Economic Feasibility for Production Design: Recent Teaching Experiences

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Abstract

A firm's decision on whether or not to manufacture a new product design requires the economic analysis of many "downstream" production-related factors. This is a very dynamic, iterative process complicated by engineering changes, market forecasting uncertainties, resource availability, refinement of quality criteria, and other factors. However, this type of experience is outside the scope of most project-based engineering design courses. In this paper, a one semester graduate course in "Production Design" is described which attempts to replicate these complex interactions across multiple teams typical of the product realization process (PRP) in industry. Student teams conduct feasibility studies for small/medium-sized production facilities to assess the technical and economic viability of new high-tech products. Students are divided into three to five interacting teams, each with complementary functional responsibility for product redesign, production planning, materials and purchasing, human and plant resources, and economic and strategic planning. This paper focuses in particular on aspects of the class concept related to engineering economics.

Production Design: The Course Concept

Recently, there has been much curriculum development in project-based engineering design courses which introduce product design methodologies adopted by industry such as Quality Function Deployment, Taguchi Method, and various design-for-manufacturing and techniques. Typically, student design projects begin with requirements definition or a concept design phase and end at completion of the detailed design phase. Final project deliverables typically include CAD models, proof-of-concept prototypes, engineering analysis results, and design-for-manufacturing analysis to minimize tooling and material costs. These types of project-based courses in product design provide a very useful student introduction to design team environments typical of many industries. Recent government- and industry-sponsored curriculum development in this area has been significant.

However, industry decision-making about whether and how to proceed with product realization typically involves many other technical and logistic considerations to assess the economic feasibility of downstream production. Our intent in this one semester graduate course has been to create a project-based student experience that explores those "production design" aspects of the *product realization process* which finally result in the set-up (or reconfiguration) and operation of a small manufacturing enterprise (SME). The final class deliverable is a *production feasibility study* to which each team contributes separate chapters. Elements of this study include:

- Product redesign for site-specific and resource-specific production
- Translating quality criteria of the product design into production design for inspection, testing, supplier qualification, ISO-9000 certification, etc.
- Cash flow and scheduling for production planning and ramp-up, including milestones and hurdles
- Human resource requirements: job/task definitions, training requirements, and management structure
- Materials management for raw, in-process, and finished goods
- Supplier qualification, contracting, delivery schedules, etc.
- Financial risk analysis of decision alternatives for production volume, equipment investment, inventory levels, etc.
- Facility layout, equipment selection and installation, power requirements, environmental considerations, etc.

Student-led team projects are initially provided with an innovative but relatively simple product design in sufficient detail to begin production considerations. Also, a business "scenario" is provided which includes marketing projections and data on regionally available sites, labor, and suppliers. Engineers and managers from local high-tech firms provide design data, consult with teams, arrange site visits, and critique the final presentation. Projects in the last four years have included: an assembly facility for portable solar generators; an assembly facility for DNA Image Analyzers; a composite pultrusion facility; a facility to manufacture components for thermoacoustic engines.

One intent of the course design is to replicate the complex interactions across multiple teams typical of the product realization process (PRP) in industry. Data generated by the *Design Team* -- such as assembly diagrams and quality requirements -- are necessary input for the *Production Team*, which must generate process flow diagrams, facility layouts, and requirements for equipment and workers. This in turn becomes input for the *Economic and Strategic Planning Team* which must create a cash flow model that spans initial outlays, production ramp-up, and on-going manufacture. Depending on class size and other factors, two other teams are sometimes created for *Materials and Purchasing* and *Human and Plant Resources*. As in industry situations, inter-team dynamics are inevitably complicated by engineering changes, imprecise specifications, market uncertainties, and other factors.

Determining Economic Feasibility

The final deliverable for this course is a production feasibility study intended as a basis for investment decision-making by upper management and/or outside investors. Consequently, all student teams generate economic-related data which ultimately feeds into the discounted cash flow analysis created by the *Economic and Strategic Planning Team*. Students have previously taken an introductory course in engineering economics, and this provides an excellent vehicle for employing these concepts in a project-based, interdisciplinary context. Tasks for the *Economic and Strategic Planning Team* fall roughly into three stages:

1) *Early Project Tasks*

> Data requirements: determining the types of economic-related data they will need to collect and which teams they must collect from: equipment and site costs, material costs and quantities, labor rates and times, indirect costs, etc. and related time dependencies for production ramp-up. Data requirement lists are distributed to other teams.

> Modeling methods and tools: determining how to integrate data into a discounted cash flow model, designing and implementing an appropriate spreadsheet tool.

> Early trade-off decisions: participating in inter-team decision-making for cost vs. quality and make/buy decisions using only incomplete data available at this stage.

2) *Mid-Project Tasks*

> Data collection: gathering cost data from other teams and potential suppliers; continual updating as production design is refined.

> Base case assumptions: pricing, production volume, minimum attractive rate of return, available financing terms, and other assumptions are developed in project reviews and, when necessary, arbitrarily fixed by instructors.

> Modeling of uncertainty: determining realistic range assumptions for cost data as well as revenue data related to market forecasting.

> Implementing cash flow model: fitting cost and revenue projections to integrated production ramp-up schedule.

3) *Late Project Tasks*

> Model completion and net present value analysis: "freezing" of model assumptions and conducting engineering economic analysis using the spreadsheet tool.

> Sensitivity analysis: both scenario analysis for best/nominal/worst case projections and "spider plot" -type diagrams for production-related variables.

> Condensation of key findings for final report and presentation

Example: Assembly Facility for Portable Solar Generators

One recent project was a production feasibility study for manufacturing portable solar generators. Students were presented with an existing design and physical prototype provided by a local energy consultant: a 200 watt trailer-mounted PV system consisting of a trailer, PV system, battery storage and power conditioning equipment. A participating company provided a tour of a local polycrystal PV manufacturing plant, which the students treated as a potential supplier and asked questions about the quality of their PV product, delivery issues and warranty coverage. The "scenario" required a production target of 1000 units per month for an assembly facility to be sited in the Washington, DC area. An experienced member of the local chapter of the Society of Manufacturing Engineers also provided valuable consultation with students.

The Design Team redesigned the product for production, also improving the deployable PV array for storage during travel (Figure 1). The Production Team planned assembly operations and layout for 12 sub-assemblies with an average of 8 operations each. Simulation software was used to analyze capacity utilization and other workflow issues. Assembly equipment, operations, and other requirements were assessed. The Materials and Purchasing Team determined purchasing costs, along with inventory control, material handling and flow through the factory. They also determined economic order quantities and reorder points. The Human and Plant Resources Team set up the personnel structure. They determined that full production would require a total of 82 employees from unskilled workers to management for a total payroll of $174,000 per month. Job descriptions, training programs, a total quality control program, and safety/ergonomic guidelines were outlined.

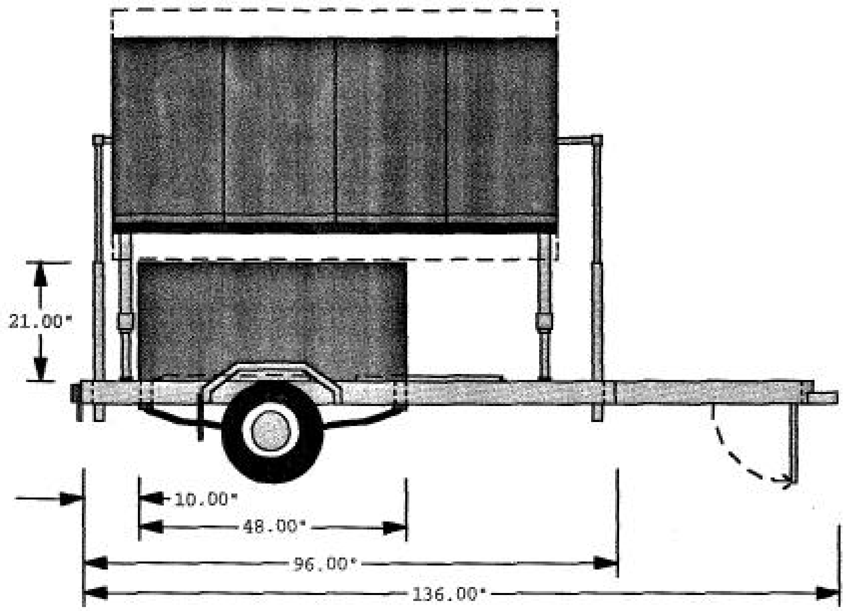

Figure 1: Production redesign of portable solar generator

Mirroring the real world, the team responsible for the engineering economic analysis received cost- and schedule-related information that was repeatedly revised from the other teams cited above due to repeated changes to the production process design. This caused considerable reworking of their cash flow model until the production configuration and ramp-up milestones were frozen at a critical design review in the last quarter of the semester. Sensitivity analysis highlighted profit dependency on material costs and sales prices. Of particular interest was that labor costs were less than four percent of total costs, an important factor for U.S. production feasibility.

One preliminary conclusion of this study was that assembly-based manufacturing for the next generation of solar consumer products may lend itself to efficient small and mid-sized manufacturing start-up companies, at a reasonable level of investment. Portable solar generators and related products require relatively low-skilled labor to assemble electro-mechanical components and subassemblies from more technically-advanced first-tier suppliers such as PV manufacturers. This result was of sufficient interest to solar entrepreneurs to merit publication in an industry magazine [1].

Conclusions

For most companies, analysis of the profit potential of a new product design requires a very dynamic and interdisciplinary process to determine site-specific and resource-specific production requirements. Contributing to this process is an essential skill for many practicing engineers, and the project-based course described above attempts to simulate this process for an effective student learning experience. Beyond the oft-cited problems with student team projects (team formation, grading, instructor role, etc.), we are still grappling with many curricular issues specific to economic assessment. These include: 1) iterative refinement of estimates -- are there methods that can help students determine the best level of detail for engineering data at each stage of the process? 2) inter-team communication of production assumptions/data; 3) development of student "templates" for team workflow and the data gathering process, spreadsheets for production cash flow, and risk analysis.

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[1] McCabe, J. and Duffey, M. "Building Education/Industry Relationships: Assembly-Based Manufacturing for the Next Generation of Solar Products," *Solar Today*, American Solar Energy Association, September/October 1996.

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