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# AN OVERVIEW OF FULLY INTEGRATED DIGITAL MANUFACTURING TECHNOLOGY

Scott Freedman

Deneb Robotics, Inc.
5500 New King Street
Troy, MI 48098-2615, U.S.A.

## ABSTRACT

Typically, the Winter Simulation Conference has generally focused on Discrete Event Simulation and Capacity Modeling. This paper will discuss integration of several of the engineering simulation systems involved in the design and manufacturing of capital intensive products. The purpose of this paper is to foster discussion on the benefits of an integrated data environment for design through production.

## 1 TRADITIONAL ENGINEERING

Recently there has been a move towards simulation in the manufacturing process. In the past, manufacturing companies have used many types of unrelated simulation systems. Mechanical engineers use mechanical models such as Finite Element Analysis to model stresses on static parts and Dynamic Analysis to model stress on parts in motion. Industrial Engineers use Discrete Event Simulation to simulate throughput and potential production problems. In between these two disciplines lies a large gray area. The wall that has been built between engineering and production constitutes the real need of the production staff to verify that a design can be built.

When engineering releases a design, the design would typically have gone through numerous revisions and prototypes. In the case of capital intensive products (i.e. aircraft), prototypes are extremely costly and time consuming. For a company to be competitive, they must circumvent the need to prototype everything. The result is that many designs are released with errors that the manufacturing staff is expected to pick up and repair on the shop floor.

Yet, in the case of aircraft manufacturing, numerous jigs and fixtures must be designed to aid the lay up and building of complex wing and fuselage sections. These fixture designs are as critical to the development of finished product as are the parts themselves.

If we look at the traditional model (see Figure 1)of how this type of engineering is done, the process of designing a part then prototyping it from either real materials or mock-up materials such as plywood and cardboard can take weeks or months. Once that mock-up is complete, engineers will find limitations to the design that were not anticipated. The result is Engineering Change Orders or ECO's. Because of the length of this cycle, engineers will frequently have only a few of these change cycles until production schedules force the release of the design.

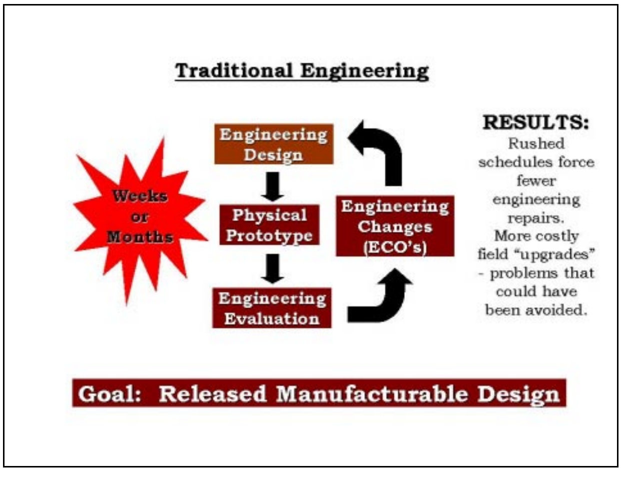


Figure 1: Traditional Engineering Cycle

When this happens, production people will find these errors and typically make notations on their drawings for future builds. This "over-the-wall" style of engineering creates two distinct databases of a design. The first is the design the engineer has, what we call "As-Designed." The second database is what we call "As-Built."

In a company that has good communication channels in place, any changes that manufacturing makes in a design will find their way back to the engineers who designed it. Unfortunately, that is rarely the case. Most companies realize that the As-Built's do not match the "As-Designed" and so are forced to keep both sets of drawings. As revision to the design come along, these As-Built modifications often do not find their way into the design since they were never incorporated into the CAD models.

So what starts out as a nuisance, now becomes a very cumbersome problem of storing two distinct sets of designs, one electronically, the other on paper.

## 2 THE VIRTUAL MANUFACTURING CONCEPT

So why is the status quo a problem? To begin with, the government expects their suppliers to be able to deliver drawings that match their aircraft. Maintenance manuals, spares parts, and field upgrades mandate that pieces fit the way the design says they do.

The problem comes back to the process. It has been too time consuming and costly to mock-up every detail of a design. The only way they were going to improve the design was to change the process. The six-week delay from design to mock-up meant there was time for a fixed number of changes. If the speed of the changes could be increased, the quality of the system would improve. Since the "hard" mock-up was not working as a solution, a software solution needed to be developed (see Figure 2).

Again, from an historical point of view, software tools have been used as a tool to attack individual problems. An example would be the use of CAD. When first released, draftsmen complained that it took much longer to draw a design on a computer than it did on paper. It wasn't until they had to make a large change to the drawing that they saw the benefit to using the software. Now, what would have taken them days to erase and redraw or draw from scratch took only minutes or hours. It was the speed of the change that generated the savings.

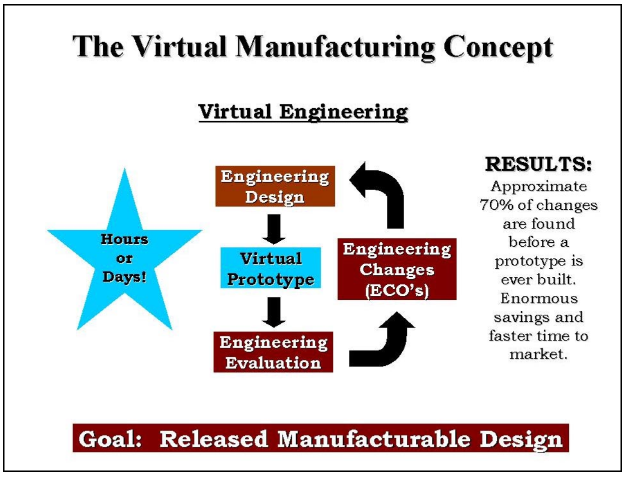


Figure 2: The Virtual Manufacturing Concept

The same is true of Discrete Event Simulation software. Industrial and Manufacturing Engineers have effectively used simulation tools to highlight and solve production problems. The missing link is what has traditionally been called "Design for Manufacturability" or DFM. It's easy to ask engineers to design a product that can be easily built, but without the prototypes or mock-ups to test it, the task is not easy to accomplish. The answer again was to turn to the software industry.

The result is a set of tools and processes initially developed by aircraft manufacturers to solve these disparities. Engineers realized that if they could dynamically check the interference between parts and fixtures, parts and parts, fixtures and people, etc., they could do a better job the first time. While it might take them a little longer to build the first "virtual" prototype, the benefit would be seen later as problems were uncovered and changes were introduced.

In the original model of "Traditional Engineering," a change to the system could take that same six-week delay. In the more dynamic "Virtual" environment, modifications can be tested in hours or days without the need for plywood or plastic models.

So, as in the historical CAD implementation, while a company may spend more time or resources building the original design, it is paid back with the first or second change.

The effect of a change versus the cost of the change can be seen clearly in Figure 3.

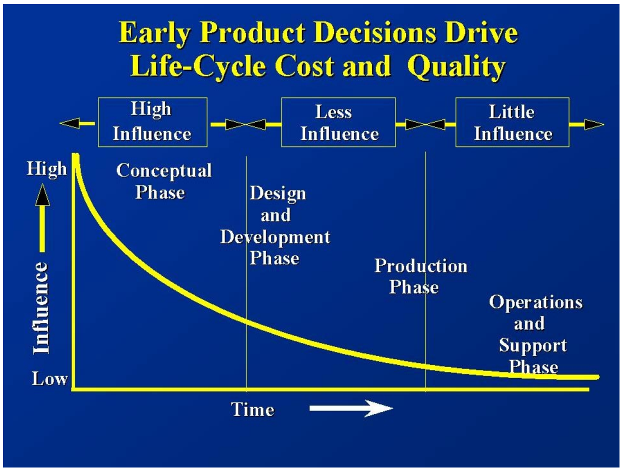


Figure 3: Change vs. the Cost of Change

It is easy to understand how a change can effect the cost of a design. The cost of a change to a design while it is still in the "Conceptual Phase" can be measured on a scale of hundreds or thousands of dollars. We are essentially taking in the cost of the engineering staff's time to review and modify a design. As the design reaches the "Development Phase," other design considerations require modification as a result of the change. Depending upon the process and the work involved, the change can be measured on a scale of thousands to tens-of-thousands of dollars. Once a design has been released and is in the "Production Phase," a change can require modification of manuals, processes, training, jigs, government approvals, etc. It is easy to see how such a change can cost a company tens to hundreds of thousands of dollars.

Use the cost of an automotive recall as an example. While the cost of a modified part may only be a single dollar, the engineering costs to find that error can be tens or hundreds of thousands of dollars. The cost in future sales and marketing may be hard to determine, but the cost of publishing technical bulletins, training of the maintenance personnel, time lost by maintenance personnel on non-billable work, and mailings to consumers all adds up.

## 3 AIRCRAFT MANUFACTURER'S LESSONS

An aircraft manufacturer recently implemented a pilot of a "Virtual Manufacturing" system. The goal was to test and quantify the benefits of just such a system over their current CAD implementation. While they expected certain gains, there were minimal expectations because the pilot was being done on a mature product.

The first surprise was the time required to build the digital model of the fixtures. Prior tests had confirmed that it would require approximately twenty hours for each virtual assembly to be imported from CAD and tested. These models show the parts coming together in the proper order as the assembly is being built.

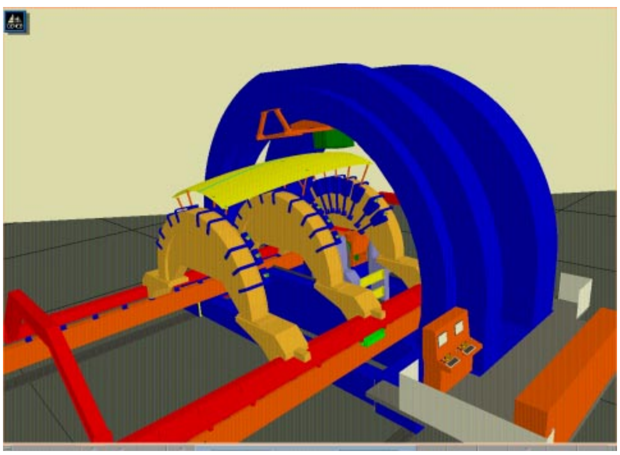

Figure 4: Automated Assembly and Riveting Machine

The product of these simulations is finally delivered to the shop floor as a visual aid to the manufacturing process. The model allows for the testing of interference between the fixture and the parts, tools, and workers. The expected twenty hours turned out to be more like eighty hours. From a support role, there was concern about training and proper application of the toolset. The eighty hours was required because the engineer had to find the fixture on the floor to back-engineer the modifications. As the engineer began building his virtual assembly model, he realized there were errors and their fixture could not be built as designed. The engineer then had to track down the shop personnel that modified the design, find out what the modifications were, then update the CAD files so that the design would work. As a result, this was the first time they had an "As-Built" that they knew matched their "As-Designed." This gave them confidence early on that the application of this type of technology on a new program would greatly reduce the need for production level change orders.

A second unexpected improvement came from their customer, the U.S. Government. Since the program was mature, there were no unrealistic expectations on improving the shop's ability to produce this aircraft. The military knows, however, that budgets for aircraft production is cyclic. They were concerned that a reduction in staffing during one of these downturns would result in a loss of experienced labor. After viewing the virtual assembly models, the customer (U.S. Government) came back with renewed confidence in the manufacturer. They believe it will make the difference in winning future programs for their facility.

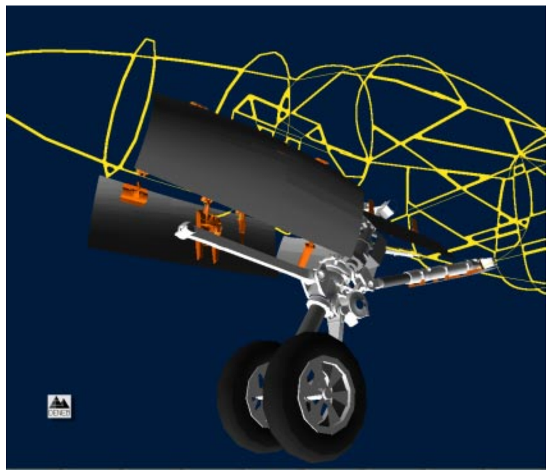

Figure 5: Interference Simulation of a Landing Gear Retrofit

There were additional advantages to the 3-D environment on the shop floor. Workers who had been shimming areas found they had misunderstood the drawings. Although minor in its impact, this discovery on a mature program demonstrates how a change in the design philosophy can reduce the cost impact of a change by a factor of 100x. By moving when a change is discovered from the Production Phase to the Concept Phase, rework and paperwork is reduced or eliminated.

## 4 THE INTEGRATED MANUFACTURING PROCESS

While the application of these simulation technologies has been effective, it is still applying point solutions to specific problem areas. Just as CAD replaced the drawing board, it was a solution to a specific problem, but it didn't change the way the underlying process functioned, it only changed the tools and the speed of the operations.

The next step in the evolution of the manufacturing environment is to an integrated umbrella application that draws from the experience and resources in a company and allows them to set up intelligent models of methods, capabilities and information to drive the engineering and manufacturing processes.

This umbrella application has an expanded scope beyond the typical Computer Aided Process Planning tools. It brings together all of the accumulated product data, processes, resources, and knowledge required to design, engineer, test, manufacture, and maintain the entire car, ship or aircraft. Typically, the knowledge required to drive this application exists within the company, but not in one place or by one person. Data needs to be collected to define the processes, resources, and products. Enterprise wide best practices can be documented and reused.

Using the design and manufacture of an Electric Drill as an example, we can define what pieces of information need to be collected.

First is the process knowledge or library. If you are going to design an electric drill and you have done it before, you would know how to determine the size of the housing, how to build a clutch, how to power it, etc. All of this information is part of the process data that exists within the company. The company can build a knowledge database by capturing all of this information in either a hierarchical format or Gantt chart. Then when the next electric drill needs to be designed you would merely start working down the chart filling in how each of these pieces is going to be modified from the last drill built.

Second would be the product library, meaning the physical parts of the overall assembly, subassemblies, and components that are designed and purchased. Our product library might break out like this:

- Electric Drill
- Electric Cord
  - Wire
  - Plug
- Housing
  - Left side
  - Right side
  - Screws – qty 4
- Motor
  - Etc.
  - Etc.

While the products would be created by whatever CAD system is in use, a PDM or product data manager such as VMP from Enovia or IMAN Unigraphics is required to maintain revision and configuration control within the CAD world. This is fundamental to the operation of the system, since maintaining the correct part revision as changes are made is necessary as different end products can be specified, such as a 110 volt and 220 volt Electric Drill.

Third would be the definition of the resources required to manufacture and assemble the drill. In this case, we might require an injection molding machine, several molds, and two people to run it. The motor winding line may require 5 people, six machines, a curing over, etc. Again, the data would be assembled into a library of resources.

The next step in the umbrella application would be to associate the products to the processes and the resources to the processes. Doing this generates connectivity between the process step, the CAD models, the simulation models, and the resources required.

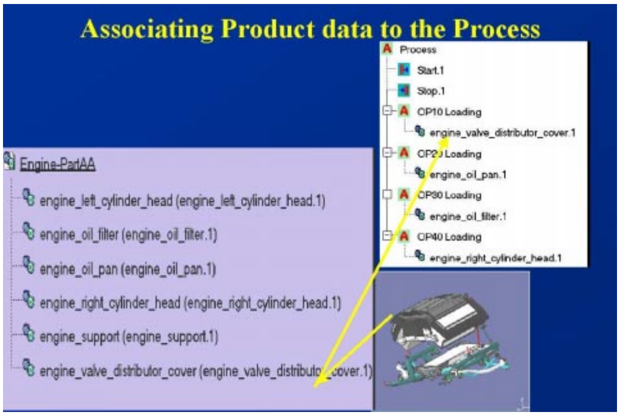


Figure 6: Associating Product to the Process Step

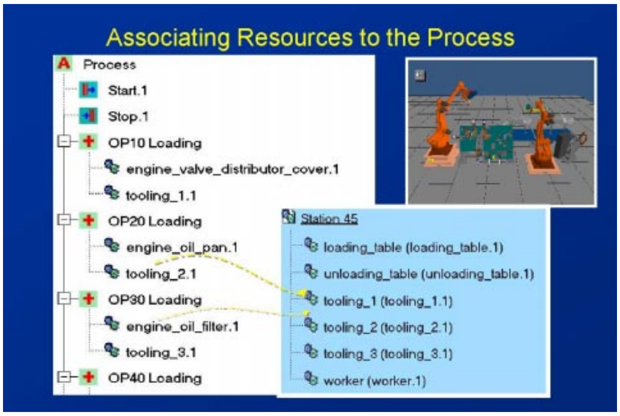


Figure 7: Associating Resources to the Process Step

Once done, we now have a high level manufacturing bill of material, or MBOM. While most of the information is at a black box level right now, it is also in the form where details can be filled in as the design takes shape.

Now is where the software tools come in. Though this umbrella software, we can choose to examine a part, like the drill housing. By selecting the part from beneath the process tree, the appropriate CAD program is launched and the part is retrieved. A selection of multiple parts can then launch the CAD program with those parts all brought up in place on the design. Right now we are looking just at the Products of our design.

In the same manner, we can select those parts and select a simulation engine. The umbrella software can start up one of a number of simulation engines, such as ENVISION™, to look at parts in motion, their interaction and interference. Using the same technique of the multiple select, and with the process information already in the library, a product such as ASSEMBLY™ can be used to build a dynamic assembly simulation that could verify part clearances with other parts, fixtures, jigs, and operators. Since the order of the assembly is already available in the library, the basic sequences need only be modified, minimum distances verified, and changes made to the CAD parts to clean up any problems.

Through simulation, the engineer has now verified that the parts can be manufactured as designed. He can then select his parts and begin using other simulation software such as Finite Element Analysis or Thermal Analysis. Once the part is completed, production capability is verified, and analysis shows the part will operate as designed, the engineer can go back to the umbrella operation and select the part, the machine that will produce it, and the type of file generation he would like to run. In this case, he might initiate a session of INSPECT™ to generate the program for a Zeiss coordinate measuring machine. Because all of the company's best practices are included in the library, the machine code that is generated incorporates all of the part tolerances, the corporate manufacturing standards, and the particulars about the available tooling.

Since all of the simulation software also generates cycle times for the operations, this information is available to the Industrial or Manufacturing Engineer. The engineer can then select on the pieces he wants produced and equipment to model from the umbrella application. The Discrete Event Simulation model will automatically be populated with the proper equipment resources, parts, and processes. The first time the model is run, the engineer will need to place the equipment in the proper location in the 3-D space of the model. From then on, it will retain the location within the environment. Even if a new simulation is started using different parts or processes, the model is able to add or modify the existing simulation model. True cycle times will be imported from the database, statistical variations can be added as required.

## 5 CONCLUSION

The simulation industry has now matured to the point that almost all manufacturing processes and flow of materials through the enterprise can be modeled and validated. The difficulty has been collecting and managing the product, process and resource knowledge base across the enterprise and to maintain configuration management of this common, shared data repository.

The only way to close the loop of design to production is to include all of the processes, products, and resources under a single umbrella application such as RaPP™. The umbrella needs to be flexible, of open architecture to allow any current or legacy knowledge base or system to integrate, and be consistent to all users across the enterprise.

The pilot work being done today is a great leap forward in reducing time to market, errors and field changes, and making a better product for less money. The vehicles you will be driving in 2000 will have been planned, validated and launched using this integrated suite of digital manufacturing applications.

## AUTHOR BIOGRAPHY

**SCOTT FREEDMAN** is the Northeast Regional Manager for Deneb Robotics, Inc., a developer of digital manufacturing solutions based in Troy, Michigan. His background includes sales and consulting in manufacturing simulation, discrete event simulation, and electronic circuit simulation. Scott received a bachelor's degree in Electrical Engineering from Lehigh University.