Implementing Concurrent Engineering Through Rapid Prototyping and Manufacturing - An NSF-Funded Project

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Introduction

Over the last 10 years the manufacturing sector in the U.S. has applied several tools, strategies, and philosophies to reverse declining trends in the global marketplace in an attempt to improve productivity, flexibility, time to market, product quality and reliability, and to reduce costs. Concurrent engineering has been successfully deployed to achieve all of the preceding benefits and has attracted significant attention from the manufacturing community worldwide. Concurrent engineering may be defined as the design of the entire lifecycle of a product simultaneously using a product design team and automated engineering and production tools. The definition underscores the importance of two key factors - people and equipment, with an emphasis on their interdependence upon each other.

Concurrent Engineering

It has long been recognized that as much as 70% of the production costs of a manufactured part are tied to the engineering design process[1]. These costs are defined implicitly by the materials, dimensions, tolerances, surface finishes, and other parameters that determine processing costs[2]. The "shadow casting" shown in Figure 1 highlights the need to incorporate manufacturability and assemblability concerns early in the design cycle. It has also been recognized that while design defects are relatively inexpensive to rectify at the conceptual/initial design stage, not much can be done once the design process has been completed and initial production begun. The stair-step phenomenon shown in Figure 2 demonstrates the relative costs associated with design changes at various stages in a product's development and release, and clearly highlights the importance of getting the design right the first time[3].

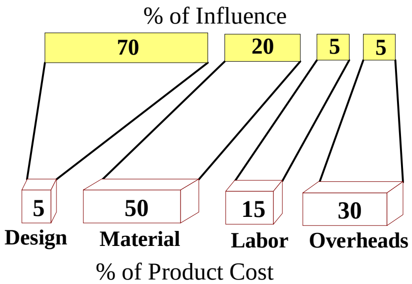


Figure 1. Shadows Cast by Product Costs

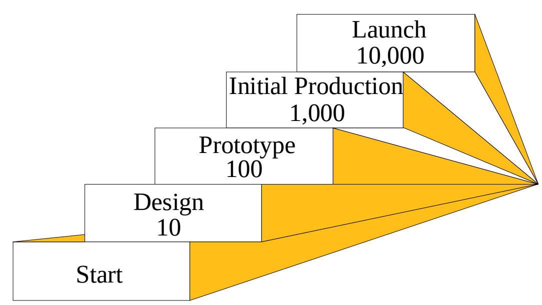


Figure 2. Design Changes and Cost Escalation

Traditional processes for design have seen a lot of functional isolation between various disciplines in a manufacturing organization leading to the age-old cliché of product designers tossing designs over the wall to the manufacturing engineering staff. This may cause the latter considerable chagrin, when presented with features that are difficult to manufacture or tolerances that are inconsistent with the process capabilities of existing equipment. When disciplines such as manufacturing, assembly, field maintenance, quality control, and marketing, are denied the opportunity to provide their input to designers at an early stage, the effects can be very drastic. The serial nature of this process, as demonstrated in Figure 3, causes the time to market to be lengthened considerably under the best of circumstances. This state of affairs cannot be tolerated when competitiveness and even survival are governed by an organization's flexibility and responsiveness to market needs, and time to market has become the dominant paradigm for world class manufacturing.

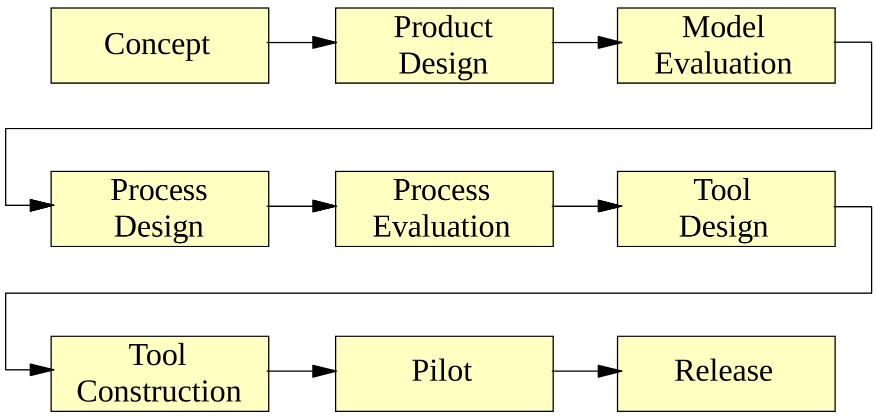


Figure 3. Traditional Engineering Process

The concurrent engineering approach, as shown in Figure 4, seeks to detail the design while simultaneously developing production capability, field-support capability, and quality[4]. The methodology features multifunctional teams that apply tools in the form of algorithms, software, and techniques to achieve concurrency in product, process, tool and system design.

Tools or schema for concurrent engineering include

1. Design for Manufacturability/Assemblability (Including design for manufacturability, design for assemblability, failure-mode and effects analysis, and value engineering)
2. Design for Quality (Including quality function deployment, Taguchi methods, benchmarking)
3. Design for the Life Cycle (Including testability / inspectability, reliability / availability, maintainability / serviceability / supportability, spare requirements / integrated logistics support, upgradeability, installability, safety, human factors, disposability)
4. Design for Cost (Including product cost models, and relationship of cost estimating and modeling tools)

The method is heavily dependent on the expertise and judgment of the individuals that make up the team. Other imperatives in concurrent engineering include strong leadership, continuous interaction among members of the team, and a focus on program objectives . As an approach concurrent engineering significantly decreases time to market, enables faster product development, improves the quality of new designs, lowers work in progress, results in fewer engineering change orders, and increases productivity. Rapid prototyping is an enabling tool for concurrent engineering, the technique and its application at GMI will be discussed in following sections.

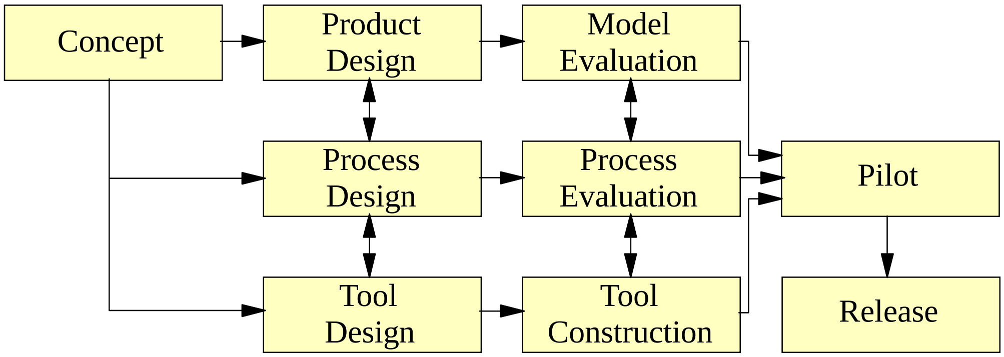


Figure 4. Concurrent Engineering Process

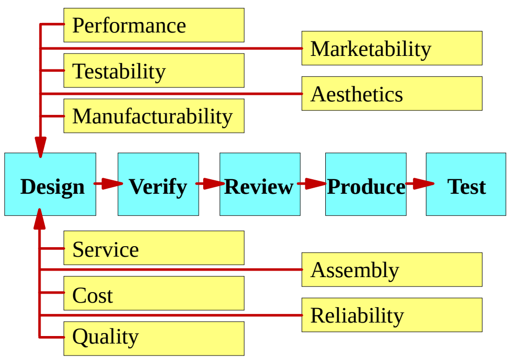
Role of Rapid Prototyping and Manufacturing in Concurrent Engineering

The stages of analysis, verification, design evaluation and review associated with product design may be undertaken using computing equipment and by building prototypes for experimental testing. Rapid prototyping and manufacturing (RP & M) is an effective tool that allows the concurrent engineering design team to undertake engineering analyses and verification within the product and process cycle, shortening the time-to-market cycle. Specifically RP & M offer the concurrent engineering team the following advantages:

1. Visualization: By allowing the team to look at a physical part, they are assured of the presence of desired design features and accuracy of the design without the complexity and (occasional) uncertainty accompanying CAD images and their interpretation.
2. Verification: Design teams often have to compromise on the quality of a part when the pressures of time do not permit full analyses or design improvement. R& M enhances the quality of the design by allowing the team to verify that the design contains the features that are desired, and conversely does not contain any features that are not desired. This allows the team to spend the freed up time on functional testing. In addition, RP techniques which employ a photo-resin (like SLA) result in prototypes that are “photoelastic”, that is, they can be placed in the presence of polarized light and, under loading conditions, seen in service, stress analysis can be conducted to locate stress concentrations within the part.
3. Iteration: The time and cost reductions of RP & M as compared to the methods used in conventional prototype builds allows design teams to go through multiple design iterations in a reduced amount of time
4. Optimization: The usage of RP & M allows design teams to play the “What if” game in design optimization after having achieved an acceptable design without excessive expenditure and time invested in the venture

5. Fabrication: RP & M can be used to extend the role played by the prototype and take it into the realm of functional testing by using the prototype to generate tooling using techniques such as silicon room temperature vulcanizing (RTV) molding, investment casting, and sand casting of aluminum and ferrous metals. The tooling is derived directly from the prototype, giving rise to the term rapid tooling.

The features and advantages of rapid prototypes make them very useful in the development of robust and manufacturable designs and are thus of considerable interest to concurrent engineering design teams.



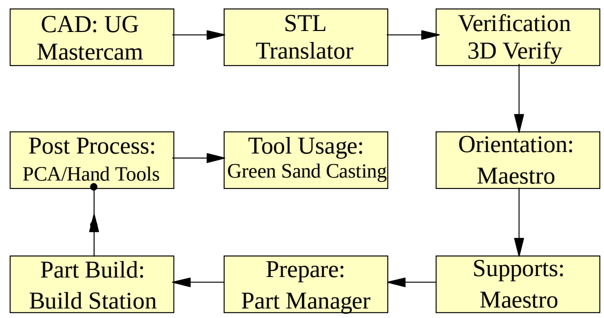


Figure 5: Role of RP & M in Concurrent Engineering

Figure 6: RP & M Process

Application at GMI

The current application at GMI involves three laboratories/functional areas/courses: polymer processing, computer integrated manufacturing, and metal casting. The application at GMI is as shown in Figure 6. Development of a new product will commence with concept development and selection. At this early stage various groups of students from the three functional areas interface with each other and bring producibility issues to the table. A single solid model of the part to be built drives the entire process. The developed solid model is then examined and modified in order to meet the producibility constraints that have been dictated by the various student teams. Parts are initially modeled and visualized using Unigraphics. A tessellated model - STL format is verified for the robustness of the tessellation and then exported to the Maestro software.

Here the part is prepared for prototyping by positioning it in the positive XYZ-workspace and orienting it for an optimal build. Once this has been done, supports are generated and merged with the model using the Partman spreadsheet-like software. In addition, build parameters are set for the resin used and building style desired, and the resulting geometry is sliced into layers that will be cured by the He-Cd laser of the build station.

The build station is then activated and it accesses the common database to download the files necessary for building the prototype. The completed prototype is drained of excess resin, supports are removed, the part is cleaned with alcohol, and cured in the Post Cure Apparatus (PCA) to remove the "tackiness" of the part. The post-processing may be completed by operations such as sanding, buffing, painting, and dyeing depending on the application. The current application will require buffing/sanding for post-processing since the prototype will be used as a pattern for green sand casting in the foundry.

Once the prototype has been built, it can be used by the students for design verification and analysis, functional testing, as a tool for process planning, fixture design, tool design, prototype tooling. At GMI the process will continue with the prototype part being used as a pattern for sand casting. Castings will then be poured in the foundry and machined in the CIM Laboratory. Once again the common geometry will be accessed by computers running CAD/CAM software and toolpaths for the NC machining process will be generated and downloaded to the CNC machines in the laboratory. The prototypes may be inspected using a Coordinate Measuring Machine to verify the accuracy of the tooling being used for the green sand casting process. Inspections may also be carried out on the finished product. Finished products will then be available for further work. An example of a project may be found in a 6-piece tetrahedron that was first designed by students in the CIM course in the Summer of 1995. Over the coming year the tetrahedron will be subjected to the 9-step process that has been outlined in this section and will be terminated with the robotic assembly of the parts.

Students from all three areas benefit by being able to relate the nuances of course and laboratory material being covered in their individual areas to the overall manufacturing process and to the objectives of the overall curriculum. The Manufacturing Systems Engineering curriculum benefits from the addition of the SLA equipment in two ways. The RP & M laboratory enhances the level of sophistication of product design and manufacture in the curriculum and also facilitates curricular integration. The introduction of the RP & M equipment also helps the positioning of the various courses and laboratories as components of the Integrated Manufacturing Enterprise Environment at GMI.

Conclusion

The manufacturing engineer of today and the coming century needs to be an individual with a variety of technical and interpersonal skills. S/he will serve her/his community in diverse roles as technical specialists, operations integrators, and enterprise strategists[5].

What industry needs from its graduate engineers are people that are conversant with various technical tools, and have the people skills that go with deploying these tools. Training for this environment is facilitated by the RP & M environment being developed at GMI.

What has been proposed and is being implemented is a methodology that is extensible to other areas within the Manufacturing Systems Engineering program, and to other engineering disciplines within the institution.

Finally, this environment is replicable by educational institutions wishing to provide their students with integrated curricula and an experience in concurrent engineering education.

Acknowledgment

The authors gratefully acknowledge the support from the National Science Foundation through NSF ILI-IG program grant DUE-9452248. They also wish to thank 3D Systems, Inc. for their support in developing the RP & M facility. They are grateful for the support provided by the staff of EDS, Flint and the Cadillac Luxury Car Division, General Motors, Flint for their assistance with the installation and maintenance of Unigraphics software. Finally they acknowledge with thanks the hardware support provided by Brent Friday, Senior Lab Technician ; the networking support provided by Scott James - Lecturer of Industrial Engineering; and the maintenance and system administration provided by Art Leonard and Matthew Kramer - students and part-time employees at GMI.

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