Int. J. Engng Ed. Vol. 20, No. 5, pp. 742–753, 2004
Printed in Great Britain.

0949-149X/91 $3.00+0.00

Manufacturing in a Global Context: A Graduate Course on Agile, Reconfigurable Manufacturing*

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This paper describes the contents and organization of an advanced, graduate-level class which, while primarily focusing on principles of modern manufacturing, connects them with product design and business process issues, and places them in the context of two important trends: globalization and information-driven economy. The course aims to analyze the technical and business dimensions of various manufacturing paradigms, and identify concepts relevant to globalization and fragmented markets. It also emphasizes creativity in designing global products and touches on preparing simple business plans for starting new companies.

INTRODUCTION

GLOBALIZATION and utilization of the Internet for commercialization are two key drivers of the current economy. Globalization means not only that large companies are becoming global in terms of their production facilities, but also that companies must produce a larger variety of products to meet customers' taste and preferences in different countries. This aspect of globalization, together with the electronic business opportunity provided by the Internet, makes it realistic to create new companies that aim at mass customization of consumer products and marketing them around the globe. Global competition, however, poses a permanent threat to such businesses. Therefore, the key to success for such companies is increased responsiveness on three activity planes: (1) product introduction, (2) manufacturing system change (a market-driven adjustment of volume and new product switchover), and (3) rapid delivery to consumers. All these characteristics must be combined with unwavering ability to produce high-quality, low-cost products.

Globalization, however, is also driving dramatic changes in the production systems of large companies. Many manufacturing companies have moved away from a mass production orientation to more agile production approaches. An increasingly important goal for many firms is to offer customers as much variety as is practical at any given time, and to be able to introduce new goods quickly as technology and customer demands change. In other words, they have to achieve production agility and rapid responsiveness in three domains: (1) product design, (2) product manufacturing, and (3) company organization.

* Accepted 3 February 2004.

We use the term 'agile manufacturing' as an encompassing concept that embraces both the ability to introduce new goods quickly and changing the organization rapidly in response to new market opportunities. The term 'reconfigurable manufacturing' relates to the ability to respond to market demands by rapidly adjusting the volumes of existing products produced and starting the production of new products.

The main feature of the course is a term-long project in which students work in teams. Every team consists of four students, and each student brings to the team a different background (e.g. engineering, business, industrial experience). The team assignment is to create a start-up company offering a new product type that fits mass-customization markets on a global scale. The team should (1) describe the product and its design, including possible product variations, (2) develop (outline) the manufacturing system necessary to make the product, and (3) prepare a business plan that covers delivery, organization and cost issues.

COURSE CONTENTS

The course is designed to run for a 15-week long semester and is usually offered every two years. The class meets once a week for three hours in the evenings. The main reason for this arrangement is that a significant number of students enrolled in the class are on a part-time schedule and so can take the course while working.

The course is centered around the idea of integration of product development, manufacturing systems and business practices (see Fig. 1). Thus it can be stated that the course takes a system-based approach, which considers not only the components (be it machines, processes, or knowledge) necessary

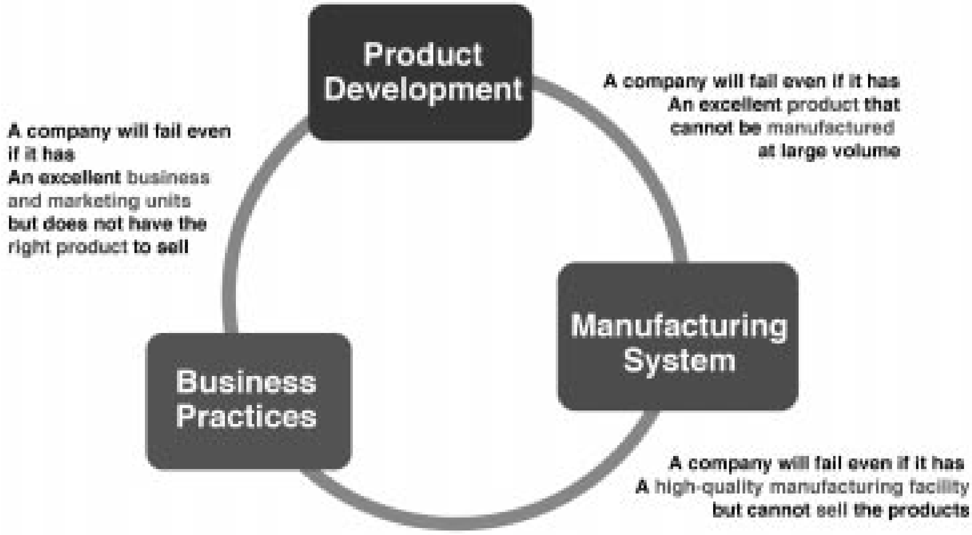


Fig. 1. Integration of product, process and business practices.

in production of consumer goods but also their interactions and impact on each other. While this idea is perhaps not entirely new, it is also set in the context of the current market paradigm of mass customization [1–3].

However, to properly understand the framework of mass customization, one has to understand the previous paradigms from which it has evolved (see Fig. 2). Thus, initially, the course reviews the evolution of production paradigms and analyzes their enablers, principles and business models. Mass customization is presented as a process of producing a wide variety of customized products at mass production cost as a strategy (or a business model) that allows a quick response to changes in customer demands.

With this background, the course then proceeds to address three primary activities that are essential for any manufacturing enterprise:

- Product development
- Manufacturing
- Business and marketing.

Product development

Product development is explained as a set of activities beginning with the identification of a market opportunity and continuing with (i) the design, (ii) manufacturing, and (iii) the marketing, sale and delivery of a product. Customer-driven product development plays an important role in the market. Identification of customer needs is continuously performed by all manufacturers. One of the leading methods is based on collection and analysis of customer surveys (students are asked to go through this exercise within the classroom boundaries).

While customer-driven development leads to valuable improvements in existing products, the

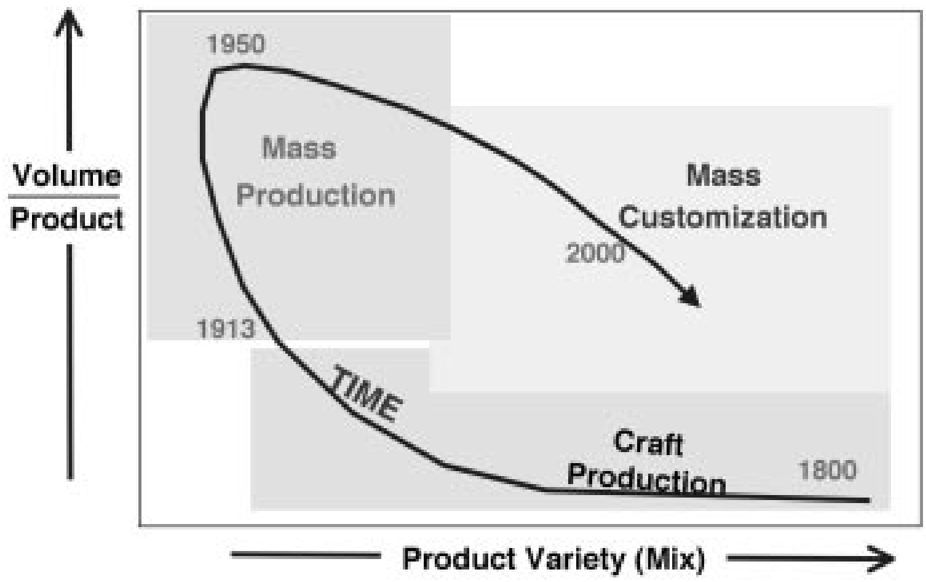


Fig. 2. Three main paradigms of manufacturing enterprises.

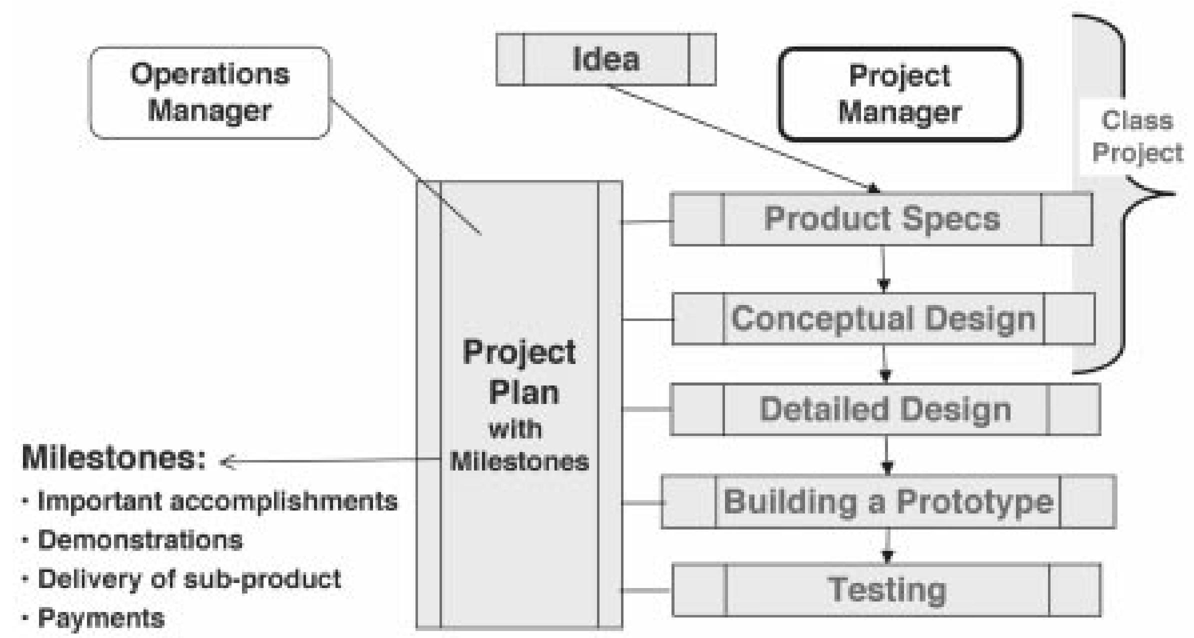


Fig. 3. Product development in a start-up company.

revolutionary products are usually based on breakthrough ideas and inventions that cannot be uncovered through customer feedback. Thus, creativity is an indispensable component of strategy in any enterprise. To address that point, the concept of 'paradoxical products' is introduced in the class. The students are then required to come up with similar conceptual ideas on their own (see the section 'Paradoxical products assignment').

The product development part of the course is concluded with a discussion of the product development process in a start-up company (see Fig. 3), and a review of the typical phases in any product development:

Phase 1: Concept assessment (market, product concept, manufacturing, business)
Phase 2: Conceptual product design and product specifications
Phase 3: Detailed product design and engineering
Phase 4: Testing and refinement
Phase 5: Production preparations.

The relevance of product architecture in the context of mass customization is explored through existing product examples. The advantages and drawbacks of product modularity (e.g. commonality vs. differentiation) are discussed in the context of cost-effectiveness and timeliness. The issue of available product variations is also covered.

Manufacturing

While primary production paradigms were introduced at the beginning of the course, this section of the course provides more detailed technical contents on underlying manufacturing systems. It starts with mass production, where standardized products are produced in very high volumes by dedicated manufacturing systems. In mass production, a clear connection between the type of manufacturing system and the business model can be established, due to the fact that, when prices were lowered, more people could afford to buy the products, resulting in more sales and, therefore, greater production at even lower costs and lower prices and so on. Such a mechanism can be adequately described by a corresponding system feedback model (see Fig. 4). In general, the course makes a strong attempt to introduce mathematical models of system behavior, which, even though simplified, enables an analytical approach to understanding complex systems. A corresponding cost model is also presented and discussed (see Fig. 5).

Discussion of mass production systems creates a background for discussion of current practices based on 'lean manufacturing' approaches [4], but more importantly also provides a contrasting example necessary for the introduction of manufacturing systems needs for mass customization. In particular, four strategies for mass customization are addressed:

- The off-the-shelf large variety
- Order options on standard products
- Point-of-delivery customization
- Highly customized (personalized) products

At this point in the course, a review of manufacturing processes takes place. Students have an opportunity to tour the Integrated Manufacturing Systems Laboratory at the University of Michigan and get acquainted with basic types of machines, tools, and other factory automation equipment. This is followed by a review of typical industrial manufacturing architectures, focusing on features of dedicated and flexible systems. The advantages

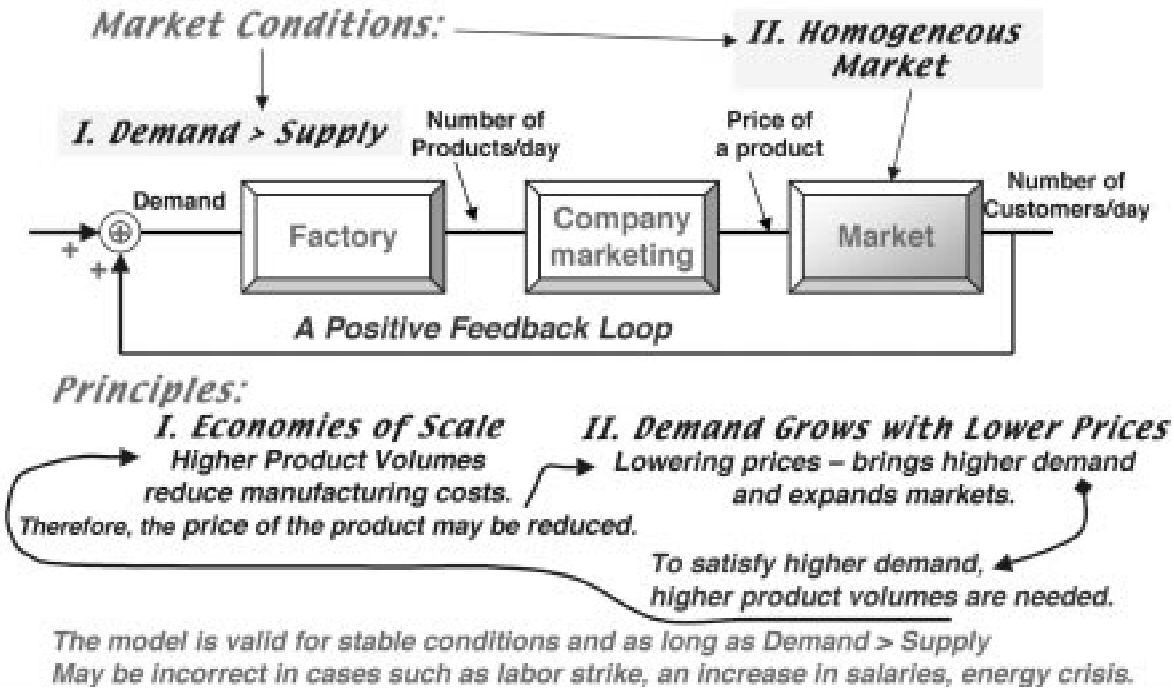


Fig. 4. Principles and model for mass production.

and shortcomings of these solutions are discussed, leading to the introduction of the basic concepts of 'reconfigurable manufacturing systems' [5].

Reconfigurable manufacturing deals with the issue of how to cope with unexpected future changes in product demand, mix, and product type from the manufacturing system perspective. The manufacturing system should be designed to be adaptable to unexpected changes by altering its structure, including the structure of its machines and controls. The issues of various system configurations and their impact on reliability and quality (see Fig. 6), as well as examples of reconfigurable machines (see Fig. 7), are also covered.

Business and marketing

In the final phase of the course, focus turns to business issues. The concept of business models is introduced and defined as a statement of how an idea actually becomes a business that is profitable.

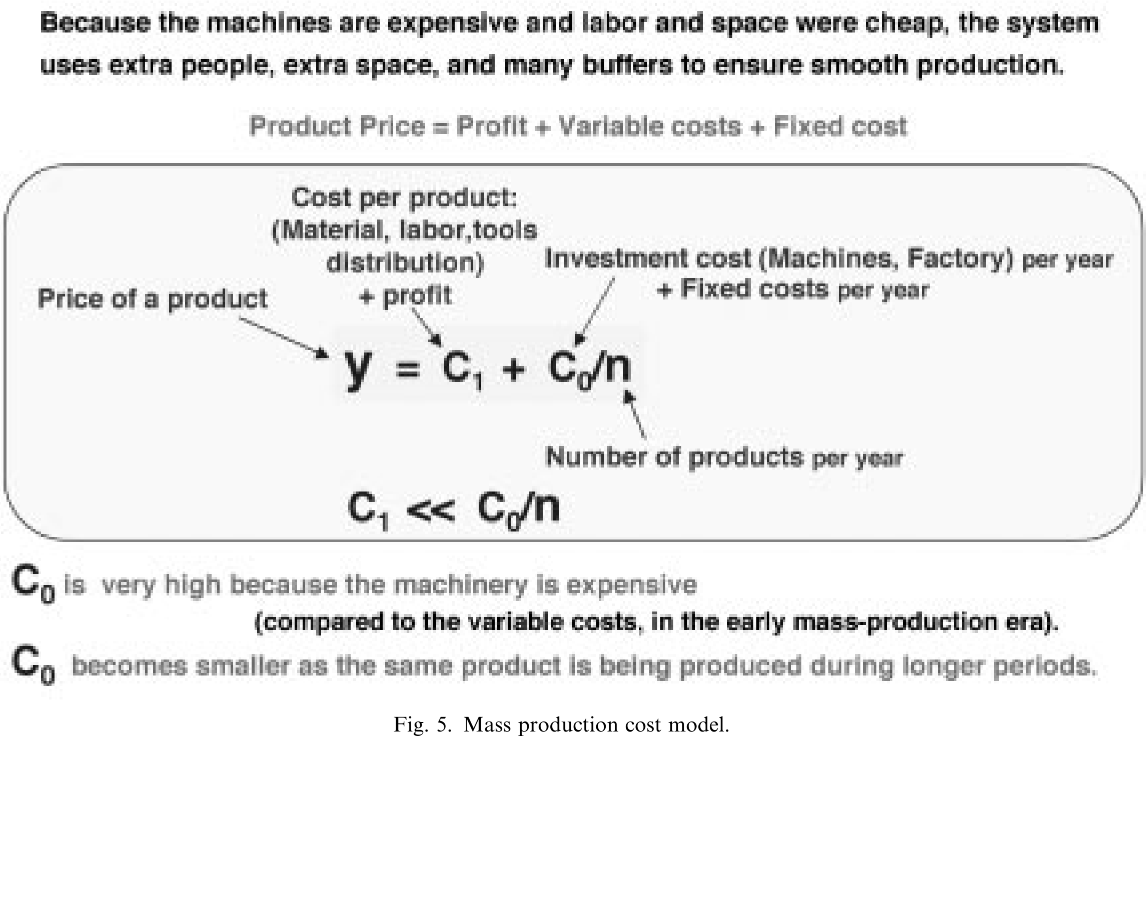


Fig. 5. Mass production cost model.

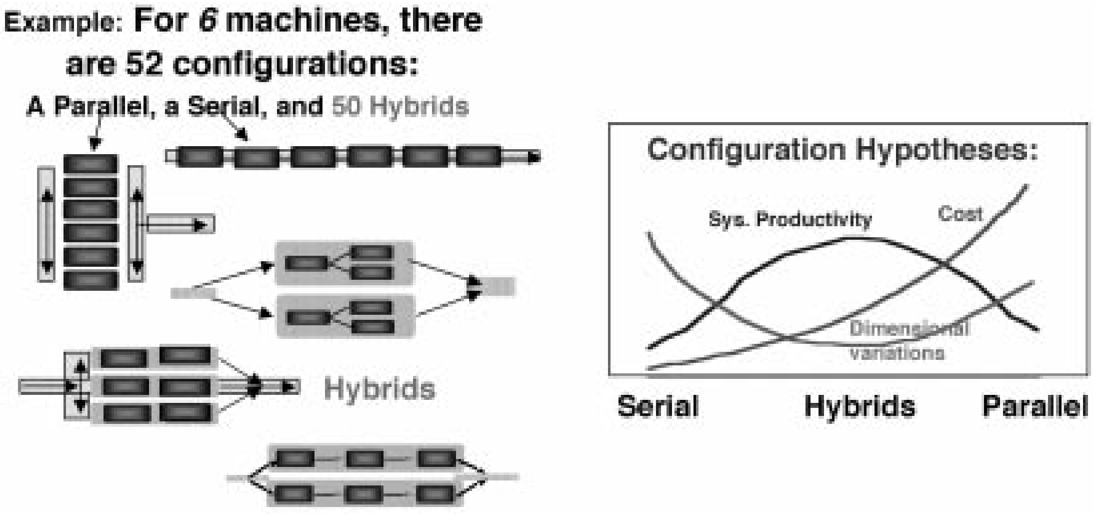


Fig. 6. System configurations and their impact.

The same product or service may be brought to market with several business models. Elements of business models (see Fig. 8) are discussed and analyzed based on examples of actual companies [6]. The corresponding financial concepts, including drivers of financial performance, return on investment, etc. (see Fig. 9), are explained, illustrated with current industry data, and interpreted. Students are required to develop a business plan for their class project and carry out corresponding financial analysis (see the section 'Class project').

Over the past 20 years, globalization has been demolishing geographical, cultural, social, technological and economic borders. For the first time in human history, any product can be made anywhere in the world. Making each part and performing each job at a place where it can be carried out most inexpensively, and selling the end products wherever prices and profits are highest—these are the challenges brought by globalization trends (see Fig. 10). Developing the right range of products for the global economy may become a business strategy that reduces or even eliminates the volatility of business cycles. With such a strategy, globalization becomes an opportunity rather than a threat.

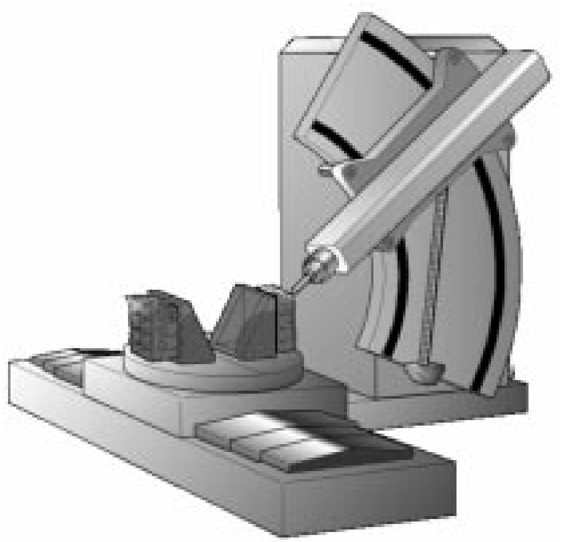


Fig. 7. Example of a reconfigurable machine tool (US Pat # 5,943,750).

Another driver having a significant impact on business performance and competitiveness is the Internet and information technology (see Fig. 11). The use and integration of these approaches is critical for business survival [7] and leading examples from current industrial practice are discussed in class.

ASSIGNMENTS AND GRADING

The primary effort of the students that defines the majority of their final grade is the team project (60%). The project assessment includes the following elements:

Product design: presentation, report, response to comments (10%)
Product manufacturing: presentation, report, response to comments (10%)
Final project presentation (10%)
Grades given by teammates (6 points distributed among 3 members) (6%)
Final project report in a business plan format (24%)

The remaining components of the grading are homework assignments (20%) and in-class participation (20%).

Homework

Homework assignments are focused on issues stemming from the content of the lectures. They usually are designed in such a way that they can serve as a starting-point for in-class discussion and can then be used to elaborate on selected details of issues raised in class (see Table 1).

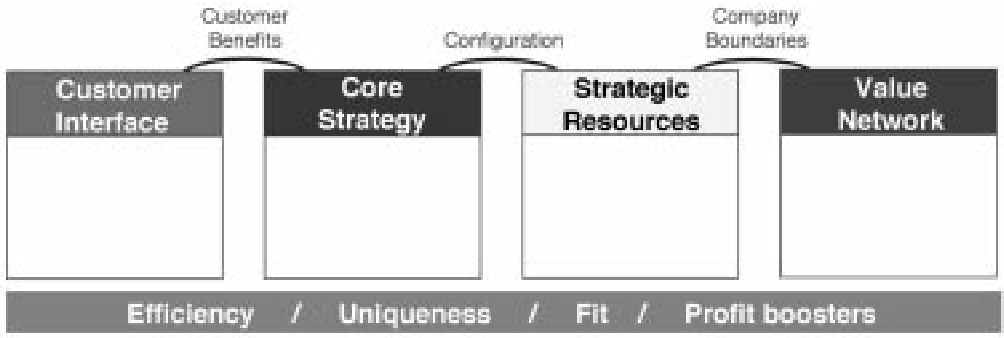


Fig. 8. Components of a business model and their interactions.

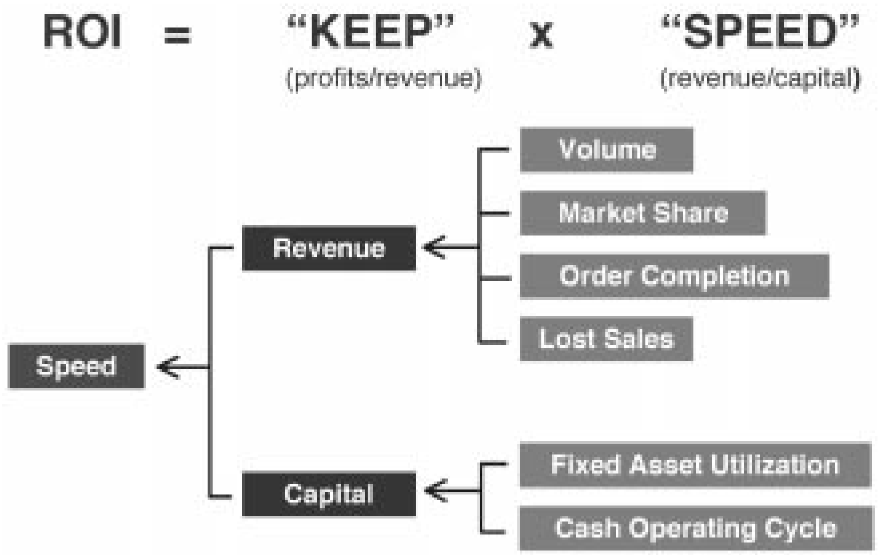


Fig. 9. Basic financial concepts.

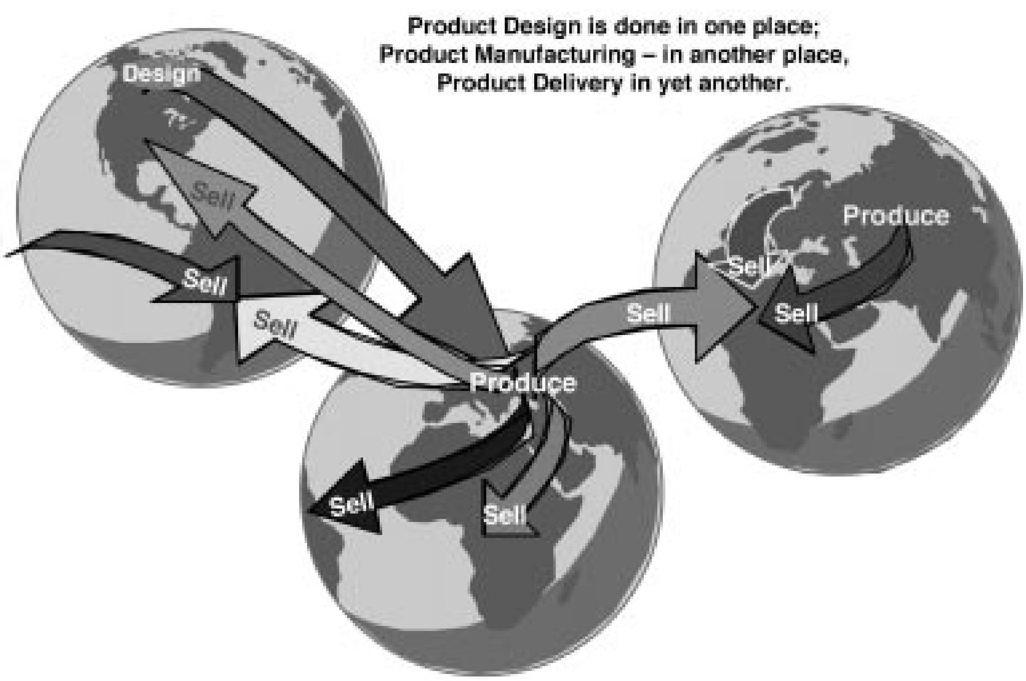


Fig. 10. Globalization impact.

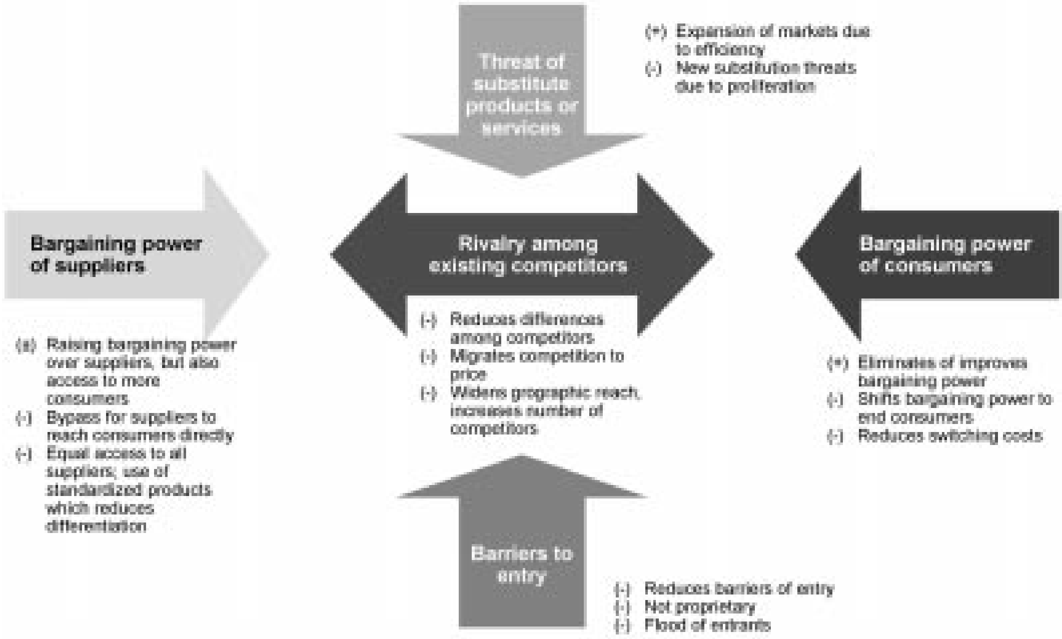


Fig. 11. Impact of the Internet on business.

Paradoxical products assignment

Usually, the primary function of a product is communicated through its name. When the main function of a product is eliminated, it seems that whatever is left of a product does not make much practical sense. Nevertheless, in some cases one gets a new product that has a new application and its own market. Such products are called 'paradoxical products'.

For example, tape recorders were originally invented in the 1930s. One day in the late 1970s, two Japanese inventors asked themselves whether there would be a use for a tape recorder that does not record. As it turned out, this was the first step towards the invention of a Walkman, which eventually created a new market.

The Walkman (cassette player) is smaller and cheaper, and has a different application than the original tape recorder. Similarly, in many other cases thinking in paradoxical terms may create a new application of existing products or an entirely a new product. Examples of paradoxical products include:

- A wheelchair that does not have a seat
- Bicycles with no wheels
- Scissors that do not cut
- A car seat that is not a seat
- Eye glasses without glass
- Car keys with no keys
- A rowboat that does not move on water
- A watch that does not show the time
- A pet that is not alive (a pet rock)

The task of each team is to 'invent' a paradoxical product (any existing product can be a starting-point) and to elaborate on the following points:

- How does the product look? (provide a sketch.)
- What are its applications?
- What is the estimated annual demand?

Table 1. Homework assignments for the agile, reconfigurable manufacturing course

HW #	Description	Due Date
1	Describe your vision of a future manufacturing paradigm.	Week 2
2	Read pp. 2–69 from J. Womack *et al.* 'The Machine that Changed the World', Harper Perennial, 1990. Answer the following: 1. Compare Mass and Lean Production in terms of cost, product quality, product variety, flexibility of production equipment, and workforce skills. 2. What are the enablers of Mass Production? 3. What are the enablers of Lean Production?	Week 3
3	Read 'A Mass Market of One' Business Week, 12/2/2002 Submit a report based on web-site analysis.	Week 4
4	Mass Production Plot Cost vs. # of products/year (n); analyze sensitivity.	Week 6
5	Analysis of different system configurations	Week 7
6	Analyze the failure of the company FriendlyRobotics, and the probability of success of the Wrinkle Reducing company	Week 8
7	Mathematical model for Mass Customization	Week 10

- Is it cheaper or more expensive than the original (ancestor) product?
- Can the product design be modular for mass-customization purposes?
- Does the US patent database include similar products?

Class project

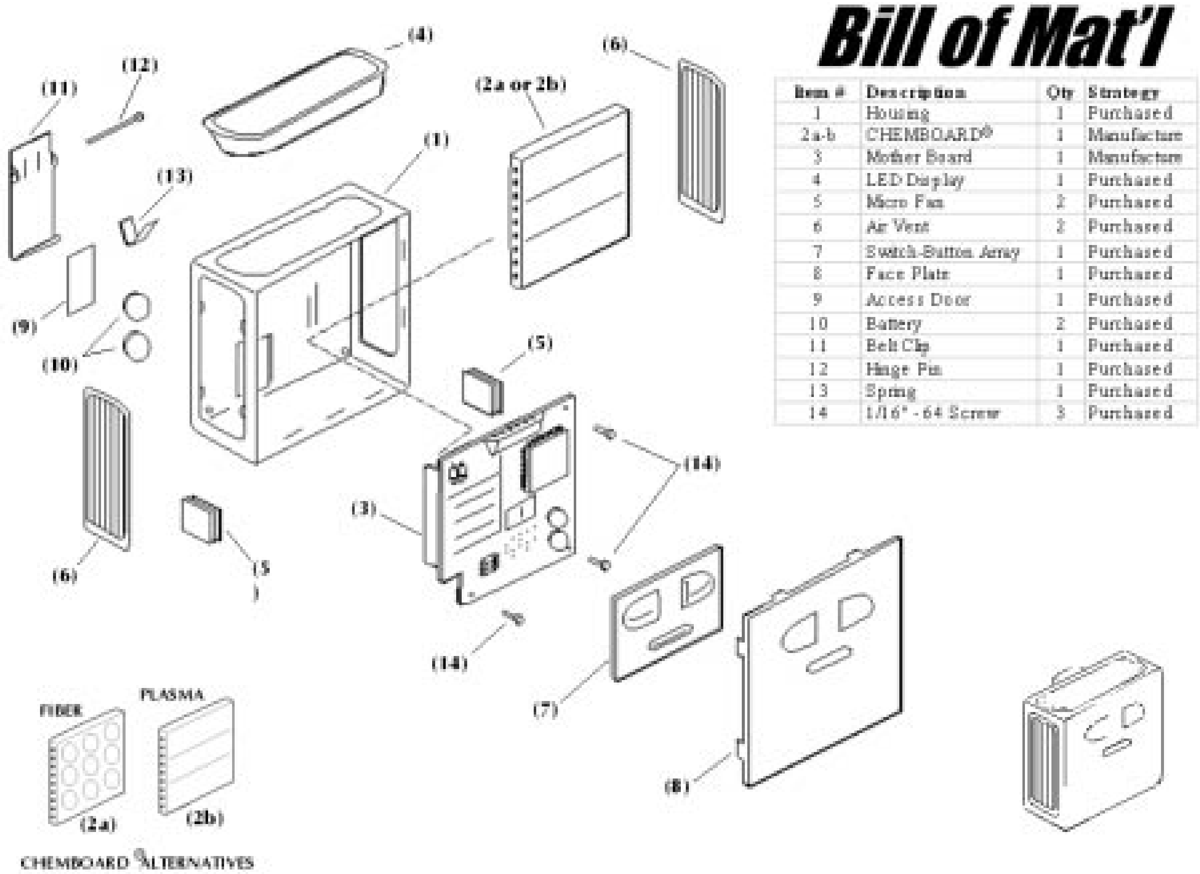
Team-based class projects are the primary activity for students and the main basis for final assessment. The main focus of the student team projects is the development of a new product for mass customization. The student team has to:

- identify a product whose market share could be significantly increased if designed with variations that fit the needs of various customers (i.e. mass customization) and whose price would be attractive if it were produced with a reconfigurable, flexible manufacturing approach;
- create a company that produces and sells the product, and develop a corporate identity (a name, logo, etc.) and its organizational structure; and
- write a report in the form of a business plan and evaluate the potential profitability of this company. In contrast to business plans offered in business schools emphasizing market analysis and finance models, the focus is primarily on <u>product innovation</u>, product <u>design for mass customization</u>, and <u>manufacturing systems</u> that can cope with turbulent markets.

In the first part of the project, students propose a product, perform product design and carry out initial market analysis. They have to give a detailed technical description of the product (including technical specifications and the specific, innovative technologies involved), including its advantages over existing, potentially competing products, and how the selected product fits the concept of mass customization. In particular, they have to analyze the proposed product variations and identify the need for them. The market analysis has to include the total market value (overall customer needs), the market share expected to be captured, and identification of potential customers.

A wide range of products have been selected by students, from products that have low-tech contents, such as luggage or clothing, to products with a high level of technological content, such as stereo systems or smart automotive mirrors. Other examples of products selected by the students in past courses included wheelchairs, bicycles, special engines, car seats, watches, backpacks, sports equipment, sunglasses, skateboards, office furniture, golf clubs, electronic equipment, and health foods. An example of a product description is shown in Fig. 12.

In the second phase of the project, teams focus



Item #	Description	Qty	Strategy
1	Housing	1	Purchased
2a-b	CHEMBOARD®	1	Manufacture
3	Mother Board	1	Manufacture
4	LED Display	1	Purchased
5	Micro Fan	2	Purchased
6	Air Vent	2	Purchased
7	Switch-Button Array	1	Purchased
8	Face Plate	1	Purchased
9	Access Door	1	Purchased
10	Battery	2	Purchased
11	Belt Clip	1	Purchased
12	Hinge Pin	1	Purchased
13	Spring	1	Purchased
14	1/16" - 64 Screw	3	Purchased

Fig. 12. Example schematic for a customizable early warning allergen device.

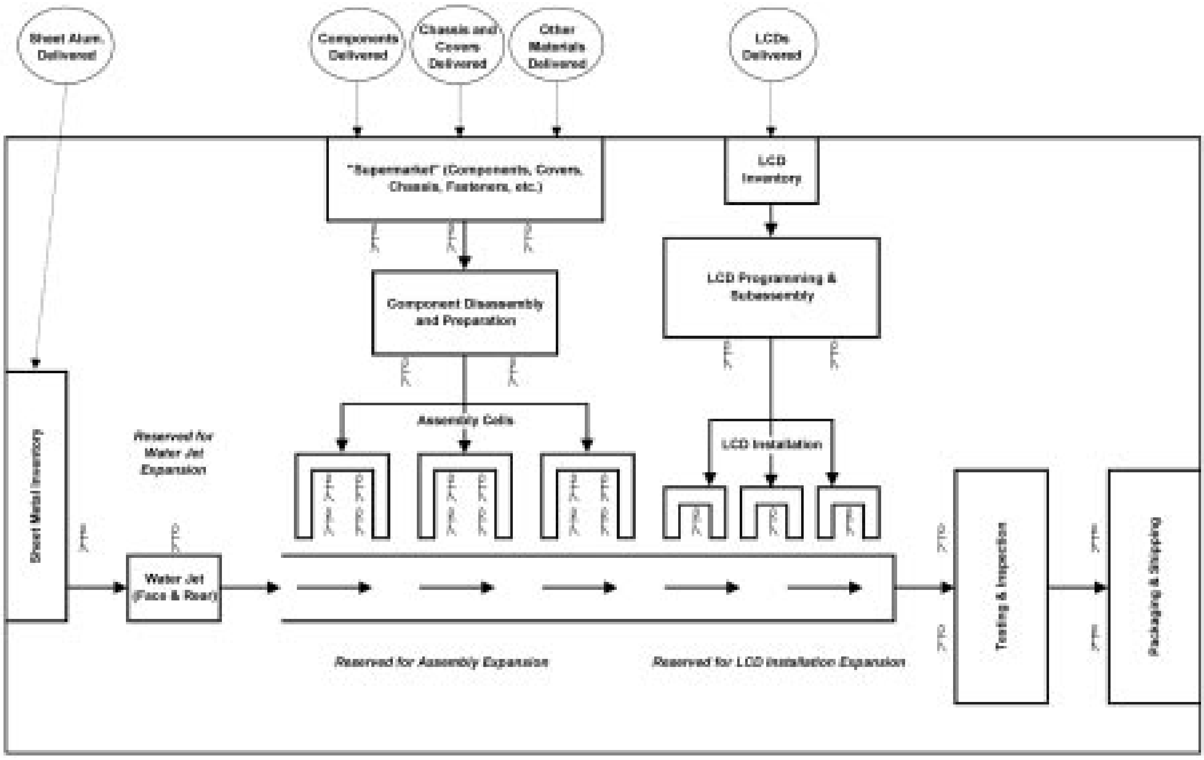


Fig. 13. Example assembly plant layout for a customizable electronic product.

on designing the manufacturing system for making the selected product. This includes a thorough description of the production system, including the various pieces of equipment, discussion of system configurations, floor layout, and estimates of investment costs. For a particular process design, the teams also explore performance specifications of the production facility, such as production capacity strategies and quality issues. The use of outside suppliers is also discussed (in-house vs. outsourced activities), as well as the size and skills of the necessary workforce. An example of a facility layout developed by one of the teams is shown in Fig. 13.

Finally, the teams focus on developing an overall vision of the company, describing the company growth goal and the strategies for achieving this goal (strategies in product design, manufacturing, marketing, etc.). They also address product distribution and delivery methods, use of information technology, and financial issues (best and worst case scenarios in sales vs. expenses projections). An outline of the financial analysis carried out for a product is shown in Figs 14 and 15.

The primary challenge faced by the students when preparing an outline of business strategies for their potential company is the fact that it is a start-up venture. Therefore, even though they may be fairly familiar with how to design a typical manufacturing facility, development of a strategy that deals with the limited resources available for a start-up project entails additional, non-technical constraints that have to be considered. The issues of core competencies [8], supply chain management (in-house vs. outsourcing) [9], and risk management all come into play.

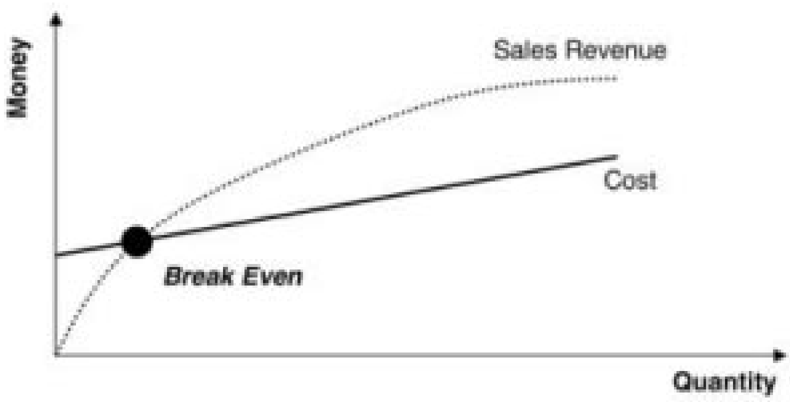


Fig. 14. Break-even financial analysis.

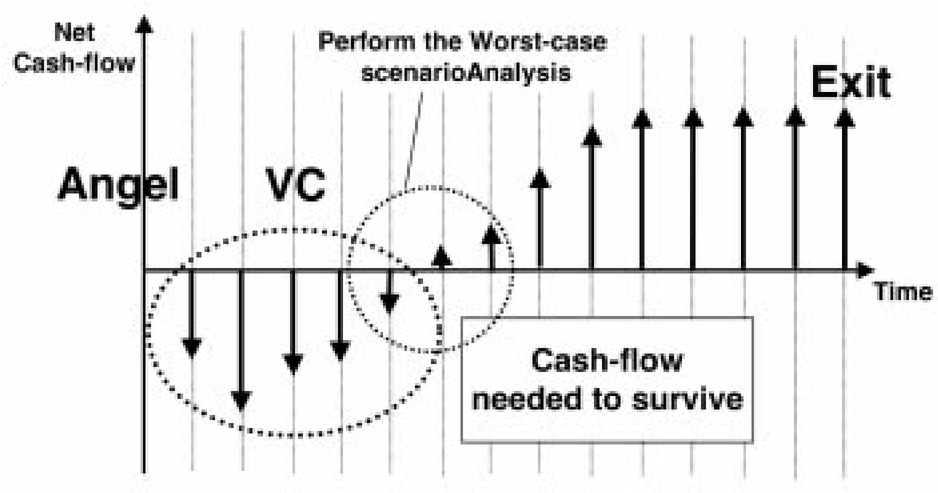


Fig. 15. Cash flow analysis.

All the work of project teams is documented in the form of two intermediate and one final report. The final report is deliberately limited to 30 pages (not including product and plant drawings, financial graphs, etc.).

Important components of the course are in-class team presentations (scheduled in weeks 5 and 9 of the class; see Table 2). Each team is granted a brief (10 minutes) time slot for its presentation and this is followed by a further ten minutes of critique and discussion. Intermediate reports eventually become part of the final report.

Team forming and assessment of collaborative efforts

Since the class project is the primary and term-long activity involving students, the organization and composition of the project teams plays a critical role in the course. The class is cross-listed in the Mechanical and Industrial Engineering Departments of the College of Engineering, as a professional degree program in Manufacturing, and in the Business School (Operations Management). Teams are formed at the first class meeting.

Students who enroll in the class have a variety of

Table 2. Syllabus of the agile, reconfigurable manufacturing course

Week	Class Contents	Time
1	Course Overview	1 hour
	Market Changes: Globalization, IT, Mass Customization, agility. Manufacturing paradigms	1 hour
	Course Requirements & Team Formation	1 hour
2	Product development	1 hour
	Product development for mass customization	1 hour
	Discussion: Home assignment #1	1 hour
3	Product development for mass customization	1 hour
	Paradoxical Products (student presentations; all teams)	2 hours*
4	Guest Lecture 1: Globalization issues	1 hour
	Mass production—model & principles	1 hour
	Mass customization—model & principles	1 hour
5	Product Design Presentations (All teams)	3 hours**
6	Dedicated & flexible manufacturing systems	1 hour
	Reconfigurable Mfg.—needs, system design	1 hour
	Discussion: Home assignment #2, student feedback	1 hour
7	Lab Tour (5:00–6:00 pm)	1 hour
	Reconfigurable Manufacturing—Machines & Examples	1hour
	Impact of System Configurations	1 hour
8	Guest Lecture 2: Machine Tools	1 hour
	Product-process interrelationships	1hour
	Discussion: Home assignment #3	1 hour
9	Product Manufacturing Presentations	3 hours**
10	Impact of IT on manufacturing	1hour
	Business models	1hour
	Discussion: Home assignment #4	1hour
11	Finance models	1 hour
	Business plans	1hour
	Class Summary: Product-process-business integration	1 hour
12	Final Project Presentations I	3 hours***
13	Final Project Presentations II	3 hours***

backgrounds and come from many engineering specialties. Teams are formed by the course instructors based on a short questionnaire completed by students before the first class, which inquires about the student's affiliation, work experience, and interests.

Typically, class enrollment varies between 28 and 40 students. This enables the formation of 7 to 10 teams, each consisting of 3–5 students. The preferred team size is four students and its combined experience in order to successfully carry out the class project should include the following areas:

- business/marketing;
- product design;
- manufacturing; and
- industrial work experience.

These requirements lead to teams including one School of Business student (MBA), one industrial engineering student, and two engineering students of other specialties (mechanical, or other).

In order to assess the collaborative efforts within the team, at the end of the course each student is asked to allocate 6 points (where a team has four members) to the other team members. If each team member contributed equally, then each collects 6 points. If a student assigns less than 1.5 points to a teammate, then a written explanation is expected. Students are asked to assign these points without consulting with the remaining team members. The results are kept confidential but have a bearing on the final grade.

Student feedback

Overall, student responses to the course has been very positive and there is usually a waiting list of students who want to take the course when it is offered. As a result, the course frequency has now been changed from every other year to once a year. Direct student feedback is collected twice during the course of the class: at mid-term and at the class end. Ascertaining student concerns is important, because the open-ended format of the class (no exams, and project- and participation-based grading) raises concerns, in particular with students who have no work experience and are not used to courses with such a structure. Final student feedback is part of the formal course evaluation process instituted by the UM College of Engineering.

The contents of the course has evolved over the years: in the early years there was more focus on Internet-based business activities, while currently it has shifted to addressing the issues related to globalization. Students play an active role in shaping the future course offerings by openly discussing ways of improving the course and its effectiveness. One of the issues brought up repeatedly is the question of how to effectively teach creativity.

SUMMARY

Our graduate course, Agile, Reconfigurable Manufacturing, takes an integrative, systems approach to leading concepts of modern manufacturing. The course contents draw on multiple disciplines and also rely on student experiences and coursework. The course content explores the technical and business dimensions of manufacturing in support of mass customization. The key feature of the course is a term-long project carried out by the students in teams.

Acknowledgments—The authors are pleased to acknowledge the financial support of the Engineering Research Center for Reconfigurable Machining Systems (NSF grant # EEC-9529125), and the contributions from students in the ME587 classes.

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