Computer-Aided Manufacturing System Engineering

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Abstract

A new type of computer-aided engineering environment is envisioned which will improve the productivity of manufacturing/industrial engineers. This environment would be used by engineers to design and implement future manufacturing systems and subsystems. This paper describes work which is currently underway at the United States National Institute of Standards and Technology (NIST) on computer-aided manufacturing system engineering environments. The NIST project is aimed at advancing the development of software environments and tools for the design and engineering of manufacturing systems. The paper presents an overall vision of the proposed environment, identifies technical issues which must be addressed, and describes work on a current prototype computer-aided manufacturing system engineering environment.

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1. INTRODUCTION

The future success of a manufacturing enterprise is likely to be determined by the speed and efficiency with which it incorporates new technologies into its operations. The process which is currently used to engineer, or re-engineer, manufacturing systems is often ad hoc. Computerized tools are used on a very limited basis. Given the costs and resources involved in the construction and operation of manufacturing systems, the engineering process must be made more scientific. Powerful new computing environments for engineering manufacturing systems could help achieve that objective.

What is computer-aided manufacturing system engineering (CAMSE)? In much the same way that product designers need computer-aided design systems, manufacturing and industrial engineers need sophisticated computing capabilities to solve the complex problems and manage the vast data associated with the design of a manufacturing system. CAMSE may be defined as:

--the use of computerized tools in the application of scientific and engineering methods to the problem of the design and implementation of manufacturing systems.

The goal of this engineering process is to find the best solution to a problem, i.e., a factory or subsystem implementation, given a specific set of requirements and constraints.

What is the scope of this problem? Engineers must address the entire factory as a system and the interactions of that system with its surrounding environment. Component elements of the factory system include:

- the physical plant or buildings which house the manufacturing facility,
- the production facilities which perform the manufacturing operations,
- the technologies used in the production facility, i.e., processes, methods, and techniques which are used to manufacture the products,
- the work centers/stations, machinery, equipment, tools, and materials which comprise or are used by the production facilities,
- the various support facilities and systems which move and store materials, handle manufacturing by-products and waste, manage information resources, maintain machinery and information systems, and support other needs of factory personnel,
- the staff organization and mechanisms which are instituted to operate and maintain the manufacturing facility, and
- the interface between the factory and its environment, e.g. movements of goods and materials, human access to the facility, links to utilities, and the controls on various forms of environmental impact (air, water, noise).

Manufacturing system engineering must not only be concerned with the initial design and engineering of the factory, it must also address enhancements and other modifications over time.

A CAMSE environment should support standard engineering methods and problem-solving techniques, automate many mundane tasks, and provide critical technical reference data to support the decision-making process. The environment should be designed so as to help engineers become more productive and effective in their work. The environment could be implemented on a high performance personal computer or engineering workstation which has been configured with appropriate peripheral devices.

Engineering tool developers will have to integrate the functions and data which are used by a number of different disciplines, for example:

- manufacturing engineering,
- industrial engineering,
- plant engineering,
- materials processing,

- environmental engineering,
- mathematical modeling/simulation,
- quality engineering,
- statistical process control,
- economic and cost analysis,
- computer science, and
- management science.

Most of the methods, formulas, and data associated with these technical areas currently remains embedded in engineering handbooks. Although some computerized tools are available, they are often very specialized, difficult-to-use, and do not share information or work together. Engineering tools built by different vendors be must made plug-compatible through appropriate open systems architectures and interface standards.

This paper describes a project underway at the U.S. National Institute of Standards and Technology to accelerate the development of this new type of computing environment. The project is currently funded by the U.S. Navy Manufacturing Technology Program. Section 1 introduces and defines computer-aided manufacturing system engineering. Section 2 presents a vision of the proposed computing environment. Section 3 describes some of the technical issues which must be resolved to achieve this vision. Section 4 briefly outlines the work that is currently underway at NIST. Section 5 provides a summary and conclusions.

2. VISION OF THE ENGINEERING ENVIRONMENT

What would the computer-aided factory engineering environment of the future look like? It would be based upon a computer workstation or network of workstations which provide an integrated set of design and engineering tools. These software tools would be used by a company's manufacturing engineering team to continuously improve its production systems. The tools would be used to maintain information about current manufacturing resources, enhance existing production capabilities, and develop new facilities and systems. Engineers working on different workstations would share information through a common manufacturing system engineering database.

Using this environment, an engineering team might be able to prepare detailed plans and working models for an entire factory in a matter of days. Many alternative solutions to production problems could be quickly developed and evaluated. This type of capability would be a significant improvement over current manual methods which may require weeks or months of intensive activity. To achieve this ambitious goal, a new set of engineering tools are needed.

A company's manufacturing engineering team require a number of different tools to support its mission. Examples of functions which should be supported include:

- identification of product specifications and production requirements,
- producibility analysis for individual products,
- modeling and specification of manufacturing processes,
- modification of product designs to address manufacturability issues,
- plant layout and facilities planning,
- simulation and analysis of system performance,
- consideration of various economic/cost tradeoffs of different manufacturing processes, systems, tools, and materials,
- analysis supporting selection of systems/vendors,
- procurement of manufacturing equipment and support systems,
- specification of interfaces and the integration of information systems,
- task and work place design,
- handling of various organizational and personnel concerns, e.g. labor issues, human factors, health, safety,
- compliance with various regulations, specifications, and standards,
- control of hazardous materials, and
- management, scheduling and tracking of projects.

For more information on the types of functions that manufacturing and industrial engineers would need to perform, see [1-3].

The tools which implement these functions must be highly automated and integrated. Automation is needed to eliminate, minimize or simplify tasks that are mundane, repetitive, time-consuming, complex, and/or error-prone. Integration is needed to ensure that tools can share common data and operate in a consistent, synergistic manner. Figure 1 illustrates some of the types of tools which might be integrated in a CAMSE environment.

The engineering tools, taken by themselves, are not sufficient to achieve productivity goals. The tools need data to be useful. Today, it is unlikely that the data required for a major engineering project could be loaded into the computer in a week's time. On-line engineering reference libraries are needed to streamline this process. On-line technical reference data must be maintained in a format that is accessible and usable by the engineering tools. Some examples of the information that might be contained in these electronic libraries include:

- production process models and data,
- generic manufacturing systems configurations,
- machinery and equipment specifications,
- vendor catalogs,
- recommended methods, practices, algorithms, etc.
- benchmarking data,
- typical plant/system layouts,
- cost estimation models, labor rates, other cost data,
- budget templates,
- time standards,
- project plans,
- laws/government regulations, and
- industrial standards.

The libraries would minimize the amount of time that the engineer spends entering data. They would also allow engineers to quickly develop solutions based upon the work of others. This on-line reference capability does not exist today.

Another critical aspect of this engineering environment is affordability. The engineering capabilities are needed by large and small manufacturing firms alike. Affordability can best be achieved by designing an environment which can be constructed from low cost "off-the-shelf" commercial products, rather than custom-built computer hardware and software. The basic engineering environment must be affordable. For both cost and technical reasons, it must be designed to be extensible, i.e., support incremental upgrades. Incremental upgrades would allow companies to add capabilities as they are needed. Commercial software products must be easy to install and integrate with other software already resident in the engineering environment. These capabilities exist to a limited extent in some general purpose commercial software today, e.g., word processors, databases, spreadsheets. Some installation and integration problems have been resolved in these software packages through vendor acceptance of certain "de facto standard" file formats. Both technical and legal problems have resulted from current dependence upon this type of standard within the software community. In any case, there are virtually no existing standards which directly support the installation and integration of software tools within a CAMSE environment.

3. TECHNICAL ISSUES

A number of technical issues must be considered in the design and development of new engineering tools for the CAMSE environment. These issues include:

- required functionality of the tools themselves,
- formalization and refinement of relevant engineering methods,
- underlying data management schemes (e.g., object-oriented approach),
- development of on-line technical reference libraries,
- user engineering and graphics visualization techniques,
- system connectivity and information sharing, and
- integration standards for the computing environment,
- incorporation of intelligent behavior in the tools.

A common conceptual foundation and systems framework for CAMSE could help developers address these issues. Three critical elements of this foundation are: 1) a common manufacturing systems information model, 2) an engineering life cycle approach, and 3) a software tool integration framework. These elements will help ensure that independently developed systems will be able to work together and share information.

The common information model should identify: 1) the elements of the manufacturing system and their relationships to each other, 2) the functions or processes performed by each element, 3) the tools, materials, and information (i.e., data) that are required to perform those functions, and 4) measures of effectiveness for the model and its component elements. There have been a number of efforts over the years to develop information models for different aspects of manufacturing [4], but no known existing model fully meets the needs of computer-aided manufacturing system engineering. A review of the strengths and weaknesses of existing models is beyond the scope of this paper.

A life cycle approach is needed to identify all of the different processes that a CAMSE environment must support. This "cradle-to-grave" approach to system engineering would define all of the phases of a manufacturing system or subsystem's existence. Some of the major phases which may be included in a system life cycle approach are: 1) requirements identification (includes product specification), 2) system design specification, 3) vendor selection and procurement, 4) system development and upgrades, 5) installation, testing, and training, 6) production operations, process monitoring, and benchmarking, and 7) system phaseout and resource recovery. Management, coordination, and administration functions need to be performed during each phase of the life cycle. Phases may be repeated over time as a system is upgraded or re-engineered to meet changing needs or incorporate new technologies.

A software tool integration framework would specify how interoperable tools could be independently designed and developed. The framework would define how CAMSE tools would: 1) deal with common services, e.g., user interfaces, peripheral devices, operating system, databases, 2) interact with each other, e.g., exchange data, maintain data integrity, resolve conflicts, and coordinate problem solving activities. Although some existing software products and standards currently address the common services issue, the problem of tool interaction remains largely unsolved. The problem of tool interaction is not limited to the domain of computer-aided manufacturing systems engineering--it is pervasive across the software industry.

4. CURRENT WORK

An initial computer-aided manufacturing system engineering environment has been established at NIST from commercial off-the-shelf (COTS) software packages. These packages have been installed on a high performance personal computer. The engineering environment is being used to: 1) demonstrate tools that are commercially available to perform computer-aided manufacturing system engineering, 2) develop a better understanding and define functional requirements for individual engineering tools and the overall environment, 3) identify the integration issues which must be addressed to implement plug-compatible environments in the future. There is no overall integration scheme or sharing of data between the tools in the current environment. Some point-to-point integration and data exchange is possible between selected tools using available data exchange formats, e.g., IGES. The environment reveals many of the integration problems faced by potential users of manufacturing system engineering environments.

An engineering demonstration using COTS tools is currently under development by project staff. The demonstration scenario is based upon a valve manufacturing facility. The scenario is designed to illustrate the various types of functions that must be performed in engineering a manufacturing system. Functions supported by the current COTS environment include: system specification/diagramming, process flowcharting, information modeling, computer-aided design of products, plant layout, material flow analysis, ergonomic workplace design, mathematical modeling, statistical analysis, line balancing, manufacturing simulation, investment analysis, project management, knowledge-based system development, spreadsheets, document preparation, user interface development, document illustration, forms and database management. Additional tools are currently under consideration for incorporation into the COTS environment.

Other ongoing project activities include: an extensive survey of existing manufacturing system engineering tools, the development of a preliminary requirements specification document for future integrated CAMSE environments, and industry workshops.

5. SUMMARY AND CONCLUSIONS

This paper has outlined a vision for a computing environment for engineering manufacturing systems. Such an engineering environment would provide an integrated set of tools to improve the productivity of manufacturing and industrial engineers. An initial environment based upon commercial, off-the-shelf tools has been assembled on a personal computer at the U.S. National Institute of Standards and Technology. The full potential of this engineering environment cannot be realized today due to the incompatibilities which exist between commercial software packages. Incompatibilities could be minimized in the future through the establishment of industry-wide consensus on common models and frameworks for engineering environments. Achievement of this goal will undoubtedly require a concerted effort by system developers, users, research institutions, and standards organizations over a several year period.

6. REFERENCES

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