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Decision Support Tools with an Economic Flavor

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Abstract
This paper discusses criteria for selecting analytical support tools for manufacturing engineering in the early phases of product development, and the lessons learned at Sandia National Laboratories in selecting and applying these tools. Example analyses of manufacturing issues for two product sets in the early phases of product development are presented.

Introduction
The IPPD (Integrated Product and Process Design) process requires manufacturing process developers to be involved earlier than ever before in product development. Early product development is characterized by the lack of detailed data and a plethora of alternatives. Designers have developed various tools to support them in early product development that focus on issues of product performance and quality. Manufacturing engineers, traditionally entering the process later, have focused on manufacturability, quality, and economics for a specified design. Hence, manufacturing process developers do not have an established set of tools to support them in the early phases of product design and the existing designers' tools tend to focus on different issues.

Sandia National Laboratories is responsible for the design and manufacture of certain non-nuclear components for our nation's nuclear weapons. Operating in an IPPD environment, Sandia's manufacturing engineers were required to develop early estimates of the cost and performance of manufacturing plans. In early pre-production, there are very little actual data on manufacturing processes and almost no detailed data on the performance of various manufacturing process steps. The manufacturing engineer needs the capability to analyze various manufacturing process flows over a large set of assumptions involving capacity, resource requirements (equipment, labor, material, utilities,...), yields, product designs, etc. If the manufacturing process involves many process steps, or if there are multiple products in a single manufacturing area that share resources, or there are multiple part starts resulting in merged flow for final assembly, then this analysis capability must somehow be mechanized. This situation led us to look to modeling and simulation tools for a solution.

Approach
Initially the quest was for a single tool to address all the issues of capacity, resources, schedule, and cost. This led to a review of a number of detailed commercial dynamic simulation packages. However, this was the wrong approach, because discussions with the

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manufacturing design engineer and process engineers indicated that the detailed data base needed to run these simulators does not exist in the early phases of product development. So many assumptions would need to be made that the results would be of questionable value and doing parameter sensitivities would be arduous. Another problem is the time and cost involved in developing detailed simulations. The emphasis in the early phases of IPPD are responsiveness and minimum investment in analysis, so one does not have the luxury of time and resources to develop a detailed model.

The Analytical Tools

To provide timely and cost-effective decision support to the manufacturing engineers, we selected two commercial software tools. The criteria for selection were that the tools must: 1) operate with limited manufacturing process data, 2) must work from essentially the same data base, since developing two data bases is costly, time consuming, and requires configuration management, and 3) be commercially available supported products. Desirable but not necessary characteristics were: the tools' data base should operate with MRPII type data and the tools should be useful in later phases of IPPD activities.

The tools selected were a dynamic simulator package called EXTEND® and a steady-state expected value factory model called Factory Commander Model®. The Factory Commander Model (FCM), is a PC-based manufacturing model that provides "rough cut" resource requirements and detailed economic data for meeting a specified demand. An FCM factory model can be developed with limited process data, and sensitivity to process parameters can be evaluated efficiently, because it is an expected value model. However, since FCM is a steady-state, expected-value model it provides no data on queue build-up, WIP, make span, or explicit effects of batch size. These issues must be addressed in a dynamic simulator.

The EXTEND dynamic simulator (EDS) is a PC-based, "point and click" dynamic simulation software tool that has a series of library functions for manufacturing simulation. The "point and click" nature of the tool and the manufacturing library reduce simulation development time. However, the overhead of these features hinders the ability to develop very detailed simulations on a PC. The tool is ideally suited to IPPD use in which the objective is responsiveness and use with limited data.

These two tools can be run from the same data base and they provide results that are complementary and useful for verification. The FCM is used first to provide an estimate of the manufacturing equipment and personnel needed to meet a target production demand. An FCM report that shows the specific process steps performed by each piece of equipment provides the routing information needed to develop the EDS simulation. The FCM equipment and personnel estimates serve as EDS initial conditions, thus guaranteeing a starting condition close to the desired capacity and thus reducing the time required to develop and conduct a dynamic simulation analysis. The FCM's automatically-produced manufacturing flow diagram is extremely helpful in reviewing model correctness with the process engineers. Subsequent EDS simulation provides information on the make span, queue sizes, WIP and capacity of the resources on hand. In sum, this pair of tools constitutes a powerful analysis capability.

The lessons learned from this project are that providing effective and efficient manufacturing support in the early IPPD phases required the use of more than a single model or simulation tool, and they must be selected based on their ability to operate with limited input data and to be developed and applied in minimum time. The tools' ability to support the effort in later phases, while desirable, it is not a necessary selection criterion. In fact, getting bogged down in detailed model or simulation development rather than data collection and process analysis is a pitfall to be avoided by the analyst. The value of a tool is the product of the quality of its results and the probability it will be used. Reduced data requirements, simplicity, and responsiveness greatly enhance the probability a tool will or can be used in the early phases of product development. In addition the ability to do early sanity checks with less detailed models provides the opportunity to detect and correct unreasonable data or assumptions in a timely manner.

Applications

The IPPD efforts supported by the authors at Sandia are the Neutron Tube (NT) and the Active Ceramic Parts (ACP) programs. The NT is a complex product that uses more than 26 purchased parts which are processed and assembled into various subassemblies leading finally to a single product, the NT. The ACP are three products which each have a simple serial process flow, but which share almost 100% of the same resources (equipment and labor). The NT has well over 230 process steps while the ACP individual components have 44 to 90 process steps. The data base for the NT manufacturing process is contained in a 4000 element spread sheet. The data base can be shared with the NT MRPII system, thereby supporting the MRPII data base development.

Active Ceramic Parts Analysis:

The FCM and the Extend models were used to estimate labor and equipment requirements for peak demand years of two ACP Production Plans (Build Plans A & B). The production requirements for Plan B were greater than those for Plan A. The FCM provided "rough cut" estimates of the manufacturing resource requirements. By using these estimates as initial conditions for the EDS model, fewer than five iterations were needed for each build plan to converge to a solution for the additional resources required by the effects of realistic dynamic scheduling. Results, summarized in Table 1, show labor and equipment requirements for three levels of production.

Table 1

	Start-up	Build Plan A	Build Plan B
Labor:			
Machinists	2	4	8
Assemblers	2	4	9
Elec. Testers	1	1	2
Matl. Transporter	0	1	1
Equipment:			
	Existing	Existing Equipment Sufficient	Add: 1 Grinder 1 Saw 1 Microscope 1 Screen Ptr.

The EDS was also used to evaluate the effect of reducing the lot size for Component 1 of the three ACP components, in the context of Build Plan B. Component 1 can be produced in lot sizes of 500 to 1500 components; the baseline discussed above used lots sizes of 1200 components.

The analysis indicated that, by using a lot size of 500, the first lot of Component 1 was completed 4 months earlier than by using a lot size of 1500 (5 months vs. 9 months). The smaller lot size for Component 1 provides a reduction in the make span of all components by reducing their waiting time in queues, thus allowing the lots of the other components to be processed sooner. About a 6% reduction in completion time was observed in the production time for the required lots of the three components.

These decision support tools can also provide a variety of economic analyses. In the case of ACP, the models were used to analyze the standard labor hours per unit for each of the products and then to calculate the cost of standard labor hours. Standard labor time is a mix of seven labor categories.

Another issue analyzed was the potential savings of outsourcing one of the ACP components. With this tool set it was possible to estimate the total cost of the three products at full production and then assess the net saving if one product was outsourced. The analysis indicated that it would be difficult to show a financial gain by outsourcing the product, once a facility was set up and a labor force trained to produce the other two products.

Neutron Tube Analysis:

Thermal treatment furnaces are critical and expensive NT production resources. Initial FCM runs indicated that for low rate production the required number of these furnaces far exceeded the process engineers' early estimates: the initial buy plan was for five furnaces and the initial analysis showed that 10 were needed. Discussions with the process engineers indicated that one of the factors causing this apparent need was that batch sizes were considerably smaller than the capacity of the furnaces. Increasing the lot size to any great extent was not practical but, after further discussions, it was decided that similar parts within a given subassembly could be batched together for a thermal run. Simulation runs at low rate production were made using this batching rule and while the required number of furnaces was reduced to seven this was still unacceptable. Next, by using data on weekly starts at each process step from the FCM and working with the process engineers, a cross-subassembly batching plan was developed. Additionally, there were some process step reassignments made for the furnaces and a second shift was added. The combined effect of these changes showed that the desired high production rate should be met with the addition of only one furnace. Without tools like the FCM and EDS, this type of analysis would be difficult and time consuming, if not impossible.

Summary

Some important lessons were learned in developing this set of analytical support tools for manufacturing process engineering. The key lesson was recognizing the difference between the analytical tool requirements in the different phases of the IPPD activities. These tools were developed to support the manufacturing engineer in the early phases of the IPPD activity. In these phases data are sparse and based on primarily engineering judgement and best guesses. The tools in this phase need to be simple, focused on first order effects, and easy to develop, de-bug, and use. Only 20 percent of our effort was spent developing the tools and running analyses. The majority of the effort was spent collecting the data and understanding the manufacturing processes. While the tools selected and developed in this phase may not be used in the later phases, which focus on detailed process optimization, the data bases developed can be migrated to more detailed tools, and the development of these data is a major resource-consuming activity. Therefore, focus in the early phase is on data collection and tools that will produce the 80 percent solution simply and efficiently. The tools and analytical techniques developed must be simple to encourage and support lots of "what-if" analysis. Exploring alternatives is the hallmark of analytical support in the early phases of process development IPPD activities.

Authors' Biographies

Tom Bomber is an analyst in Sandia's Systems Analysis Center. He worked 20 years in the government and 10 years in industry at Ball Aerospace prior to joining Sandia. Tom's experience includes analyzing a variety of complex weapon systems.

Joe Baxter is an industrial engineer in the System Analysis Center. Prior to joining Sandia, he worked at Digital Corp., BDM, and Martin Marietta. Joe has considerable experience in analyzing manufacturing processes.

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