Integrated DFMA and Manufacturing Management for Engineers

A. Dale Flowers, Frank Adamo, Thomas P. Kicher
Case Western Reserve University/Ford Motor Company/
Case Western Reserve University/
The Institute for Management and Engineering
Case Western Reserve University
302 Nord Hall, 10900 Euclid Avenue
Cleveland, Ohio 44106

The purpose of this paper is to describe an integrated engineering and management course that engineers take in the Master of Engineering and Management Degree program pioneered at Case Western Reserve University. In the first section of the paper, we will provide background about the degree program to provide the context for the specific course to be described in the following sections. In the second section of the paper, we describe the engineering part of the course, the Design for Manufacturing and Assembly component. Then we describe the Manufacturing Management component of the course, with special emphasis on how it integrates with the engineering component.

Background on the degree program

The Case School of Engineering, in partnership with the Weatherhead School of Management, launched a new Master of Engineering and Management (MEM) degree program in 2001. This unique program combines the engineering and management disciplines. The program was developed in consultation with more than 50 major companies nationwide, including more than 150 engineers from those participating companies. The input from the companies indicated that industry needs engineers with not only a solid foundation in engineering but also additional knowledge and skills in management and business.

After extensive competitive benchmarking with many of the leading programs in the country that were joint business and engineering programs, we decided to take a different approach. Virtually all other programs take advantage of existing business and engineering courses and double count them in such a way that the student earns two degrees (an M.S. in engineering and an M.B.A. in business, for example) in less time in the joint program than would be required if the student completed the programs one at a time. This means engineering courses are taught by engineering faculty, and business courses by business faculty. Thus, in these other programs, it is left up to the student to integrate the subject matter between the two degrees.

Our new approach was to design, develop, and deliver an integrated learning experience wherever the input from our corporate partners suggested that was preferable. This meant that a faculty team consisting of engineering and business faculty would work together to design an integrated learning component (course) for the program, as evidenced by the drafting of a syllabus. All of the faculty involved in developing the program would review and comment on this syllabus until it was formally approved by the team. Then the faculty designers would...
actually develop the course. This included creation or selection of case studies and exercises, field trips, exams, presentations, reading material, etc. Finally, these same faculty colleagues would deliver the course to the students enrolled in the program. We felt this design, development, and delivery continuity would benefit such an ambitious undertaking. In this approach, it is clearly up to the faculty to design an integrated learning experience for the students, rather than left up to the students to integrate the different courses from the various disciplines.

The faculty participants in this process have tended to adopt one of two models for the instructional delivery. In the first model, they do a lot of coordination in the design and development, but split up the delivery such that one of them may teach one or a series of classes as a part of the course, but without the other’s attendance and participation. In the second model, it is common for both faculty members to attend virtually every class. One of them is the class leader for the day, but the other actively participates in the discussion and delivery as well. Students have expressed a clear preference for the second model, but without being critical of the first. Finally, elements of the curriculum that are essentially 100% engineering or 100% business were designed by one professor from the appropriate discipline and are taught by that one professor, since an integrated learning experience was unnecessary. For the technology entrepreneurship track that is the focus of this paper, 30 of the 42 required credits for the degree are of the integrated design type, reinforcing the close relationship that engineers and managers have in companies.

The program accepted its first group of students in the summer of 2001, and offered only the technology entrepreneurship track to the first entering class. It was open to all engineering disciplines. The course described in this paper is a part of the technology entrepreneurship track. In 2002 we introduced a concentration in biomedical entrepreneurship within the MEM program. The educational objective of both tracks is to provide engineers with the business and management context required to enable them to drive innovation within their companies while serving in a technical capacity. In interactions with our corporate partners, we refer to graduates of this program as “business minded engineers.”

The program includes the academic coursework as well as an experience component (e.g., an internship). Students may enter the program as undergraduates with senior status, typically in the summer between the junior and senior years, and the program does not interfere with completing the undergraduate degree requirements. By making use of summers for both course work and internships, the degree is completed in one additional year beyond the BS, for a total of five years. Students complete a total of 42 credit hours for the program, with 12 being completed in a summer term, and 15 each in a fall and spring semester.

The core courses (with credit hours in parentheses) for the MEM degree include: Professional Development (3); Project Management (3); Accounting, Finance and Engineering Economics (3); Materials and Manufacturing Processes (3); Product and Process Design, Development and Delivery (6); Information Technology and Systems (3); Engineering Entrepreneurship (6); and Understanding People and Change in Organizations (3). For the Technology Entrepreneurship track in the program, the additional courses include Design for Manufacturing and Manufacturing Management (6) and Engineering Statistics and Quality (6).
Design for Manufacturing and Manufacturing Management I

The first component of the course is the DFMA component and is offered during the fall semester of the academic year. The primary text for the course is the Dieter reference. Supplemental readings include selected chapters from the Boothroyd et al. reference. We license the software from this same source to support the student teams in their DFMA analysis. A major focus for the course has been the real world analysis of an existing product from a DFMA perspective. We enjoy a good relationship with Royal Appliance, Inc. that is headquartered in Northeast Ohio, along with their design partner Nottingham-Spirk Design Associates. The Engineering Manager from Royal Appliance and the Director of Engineering from Nottingham-Spirk typically participate in the course in the following significant ways.

First, they help us choose a product that is currently for sale in the marketplace that resulted from their collaboration. This is usually a product from their Dirt Devil product line of vacuum cleaners. A vacuum cleaner is a good choice for this course since it draws on many engineering disciplines from the enrolled students.

In addition to the selection of the product, the two company representatives attend and participate in a mid-term progress report from each of the student teams. These are done privately so that no team sees or hears the interaction between other teams and the company personnel. This is because the teams are allowed to design and ask questions about the product, and the company personnel provide the real life answers to those questions. Questions include such items as: Where is the product manufactured and assembled? What is the production volume per year? Etc. This mid-term session with its associated deliverables counts 10% of the course grade.

Finally, the company representatives attend and participate in extensive final project presentations made by all teams. The entire class attends all these presentations so they can benchmark their performance versus that of the other teams. This session and its attendant deliverables (including a detailed final report) count for 50% of the course grade. Of this, 10% is a peer evaluation that each member of the team completes for each other member with guidelines that prevent grade inflation. The company personnel provide feedback forms to the instructor for each team that is integrated into the instructor’s evaluation of the teams’ performances. There is a comprehensive final examinations that counts 30% of the grade, and individual class participation and contribution counts the final 10%.

The main subjects that are studied during this semester include:

- Design Process & Gathering Information
  - Define Problem
    - Problem statement
    - Benchmarking
    - QFD
    - PDS
    - Project planning
  - Information Gathering
    - Internet
• Patents
• Trade literature
• Concept Generation
  o Brainstorming
  o Functional decomposition
  o Morphological chart
• Concept Evaluation
  o Pugh method
  o Decision matrices
• CAE Modeling & Simulation
• Design for Manufacturing
• Design for Assembly
• DFMA Software review
• Legal and Ethical Issues in Design

The format used for the class meetings is a combination of interactive presentation and discussion, and team and individual exercises. An example of one of the exercises is an in-class analysis of a pair of electric can openers from a DFMA perspective. Suppose we have six interdisciplinary teams of engineers in the course. We would purchase three copies each of two different can openers. We would give each team one of the two for the first of two analyses that each team will perform, along with rudimentary tools to disassemble and reassemble the can openers. After the allocated time for analysis of the first can opener has passed, we have the teams exchange them so that each team has a can opener they have not yet analyzed. Each team performs the analysis of the second can opener and then teams make short presentations of their findings and observations including any suggested improvements, and a breakdown of their estimates of the manufacturing costs of each component along with the selling price in the market. The team that comes the closest to the actual selling prices gets to choose which of the can openers it would like to keep, and so on down the line until the last teams get whichever can opener units remain.

In addition to the classroom and project activities, we have also integrated three field trips into the course, each with a specific purpose. The first is a visit to the Headquarters, engineering, and testing facilities of Royal Appliance. In addition to a tour of the facilities and introduction to the products and testing facilities, the class is introduced to the specific product that will be used for the semester project. Royal Appliance graciously donates one or two units of the selected product so that student teams can disassemble and reassemble the units to facilitate their project analysis.

The second visit is to Moen Inc. design and test facility for a tour and presentations about the product design and manufacturing processes in use in this consumer products company. Among the more startling revelations from this visit is that from initial concept to manufacturing, a new faucet takes typically four to six weeks! The final visit is to Argotech Inc., a manufacturer of jet engine fuel pumps and associated products. Argotech has a DFMA culture that they attribute as a primary reason for their success in their industry (they command a dominant market share). Their product is an industrial product that is highly engineered, and provides a contrast to the
consumer products at Moen. Argotech explains the multi-multi million dollar impact that their DFMA culture has had on the company.

This set of experiences in the fall semester sets the stage for the second part of the course that follows during the spring semester.

Design for Manufacturing and Manufacturing Management II

The second part of the course focuses on the manufacturing management aspects, after the DFMA components have been emphasized in part I. One of the goals of part II is to reveal to the engineers the impact that the decisions made in the DFMA process will have on manufacturing operations and the management of same. That is a constant and recurring theme throughout the second semester of the course. In addition, many engineers will run plants or manufacturing divisions or even companies during their career. The second part of the course provides a significant exposure to state of the art practices for these career experiences.

The primary text for this part of the course is the Vollmann et al.⁶, while the software support comes from Emmons, et al.⁵. In addition, there is an extensive course pack of readings from current engineering and business publications that relate to the specific topics being studied in the course. The purpose of these supplemental readings is to establish the relevance of the course subjects to current industrial practice. An example is the Cusin³ article that is used in conjunction with the study of economic lot sizing in production.

The product used in the fall semester course provides the focus for a series of manufacturing management case studies that are developed based on the product. Plausible (but hypothetical) product extensions to the base product are proposed such that three products result (typically, an economy model, a standard model, and a deluxe model). These three then form the basis for the following six case studies:

1. Creation and explosion of a bill of material and associated files
   a. Master schedule
   b. BOM file
   c. Inventory status
   d. Item master
   e. Capacity
2. Economic lot sizing
3. Capacity requirements planning
   a. Assembly labor
   b. Machining
4. Sales forecasting and finished goods inventory management
5. Multiple location production planning
6. Supply chain design

These case studies are all done in teams and are submitted in a consultant report format. Many of our students are hired by consulting firms, but we can also argue that all engineering and management work is in a certain sense consulting, even if it is to your own organization. This
format facilitates practice for the students in writing good reports as well, a skill that they appreciate even more after graduation. Collectively, these case studies account for 50% of the student’s grade for the course. Each student on the team is required to serve as the lead consultant for at least one of the case studies, which both distributes the work and provides each student with an opportunity for a leadership position during the semester.

There is a mid-term and a final in-class examination that each count 25% of the grade. The class sessions in this course are also in interactive presentation format. We often use six or seven common plant tours that all students complete in the first semester of the program to illustrate the concepts we are studying in this course. This facilitates class participation in the discussion since the previous tours are a common background experience for all our students.

The major subjects studied during this semester course are:

- Introduction to ERP
- ERP files and the BOM explosion
- BOM structuring and part commonality
- Economic lot sizing
- Capacity planning
- Production activity control (shop floor control)
- Shop loading and scheduling
- Demand management and forecasting
- Independent demand inventory management
- Master production scheduling
- Production planning
- Hierarchical production planning
- Distribution systems planning
- Lean manufacturing
- Just-in-time systems
- Supply chain management

A plant tour is also integrated into this course to Undercar Express LLC. This is a small remanufacturing company specializing in brake calipers. It won the Weatherhead 100 award in 2002 for being the fastest growing company in our region over the previous five years, having grown just under 5000 per cent during the five year period! It employs a sophisticated suite of software applications including fax character recognition for order taking, an integrated image and data product data base, and Microsoft’s entry into the small company ERP market with Great Plains Software. Demonstrations of all these software products are featured, along with a tour of the physical facility that features just-in-production via cellular manufacturing. The company holds no finished goods and generally ships 100% of its customer orders within 3 days. Even though a small company, it is a state of the art company and it allows the students to see the integration of the physical operation with the information technology aspects.
We also typically have a semester ending presentation from an Oracle representative to talk about “next generation systems.” Since the course emphasizes enterprise systems and decision support tools, this is a fitting climax to the semester.

In every class, we emphasize specific relationships between the manufacturing management problems currently being studied and the DFMA focus from the previous semester. For example, we use the classic Collier\(^2\) article to illustrate the major impact of standardized parts on both inventory and capacity management in a manufacturing operation. This ties directly back to the DFMA principle of minimizing the part count. Even at the end of the course in the distribution and supply chain areas, we emphasize the impact that part and product design can have on packaging and shipping, and the attendant supply chain costs.

Summary and conclusions

At this point the reader can see that this two course sequence provides the engineering students in our program with a \textit{vertically integrated} view of DFMA concepts and manufacturing management. In many courses, case studies from many different companies are used to study different subjects. Of course, such an approach can be valuable to expose the students to a variety of different company settings. However, students often never experience in their entire degree program an integrated view of one organization, and it is one organization for which they will typically work. We do provide broad exposure to many different companies as a part of our MEM curriculum, but we feel this integrated view of one operation is also an important experience for our students. In addition, the integration of the various plant visits and industry guests in our classroom activities meets the objective on integrating real world, experiential activities into the student’s education. This is a part of the vision for our University, and we believe it greatly facilitates a very graceful and successful transition of our students from the educational program into mainstream industrial companies. We invite feedback and suggestions from the reader, and are happy to engage in benchmarking activities with other institutions.

Bibliography