A CONCURRENT ENGINEERING MODEL OF THE DESIGN AND MANUFACTURING PROCESS FOR ELECTRONIC ASSEMBLIES

by

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Abstract:

The global marketplace for manufacturing of electronics has become increasingly competitive and promises to become even more so in the next decade. In order to remain competitive, U.S. manufacturers must utilize the abundant resources of the information age along with the philosophy embodied by Concurrent Engineering to reduce costs and improve efficiency in all aspects of their enterprise. Westinghouse Electric Corporation's Electronic Systems Group has given high priority over the past five years to reducing the life cycle cost of products through the application of concurrent engineering methodology. Leveraging the development of individual software tools with systems level integration projects, a concurrent engineering infrastructure is being created within the development and manufacturing organizations. This infrastructure has and will continue contributing to overall reduction in product development time and cost as well as capturing information from processes and individual engineers to be used in subsequent designs.

Introduction

A widely accepted definition of Concurrent Engineering (CE) identifies it as "a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements."[1] A 1990 survey by *EDN News* revealed that 51% of engineers consider knowledge of manufacturing issues unimportant.[2] It is imperative that these engineers understand CE and begin to use its concepts.

Concurrent Engineering is both a formal as well as an informal process. The basic essence of CE involves convincing the appropriate personnel that they will benefit from embracing the doctrine of CE. Although quite a few engineering and manufacturing personnel have been using CE for many years, it has been the informal part of the equation such as small meetings between design and manufacturing and design reviews which have been the sole extent of the practice. Although the results of these interactions are not captured as an independent metric, they have a definite effect on lowering the overall product cost. The human interaction portion of CE is important in order to maximize the use of specific skill sets and the information gained through years of experience, yet it seems prudent to develop the means to capture these skill sets and information through the use of specially designed software tools and integrated systems.

The formal nature of concurrent engineering involves the specific meetings that are set up to allow design and manufacturing personnel to exchange producibility information and the tools, both hardware and software, that are put in place to allow this exchange of information. Making this exchange of ideas more efficient reduces the overall life cycle cost of the product. The aforementioned concepts will be explored as part of a paradigm for the entire concurrent engineering architecture involved in the design and manufacture of electronic assemblies.

Discussion

Westinghouse Electronic Systems Group (ESG) has been involved in several CE initiatives as well as development of independent software tools over the past several years to support CE efforts. Descriptions of several of these initiatives are as follows:

> ***Advanced Quality Engineering System (AQES)*** - a U.S. Air Force Phase II Industrial Modernization Incentive Program (IMIP) to improve quality through the design and integration of a toolset which included: on-line specifications and requirements, a Process Capability DataBase (PCDB), manufacturing process simulation, and an expert system for design analysis (Integrated Product Engineering eXpert -IPEX).
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> ***DARPA Initiative for Concurrent Engineering (DICE)*** - a Defense Advanced Research Planning Agency (DARPA) funded program investigating the application of advanced computer science technologies, such as object-oriented databases and blackboard architectures, to the problem of concurrent engineering.
>
> ***Intelligent Manufacturing Decision Support System (IMDS)*** - a knowledge based system for capture, storage, and retrieval of engineering issues based on object-oriented data structure, being developed in conjunction with University of Maryland Baltimore County under the Maryland Industrial Partnerships (MIPS) program.

Leveraging these and other programs against each other, ESG has been able to develop an enterprise-wide CE architecture which will lead to lower product cost, reduced cycle time, and a more reliable product.

The most widely used approach to concurrent engineering involves concentrating on the communication links between design and manufacturing engineering in order to increase producibility and reduce cost. Although this approach shows rapid return on investment and is one of the key problem areas in a product life cycle, it is only by looking at the entire design and manufacturing process that we can truly embrace concurrent engineering and reap the benefits of a totally integrated life cycle.

The most widely accepted method of developing and manufacturing a new electronic product has consisted of a sequential process as follows:

1) Customer provides requirements to electrical and mechanical designers
2) Electrical design is performed
3) Mechanical packaging design is performed
4) Manufacturing is given completed design to build

There are a number of inputs and outputs associated with each of these four tasks which cross disciplines and from which benefits could be derived by maintaining a single source of data with the most knowledgeable functional group responsible for the integrity of the data.

The central focus of the product life cycle is the actual mechanical packaging design of the product. It is at this point that the customer requirements are translated into reality and the final product takes shape. It is for this reason that we have concentrated our efforts on feeding information to this point in the life cycle and also using this as a checkpoint in determining producibility of the product. If information from other points in the product life cycle can be fed back to the mechanical designer, the final design will be more producible and at a lower cost with less effort expended.

The implementation of a total concurrent engineering paradigm can be divided into several logical subsystems each containing a combination of data repositories, decision making systems, human inputs, data formatting and transfer systems, and feedback loops. The subsystems and their components which are integrated to form the completed CE system (figure 1) are as follows:

- **Inputs to Mechanical Design**
  - Customer requirements & specifications/standards
  - Electrical design information
  - Parts characteristics database
  - Bill of Materials database
  - Requirements database
  - Westinghouse Information System for Engineering (WISE)
- **Outputs from Design**
  - Batch data for transfer to IPEX and generation of a producibility report
  - Final CAD data
- **Data to Manufacturing**
  - Process Capability Database
  - Post-processor (EDGE)
  - Inputs from parts characteristics database, Bill of Materials database, Final CAD data
- **Manufacturing**
  - Inputs from post-processor
  - Process simulation
  - Factory Local Area Network (LAN)
  - Cell Controller
  - Outputs in the form of "as-built data" database
- **Expert System**
  - Inputs from "as-built data" database, Process Capability Database, Requirements database, and Parts characteristics database
  - Knowledge Base Committee to determine rules for expert system (IPEX)

Inputs to Mechanical Design

The initial information provided to the designer of a new system includes a set of customer requirements describing the system performance as well as what quality standards the system must meet during design and manufacture. Designers will typically sift through this information manually, form an initial design concept, and, through a series of iterative redesigns, develop a final design which meets all of the necessary requirements.

Automation of this initial phase of product design can greatly reduce the time required to determine conformance to specifications and requirements. The creation of databases to house information with regards to Bill of Materials (BOM), parts characteristics, and applicable design requirements allows this information to be presented to the designer in a tailored format based upon the specific project. The existence of a parts characteristics database contains vendor information on numerous parts which are used in electronic design to permit rapid access to data which is normally found in catalogs. The Westinghouse Information System for Engineering (WISE) allows the designer to access Contract Specification Requirements Data (CSRD) and BOM data while an On-Line Military Specification Access workstation provides access to documents such as Mil-Std-2000 with applicable tailoring from the CSRD. As opposed to sorting through the total data available, the designer is given a specific subset of information from which to create the design. This reduces investigative time and allows the designer to concentrate on the actual physical design task.

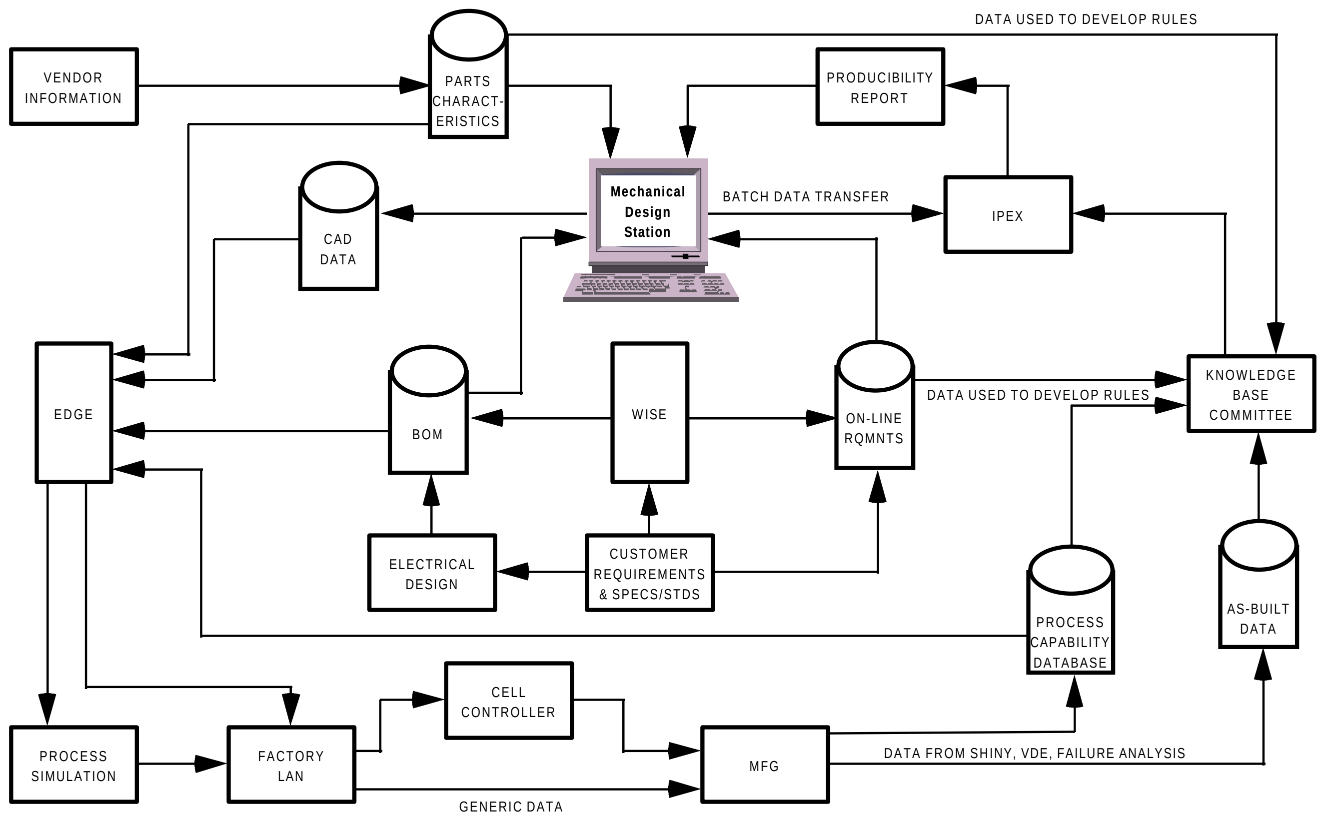

Figure 1

Outputs from Design

There are actually two different outputs from the design process. The intermediate output is the design being iterated by the CE team based on customer requirements, inputs from the designer, and other appropriate factors such as product cost. Final output is a package consisting of the CAD data which describes the design along with the finalized BOM for use by manufacturing in actually assembling the product. The intermediate output is the area where much effort has been and will continue to be focused by Westinghouse. In this paradigm, an expert system (IPEX) has been developed which operates on the intermediate data to determine the producibility of the design according to inputs from several sources. (discussed later in this paper) The result of this analysis is a producibility report which will inform the designer as to the actual manufacturability of the design based on the current factory, equipment, parts, and preset design restrictions. Once the expert system and CE team has determined that the design meets the required producibility guidelines, the design is released to manufacturing via the BOM and CAD data.

Data to Manufacturing

Manufacturing, upon receiving a completed design, must have in its possession enough information to drive its own decision-making process and provide appropriate information to assembly equipment and personnel. A post-processing system must be in place to convert the CAD data and BOM list to information which can be utilized in the Computer Integrated Manufacturing (CIM) environment. An Expert Data GEneration system (EDGE) provides this post-processing capability acting on information from the Parts characteristics database, BOM, and CAD data. The purpose of this system is twofold:

- Convert BOM information to useable factory data by looking at raw information on parts such as lead position, temperature restrictions, and materials compatibility and to determine the assembly sequence.

- Convert CAD data to a format which can be used by automated machinery such as pick and place robots and automated inspection systems.

The existence of a Process Capability DataBase (PCDB) containing information on each process would also be used to feed this processor. An example of information contained in this database for an IR oven would be:

- belt speed - min and max
- temperature - min and max
- product size limitations - min and max
- data available for capture such as date and time of process and temperature readings
- maintenance requirements
- known process problems which can be eliminated by a change in the design or assembly sequence

Processing the design data against the information contained in the PCDB would give manufacturing the best possible assembly scenario. This would eliminate potential problems based upon an improper assembly sequence or incorrect use of equipment.

Manufacturing

Once the design information has been processed into a form which is useable by manufacturing, it is provided via one of two paths. Much of the information is now accessible directly by the assembly equipment since it is in the form of placement instructions and handling data. This information is directed across the factory information network (as generic data) to the appropriate machines. Cell controllers would serve as interfaces to pass required process data to non-intelligent machines. An additional use of the processed information is to use it as input for computerized simulations of the manufacturing processes such as soldering and cleaning. The results of these simulations are used to set machine parameters for the particular product. By simulating the process on a computer to predict assembly parameters, the process engineer is relieved of the need to run multiple assemblies in order to develop process parameters.

The results of each manufacturing process and any subsequent inspection operations are passed to a database containing "as-built" data. This data is used to analyze the results of the build cycle for the particular design in order to generate new knowledge for subsequent product designs. This data also is used to perform Statistical Process Control (SPC) analysis on the manufacturing processes in order to keep the process in control. Additionally, information regarding specific processes or equipment is entered into the Process Capability DataBase (PCDB) for access by engineers or other systems interested in determining the current factory and equipment capabilities

Expert System

The Knowledge Base Committee (KBC) and its inputs to the Integrated Product Engineering eXpert (IPEX) knowledge base are the most critical part of the entire paradigm. It is the function of the KBC to determine what information from each area of the product life cycle is appropriate for inclusion as rules in IPEX's knowledge base. Information from the "as-built data" database, process capability database, requirements database, and parts characteristics database is used to make rules determinations The resulting knowledge base is the sum total of the information available to the designer for designing the most producible product in the existing factory environment and according to the requirements imposed by the customer. Validation of the information contained in IPEX will lead to future designs being produced faster, with less iterations, and in a manner consistent with optimal process parameters in the manufacturing environment.

Benefits

A key part of implementing concurrent engineering and identifying the savings from its implementation is the definition of metrics with which to measure the savings. The identification of metrics for improvements to white collar productivity is not as straight forward as identifying savings in a factory environment. Using metrics such as the following:

- final product cost versus target cost
- cycle time from initial concept to delivery of first production article
- number of issues generated before and after design review
- number of revision notices (RNs) generated after final design release
- rework and yield levels
- scrap rate and cost

projected savings in the areas of hardware design development and transition to production have been estimated within the following ranges:

Subfunction	Projected Improvement
Hardware Design Development	5-15% labor 5-15% material 10-20% cycle time
Transition to Production	5-15% labor 5-15% material 10-20% cycle time

The rationale for projecting these savings based upon the described architecture include:

- Improved effectiveness of the communication process by implementing analysis and reporting tools that provide timely, relevant, and complete information.

- Reduction of paper reports and outdated information through the use of on-line data access and real time reporting.

- Reduction in training time for new personnel through the use of standardized user interfaces to access information contained in IPEX and PCDB.

- Reduction in data entry time through the used of shared data which is entered at the point of data creation (in keeping with the enterprise data concept).

- Reduction in cycle time for RNs and ECNs due to faster access to required information for decision making.

Actual implementation on several major programs have produced documented savings as follows:

Program	Savings	Key Area of Savings

A	40%	Cycle time reduced from 10 to 6 months on digital modules through simultaneous process development and mechanical design for real-time feedback prior to final design release.
B	75%	Development of microwave modules reduced from 60 to 14 days
C	35%	Program schedule reduced from 24 to 16 months by improved flowdown of requirements and use of "heritage" (previously used) design information

The reason for the large discrepancy between projected and actual savings is due to the nature of individuals to underestimate goals which they are trying to attain. The 35-75% savings are consistent with those found in several case studies at other corporations.[3]

Conclusions

The completed architecture identifies all of the components required to institute a formal toolset for concurrent engineering in an electronics design and manufacturing environment. Many of the items in the toolset are already in existence in most companies in one form or another. The major task is to establish the methodology for integrating the available pieces and working towards an integrated system with each of the subsystems operating together for maximum efficiency.

The implementation of a Concurrent Engineering paradigm will provide numerous benefits with regards to designing and manufacturing electronic assemblies. Measurable savings will be realized in each independent step of the design and manufacturing process and also in the product life cycle as a complete entity. Management must recognize the informal part of the CE equation and support this effort when quoting for new opportunities. The formal structure for CE should also be considered and a strategic plan put together to include both the infrastructure and the tools/equipment to support this effort. Although the initial steps to embrace CE may seem to be a divergence from traditional design and manufacturing methodologies, in reality, they are only an acceptance of what must be done to compete successfully in the global economy. The end results of implementing CE will be lower product development cost, shorter concept to delivery time, and a design which better meets the requirements of the customer thus placing the CE practitioner in a position to compete successfully in the global economy.

Acknowledgements

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[1]*IDA Report R-338*, "The Role of Concurrent Engineering in Weapons System Acquisition," Winner, Robert I. et al., IDA, Alexandria, Va
[2]C. J. Murray, "Design's Hot Trend: Concurrent Engineering," *Design News*, 54-60 (July 8, 1991)
[3]S. Evanczuk, "Concurrent Engineering - The New Look of Design," *High Performance Systems*, 16-27 (April 1990)