

OPRE 6340/MECH 6335: Flexible Manufacturing Strategies, Fall 2024
Professor Kathryn E. Stecke
Course Pack

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Service Robotics

- “One Shot Additive Manufacturing of Robotic Finger With Embedded Sensing and Actuation,” International Journal of Advanced Manufacturing Technology (2023)
- “Inexpensive Monolithic Additive Manufacturing of Silicone Structures for Bio-Inspired Soft Robotic Systems,” Engineering Research Express (2023)
- “Principles on the Benefits of Manufacturing Process Flexibility,” Management Science (4/95)
- “Classification of Flexible Manufacturing Systems,” The FMS Magazine (4/84)
- “Flexibility in Manufacturing: A Survey,” International Journal of Flexible Manufacturing Systems (7/98)
- “More Models, Fewer Platforms,” Ward’s Auto World (4/06)
- “Critical Differences,” Ward’s Auto World (6/06)
- “Jurassic QFD: Integrating Service and Product Quality Function Deployment,” Eleventh Symposium of Quality Function Deployment (6/99)
- “Get the Most from CNC Automation Investments,” Modern Applications News (2/07)
- “An Integrated Model for Part-Operation Allocation and Investments in CNC Technology,” International Journal of Production Economics (12/02)
- “The Promise-and Peril-of Integrated Cost Systems,” HBR HBR (Jul-Aug 1998)
- Baker Precision Instruments, Inc. HBS 9-687-052 (1/02)
- “Fused Filament Fabrication of Commercial Conductive Filaments: Experimental Study on the Process Parameters Aimed at the Minimization, Repeatability and Thermal Characterization of Electrical Resistance,” International Journal of Advanced Manufacturing Technology (2020)
- “Design and Calibration of 3D Printed Soft Deformation Sensors for Soft Actuator Control,” Mechatronics (2023)
- “Design and Construction of a Variable-Aperture Gripper for Flexible Automated Assembly,” Robotics and Computer-Integrated Manufacturing (2017)
- “7 Ways to Manage Change When Implementing New Technology,” Epicor (8/19)
- “Fitting Flexible Manufacturing Systems to the Task,” Industrial Engineering (11/94)
- “Must CIM be Justified by Faith Alone?,” HBR HBR (Mar-Apr 1986)
- Chaircraft (B) HBS 9-679-094 (4/84)
- “The Move to a Greater Return on CNC,” Centrifuge Brand Marketing, Inc. (12/18)
- “Manufacturing in the 21st Century,” Managing Automation (10/99)
- “Manufacturing Strategies in the 21st Century,” Japan-US Symposium on Flexible Automation (7/00)

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Course Synopsis

U.S. manufacturing companies can be threatened by radical changes in the competitiveness within their industries. Automated manufacturing is viewed as one means of helping to regain or maintain international competitiveness. The use of automation in manufacturing (machining, fabrication, assembly, etc.) is continually increasing. A flexible manufacturing system provides just-in-time performance and can allow competition along the dimensions of time, service, quality, delivery, flexibility, and sometimes cost.

The course is interspersed with lectures, cases, visiting speakers, and short films on various types of automation, problems that need to be addressed, and solution methods. Examples of many international systems (from Italy, Germany, Japan, Czechoslovakia, England, U.S., and others) will be discussed to show the wide variety of system designs (and problems). Strategic as well as economic justification issues will be addressed.

A special half-day session will be a tour of the fully automated flexible systems at the Texas Instruments DMOS5 Wafer Fab Plant on **Friday, October 25** to see first-hand what unique operational problems (and opportunities) exist. It is an integrated circuit manufacturing facility. The DMOS5 tour includes an introduction to Texas Instruments and the semiconductor manufacturing process. You will see an overview of a device from start to finished product and some of the many aspects of a 300mm factory. You will see a wafer up close and a peek into TI's first 300mm cleanroom. Detailed discussions with the system managers and operators can take place.

Part of the course focuses on operational issues and problems, and includes case analyses to demonstrate the problems actually faced. We learn by analyzing the case situations of real firms as they fumble, or succeed, in dealing with the opportunities that are potentially available from the new technologies. The cases detail several Japanese and American flexible manufacturing systems. We also learn from the readings, lectures, tours, and group presentations on particular topics.

General Information

The course reading materials come solely from the cases and readings in the Course Pack and in some handouts during the semester. I am in my office most afternoons and evenings. Please stop by (**SOM 2.422**), call me (**972-883-4781**), or leave me a note.

In order to emphasize the role of the general manager in operations in a modern automated manufacturing environment, cases will be used throughout the course. In each instance, there will be a decision orientation with a specific manager or group of managers having responsibility to develop specific action plans. **One objective of this course** is to help you to understand how modern operations function within a firm, the primary operating tasks that must be dealt with in different environments, and the ways in which operations can be organized to accomplish these tasks.

Another objective of the course is to improve your decision-making ability for complex situations. Contemporary operations consist of knowledge, technology, capital, and human resources that interact with one another, and any proposal must consider system-wide consequences. Operating managers are paid for making decisions and not only for performing analyses; however, studies of operating managers indicate that those who perform extensive analysis consistently make better decisions than their "*shoot from the hip*" counterparts.

Some additional particular *objectives* of this course are to:

1. Develop a managerial point of view--a capacity for analyzing operating problems in technologically advanced systems on a functional, business unit, and company-wide basis.
2. Integrate the knowledge gained in previous business courses and extend that into the area of contemporary automation operations problems.
3. Suggest the range of general management issues that must be considered in technologically advanced enterprises in effectively handling individual operating decisions with a strategic point of view.
4. Introduce the details concerning the variety of types of flexible automation, including flexible manufacturing systems, integrated circuit fabrication and assembly, and robotics, with an emphasis on how these differ from conventional manufacturing.
5. Understand the strategic benefits as well as economic justification issues.
6. Learn about the design, planning, scheduling, control, and integration problems that are unique to automation.
7. Understand the benefits and problems of many types of flexibility.

Course Preparation

Each small group of four to six students will write a short, applied research paper on a topic of the course or a related topic selected with the permission of the instructor. These will be on some mutually agreed upon topic, such as system integration issues, tool management, flexible assembly, flexibility issues, and automation software issues, for example. The main purposes of this group project are to let you explore in some detail a topic concerning flexible automation that is of interest to you, and to have the entire class learn from your research effort. Second, I am interested in having you polish your interpersonal and communication skills.

A proposal for the paper in the form of a title, a one-page summary of objectives, abstract, and expected outcomes for this topic is due by **Monday, October 28**. The final paper should not exceed 12 double-spaced pages, including references and supporting materials, such as exhibits, tables, figures, and/or appendices. The oral reports will be presented in class on **November 21** and the final paper due on **December 5**. Accompanying each written report could be copies of the overheads used in the oral presentation. Preparation and distribution of all materials (copies of overheads, if you like) to your classmates is the responsibility of each group. Topics will be accepted on a first-come/first-served basis, so it is in your interest to form your groups and select your topics as soon as possible, and by **October 28** at the latest.

Generative AI tools like ChatGPT do not need to be used. If you choose to use it after your entire 12-page report is finished, check what it “suggested” (in case it is nonsense or change what you meant to say). Include an acknowledgement of how and where you used it and the results (just after your list of references). Turnitin or other methods may be used to detect the use of AI. Inappropriate use of AI may result in penalties.

The final grade is determined by the midterm (40%), final paper and presentation (40%), and class participation (20%). I keep accurate records of class participation, which consists of any questions, comments, suggestions, and analyses that facilitate class learning. I evaluate the quality of your contribution, not how many times you speak.

In order to obtain the full benefit of the case approach, it is necessary that everyone comes to class well prepared for an intelligent and interesting class discussion. This does not mean that “you have solved the case” or “have all the answers” to the case. Given the complexities of the real world, there is no answer. However, it does mean that you have thoroughly read the case and other assigned materials, have intelligently thought about the issues raised by the case and associated assignment questions, and have done whatever quantitative analysis is appropriate. In class, your instructor will act as moderator, questioner, and lecturer to help guide the learning process. By actively participating in class discussions, you will sharpen your own insights, and those of your classmates. You will not only learn the “content” of the course, but perhaps more importantly, the “process” of analysis, formulation, and implementation.

Laptops and Cell Phones

Computers are not useful for our case discussions. I know that some students like to take notes in class on their computers. Every term, some students complain to me that the sounds from laptop users are highly distracting to them. Also, there is research that shows that learning is enhanced from the process of manually taking notes in class. Therefore, laptop use is not allowed. Cell phones should always be turned off. If you must send or review a text, please leave the room.

Attendance

There are occasional legitimate conflicts that prevent a student from completely preparing a given case, or from attending class. If you are not able to fully prepare for class, please attend anyway and participate as best you can. But please tell me of your situation before class, so that I will not ask you questions that you are not prepared well enough to discuss. If you must miss a class, please inform me so that I understand your situation. By enrolling in this course, you are agreeing to do your best to attend and contribute to the group learning experience.

Reserve

The following book is on reserve in McDermott Library.

- Horst Tempelmeier and Heinrich Kuhn, Flexible Manufacturing Systems: Decision Support for Design and Operation, John Wiley & Sons, NY (1993).

Course Outline

Session 1, August 22 - Course Introduction.

Learning objectives for this session:

- **Develop an understanding of what an automated, flexible machining system is and what its capabilities are.**
- **Become familiar with the basic vocabulary of flexible automation.**

1. Read:

- “CNC Mini Mills Enable Medical Manufacturer to Produce an Artificial Disc that Could Revolutionize Treatment of Back Injuries,” Tooling & Production (June 2012).
- “Not Your Father’s Space Shuttle,” Modern Applications News (March 2007).
- “European Fab Shops Profit with Automation,” Modern Applications News (July 2006).
- “CAM Cuts Errors 80%, Programming Time 66%,” Modern Applications News (May 2005).
- “Designing with CAD, Artist Sculpts Choppers,” Modern Applications News (May 2005).
- “CAD, CAM, or CAD/CAM? Is It For Your Shop?,” Modern Applications News (April 2004).
- “James F. Manji, “Microbrewery Draws Big Benefits from PLC Control,” Managing Automation (April 1998).

2. Flexible manufacturing systems (FMSs) and their components and benefits will be defined. Differences from conventional systems will be explained. Many examples of existing systems from various countries will be described, in order to demonstrate the wide variety of systems (and problems).

Session 2, August 29 - Introduction to Flexible Automation.

Learning objectives for this session:

- **Develop an understanding of what an automated, flexible machining system is and what its capabilities are.**
- **Become familiar with the basic vocabulary of flexible automation.**

1. Read:

- “Major Detroit Automotive Manufacturer’s Conveyor Problem Leads to a Case of the Munchies,” Tooling & Production (July 2016).
- “Small Fixes Have Big Green Pay-offs,” Modern Applications News (April 2009).
- “Getting by With a Little Help from Friends,” Modern Applications News (April 2008).
- “Mobile Parts Hospital Uses Quick Change Tooling,” Production Technology News (Feb 2004).
- “Computer Numerical Controls,” Modern Applications News (July 2003).
- “FMS Turns Work Cells Into Manufacturing High Flyers,” Modern Applications News (December 1999).
- Martin Piszczalski, “Strategies for Spending Millions,” Managing Automation (August 1987).
- Paul Kinnucan, “Flexible Systems Invade the Factory,” High Technology (July 1983).

2. A film featuring several U.S. FMSs will be shown.

Session 3, September 5 - Strategic Considerations of Flexibility.

Learning objectives for this session:

- **Understand the risks involved when innovating with new technologies.**
- **Recognize the organizational support that is needed to support technological change.**
- **Understand the significant advantages from flexible automation and the value of flexibility.**
- **Appreciate the newer strategies in selling and using FMSs.**

1. Read:

- “Alcoa Signs \$2.5 Billion Supply Contract with Boeing for Fasteners and Titanium Seat Track Assemblies,” Tooling & Production (July 2016).
- “High-speed Machining Cells Allowed Boeing to Create Higher Quality Parts 30% Faster Than Ever Before,” Tooling and Production (October 2013).
- “A Plastic Dream Machine,” Business Week (June 2005).
- “Breakthrough 5-Axis Technology Dramatically Improves Production of Eurofighter Large Parts,” WolfTracks (2001).
- “LTV Aerospace to Remain Independent Under Lockheed,” Aviation Week and Space Technology (February 10, 1992).

2. Prepare Vought Aero Products: Factory of the Future.

- a. What were the major barriers to successful introduction and implementation of the flexible machining cell (FMC)? How were these barriers overcome? Why did Vought succeed where others failed? What were their particular operating problems? What did the company learn about managing advanced and automated manufacturing projects from the FMC?
- b. What is the role of the Industrial Modernization (IMOD) group at Vought? What is the role of the Manufacturing Development and Support (MD&S) group? Are both groups necessary?
- c. Should Vought build the Integrated Machining System (IMS)? Why or why not? What are the risks of each project? How do its risks and benefits compare with those of the Flexible Composites Center (FCC)?

Session 4, September 12 - Seru Production Systems.

Learning objectives for this session:

- **Learn about a new Japanese organizational and production system, *seru*.**
- **Observe why it is better than conventional systems (more flexible, more efficient, and more productive).**

1. Read:

- Yong Yin et al., “The Evolution of Production Systems from Industry 2.0 through Industry 4.0”, International Journal of Production Research (January 2018).
Download and print it from <https://www.tandfonline.com/doi/full/10.1080/00207543.2017.1403664> .
- Yong Yin et al., “Lessons from *Seru* Production on Manufacturing Competitively in a High Cost Environment,” Journal of Operations Management (March 2017).
Download and print it from <https://www.sciencedirect.com/science/article/pii/S0272696317300116> .
- ChenGuang Liu et al., “An Implementation Framework for *Seru* Production”, International Transactions in Operational Research (January 2014).
Please download and print this from <http://onlinelibrary.wiley.com/doi/10.1111/itor.12014/full> .
- K. E. Stecke et al., “*Seru*: The Organizational Extension of JIT for a Super-Talent Factory”, International Journal of Strategic Decision Sciences (March 2012).
- Yong Yin et al., “The Evolution of *Seru* Production Systems Throughout Canon”, Operations Management Education Review (December 2008).
- S. Blue, “Why Smart Manufacturing is a Dumb Idea,” Tooling & Production (August 2018).
- “Radical New Way to Build Vehicles,” Ward’s Auto World (September 2011).
- “Comau Sells Smart Assembly,” Ward’s Auto World (February 2010).

2. Class introduction: What are your experiences and interests in flexible automation? What types of automation are you familiar with?

Session 5, September 19 – Professor Yonas Tadesse will discuss the Adaptive Manufacturing and Innovation in Robotics.

Learning objective for this session:

- **Understand adaptive systems with flexible grippers and controls, minimizing waste, and modifications in industrial assembly.**

Read:

- Josie Hughes, Kieran Gilday, Luca Scimeca, Soham Garg, and Fumiya Iida, "Flexible, adaptive industrial assembly: driving innovation through competition: Flexible manufacturing," *Intelligent Service Robotics*, Vol. 13, pp. 169-178 (2020).
- Gianni Stano, S M Al Islam Ovy, Jakob Ryan Edwards, Matteo Cianchetti, Gianluca Percoco, and Yonas Tadesse, "One-shot additive manufacturing of robotic finger with embedded sensing and actuation," *International Journal of Advanced Manufacturing Technology*, Vol. 124, Nos. 1-2, pp. 467-485 (2023).
- S M Al Islam Ovy, Gianni Stano, Gianluca Percoco, Matteo Cianchetti, and Yonas Tadesse, "Inexpensive monolithic additive manufacturing of silicone structures for bio-inspired soft robotic systems," *Engineering Research Express*, Vol. 5, No. 1, p. 015016 (2023).

Session 6, September 26 - Manufacturing Flexibility

Learning objectives for this session:

- **Discover how a lot of benefits can be obtained from a little flexibility.**
- **Explore how flexibility can help in risk mitigation.**
- **Learn about the state-of-the-art research and practices in flexibility and risk mitigation.**

1. Read:

- W.C. Jordan and S.C. Graves, "Principles on the Benefits of Manufacturing Process Flexibility," *Management Science*, pp. 577-587 (April 1995).
- Jim Browne, Didier Dubois, Keith Rathmill, Suresh P. Sethi, and Kathryn E. Stecke, "Classification of Flexible Manufacturing Systems," *The FMS Magazine*, pp. 114-117 (April 1984).
- Andrea Krasa Sethi and Suresh P. Sethi, "Flexibility in Manufacturing: A Survey," *International Journal of Flexible Manufacturing Systems*, (July 1990).
- Jerry Flint, "More Models, Fewer Platforms," *Ward's Auto World* (April 2006).
- Drew Winter, "Critical Differences," *Ward's Auto World* (June 2016).

2. A film will show the new machine tools of Fritz Werner Werkzeugmaschinen AG, Berlin and demonstrate their newer strategic shift into the high-volume market.

Session 7, October 3 - *Quality Function Deployment in Flexible Manufacturing: Guest speaker, Glenn Mazur, President, Japan Business Consultants, Ltd. and Director of the QFD Institute.*

Learning objectives for this session:

- **See how customer value can be connected to manufacturing setup requirements.**
- **Understand that flexible manufacturing delivers value because it allows a company to vary its products in accordance to customer needs.**

Read:

"Jurassic QFD: Integrating Service and Product Quality Function Deployment," *Eleventh Symposium on Quality Function Deployment*, Novi, Michigan (June 1999).

Session 8, October 10 - Flexible Manufacturing Capacity Expansion Decisions, Implementation Plans, Technological Adoption Decisions, and Economic Justification.

Learning objectives for this session:

- **Understand the capacity implications of new technology acquisition decisions over time.**
- **Develop an understanding of the cost calculations and capacity analyses for various alternatives.**

1. Read:

- “Get the Most from CNC Automation Investments,” Modern Applications News (February 2007).
- “An Integrated Model for Part-Operation Allocation and Investments in CNC Technology,” International Journal of Production Economics (December 2002).
- Robin Cooper and Robert S. Kaplan, “The Promise-and Peril-of Integrated Cost Systems,” Harvard Business Review (July-August 1998).

2. Prepare Baker Precision Instruments, Inc.

- a. What could be done in the short term? How would you deal with the immediate capacity crunch? How would you phase in any new FMSs?
- b. How much capacity should be acquired and when? Develop a capacity expansion plan that takes into account demand projections from 1996 through 1999 so as to achieve the objectives of low cost, fast, reliable delivery, and good quality.
- c. How did you consider the setups between families and within families?
- d. What kind of capacity would you recommend Baker buy? In the long run, what are the pros and cons of both FMS types? Take into account both qualitative and quantitative factors.

Session 9, October 17 - Midterm Exam.

Session 10, Friday, October 25 - A tour of Texas Instruments DM0S5 Wafer Fab Plant in Dallas will be held. It is an integrated circuit manufacturing facility. It is the 15th largest clean room in the world. We'll tour the entire line, seeing the diffusion process, plasma etching, photolithography, chemical and mechanical polishing, and more. We'll talk with the Industrial Engineer who does the scheduling, and other operators. We can stay until our questions are answered.

Monday, October 28 - Your one-page paper summary is due.

Session 11, October 31 - Syed Imranuddin will discuss the 3D-printing of piezoresistive sensors for soft robotic grippers that can be used in flexible assembly systems.

Learning objectives for this session:

- **Understanding the basics of fused filament fabrication 3D-printing technology and its use in fabricating piezoresistive sensors.**
- **Learning steps that can be taken to enhance 3D-printed piezoresistive sensors and its potential significance for soft robotics and flexible assembly systems.**

1. Read:

- G. Stano, A. Di Nisio, A. M. Lanzolla, M. Ragolia, and G. Percoco, "Fused Filament Fabrication of Commercial Conductive Filaments: Experimental Study on the Process Parameters Aimed at the Minimization, Repeatability and Thermal Characterization of Electrical Resistance," International Journal of Advanced Manufacturing Technology, Vol. 111, pp. 2971-2986 (2020).
- Q. Ji, J. Jansson, M. Sjöberg, X. V. Wang, L. Wang, and L. Feng, "Design and Calibration of 3D Printed Soft Deformation Sensors for Soft Actuator Control," Mechatronics, Vol. 92, p. 102980 (2023).
- G. Rosati, S. Minto, and F. Oscari, "Design and Construction of a Variable-Aperture Gripper for Flexible Automated Assembly," Robotics and Computer-Integrated Manufacturing, Vol. 48, pp. 157-166 (2017).

Session 12, November 7 - *Introduction of New Technology, Strategic Automation Acquisition, and Other Types of Flexible Automation.*

Learning objective for this session:

- **Become familiar with the problems and typical pitfalls in first evaluating, then implementing, a new technology.**

1. Read:

- Jared Lindzon, “7 Ways to Manage Change When Implementing New Technology,” Epicor (August 2019).
- Bharat K. Kaku, “Fitting Flexible Manufacturing Systems to the Task,” Industrial Engineering, Vol. 26, No. 11 (November 1994).
- Robert S. Kaplan, “Must CIM be Justified by Faith Alone?,” Harvard Business Review, Vol. 64, No. 2 (March-April, 1986).

2. Prepare Chaircraft (B).

- a. Evaluate the key management decisions made concerning the Hancock Cutter:
 - Decision to purchase the automated equipment;
 - Implementation decisions.
- b. What should Mr. Mitchell do now?
- c. What are the long-run implications of the Hancock Cutter experience for Chaircraft?

Session 13, November 14 - *The Future of Flexible Automation: Reconfigurable Manufacturing Systems.*

Learning objectives for this session:

- **Learn about several approaches to operate an FMS over time, where each approach is appropriate under different circumstances.**
- **Learn about the next generation in flexible manufacturing, reconfigurable manufacturing.**

1. We'll discuss the future developments of flexibility in manufacturing.

2. Read:

- “The Move to a Greater Return on CNC,” Centrifuge Brand Marketing, Inc. (December 2018).
- Erin Callaway, “Manufacturing in the 21st Century,” Managing Automation (October 1999).
- Shamel Rushwin, “Manufacturing Strategies in the 21st Century,” Japan-US Symposium on Flexible Automation (July 2000).

3. FMS Video

Session 14, November 21 - *Group Paper Presentations.*

December 5 - *Papers due.*