator to master.

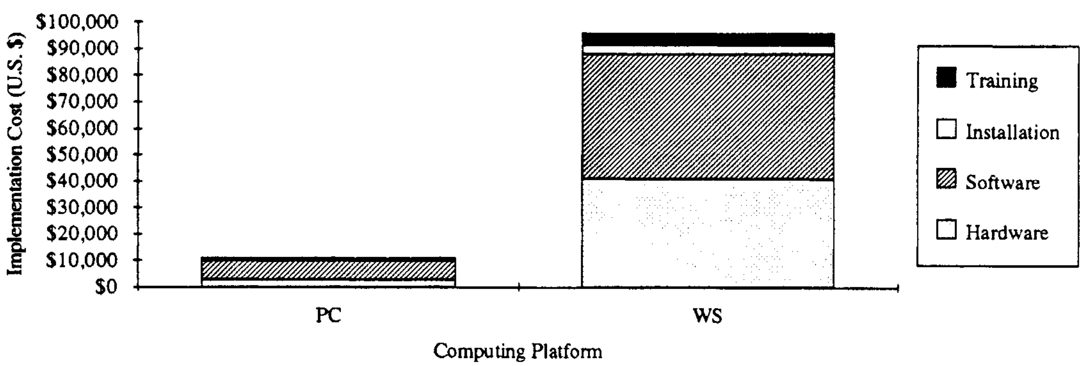

Figure 12. Mean Implementation Costs of Casting Software

User Evaluation of Casting Design Software

The user survey asked respondents to assess the software package(s) they used with respect to ease of training, ease of use, predictive accuracy, vendor support, and overall satisfaction. Figures 13a and 13b, below, show the mean rating and standard deviation for both the PC and WS packages (respectively) for each criterion (response scale is anchored at 0-Very Low to 4-Very High). Users generally reported easier training with the PC packages, while the WS software was often assessed higher on predictive accuracy and overall satisfaction; but this should not be taken as conclusive.

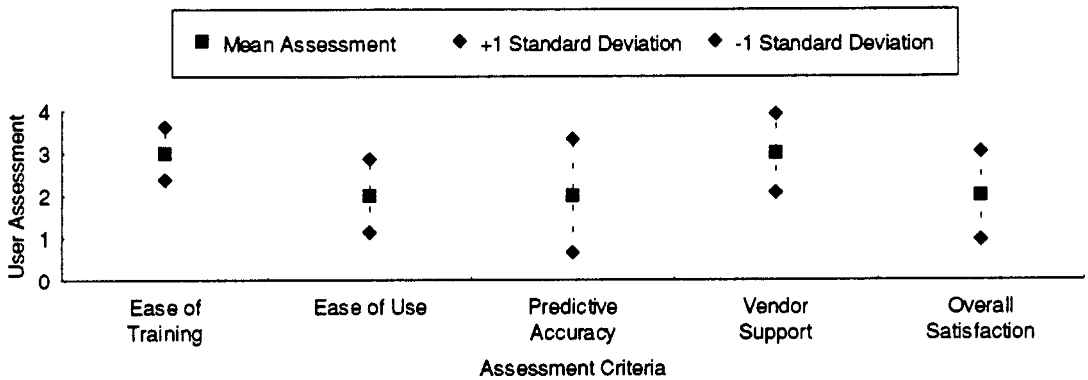

Figure 13a. PC Environment: User Rating of Solidification Package Performance

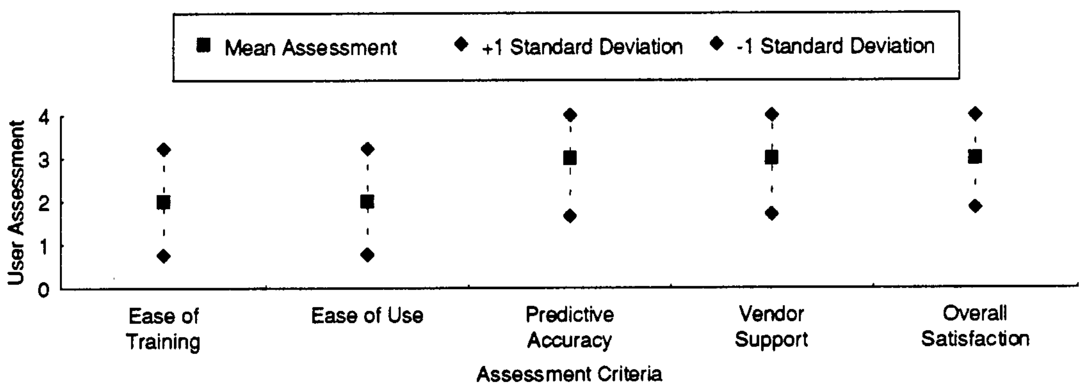

Figure 13b. WS Environment: User Rating of Solidification Package Performance

Percentage of Parts Developed With Software

Figures 14a and 14b depict the percentage of parts for which casting software is being used, for the respective computing environments. The PC platform users primarily use this software for a small percentage of parts, while the WS software users report that they design with the software in fairly even proportions up to about 50% of their cast parts. It is thought that initially, the software is used only on the most difficult-to-cast parts; however, differences in man-power availability would also have an impact on the percentages designed with software. Further follow-up and study is needed to determine the reason(s) for this difference.

The length of time that the software has been available may also impact these percentages. Follow-up conversations with some of the users revealed that more than half of them had used the software for less than two years, and expect to see increased percentages with further use. Work is underway to characterize the relationship between the amount of time the software has been used with the percentage of parts designed with casting software.

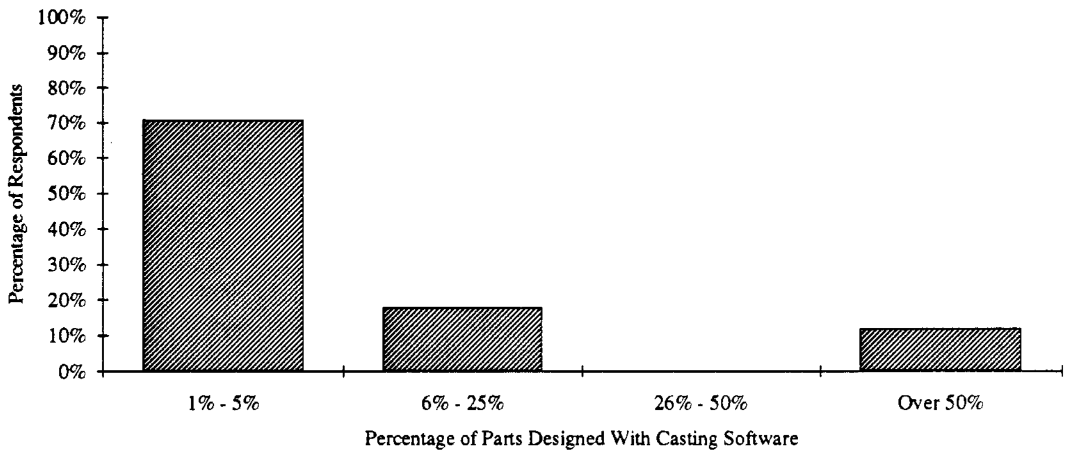

Figure 14a. PC Environment: Percentage of Parts Designed with Casting Software

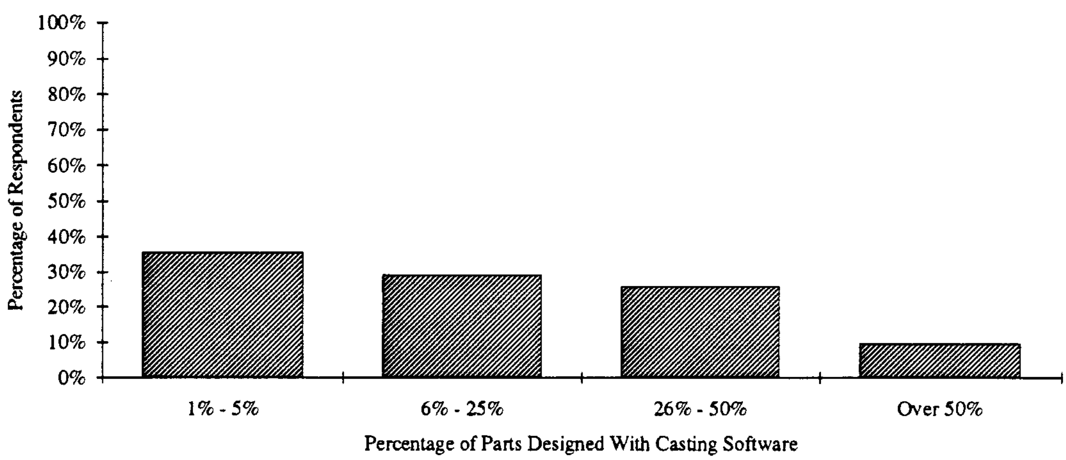

Figure 14b. WS Environment: Percentage of Parts Designed with Casting Software

Benefits Realized

Theoretically, current casting design software should improve the analysis of casting design tasks, eliminating design efforts wasted on poor initial designs and thus providing a better tooling design to the pattern/die maker. This should directly eliminate iterations in the construction of tooling (inefficient to expendable mold processes, and possibly fatal to die cast and permanent mold shops). Because the molds are better, rework and the associated labor costs and production time are indirectly reduced. And since the casting design is more accurately modeled, there is a reduced need for large safety factors, resulting in a yield increase.

Figures 15a and 15b depict the benefits realized by foundries from using casting software. The percentage improvement (reduction in time, costs, re-work; increase in yield weight of castings vs. total metal poured) is reported for those parts the software was used with, in each computing environments. Plotted are the mean and one standard deviation of the percent improvement for each benefit. On the average, improvements were realized on all benefits.

At first glance, the benefits reported by the PC platform users exceed those of the WS platform users. However, as was just reported, the percentage of parts that were developed using casting software are lower among the PC users than among the users on the WS platforms, Perhaps the PC users target the more difficult to cast parts, which may have the biggest savings return. Perhaps the WS users employ the software on low return, but high volume parts to save money. As mentioned before, the length of time that the software has been available for use can also be expected to impact the reported benefits. Such possibilities as these require further study.

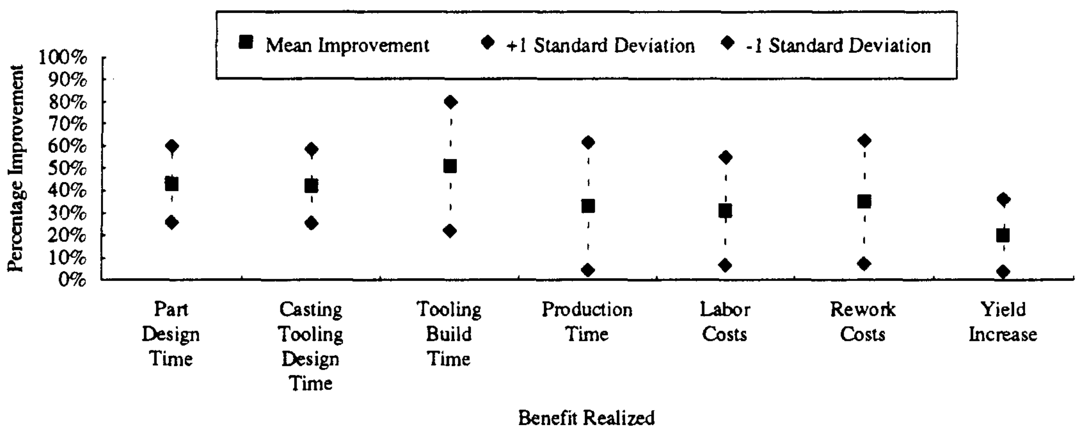

Figure 15a. PC Environment: Benefits Realized from Casting Software

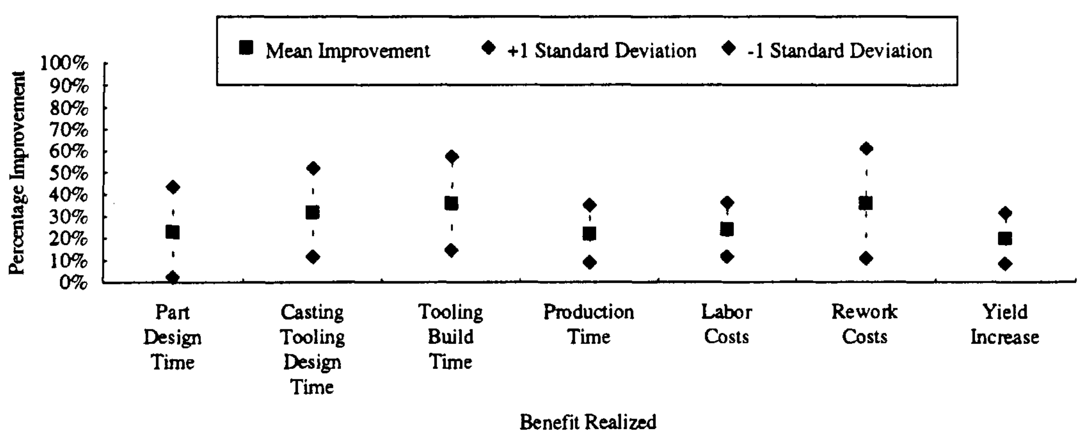

Figure 15b. WS Environment: Benefits Realized from Casting Software

Integration Potential

Portrayed in Figures 16a and 16b is the manner in which CAD data transfer formats are being used. While solidification packages usually include their own geometric modeler, in almost all cases studied, the transfer of data is from CAD package to solidfication package. Differences between the environments with respect to the primary data transfer formats utilized are primarily the result of the difference in CAD packages being used in each environment. However, in both environments, no digital information is fed backward for design improvement, and rarely is it fed to downstream applications directly, such as CNC machining or even graphing software.

Some users have resorted to coding their own interfaces for passing on solidification results, while some have been able to have the vendors write routines of this nature for them. Analysis of user comments indicates that CAD package feedback interfaces were requested in 44% of the returns as desired solidfication package improvements. Casting software used for other than solidification analysis is stand-alone software, without a data transfer capability.

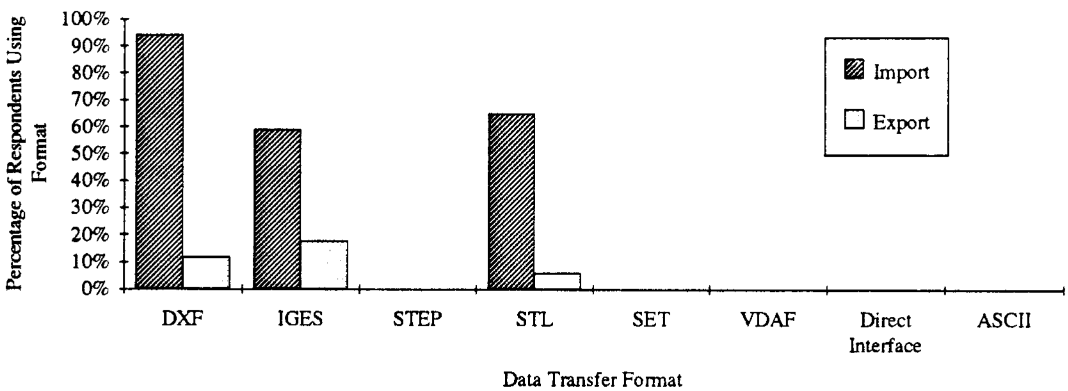

Figure 16a. PC Environment: Use of Data Transfer Formats

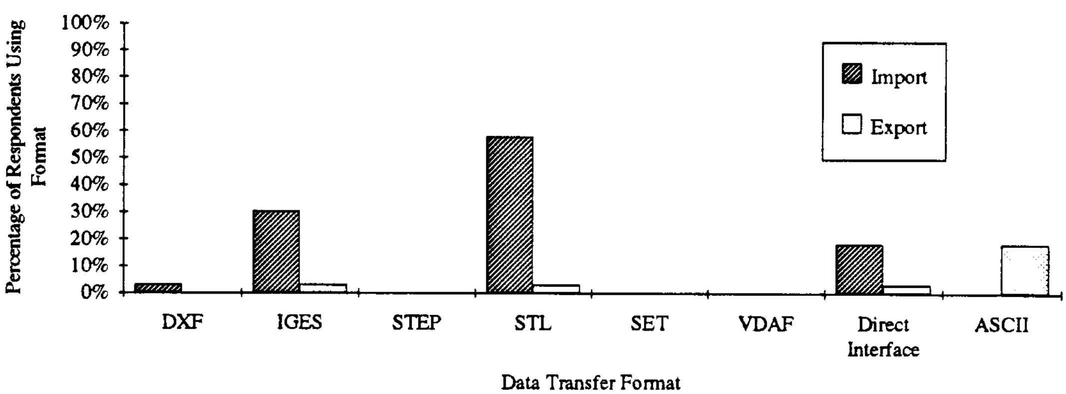

Figure 16b. WS Environment: Use of Data Transfer Formats

Analysis of reported user import and export problems with solidification software shows that many problems occur with the most common data transfer formats. Figure 17 shows the frequency with which the various formats were included in described problems. Initial attempts at geometric data transfer resulted in format standards that were sometimes problematic. DXF and IGES formats have had known problems, and corrective revisions have been propagated - but these standards have limitations that will be difficult to overcome. The direct interface between packages is a popular option, but complete interface code is required for every package combination one wishes to link, an expensive proposition.

The figure shows that a large number of problems were reported with the .STL format. Further analysis revealed that the majority of these complaints were with one vendor's .STL interface, and not all packages have this problem. However, the .STL representation is not as complete as the other transfer formats; for example, there is no support for transferring part or material layers, and the faceted solid representation means that there is most often a loss of precision in the data model. More recently, the STEP data transfer standard has reached a stage where vendors can reasonably be expected to code interfaces. This standard is expected to be much more complete in its data representation (going beyond CAD data to include material and process parameters) than the previous North American (DXF, IGES) and European standards (SET, VDAF).

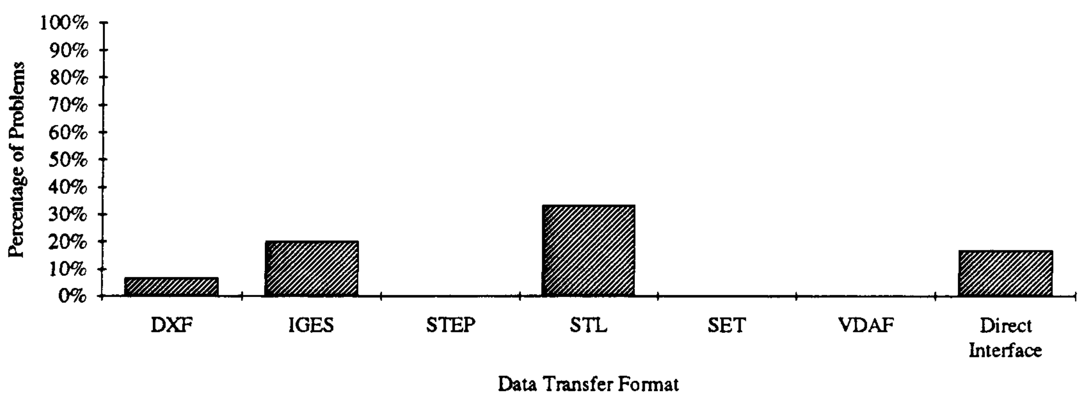

Figure 17. Industrial Practice Profile: Frequency of Problems Involving Data Transfer Formats

The net result of the current formats employed, their inherent limitations, and the problems encountered with some current package interfaces is reflected in the frequency with which the users transfer data after the solidification analysis is performed. Figure 18 depicts the very low frequency with which data is sent to downstream applications. The prevailing context for the few cases in which data are passed on tends to be ASCII text tables of time and temperature information. Better solutions for data transfer are needed.

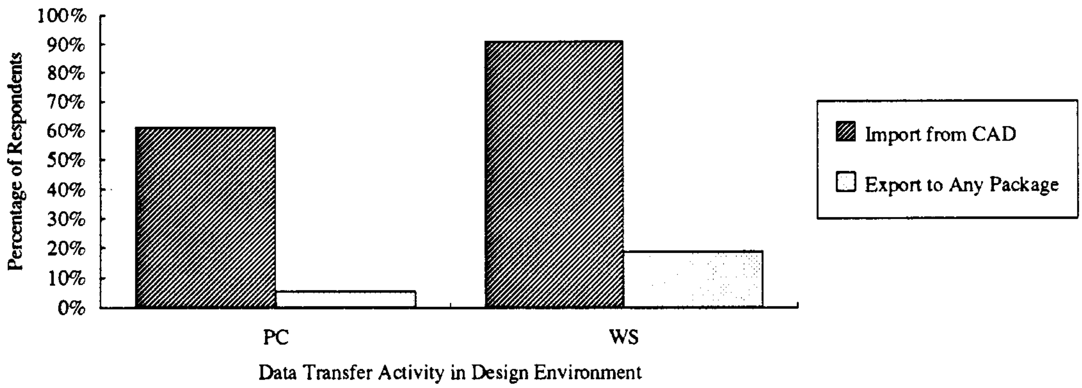

Figure 18. Industrial Practice Profile: Data Transfer with Solidification Software

Conclusions and Recommendations

This paper documents the preliminary findings of an ongoing research project. It should also be noted that the software described here is constantly being improved, with new features appearing regularly. Recognizing these important caveats, the following conclusions and recommendations are suggested.

Preliminary Conclusions

Current, off-the-shelf casting design software is being used to provide substantial benefits to the foundry industry. These benefits occur regardless of the major metal(s) being cast or the major casting process(es) being used. However, among the companies surveyed, the smallest firms are not using casting software in proportion to their prevalence within the foundry industry.

The firms using the casting software in this survey tended to be suppliers of products requiring careful attention to the material consistency of the end casting. Another set of users, the die casters, reported during follow-up contact that the high cost of re-tooling a poor die design was a critical factor in their business survival. These facts seem to provide some of the impetus for the use of casting design software.

The transfer of data between off-the-shelf casting design packages is currently a mixed bag of stand-alone or one-way data transfer, when practiced at all. While geometric and topologic data transfer from CAD to solidification application is done regularly, the users report problems with the current data transfer formats or interfaces in many cases. This one-way transfer is the extent of integration at the present time. In only very rare instances is data being digitally passed to downstream processes, and for the most part this is accomplished through ASCII text interfaces written or initiated by the users. If casting design is to be integrated by means of data transfer, improved standards and better vendor implementation of these interfaces are firm requirements.

An alternative, integration by means of internal database information transfer, requires significant user effort to extract, validate and maintain, and return the necessary data among all the packages present in the firm's casting design environment. Few casting software packages offer direct import/export capabilities for their internal databases; therefore the prospect of integrating off-the-shelf packages by this means will also require major improvements to the current software.

Preliminary Recommendations

Support for the establishment and refinement of casting data transfer standards, such as STEP, by the casting industry is strongly recommended. Pressure for the implementation of software functions supporting the ease of data transfer should be a foundry industry priority, and a major sales feature opportunity for software vendors.

Identification of a robust model for casting design development through software in the foundry industry would lead to significant benefits. Identification of successful implementation and usage strategies by the industry would help drive software development directions that would provide the greatest benefits. Demonstrations of the technology in such a scenario(s) can be expected to improve industrial acceptance of the technology.

Further research is needed to create new, or refine existing software tools for accomplishing, supporting, integrating, and optimizing the following casting design functions:

- Mold/die design
- Gating/runner design
- Riser design
- Defect prediction (such as oxide films and inclusions)
- Microstructure and mechanical structure prediction
- Residual stress analysis
- Process parameter specification
- Melt control
- Casting dimensional control

In order to adequately manage the casting design process in an integrated environment, the development of a means to track the progress of, and allow access to, design data is also required. Based on the preliminary data from the survey, an integrated casting design environment may be envisioned. Figure 19 is one such representation.

Acknowledgments

This project is supported through the American Metalcasting Consortium. The authors would also like to thank the participating software vendors and their customers for their time and efforts.

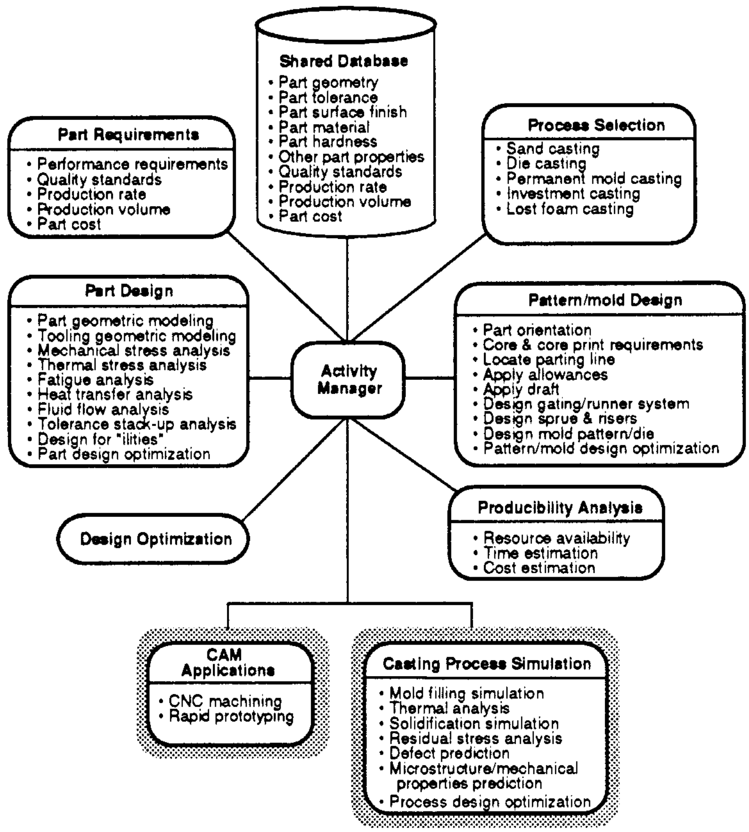

Figure 19. A Computer-Integrated Casting Design Environment

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Paul, A. J. and Yu, K. O. (1995). Computational software for the casting industry - A perspective on current and future issues. In Voller, V.R., Marsh, S.P., and El-Kaddah, N. (ed.) Materials Processing in the Computer Age -II. The Minerals, Metals & Materials Society, pp. 21-32.

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APPENDIX 1: Survey Materials

METALCASTING LEAD TIME AND COST REDUCTION PROJECT
American Metalcasting Consortium — 1995

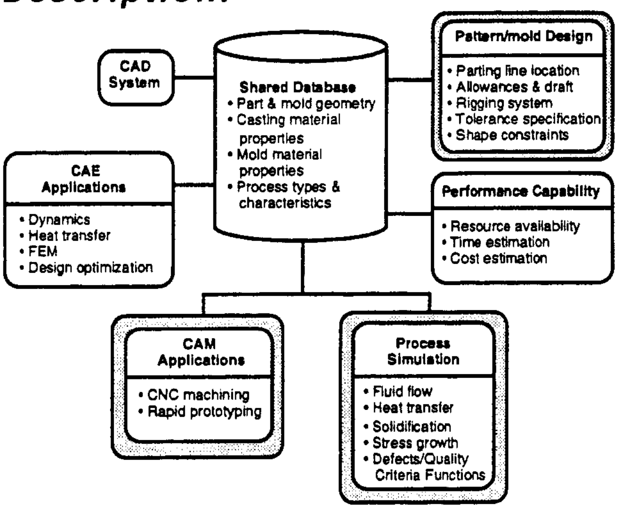
Overall Goals: Casting applications development; casting lead time reduction; technology transfer

Project Task: Casting Software Tools

Goals & Objectives:

- Assess current practice and identify barriers to seamless transfer of information between design and manufacturing
- Recommend software development to ensure seamless information transfer

Description:



CASTING DESIGN SOFTWARE ENVIRONMENT

Effective software tools are needed to drastically reduce lead time and cost of castings. The Casting Software Tools Project Task will determine the capabilities of off-the-shelf software to perform the primary casting design/manufacturing functions and, in particular, their potential for integration in a computer-based casting design software environment (see Figure). The study will document the capabilities/limitations of software packages in current use, and develop a functional design of an integrated casting design environment.

Deliverables:

- Software user/vendor survey results and software/suppliers database
- Functional design of integrated casting design software environment
- Technology assessment and identification of technology gaps

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METALCASTING LEAD TIME AND COST REDUCTION PROJECT
American Metalcasting Consortium - 1995

Product Information Form

Instructions:

Please check the prelisted information for accuracy, drawing a single line through discrepant information, and clearly printing the correction or adding omitted information. Please complete both sides of this form and return. Additional copies may be made from the accompanying blank form.

Package name: ______________________ Current version: __________

Number of installations: Locations (sites): __________ Seats (individuals): __________

Software package cost (*assume industrial customer*):
Minimum: __________ Maximum: __________
Additional seat charge: __________

Platforms supported (*please check all that apply*):
Operating systems: ☐ Unix or AIX ☐ Windows NT ☐ Other: __________
☐ MS-DOS ☐ Windows ☐ Other: __________

Hardware systems (*please note minimum and recommended hardware configurations at right, below*):

	Model(s)		Fixed Disk:	RAM:
☐ HP	______	Minimum	______	______
	______	Recommended	______	______
☐ Silicon Graphics	______	Minimum	______	______
	______	Recommended	______	______
☐ DEC	______	Minimum	______	______
	______	Recommended	______	______
☐ IBM	______	Minimum	______	______
	______	Recommended	______	______
☐ 386 / 486	______	Minimum	______	______
	______	Recommended	______	______
☐ Pentium	______	Minimum	______	______
	______	Recommended	______	______
☐ Other:	______	Minimum	______	______
	______	Recommended	______	______

Import data formats:
☐ IGES ☐ STEP ☐ .STL
other import formats (*please specify*):
____
____

Export data formats:
☐ IGES ☐ STEP ☐ .STL
other export formats (*please specify*):
____
____

Casting processes supported (*please check all that apply*):
☐ Sandcast ☐ Investment ☐ Diecast ☐ EPC ☐ Permanent mold
Other (*please specify*): __________
____

Alloys supported (*please check all that apply*):
☐ Steel ☐ Iron ☐ Aluminum ☐ Magnesium ☐ Zinc ☐ Copper
Other (*please specify*): __________

over

Internal databases maintained (*please check all that apply*):

☐ Materials:
☐ importable ☐ exportable ☐ neither

☐ Geometric / topologic:
☐ importable ☐ exportable ☐ neither

☐ Processes:
☐ importable ☐ exportable ☐ neither

Others (*please list*):

____
☐ importable ☐ exportable ☐ neither
____
☐ importable ☐ exportable ☐ neither
____
☐ importable ☐ exportable ☐ neither
____
☐ importable ☐ exportable ☐ neither

Casting design tasks supported (*please check all that apply*):

☐ Part design: ☐ 2-D ☐ 3-D
☐ Tooling design: ☐ 2-D ☐ 3-D
☐ Mechanical stress analysis
☐ Thermal stress analysis
☐ Fatigue analysis
☐ Heat transfer
☐ Fluid flow
☐ Solidification analysis
☐ Defect prediction
☐ Gating / runner design
☐ Riser design
☐ Parametric (dimensional) analysis
☐ Design for manufacturing / assembly
☐ Statistical variation simulation
☐ Process parameter estimation (charge, etc.)
☐ Production process monitoring
☐ Quality control
☐ Other: ______________________

Additional modules available (*please list*):

____
____
____
____
____
____

Supporting software required (*if any*):

____
____

Estimated installation / training requirements:

Installation charges: ______________________
User skill level: ______________________
Training time (hours): ______________________
Training course(s) offered? ☐ yes ☐ no Cost: ______________________

Particular package strengths (*please list*):

____
____
____
____
____

Product contact person:

Name: ______________________
Address: ______________________
____
____
Phone: ______________________
Facsimile: ______________________
E-mail: ______________________
Preferred contact time(s):

Please return to:

Dean Jensen
Project Research Engineer
Center for Computer-Aided Design / 427 IATL
The University of Iowa
Iowa City IA 52242-1000

Thank you for your assistance!

over

METALCASTING LEAD TIME AND COST REDUCTION PROJECT
American Metalcasting Consortium - 1995

Company Information Form

Instructions:

Please print clearly, completing both sides of each form, and return. The information requested in the forms will be used for summary information only. The information will be kept in strict confidence, and at the completion of this project all references to actual persons or firms will be deleted.

How does your firm use software in performing the following tasks?

(please check all that apply)

Product Design:	Task outsourced	Task not done at all	Done here, manually	Would do here, if software were available	Done here, on a PC	Done here, on a workstation	(please list software used; or firm name, if task is outsourced)
Part design	☐	☐	☐	☐	☐	☐	
Tooling design	☐	☐	☐	☐	☐	☐	
Mechanical stress analysis	☐	☐	☐	☐	☐	☐	
Thermal stress analysis	☐	☐	☐	☐	☐	☐	
Fatigue analysis	☐	☐	☐	☐	☐	☐	
Heat transfer analysis	☐	☐	☐	☐	☐	☐	
Fluid flow analysis	☐	☐	☐	☐	☐	☐	
Dimensional analysis (tolerence stacking)	☐	☐	☐	☐	☐	☐	
Design for manufacturing / assembly	☐	☐	☐	☐	☐	☐	
Other ______	☐	☐	☐	☐	☐	☐	
(please list) ______	☐	☐	☐	☐	☐	☐	

Casting Design:	Task outsourced	Task not done at all	Done here, manually	Would do here, if software were available	Done here, on a PC	Done here, on a workstation	(please list software used; or firm name, if task is outsourced)
Pattern design	☐	☐	☐	☐	☐	☐	
Mold / die design	☐	☐	☐	☐	☐	☐	
Dimensional analysis (draft & allowances)	☐	☐	☐	☐	☐	☐	
Gating / runner design	☐	☐	☐	☐	☐	☐	
Riser design	☐	☐	☐	☐	☐	☐	
Mold filling simulation	☐	☐	☐	☐	☐	☐	
Solidification simulation	☐	☐	☐	☐	☐	☐	
Residual stress analysis	☐	☐	☐	☐	☐	☐	
Defect prediction	☐	☐	☐	☐	☐	☐	
Microstructure / mechanical properties prediction	☐	☐	☐	☐	☐	☐	
Process parameters (charge, shot profile, etc.)	☐	☐	☐	☐	☐	☐	
Melt control	☐	☐	☐	☐	☐	☐	
Production process monitoring	☐	☐	☐	☐	☐	☐	
Other ______	☐	☐	☐	☐	☐	☐	
(please list) ______	☐	☐	☐	☐	☐	☐	

over

Company name: ______________________________

Alloys cast (please list):

____

____

Casting processes used (please list):

____

____

Primary products / industries served (please list):

____

____

____

Business nature (please check all that apply):

- ☐ Castings are provided for other manufacturer's products
- ☐ Castings are provided for self-manufactured products
- ☐ Design consultation or tooling is provided to other firms
- ☐ Other (please specify): ______________________________

Company volume (estimated):

Tons cast / year ____________

Number of different parts cast / year ____________

Company size (estimated, *for this location*):

Number of employees in:

Product design ____________

Pattern / die design ____________

Tooling production ____________

Casting production ____________

Gross Sales (U.S. dollars) ____________

Number of plants (*all locales*) ____________

Should follow up be necessary, please list a technical contact person:

Name: ______________________________

Title: ______________________________

Address: ______________________________

____

____

Phone: ______________________________

Facsimile: ______________________________

E-mail: ______________________________

Preferred contact time(s):

Please return to:

Dean Jensen
Project Research Engineer
Center for Computer-Aided Design
427 Iowa Advanced Technology Labs
The University of Iowa
Iowa City IA 52242-1000

phone (319) 335-3374 / 3370
fax (319) 335-3380

Thank you for your assistance!

Company Information Form - continued from other side

METALCASTING LEAD TIME AND COST REDUCTION PROJECT
American Metalcasting Consortium - 1995

Software Information Form

Instructions:

For each software package identified on the Company Information Form, please fill out a Software Information Form. *Additional copies of this form may be made as needed.* The information requested in the forms will be used for summary information only. The information will be kept in strict confidence, and at the completion of this project all references to actual persons or firms will be deleted.

Software package: ______________________ **Version:** ________

Percentage of parts cast in your company for which this software is used: ________

Number of computers with access to this software in your company: ________

Best estimate of the total man-years expended to operate and support this software: ________

Best estimate of the total costs to implement this software ($ U.S.):

Hardware: ____________ Software: ____________

Installation: ____________ Training: ____________

How does this software rate for:

	Very Low	Low	Average	High	Very High	Don't Know
Ease of training	☐	☐	☐	☐	☐	☐
Ease of use	☐	☐	☐	☐	☐	☐
Predictive accuracy	☐	☐	☐	☐	☐	☐
Vendor support	☐	☐	☐	☐	☐	☐
Overall satisfaction	☐	☐	☐	☐	☐	☐

Particular package strengths:

____

____

Desired features not provided:

____

____

 Package Name:

Data Import

From what other packages do you import information?

____

____

In what format(s) do you import the information? (please check all that apply)

- ☐ IGES
- ☐ STEP
- ☐ STL
- ☐ DXF
- ☐ Other (please list): ____________________

What problems, if any, have you encountered in importing this information?

____

____

____

From what other packages would you <u>like</u> to import data?

____

____

Data Export

To what other packages do you export information?

____

____

In what format(s) do you export the information? (please check all that apply)

- ☐ IGES
- ☐ STEP
- ☐ STL
- ☐ DXF
- ☐ Other (please list): ____________________

What problems, if any, have you encountered in exporting this information?

____

____

____

To what other packages would you <u>like</u> to export data?

____

____

Software Information Form - continued from previous page.

Best estimate of the net percent improvement currently derived from use of the software (comparing similar parts before and after using software). Provide comments on page four.	N/A	10%	20%	30%	40%	50%	60%	70%	80%	90% or more
Leadtime reduction for										
- Functional part design (concept to final part design)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
- Casting tooling design (patterns/dies, including casting allowances, rigging)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
- Construction of tooling (pattern/dies) to first production of acceptible castings	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Production time reduction	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Labor costs reduction	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Re-work costs reduction	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Yield increase	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

List other areas of currently derived improvements, if any: (such as machining, heat treatment, casting complexity, quality, etc.)	N/A	10%	20%	30%	40%	50%	60%	70%	80%	90% or more
______________________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
______________________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
______________________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
______________________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
______________________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
______________________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Expected future improvements from using this software:	N/A	10%	20%	30%	40%	50%	60%	70%	80%	90% or more
______________________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
______________________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

4/4 Package Name:

Comments:

Should follow up be necessary, please list a technical contact person:

Name: ____________________

Title: ____________________

Address: ____________________

____

____

Phone: ____________________

Facsimile: ____________________

E-mail: ____________________

Preferred contact time(s):

Please return to:

Dean Jensen
Project Research Engineer
Center for Computer-Aided Design
427 Iowa Advanced Technology Labs
The University of Iowa
Iowa City IA 52242-1000

phone (319) 335-3374 / 3370
fax (319) 335-3380

Thank you for your assistance!

Software Information Form - continued from previous page.

APPENDIX 2: Listing of Responding Casting Software Vendors

Vendor	Package(s) Offered	Platform(s)
AFSoftware	AFS Solidification System (3-D)	PC
	AFSolid (2-D)	PC
	AFS Investment Feeding System	PC[1]
	AFS Gating System	PC
	AFS Risering System	PC
	AFS Weight/Order	PC
Aluminum Pechiney	SIMULOR	WS[1]
EKK Computer Modeling	CAP	PC[1], WS
	AMESH	PC[1], WS
	WRAFTS	PC[1], WS
DMT	CASTFLOW	PC[2]
	CASTHERM	PC[2]
Delcam International	DUCTcast	PC[1], WS[1]
Flow Science	FLOW-3D	PC[1], WS
Foseco (FS) Limited	Solstar	PC[1]
JML Research	SWIFT	PC, WS[1]
Magma Foundry Technologies	MAGMASOFT	WS
	MAGMAstar*	PC[1]
	MAGMAfem	PC[1], WS[1]
MountainTop Technologies	RAPID/CAST	WS
UES	ProCAST	WS

Notes: [1] Product available, but not employed by any user respondents in this survey.
[2] Products support only the die cast process.