

**LEADERS FOR
MANUFACTURING**

SEE PAGE 2

Leaders for Manufacturing... with a "Big M"



BY JUDITH V. STITT

The LFM logo (above) is an abstract view of three people (from MIT Schools of Engineering and Management, Industry) "joining hands" in partnership. Three ellipses link while retaining individual strength, representing a well-integrated team in a smoothly functioning manufacturing process. The symbol's rounded, "friendly" qualities suggest the relational aspects of resolving even very technical manufacturing issues.



Judith V. Stitt has been manager of Communications with the Leaders for Manufacturing Program since early 1989. From 1984 through 1988, she was technical writer/editor for the Ceramics Processing Research Laboratory in MIT's Department of Materials Science & Engineering, a position to which she brought seven years' experience as a technical and instructional systems writer and production manager. She earned a BS degree in chemistry from Allegheny College in Meadville, PA, in 1977.

Promoted to plant manager just eight months after his 1990 graduation, then transferred with a second promotion one year later, **Timothy Loucks**, 33, credits his Leaders for Manufacturing (LFM) educational experience at MIT as "pivotal to my success at International Paper, making it possible for me to become an apostle of radical change."

Loucks started work as an industrial engineer three summers ago at Strathmore Paper's Westfield, MA, Finishing Operation in the Fine Papers Division, arriving as an alumnus of the LFM Fellows Program's first graduating class.

True innovation
in manufacturing
requires a full
and equal partnership
between academia and industry.



Tim Loucks '90 (l) confers with Tom Tubbs, sheeter operator (r), about the quality of a finished sheet of 50-lb offset printing paper at International Paper's Ticonderoga Mill.

The following February, he was charged with overseeing, together with eight supervisors, the plant's 175 other employees on three shifts in operations, production, and maintenance.

Now superintendent of the finishing operation at International Paper's Ticonderoga Mill in Ticonderoga, NY (part of the Springhill business unit in the Pulp and Paper segment), Tim is responsible for scheduling and distribution as well as production, and supervises twenty-five salaried employees along with 175 hourly workers.

In his two years with International Paper, Loucks has been instrumental in

consolidating two facilities into one, during the process relocating over a million pounds of finished goods inventory without missing a single shipping day. He has also worked to revamp an existing department from a functional to a cellular orientation, reducing lead-times and work-in-process inventory and providing employees with a new job focus: working as a group rather than following strict job classification lines. Along the way, he has restructured several departments to eliminate inefficient manual operations by fully utilizing existing automated equipment, and championed a new strategy

for finishing product in a central location rather than in outlying areas.

Loucks shrugs off such accomplishments with the quip that "none of them is really all *that* significant!" LFM administrators speculate that such high personal standards, along with Tim's responsibility and maturity, were honed during his undergraduate years at West Point. Indeed, during Loucks's stint in the Fellows Program, half-jests began to propagate from Leaders HQ that "*all* incoming fellows should be sent off to boot camp!" (Proof that jests can take on a life of their own is offered in the "Curricula" section that follows.)

VISION

The Leaders for Manufacturing Program is a partnership between MIT and U.S. manufacturing firms to discover and translate into teaching and practice principles that produce world-class manufacturing and manufacturing leaders. This partnership is motivated by our shared belief that excellence in manufacturing is critical to meeting the economic and social needs of individuals, firms, and society, and that the health of U.S.-based companies operating in global markets is essential to the nation's well-being.

Loucks is one of nearly ninety graduates now of MIT's rigorous two-year Leaders for Manufacturing Fellows Program who have earned dual master's degrees, in engineering and management. Launched in the spring of 1988, Leaders for Manufacturing is a partnership of thirteen major U.S. manufacturing companies with the Sloan School and five departments in MIT's School of Engineering. The program is one Institute response to increasingly urgent questions about how to improve the U.S. productivity growth rate. To study the issue, in late 1986 MIT convened its Commission on Industrial Productivity, which in 1989 published a report of six interrelated behavior patterns that weaken U.S. productivity performance, and five goals for industry, labor, government, and education to adopt as corrective measures.¹

To implement some of these recommendations, the Institute approved (as a five-year experiment, initially) the Leaders for Manufacturing Program. "LFM is about leadership," emphasizes Ford Professor of Engineering **H. Kent Bowen**, the program's engineering co-director during its first three years. "If there is a single message coming from manufacturing executives, it is that U.S. firms need leaders to transition companies from 'the old paradigm' to 'the new paradigm'."

Just as important as its leader "products," program participants believe, is LFM's leadership development process: the Leaders Program is founded on the belief that true innovation in manufacturing requires a full and equal partnership between academia and industry.



The Leaders for Manufacturing Program's "total-enterprise" approach to manufacturing

Thomas L. Magnanti, George Eastman Professor of Management Science, co-director of the Leaders Program and of the Operations Research Center, and director of the Institute's Decision Sciences Program, reflects that "in the past, interactions between MIT and industry have been much more superfi-

cial. Industry might provide field sites for our work and some financing, and once or twice a year we'd report on what we were doing. Leaders is a *partnership*, not a sponsorship, a real collaboration between MIT faculty and students and thirteen leading corporate U.S. manufacturers."

¹ Michael L. Dertouzos, Richard K. Lester, Robert M. Solow, and the MIT Commission on Industrial Productivity, *Made in America: Regaining the Productive Edge*. The MIT Press, Cambridge, MA, 1989, pp. 44 and 132.



BRADFORD HERZOG

George Eastman Professor of Management Science **Thomas L. Magnanti**, founding co-director of the LFM Program



IVAN MAASER

Ford Professor of Engineering **H. Kent Bowen**, founding co-director of the LFM Program



IVAN MAASER

Professor **John B. Heywood**, director of MIT's Sloan Automotive Laboratory and acting LFM engineering co-director in 1991-1992

The Leaders Program addresses manufacturing issues "holistically, rather than take rifle-shots at individual issues to achieve quick fixes," adds Bowen. The program's "total enterprise approach" bridges the traditional technology/management cultural divide through a broad understanding of manufacturing that integrates key functions and disciplines involved in creating, designing, making, and selling/servicing products. Program participants term this concept "big-M Manufacturing" to include not simply the critical functions within a corporation, such as engineering, operations, and marketing, but also customers, vendors, suppliers, community, and government.

THE COLLABORATION

The program is building a culture its participants call "the LFM Way," using total quality management (TQM) processes to manage and improve all aspects of itself. The key tenets of total quality management—which has been described as a "thought revolution" that has catapulted Japan's stature in the global marketplace—are a focus on customer satisfaction, continuous improvement, and total involvement in these activities at all organizational levels. TQM's teamwork and continuous improvement are integral to changing the environment in which LFM participants function, impacting the ways in which the program's faculty are mea-

sured, rewarded, and teach; its students learn; and its researchers address technical challenges.

The program's approach emphasizes people and nontraditional, multidisciplinary teaching and research. Professor **John B. Heywood** (Mechanical Engineering), director of MIT's Sloan Automotive Laboratory and acting engineering co-director of LFM this past year, summarizes LFM's functioning as being "faculty and students joining industry engineers and managers to work on the complex, multifaceted issues that limit our manufacturing capabilities." Leaders students and faculty frequently draw upon industry practitioners and plant facilities to generate and analyze data in the companies' "living laboratories." The companies contribute to both the LFM curricula and research agendas, as well as to the solution of specific issues they themselves deem important.

In the past few years, Leaders faculty have spent their sabbatical leaves working closely with partner firms. For example, during his 1990-91 sabbatical, Magnanti spent seven months at Digital Equipment Corporation learning about the company's manufacturing operation by participating in ongoing projects such as studies of productivity measurement and the company's distribution system.

"LFM pioneers new modes of industrial cooperation," says William C.

LFM PARTNERS

Aluminum Company of America
The Boeing Company
Chrysler Corporation
Digital Equipment Corporation
Eastman Kodak Company
Ford Motor Company
General Motors Corporation
Hewlett-Packard Company
Intel Corporation
Johnson & Johnson

Massachusetts Institute of Technology

School of Engineering
Aeronautics and Astronautics
Chemical Engineering
Electrical Engineering and Computer Science
Materials Science and Engineering
Mechanical Engineering
Sloan School of Management

Motorola Incorporated
Polaroid Corporation
United Technologies Corporation

Effective collaboration requires considerable bridge building.

Hanson, vice president, Logistics, Digital Equipment Corporation and Leaders Governing Board member. "A deeper level of understanding is vital to manufacturers' future success." In 1989, two key Digital employees joined eight faculty to teach lab sections and to lecture in the Mechanical Engineering Department's required design course. Michael Kleeman, senior mechanical engineer for Digital's low-end systems electromechanical design and support, and William Schmidt, engineering consultant with Digital's mid-range systems, each spent twenty hours a week working with Professors



Professor **Warren Seering**, co-head of the LFM Research Program

Woodie Flowers and Warren Seering. Each had complete charge of his lab's students and collaborated with faculty on twice-weekly lectures for all of the students.

Schmidt and Kleeman focused on "real-world" design concerns such as safety, aesthetics, cost, quality, reliability, and materials. Students were enthusiastic, and Flowers expressed appreciation for the pair's bringing "invaluable industrial experience to the course, including lots of input about the quality of the design work."

Magnanti suggests that the Institute "differs markedly from most U.S. universities, in that its management school is 'in and of' MIT—not a near-autonomous academic unit. For example, approximately 20 percent of the full-time equivalent students at the Sloan School are enrolled in degree programs elsewhere at MIT, primarily in the Engineering School. At most other major management schools, this percentage is close to zero because students from

MISSION

The purpose of the Leaders for Manufacturing Program is to identify, discover, and translate into practice the critical factors that underlie world-class manufacturing in a way that:

- attracts potential leaders with a global perspective and develops them to bring about world-class manufacturing
- establishes and verifies a new set of principles and practices for manufacturing
- stimulates new and innovative modes of operation for academia and industry
- achieves a high level of cooperation between academia and industry to integrate the technical, managerial, human, and organizational dimensions of manufacturing
- establishes ongoing collaborative processes for problem identification, discovery, and knowledge transfer

other parts of the university cannot attend the management school." "Collaboration isn't easy," he adds. "Engineering and management schools have different cultures, educational philosophies, and world views. Effective collaboration requires considerable bridge building, development of mutual respect and understanding, and a willingness to be flexible."

Results of such potentially difficult interactions, however, have been so promising that for the past year indus-

try and Institute partners have worked to extend the Leaders Program beyond its initial five-year experimental stage to a self-sustaining mode. Intel Corporation's and Ford Motor Company's joining the partnership this spring represent additional votes for the program's objectives and processes.

Industry and Institute partners jointly determine everything from program content and processes to products. The LFM Governing Board—senior executives from the partner com-

panies, the deans of MIT's Schools of Engineering and Management, and other high-level Institute faculty/administrators—meets twice a year to set policy and direction. Board members are also involved through the year in the program's direction and its implementation within their firms. The LFM Operating Committee—key company executives and a half dozen senior faculty—meets three times a year to guide curriculum design, research agendas, governance, and administration.

LFM GOVERNING BOARD (AS OF JUNE 1992)

Aluminum Company of America

Vincent R. Scorsone
Executive Vice President, Chairman's Council

The Boeing Company

*A.D. Welliver
Corporate Senior Vice President, Engineering & Technology

*Deane D. Cruze
Corporate Senior Vice President of Operations

Chrysler Corporation

Dennis K. Pawley
Executive Vice President

Digital Equipment Corporation

*William C. Hanson
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Eastman Kodak Company

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Ford Motor Company

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**John M. Matson
Vice President, Operations Technology & Development

Massachusetts Institute of Technology

*H. Kent Bowen
Co-director, Leaders for Manufacturing Program

*Thomas L. Magnanti
Co-director, Leaders for Manufacturing Program

John B. Heywood
Acting Co-director, Leaders for Manufacturing Program

*Donald B. Rosenfield
Director, Leaders for Manufacturing Fellows Program

Joel Moses
Dean, School of Engineering

*David N. Wormley
Associate Dean, School of Engineering

*Merton C. Flemings
Department Head, Materials Science & Engineering

*Lester C. Thurow
Dean, Sloan School of Management

Robert B. McKersie
Deputy Dean, Sloan School of Management

Timothy P. Loucks '90
International Paper

Mark G. Atkeson '91
United Technologies Corporation

Motorola, Incorporated

*Mauro J. Walker
Corporate Vice President
and Motorola Director of Manufacturing

**William M. Beckenbaugh
Vice President and Director, Corporate Manufacturing
Research Center

Polaroid Corporation

*Joseph R. Oldfield
Vice President, Product Development
and Worldwide Manufacturing

United Technologies Corporation

*Robert J. Hermann
Vice President, Science and Technology

* founding Governing Board member

** founding Operating Committee member

AN IMPORTANT STEP

In general, Alcoa's experience [with the Leaders for Manufacturing Program] has been excellent. We have sponsored six internships to date, hired one student as a production supervisor at one of our plants, hired a second student to work in our corporate manufacturing technology group, and sponsored our first Alcoa who will conduct her internship with one of the LFM sponsoring companies. For 1992 we plan to enroll another Alcoa in the program and sponsor three additional internships.



Alcoa considers the LFM Program an important step in bringing world-class people and understanding into our manufacturing facilities. The quality and efficiency of our manufacturing processes are fundamental to the success of our company and the ultimate satisfaction of our many stakeholders. LFM is one element of maintaining a position of world leadership in manufacturing not simply for Alcoa but for our entire country as well.

We are especially pleased with the quality of the internships and resulting theses. On-site involvement of faculty and students has provided Alcoa management with new ideas and directions. Likewise, exposure of faculty and students to actual manufacturing situations and problems will improve the teaching/learning process and provide a test bed for manufacturing theories and methodologies.

We look forward not only to staying with the program but to expanding the internship to include many additional Alcoa locations.

VINCENT R. SCORSONE
EXECUTIVE VICE PRESIDENT -
CHAIRMAN'S COUNSEL
ALUMINUM COMPANY OF AMERICA

FACULTY

The Leaders Program's success hinges on its developing its resources to better enable capable, diverse young people to lead globally competitive manufacturing operations. Critical in this respect are the roles of faculty and the curricula they develop.

During its first year, the Leaders Program awarded chaired professorships to twenty senior faculty to give them time and intellectual space to undertake the "big-M" mission. Fifteen Leaders professors now serve as "coordinating liaisons" with partner companies, becoming well versed in their company's organization, culture, products, technologies, challenges, and needs in order to facilitate closer working relationships with the Leaders Program. Professor Seering observes that his liaison role with Digital Equipment has enabled him "to talk more often and at greater length with key decision makers than I'd otherwise have been able to do. That's given me a much better understanding of how decisions are made there, how information is gathered and used, and how the manufacturing side of the company is structured and operates."

Currently the Leaders Program closely involves fifty faculty drawn from many disciplines and functions, actively encouraging them to work across traditional disciplinary boundaries. Professor **Roy Welsch** (Statistics and Management Science), liaison faculty for Polaroid, notes that "the Leaders Program has greatly improved my interaction with engineering faculty, and made my life at MIT much more interesting and rich as a result." The faculty involved with Leaders include three Presidential Young Investigators; seven MIT faculty members of the National Academy of Engineering² have made key contributions to the program, as well.

LFM faculty, who have made hundreds of trips to partner sites to learn about issues the firms face and to help resolve them, are incorporating manufacturing-related information into existing courses, including examples gleaned from LFM research projects. Assistant Professor **Steven Eppinger** (Manage-



Leaders for Manufacturing Professor **Roy Welsch**, co-head of the LFM Research Program

ment Science), who holds SB, SM, and ScD degrees in mechanical engineering from MIT, affirms that "LFM has impacted the way we teach Operations Management to the Sloan master's students. The time faculty spend with LFM companies provides us with relevant experiences for motivating our students and discussing timely operations issues in class."

LFM ensures a constant infusion of innovative ideas by supporting and actively promoting its younger faculty. Sixteen untenured faculty have received unrestricted research grants; seven have been promoted (three to tenure) while conducting nontraditional, interdisciplinary, manufacturing-related research supported by Leaders. Assistant Professor **Mark Jakiela**, an NSF-funded Presidential Young Investigator in Mechanical Engineering and LFM research liaison for Polaroid, acknowledges the partner company for having "gone out of its way to support my research. They consistently bring up interesting, industrially pertinent problems that lead to great research projects."

In memory of her late husband, Anne Bowers Noyce recently established Robert N. Noyce Career Development Professorships in the School of Engineering and the School of Management. These have been awarded to

² Of interest to the Sloan community, and one indicator of the MIT Sloan School's niche among management schools, may be the fact that its faculty includes three members of the National Academy of Engineering: Jay W. Forrester, John D.C. Little, and Thomas L. Magnanti, the latter two of whom have contributed to the Leaders Program.



MARK OSTOW

Assistant Professor **Steven Eppinger** (Management Science) has three engineering degrees from MIT and is research liaison with General Motors.

Jakiela and to Assistant Professor **Rebecca Henderson** (Strategic Management), who teaches Sloan's core course in corporate strategy and an elective in strategy. "Leaders has greatly facilitated my research," Henderson says. "It enables me to be privy to information that would have taken years to gather on my own." With Assistant Professors Eppinger, **Karl Ulrich** (who, like Eppinger, holds SB, SM, and ScD degrees in mechanical engineering from MIT), and **Marcie Tyre**, Henderson has developed a management and technology module required of all first-year Sloan Master's degree candidates.

Senior Lecturers **Donald Ephlin**, retired international vice president of UAW, and **Donald Davis**, retired CEO of The Stanley Works, bring additional expertise to the program (see "A few minutes with Don Ephlin" and "A few minutes with Don Davis" elsewhere in this article).

STUDENTS

And then there are the students. John F. Floyd, director of Paint and Pilot Operations, Chrysler Corporation and formerly a member of the LFM Operating Committee, considers "a major benefit of the LFM Program to be its role as a conduit between highly educated—exceptional—graduates and American manufacturing."

To date the Leaders Program has funded graduate educations for more than 370 young men and women: 172



MARK OSTOW

Rebecca Henderson, the first Robert N. Noyce Career Development Assistant Professor at Sloan, and Assistant Professor Steven Eppinger are co-developers of a management and technology module required of all first-year Sloan master's degree candidates.

admitted to the two-year, dual master's degree Fellows Program, and (through its Research Program) about 200 graduate research assistants in various departments studying manufacturing-related issues ranging from the development of cost models and testing strategies to the development and implementation of new technologies.

THE FELLOWS PROGRAM

Donald B. Rosenfield, director of the LFM Fellows Program and senior lecturer at the Sloan School, projects that "tomorrow's manufacturing leaders will have to be able to fully understand both the technology and management issues of their industries. Beyond this, they must be able to integrate technology and management to deal with the complexities and ambiguities of running an integrated enterprise." The LFM Fellows Program, he adds, "is designed to attract students who can meet these challenges."

This year, Leaders is offering financial aid for tuition and a monthly stipend to its fellows as a combination of research assistantships and fellowships. Students are expected to join a U.S. manufacturing firm at graduation and continue working in manufacturing for their careers.

Others are joining the program's initiative to attract the best and brightest to manufacturing. Last year the Intel

BENEFITS FOR THE NATION

As a founding partner of the Leaders for Manufacturing Program, The Boeing Company is committed to the principle that excellence in manufacturing is vital to the nation's economic and social needs.



Since its inception in 1988, the program has demonstrated that success in the global environment now depends on integrating customers, vendors, suppliers, government, and all corporate functions into the manufacturing process. Like Boeing, the LFM partners are committed to combining the resources and skills of industry and academia to develop new processes that will enhance America's competitive position.

As the accompanying article notes, Boeing itself has already achieved process improvements based on studies performed by program participants. Yet the work done so far is only a beginning. Greater gains are still to be made.

By training those individuals with outstanding talents and abilities, MIT and industry will continue to send a clear signal of what must be done to secure our economic future.

Boeing is confident that this link between business and academia will yield benefits not only for manufacturers but for the nation as well.

F.A. SHRONTZ
CHAIRMAN AND CEO
THE BOEING COMPANY

Foundation created several fellowships in memory of Intel's late founder, Robert N. Noyce, PhD '53, Physics, for graduate students with technical undergraduate backgrounds who aim to improve U.S. industrial competitiveness in the world marketplace. One of the first Noyce fellows is **Lynn Cascio '93**, who graduated fifth in her class of 943 from Clarkson University (BS '86, Electrical and Computer Engineering). Cascio, who says she entered manufacturing because it is "a dynamic, vital field that offers many professional challenges and rewards," joined LFM after working as an advanced electrical engineer for Polaroid Corporation, then as a product manager with Harris Scientific Calculations. "LFM's mission," she says, "strikes the right chord with my own values."

Admissions

Applicants to the LFM Fellows Program (twenty admitted for the Class of



Donald B. Rosenfield, director, LFM Fellows Program

1990, up to fifty to be admitted per class eventually) must demonstrate



Lynn Cascio '93, Noyce Fellow

teamwork/leadership abilities, commitment to manufacturing, superior aca-

SAMPLE RESEARCH PROJECTS

INTERNSHIPS (FELLOWS PROGRAM)

Understanding process limits and manufacturing implications; Inventory reduction in a large job shop
— ALCOA

Application of photogrammetry in aircraft manufacturing; Applicability of the Toyota production system to aircraft manufacturing
— BOEING

Installing new performance measures to drive continuous improvement; Evaluation of simultaneous development efforts with manufacturing process suppliers
— CHRYSLER MOTORS

Cost and quality drivers in PCB assembly; Productivity improvements of laser-etching process for thin-film head slider production
— DIGITAL EQUIPMENT CORP.

Effective prototyping during product development; Reducing process variability in batch chemical manufacturing through data acquisition and analysis
— EASTMAN KODAK

Analysis of health risks associated with electric shock due to electric vehicle voltage; Modeling manufacturing costs early in the design process and evaluat-

ing design for assembly tools
— GENERAL MOTORS

Process development and modeling; Process improvement and strategic analysis of fused-silica capillary tubing manufacturing
— HEWLETT-PACKARD

Integrated computer system design for greater process control to eliminate sterility assurance tests and reduce product cycle time; Process improvement to enhance yields of a chemical coating process
— JOHNSON & JOHNSON

Optimizing factory scheduling to meet customer want date and minimize

WIP inventory; Process improvement of testing and repair in printed circuit board assembly
— MOTOROLA

Improving management information systems to improve resource allocation for new product development; Internal customer focus as a strategy for product/process development
— POLAROID

Rule-based design of tooling to reduce lead time; Environmental, technical, and operational analysis of replacing lead solder in SMT assembly
— UNITED TECHNOLOGIES CORP.

ademic achievement, and usually a few years of work experience.

Another admissions consideration is range of interests and experiences. As one example: before he joined Leaders, **Mark Atkeson** '91, 28, worked as a project coordinator for Cincinnati Milacron in the People's Republic of China, and then as a marketing representative with Sony Corporation in Tokyo. Now a program manager with United Technologies Corporation and based in Europe, Atkeson observes that "our ability to compete in manufacturing is already being measured in a global arena. The Leaders Program emphasizes the importance of learning from our overseas competitors, a function that will become increasingly valuable as the United States enters into international partnerships to develop new technologies and markets around the world."

One way the program is accelerating technology transfer into the partner companies and increasing the partners' rate of learning about careers and organizational change is by admitting more fellows who have worked with its partner companies. Forty percent of the Class of '94 have worked with one or more partner companies; 27 percent are sponsored by partner companies.

Leaders actively seeks qualified underrepresented minorities and women. The forty students in the Fellows Program Class of 1993 include nine women and three underrepresented minorities. The forty-five students in the Class of 1994 include seven women and four minorities.

Curricula

The overall strategy of the LFM Fellows Program is to offer outstanding young technologists an educational experience centered in the whole manufacturing enterprise, rather than focus more narrowly on manufacturing engineering, operations, or management. A program hallmark is its integration of engineering and management concepts and methods (i.e., consideration of technical aspects of manufacturing in light of management implications, and vice versa) in classes, seminars, workshops, plant visits, and internships.

After clearing the twin hurdles of standard entrance requirements for MIT's School of Engineering and the Sloan School, then negotiating LFM's

Profile: Fellows Class of 1994

Number of candidates:	250
Number of class members:	45
Women:	7
Underrepresented minorities:	4
Average GMAT score (<i>Range</i>):	710 (580 - 770)
Undergraduate grade-point average (out of 5.0) (<i>Range</i>):	4.74 (4.39 - 4.99)
Representative undergraduate majors:	
Aeronautics & Astronautics	
Chemical Engineering	
Electrical Engineering & Computer Science	
Mechanical Engineering	
Materials Science & Engineering	
Average years full-time work experience (<i>Range</i>):	3.8 (0 - 9.5)
Average age (<i>Range</i>):	26 (21 - 33)

TYPICAL LEADERS FELLOWS CURRICULUM

(Subjects)

YEAR 1 SUMMER

Systems Optimization & Analysis for Manufacturing
Engineering Probability & Statistics
Financial & Managerial Accounting
Applied Macro- & Microeconomics
Total Quality Management

FALL

Operations Management
Managerial Behavior in Organizations
Communication for Managers
Strategic Management (half semester)
Engineering elective
Proseminar in Manufacturing
Fundamentals of Manufacturing Processes or engineering elective

JANUARY

Extended plant tour
Initial internship visit

SPRING

Financial Management
Industrial Relations & Human Resource Management (half semester)
Introduction to Marketing (half semester)
† Product Design & Manufacturing
Proseminar in Manufacturing
‡ Materials Processing or engineering elective
Elective

YEAR 2 SUMMER/FALL

Internship

JANUARY

Thesis
Organizational Leadership & Change

SPRING

Manufacturing Policy
Management of Information Systems
Elective
Optional elective

Recommended for ME † Recommended but not required ‡ Recommended for ChE, MSE



KATHERINE MILLER

Scott Jacobsmeyer '94 on the Outward Bound® high ropes course on Thompson Island

own gauntlet of leadership and commitment selection criteria, the new Leaders fellows meet on campus—the LFM Fellows Program starting line—early in June. Later that week they embark on an exhilarating Outward Bound® adventure—Tim Loucks's unintended legacy. After a day on Thompson Island in Boston Harbor participating in such breath-catching activities as traversing a high-tension wire thirty feet in the air and scaling a sixteen-foot wall, the fellows are closer knit as a group, better able to draw on each other's strengths to deal with the intellectual rigors of the twenty-four months ahead.

And so the real adventure begins. The fellows—many of whom have not attended classes in years—knuckle down to an MIT-esque summer of thirty hours of class time per week. For the next nine months, the courseload lightens to twenty-five hours a week. Following a six-and-a-half-month internship at the partner companies, a fifteen-hour-a-week courseload for their final five months gives the fellows time to finish their theses. In two years, LFM fellows fulfill the Sloan core requirements plus another 138 units.

The Sloan School's "management core" develops the fellows' functional expertise in finance, marketing, and



L to r: Scott Packer, a research engineer from the United Technologies Research Center; Mark Atkeson '91; Paul Jacobs, Pratt & Whitney project leader for advanced sensors; and Frank Pinney, Pratt & Whitney manager of CIM Systems and Technology. The photograph shows Mark controlling the CMM (coordinate measuring machine) with a remote control unit. Coordinate measuring machines are automated, programmable, high technology dimensional measuring systems that digitize geometric data from a real part (such as a gear), which can then be compared automatically to theoretical values for that part.

operations; in the disciplinary underpinnings of economics, information technology, modeling and optimization, and probability and statistics; and in their understanding of people and organizations through human resource management and organizational behavior.

An engineering "manufacturing core" that codifies basic manufacturing principles from an engineering standpoint is evolving from the participating engineering departments' diverse requirements. This core, available as several options selected by many students, includes courses in system optimization and analysis for manufacturing, engineering probability and statistics, product design and manufacturing, fundamentals of manufacturing processes, and two departmental electives. An Alfred P. Sloan Foundation grant helps fund the core development effort.

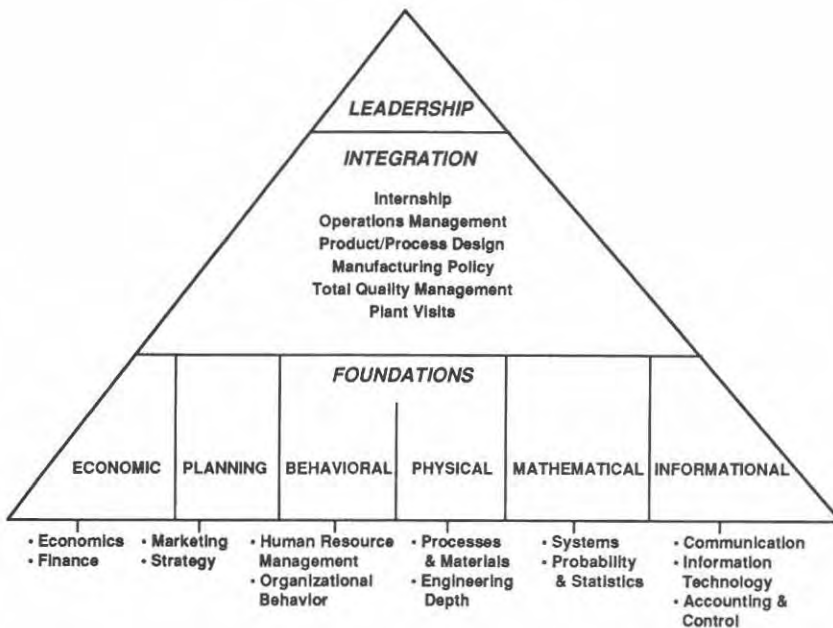
By the time LFM fellows graduate, they have developed a new way of thinking that cuts across technologies, systems, functions, and organizations. As **Kemp Wills** '91, at age 28 manager of Operations Systems for Johnson & Johnson (consumer products) describes it, "Leaders works at *integrating*, rather

than just combining, management and engineering. A standard master's degree program in engineering would not address the tough implementational issues that companies face, such as when to switch to a new technology and how to manage that transition; nor would a standard management program focus on the importance of understanding the underlying technologies that drive our competitive markets."

The fellows' curricula contain a rigorous dose of engineering and management theory and applications, but emphasize teamwork, change management, learning by doing, and the integration of technology and management. Students have plenty of opportunity to learn and experience leadership. Three themes comprise the LFM "educational pyramid": *leadership* embraces all other activities and gives them focus, while *integration* brings together the supporting disciplinary building blocks—the *foundations* of technical and nontechnical knowledge within the disciplinary curricula.

A Leaders education is more than courses. The partners require LFM cur-

**LEADERS FOR MANUFACTURING
EDUCATIONAL PYRAMID**



A Leaders education
is more
than courses.

ricula to develop know-how as well as know-why through skill building (e.g., in teamwork, TQM, and leadership) and attitude development (e.g., a continuous improvement mindset, close integration of technology with management, and consideration of people as knowledge assets). Faculty and company employees mentor the students and provide extracurricular educational experiences such as visits to plant sites around the country. The program encourages its fellows' participation in the management of program activities and improvement projects. Fellows develop leadership through teamwork exercises such as the Outward Bound® experience as well as in classes and group projects they lead, and during their internships.

During the first summer term, one of the world's foremost experts in the area of total quality management, Professor **Shoji Shiba** of the University of Tsukuba in Japan, teaches the fellows TQM concepts and techniques. The experience impacts their subsequent learning experiences in the program and after graduation. The course focuses on managerial tools, especially those that facilitate teamwork. Together with mutual learning, good listening skills, precise and objective



LFM Class of 1991 fellows on internship standing in front of a Boeing 747-400 cockpit section. L to r: Kemp Wills, Mark Jenks, Jackson Chao, Mark Coleman, Patrick Shanahan

language, intuition, and logic, these tools are central to TQM's methods for collecting and processing qualitative data.

The LFM emphasis on total quality management has inspired the Institute to work with the Center for Quality Management (see "Beyond the Institute," following) and participate in Motorola University's "TQM University Challenge." As a result of the latter, MIT is now working with IBM to integrate TQM principles and concepts into management and engineering curricula and the administrative processes supporting their development. Sloan School Deputy Dean **Stephen Graves** says that "the Leaders for Manufacturing Program has led the Institute in its study, teaching, and adoption of TQM practices. We hope that MIT can learn from the Leaders Program's experiences, and that we will be able to dis-



BRADFORD HERZOG

Deputy Dean and Professor **Stephen Graves**, former acting co-director of the LFM Program and member of the program's Operating Committee

seminate TQM practices throughout the rest of the Institute. We are already introducing TQM at Sloan as part of our continuing efforts to improve our students' educational experiences."

A CEO seminar series initiated by Don Davis offers students additional opportunities to interact with manufacturing leaders and encourages students to seek leadership opportunities. The required "Proseminar," which focuses on manufacturing and leadership, opens to the fellows just such opportunities, which they have taken to work, for example, with an after-school "latch-key" program for children; with a junior high to teach a manufacturing unit and conduct a plant tour; and with the Massachusetts Pre-engineering Program to set up daily activities for students that focus on teamwork, hands-on science experiments, and real-world engineering, and to help them

A "really Big-M" perspective of manufacturing leadership

A FEW MINUTES WITH SENIOR LECTURER **DON DAVIS**,
RETIRED CEO, THE STANLEY WORKS

At their first LFM "town meeting" this June, members of the Class of '94 had an opportunity to indicate preferences as to which of ten program committees they might want to join. Don Rosenfield's announcements of nine committee names elicited sprinklings of hands raised dutifully, and politely held aloft for a careful counting. The tenth committee might be said to have won the popularity contest hands down, if not for the fact that most hands (too many to count, Rosenfield and notekeepers decided) in the room shot up—far too quickly and determinedly to be termed "politely"—at its mention: "the Davis Seminars."



MARK OSTROW

Less than two weeks into their first term, the new fellows were obviously well aware of how greatly the Leaders Program has benefited from the time, thought, experience, and remarkable human network brought to the table by Donald Davis, CEO of The Stanley Works in New Britain, CT, for twenty-one years, starting in 1966. During that time, Stanley's annual sales rose from \$230.6 million to \$1.9 billion, and its net income increased from \$11.1 million to \$103.5 million while the firm braved fierce global competition by reducing overhead and inventories, improving production, consolidating, and trimming its workforce through attrition. Since 1989, beginning with the first class of LFM fellows, Davis has conducted a two-part "CEO seminar series" that has consistently won high praise from each class of Leaders fellows.

During the incoming class's fall

term, Davis's seminars address competitiveness in world markets, "dealing mainly with macro issues at the federal level," he says—"a moving target: they're changing all the time, very current." Participants, Davis says, "talk about the *keritsu* approach in Japan, and whether we should have industrial policy. We talk about the impact of federal policy on the deficit, the budget, the cost of mandated benefits, environmental issues—all kinds of issues dealt with in Washington at the federal level that impact industry trying to compete in world markets." The thrust of these seminars, Davis says, is to give students "an opportunity to think hard about current issues that have a real dynamic in determining how successful American manufacturers can be in the world markets."

In the spring, Davis concludes the series with second-year fellows just returned from their six-and-a-half-month internships at partner

fill out college applications and find scholarship money. LFM fellows take time for such activities in recognition of the facts that today's young people will be tomorrow's employees, and the success of manufacturing leaders largely depends on the skills of their workforce.

In keeping with its commitment to continuous improvement and TQM discovery processes, the Fellows Program changes dynamically in response to participants' experience. Since its inception in 1988, the program has added new courses and modified existing ones; faculty have changed their teaching styles to emphasize experiential learning and teamwork. LFM Fellows Program graduates as recent as a year ago, in fact, recognize the value of what is now available to Leaders fellows. **Scott Roodvoets '91**, 28, "would have liked to have had the KJ [a TQM] Method. I also see the classes behind us



Phil Martin (*left*), drawbench operator, confers with **Scott Roodvoets '91** (*right*), tube mill area supervisor, about a proposed cell layout to incorporate the 18,000-lb drawbench shown behind them at the tube mill in Alcoa Tube/Extrusion System's Lafayette Works in Lafayette, IN.

company sites. This time the seminar focuses on leadership, ethics, and values—"subjective issues," Davis notes, "that don't lend themselves to textbooks or right and wrong answers." Drawing upon the students' internship experiences, Davis asks the fellows "to describe examples of good leadership and ineffective leadership they observed [there]."

For about half of the seminars, Davis arranges for a CEO or someone of similar stature (e.g., a U.S. senator, a consultant in the field of ethics) to meet with the students, "so the students can not only probe and quiz about the kinds of issues the executives have dealt with over the years, but particularly so they can observe first-hand that there can be totally different approaches to effective leadership." Davis wants the students "to get the idea that a leader is only good when he or she has followers—that leaders are not assigned their jobs and don't get their leadership roles by trappings or titles or offices. They have to earn leadership, and it's only when they earn it through respect and the loyalty of followers that they are effective leaders. It's difficult to talk about and teach this, but it can be observed."

"After all, this is a *Leaders for Manufacturing Program*," Davis points out. "Tremendous attention is put on the manufacturing part, and I think it's incumbent on all of us to find more ways to develop the leadership talents of students while they're here. Every student accepted in this program has tremendous leadership potential. But like anything else, you have to consciously look for opportunities to practice leadership. You have to expose yourself to situations where you can experiment."

Davis urges the fellows to find projects "outside the academic program, such as Big Brother, Big Sister, or other community activities that are appropriate and convenient for them, because it's my conviction that unless people develop a sense of responsibility for the community outside of their own family and work early in life, the chances of their doing it later are much decreased. It's a whole range of things that the program is trying to emphasize relative to leadership development."

From Davis's seminars have sprung student initiatives ranging from service in the local community to studies of federal policy. In the fall of 1991, Davis notes, as a

result of seminar discussions on industrial policy, fellows developed a strong interest in determining "whether it's possible to have national strategic planning about emerging technologies without having politicians make the wrong decisions for the wrong [political/constituent] reasons, rather than national interest." Students planned to continue the investigation this past spring, to develop a vehicle for use at the federal level to set priorities and determine which emerging technologies should be supported without having the decision become, to use Davis's term, "a political football." As the 1992 election year developed, however, and major institutions and national publications began addressing such questions in earnest, publishing their findings in extensive reports, "we had to take a hard look at what we realistically could contribute, with our more limited resources," **Michael Blatz '93** concedes.

Scooped once, now, by the major leagues on a suddenly popular topic, the fellows will be listening all the more intently during Davis's seminars for their next chance to contribute to manufacturing at the national level.—J.S.

doing a lot more group leading than my class did.”

Jamie Bonini '92, 30, joined the program “as a skeptic. Few faculty, especially engineering professors, have really experienced ‘small-M’ manufacturing to understand the tremendous human element that limits the complexity with which you can solve problems.” This year, Bonini received one of the Society of Manufacturing Engineers’ Outstanding Young Manufacturing Engineer awards. He was also shown supervising a 130-worker

crankshaft assembly at Chrysler Corporation (a function he went back to manage overall for his LFM internship) in the recent nationwide PBS special *Made in America?* Looking back on his Leaders experience, he says that he benefited especially from Shiba’s class in TQM and from product development courses introduced by Adjunct Professor **Don Clausing** (Engineering Innovation and Practice) and Professor **Thomas Eagar** (Materials Science and Engineering). In these courses, students “learn through experience; you see how

something conceptually very simple can be challenging in practice. To experience that is a powerful learning tool.” For Bonini, the most important thing about the Leaders Program “is its real effort to become a learning organization: it is deeply imbued in the LFM culture to get feedback and continue to improve what we’re doing. This process of ‘take a step, make some improvement, take a step, make some improvement’ is new for academia.”

The Leaders Program has developed new courses on leadership and organi-

Championing “the soft side” of world-class manufacturing

A FEW MINUTES WITH SENIOR LECTURER **DON EPHLIN**,
RETIRED INTERNATIONAL VICE PRESIDENT, UNITED AUTO WORKERS

Originally a millwright, eventually international vice president of the United Auto Workers, and now a senior lecturer appointed through the Sloan School, Don Ephlin



MARK OSTROW

brings to the Leaders Program, in his own words, “experience in the ‘people’ side of things—helping people work with each other.” Ephlin himself works with the LFM co-directors to ensure that the human facets of manufacturing receive the attention they warrant in a university environment renowned for its technical emphasis, and quietly carries the banner of “the soft side of manufacturing” into LFM Governing Board and other program meetings. Not least important, he spends time with Leaders fellows, answering questions about labor issues and helping students strengthen their understanding of manufacturing areas in which they have little experience.

“Don Ephlin brings a lifetime of practical experience in working with manufacturing problems and human resource issues from the fac-

tory floor to the boardroom,” Professor Thomas Kochan acknowledges. “He brings a perspective from his role in advocating worker issues and interests that none of us can replicate, and relates them to the competitiveness of the employer and the industry at large. He brings an understanding of the importance of worker participation and representation in a complex organization that prepares our students for the real-world experiences they will find when they leave the Institute.”

Among the opportunities Ephlin has taken to share his extensive understanding with the Leaders fellows was an extended plant tour he took with the students this past January. The partner company plant sites visited included General Motors’ Saturn automotive plant in Spring Hill, TN—a four-million-square-foot complex run by 3,500 people who build, Ephlin emphasizes, “everything from engine, transmission, and body parts to final assembly, all under one huge complex.” [See *MIT Management*, Spring 1992, for more about Saturn.] Ephlin was instrumental in bringing Saturn about (as evidenced by the nearby Don Ephlin Parkway), having commissioned a pilot study in 1983, leading negotiations around its recommenda-

tions, then forging these into a labor agreement that served as a basis for going forward with the plant, which began production in 1990.

Saturn was “designed with tremendous involvement by workers to be the most efficient workplace in the country,” Ephlin says. The union “is directly involved in management at every level, from the shop floor to the highest ranking policy committee.” Saturn manufacturing workers collaborated closely with designers and engineers to put together a vehicle that is, Ephlin says, “totally new from the ground up, designed specifically to be competitive with foreign imports.” As a result, their car ranked second in the widely regarded J.B. Power Company’s automotive power study early this year.

Ephlin describes the Saturn plant as a “giant laboratory with state-of-the-art equipment [that] might best be viewed as a research and development program. It’s probably the most far-reaching new approach I’ve been involved with, where workforce, union, and management all work closely to achieve common objectives.” In his view, “the people system is the most innovative part, the total involvement of the union in the

zational change, and product design for manufacturability. The marketing course that the fellows take with other Sloan students places considerable emphasis now on quality function deployment, and the probability and statistics course emphasizes applications to quality control and process improvement. One course under development is Accounting for Manufacturing, introduced last year to highlight deficiencies in and present alternatives to traditional financial and managerial accounting methods. The instructors,



Left: Associate Professor **Charles Fine** (Management Science), innovative teacher of managerial accounting and faculty advisor to Boeing interns

management of the operation. The local union president and the president of Saturn Corporation are partners; they work very closely together, they sit together on the committee." Although General Motors facilities everywhere are noted for their executive dining rooms, at Saturn everybody including the president eats in the same cafeteria. Historically, labor/management situations in Europe and Japan, Ephlin points out, have been less "we/they" relationships than has been the case in the United States. "Other systems seem to be doing a better job of molding teams. Only in America are the hourly workers the most expendable part of the system. As soon as there's a downturn, we dump them out, so it's very hard for them to have loyalty to the company or to a product . . . they're expendable."

"The whole [Saturn labor/management] relationship," Ephlin emphasizes, "is totally different than anything else in the country." For example, everyone is on salary and there are no layoffs, so "the relationship encourages people to be involved in the team." Moreover, Saturn is phasing in a "risk and reward" system through which workers can receive a little more or less than the industry-wide compensation, depending on such factors as their products' quality and profitability. During a new hire's first year, Ephlin says, "the risk side is that an employee can lose 5 percent of the pay if he or she does not complete the training. Five percent of every worker's time is devoted to training, to improve skills

related to the job and team membership, problem solving, statistical process control, and quality control." Much of this training, he adds, is developed at Saturn and delivered at a huge training facility there. The reward system "is to get as many Saturn people [labor as well as management] as possible on the same bonus arrangement, measuring quality, productivity, and time, not just profitability or productivity. The atmosphere makes it possible for a worker to really participate and help design his or her own job and workplace—a *team* workplace; to help buy the equipment, help set up the production system, and know that he's going to *be* there at Saturn—not thrown out to the wolves."

During their tour of Saturn, the fellows had the opportunity to sit with union and management people to discuss issues in such areas as human resources. Ephlin recalls one student commenting "that 'the metric in difference in Saturn is not in technology, even though they have a lot of new technology.' If it made that impression on them," he says, "it's wonderful, because these students come from a technical background. When all is said and done, whether we are going to be able to compete or not is not going to be the technology, because anybody can duplicate that in short order. The only thing that makes one company in one country more successful than another company somewhere else is whether the people work as a team, how well they mobilize themselves."

During some evenings on the plant tour, Ephlin sat with the fellows "for hours, carrying on a discussion, because they have many questions. Many times, even if they had worked in a plant as an engineer, they had had no opportunity to really understand labor/management issues. Having the opportunity to question me and get different perspectives—this is one reason I went on the trip: to spend time with them so they're comfortable asking questions. Some call me at home now, to try to understand something that's happening, maybe in the company where they work. I have years of experience that I can share with them."

"If we're talking about producing a different kind of person," Ephlin muses, "we've got to get them into the 'soft' side of business. America's technical expertise has been the best in the world. We led in all these industries. Other people took it away from us. Well, that's the *management* of the operation, not the technical part. We had the technology *first*, but we didn't know how to manage it or the processes. We've got to be leaders technically, also. This school knows how to do that better than anybody. But the other side is where the nation needs the most help."

"We live in a competitive world," Ephlin says. "It's more important than ever that leaders have broad experience in teambuilding. I hope my years of trying to bring about change will give the students some idea of what can be achieved when people are all working for common objectives."—J.S.

THE LEADERS PROGRAM IS ADDING VALUE

It's no secret that the last couple of years have been very tough ones for the U.S. auto industry. To get through the recession, we at Chrysler have cut our annualized costs by more than \$3 billion, or more than 10 percent of our total costs. We've left no stone unturned in our quest to maintain our competitiveness. As I say in one of our TV commercials, if we found something that didn't add value, we dumped it.

But one thing we have *not* dumped is our relationship with MIT's Leaders for Manufacturing Program. Chrysler is one of the founding partner companies in the Leaders Program, and we remain an active participant precisely because we believe that the Leaders Program is adding value by helping to make us more competitive where it counts the most: on the factory floor.

Frankly, we—like many of America's industrial companies, and *unlike* the Germans and the Japanese—have had trouble attracting “the best and the brightest” to pursue careers in manufacturing. The Leaders Program, however, is helping to elevate the image of manufacturing in this country to its rightful place of honor. It's helping to attract the best and the brightest to manufacturing, and it's also helping to transform employees that we send to the program into the best and the brightest of tomorrow.

LEE A. IACOCCA
CHAIRMAN AND CEO
CHRYSLER CORPORATION



Associate Professor **Charles Fine** (Operations Management) and Assistant Professor **Fred Kofman** (Management Accounting and Control), engage one another during classes in debates, encourage discussion, and apply novel accounting measures to student performance. The program also plans to develop a course that combines technical aspects of computer hardware/software systems with aspects of management information systems. This will lead to concepts and practices that address the integration of information systems within the total enterprise.

Internship

The six-and-a-half-month on-site research internship exposes LFM fellows to real manufacturing concerns. Projects focus on critical manufacturing problems, and identify principles that should be taught and practiced. Inevitably the internships strengthen collaborations between MIT and the partner companies.

During the internship, each fellow works in a team of engineering and management faculty and company practitioners on intellectually challenging, “big-M” manufacturing issues critical to the host company. Each partner company opens up areas within one or more manufacturing facilities and provides experienced engineers and managers as project supervisors. Afterward, each fellow writes a single thesis (eighty-six completed during the program's first four years) that integrates engineering and management issues he or she dealt with on-site.

Some internships have been collaborative efforts between the industry partners. Digital Equipment, for example, has conducted projects with Motorola and Boeing to enhance existing business relationships—in the former case as customer, in the latter as supplier. William M. Beckenbaugh, vice president and director, Corporate Manufacturing Research Center, Motorola and a member of the LFM Governing Board, said that aside from their technical accomplishments, the team of four Class of '90 fellows “enhanced communication between our two companies, helping us better understand our customer/supplier relationship and technology issues. Motorola, which has a corporate goal of total customer satisfaction, gained insights about Digital's

needs and consequently will come much closer to achieving that objective.”

Kemp Wills, assigned to Digital Equipment in 1990–91, and Boeing-sponsored LFM fellow **Patrick Shanahan '91** worked together to assist Digital in its role as prime systems integrator for the shop-floor control system at Boeing's new highly automated sheet metal center in Seattle. “Pat and Kemp were members of their companies' teams, but were part of a larger, solution-oriented DEC/Boeing team, too,” says Charles Fine, their Sloan faculty advisor. “The intercompany team designed the management structure for the bottleneck cell in the sheet metal center. Kemp and Pat modeled effective intercompany team behavior and influenced interactions between the two companies.” Shanahan observes that “faculty ask very directly for explanations of ingrained company behaviors. That's a main benefit of having faculty work with company people. Employees need to explain why they are doing something poorly or well.” Wills adds that employees “don't feel threatened by the faculty's asking any question. The faculty are respected and seen as working only to help.”

Not all internship facilities are in the United States. In 1991, **Terri Mock '92** spent part of her internship working with a computer-controlled Eastman Kodak manufacturing facility in England to analyze several months' worth of data about a key photographic chemical process. She worked with her overseas colleagues via telephone conferencing, fax, voice mail, electronic mail, and data transmission to develop a plan for addressing the main issues. Alun James, technical staff head of the Synthetic Chemicals department, discovered from Mock's analyses an error in a plant “recipe” as well as algorithms needing modification to control process pressure/temperature properly and reduce variability. He says the project taught him that “these days, communication on things like this is no problem. It was as if Terri were working next door.” Partly as a result of Mock's work, the chemical process has been so automated that operators now need only check it periodically. “Batch setups” that necessitated extensive operator involvement and delays, and sometimes damaged equipment, have also been eliminated. James estimates that

for his one-half to one day per week spent on the several-month long project, learning from Mock the analytical techniques she was using, Kodak will save \$150,000 annually in operational costs and increased capacity. In addition, operator complaints are down, as are pressures James faces to address the associated problems.

Many internships focus on total quality management. For example, **Brad Koetje '91**, in his thesis, "Improving Cycle Times in Batch Chemical Operations," described a cost-of-quality model that he designed and implemented to highlight opportunities, prioritize improvement projects, and evaluate results at Eastman Kodak.

Internships also impact host companies' bottom lines:

- A team that included **Jackson Chao '91**, 28, and Professors Graves, **Thomas Kochan** (Human Resource Management), and **Alvin Drake** (Electrical Engineering) found that The Boeing Company could save tens of millions of dollars annually in inventory carrying costs for 747 and 767 plane assembly by focusing less on head count reduction and more on reducing the flow time by a certain number of days. Boeing has implemented the team's recommendations.

- A team at Kodak that included fellow **Christopher Papouras '91**, 25, and Professors Graves and George Stephanopoulos (Chemical Engineering) focused on reducing the time from customer order to delivery. The team developed a plan for a more flexible, responsive ordering and production system that has the potential to reduce Kodak's inventory by approximately \$1 million. Kodak has implemented some of the recommendations.

On the Job

By June 1992, of thirty-four LFM fellows graduating that spring who had confirmed their plans, 68 percent had taken positions in partner companies³ and 24 percent had joined other manufacturing companies; one student entered a PhD program, another opted for part-time work to accommodate new motherhood, and a third accepted a position in the operations section of a consulting firm. An earlier survey

showed that twenty-three graduating fellows who had accepted positions by that time chose from an average of 3.2 job offers, accepting starting salaries (including signing agreements) averaging \$65,000. The chief reasons the fellows gave for choosing the jobs they did: "potential impact" and "growth potential."

Major corporations unaccustomed to strong performers in the manufacturing function are learning how to tap their motivation and nurture it. "LFM is teaching us how we can bring very bright, creative, and knowledgeable students from any university into the workforce and assimilate them," Digital's Bill Hanson reflects. "This is requiring industry to address its hiring, mentoring, and salary practices, causing us to change."

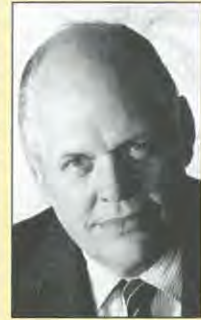
Boeing, for example, hired Jackson Chao '91 to report directly to its vice president of Operations, 777 Division while implementing a strategic initiative to reduce inventory in the Commercial Airplane Group. Chao and the three managers reporting to him are one year into the process of helping the division's functional organizations and factory establish a system for reducing both inventory carrying costs for 300 planes and the 777's manufacturing cycle time. Chao says his team aims to "work ourselves out of a job" by transferring "ownership" of what they are doing to the Boeing organizations, "eventually integrating our measures, practices, and philosophy into the functions' and factory's day-to-day responsibilities."

The program is the first in Boeing's Commercial Airplanes Group to integrate inventory holding cost into the overall cost structure as a tangible measure, and the efforts of Chao and associated managers have reduced program lot sizes in some areas by as much as 80 percent. The program is now working with suppliers to reduce inventory and cycle time further, and is integrating inventory carrying costs and cycle time measures into the performance management system so that employees will be judged accordingly.

Scott Roodvoets now supervises tubing production at an Alcoa tube mill in Lafayette, IN. As one of two production managers reporting to the plant

A VALUABLE INVESTMENT

The LFM Program has been a valuable investment in many ways, enhancing the already strong relationship between DEC and MIT. This growing partnership allows us to increase our ability to communicate and transfer technology and knowledge across our boundaries.



The LFM curriculum prepares people for industry with a rich mixture of technical as well as management education, better insuring that we are able to satisfy our customers' needs and not get lost in functional specialties.

The program has caused us to exchange personnel between our institutions. A key faculty member spent his sabbatical at DEC, and a number of our engineers and management personnel have been involved in various teaching roles at MIT.

Our future success depends on our ability to attract talented new people into our organization. Through LFM, we have hired eight outstanding future leaders, and provided four high-potential employees the opportunity to return to MIT for this critical manufacturing leadership education.

Perhaps in the long run one of the most important benefits will be the joint research projects that engage students, MIT faculty, and DEC personnel. The task facing all of us is to undertake research that fosters the level of breakthrough associated with the Athena Project [an experiment in distributed academic computing at MIT that completed its eighth and final year in 1991. Its outgrowth, the Athena Computing Environment, offers computing resources to all undergraduate and many graduate students and faculty via about 1200 Athena workstations in forty-one locations.]

KENNETH H. OLSEN
PRESIDENT AND CEO

DIGITAL EQUIPMENT CORPORATION

³ Seventy-six percent might now be considered to have joined partner companies, since three students accepted positions with Ford, which later became an LFM partner.

ENGINE FOR GROWTH

MIT's Leaders for Manufacturing Program is an engine for American economic growth. It generates a precious commodity—young people schooled in engineering and management who are focused on manufacturing as a career.



At Kodak, our future depends on bold ideas and capable minds. This program develops graduates with just these abilities. And it succeeds through productive partnerships involving business, academicians, and students. By welcoming our input, manufacturing study is able to go beyond classroom theory to reflect the kind of urgency that business leaders face today.

Students work on site with Kodak people, searching together for solutions to real manufacturing problems. In our Synthetic Chemical Division, program participants have helped us uncover ways to refine our techniques, reducing inventory and cycle time and facilitating greater quality and process control. This year we will bring several LFM graduates inside our Apparatus Division to apply their learning to Kodak projects as full-time employees.

Leaders for Manufacturing also creates a network, allowing participating companies to exchange new ideas targeted at reestablishing America's manufacturing dominance. In this way, the initiative provides a passport for business leaders to add their own perspective in helping develop a new manufacturing curriculum.

Industry drives American growth. It creates employment and opportunity and supports our quality of life. To preserve these blessings, it is critical that we nurture our nation's best and brightest minds today, empowering them to meet the real needs of manufacturing tomorrow.

KAY R. WHITMORE
CHAIRMAN, PRESIDENT, AND CEO
EASTMAN KODAK COMPANY



Tom Taylor '91 (l), line supervisor at General Motors' Delco Chassis facility in Dayton, OH, consults with Larry Herron (r), operator of the hot eject integral mold machine behind them, about the thickness of a front disk brake pad produced by the machine.

manager, he oversees five first-line supervisors and seventy union employees. Since June 1991, the plant manager, the other production manager, and he—all young, all hired at the same time—have improved by 40 percent the plant's promised performance (number of orders shipped during the week scheduled) and raised plant productivity (measured in pounds shipped per employee hour) 35 percent. The management team accomplished this with a recently demoralized workforce: previous management had deadlocked with the union on how to operate a planned modern manufacturing cell, Roodvoets explains, so "instead of building it here, they opened another plant. That had a tremendous emotional impact on people—they actually took the equipment out of here and moved it down there. When we came, people thought Alcoa was looking to sell this place." The new management team's most important communication to employees, Roodvoets says, is its attitude "that this place is going to *survive*—we're going to make sure it runs, and runs *well*."

The team is doing just that: having developed a plan for reorganizing equipment into manufacturing cells, the managers are working to secure needed funds. During the interim, they have rearranged equipment to simulate cells, and begun discussions with the union to combine jobs, increasing worker skill

and flexibility. Roodvoets proffers a measure of credit to the Leaders Program for the opportunities it opened for him to land such a challenging job, as well as for the tools and know-how it gave him to handle the responsibilities. "I certainly approach my job with more confidence," he says. "I realize that if something needs to be done, I've got to do it. I'm the boss, and I don't necessarily need to ask for permission. I just need to do it—and I *can*."

Tom Taylor '91, 30, supervises thirty manufacturing line workers at General Motors' Delco Chassis facility (a processor of powdered metal for brake shoes and linings) in Dayton, OH. Historically, Delco's management emphasized controlling labor costs while allowing scrap worth millions of dollars—25 percent of the operating budget—to accumulate annually. Taylor has been instrumental in reducing scrap from \$109,000 over budget per month to \$4,000 per month savings to budget. "Since the system was designed solely to control labor efficiency, the hard part has been trying to convince people to focus on reducing scrap and increasing machine reliability and capability," Taylor says. A new plant manager's belief in lean production, however, along with lateral moves designed to promote new thinking, have created an environment that encourages change. According to Taylor, "we set about collecting data to define the problem bet-



MICHAEL GAFFNEY

In an Ortho Diagnostic Systems, Inc. production laboratory (l to r): Chuck Hamilton, manager, Systems and Programming; **Ginny Maggs '90**, coordinator, Manufacturing Technologies; and Debby Geigert, manager, Documentation Management Group, review records from a batch of material. The three compose a team that is implementing a new manufacturing control system at Ortho.

ter. We did a Pareto analysis of scrap to see if it were related to certain machines, part numbers, or process flows. The analysis helped us prioritize the problems we needed to attack."

Taylor and his colleagues identified four principal problems and took steps to correct them. Scrap resulting from:

- breakdowns (40 percent of total scrap) was reduced 30 percent in six months by instituting more scheduled maintenance, implementing operator suggestions, and keeping log books of breakdowns for follow-up Pareto's.
- part thickness problems (10 percent of total scrap) was reduced 80 percent by asking operators to measure the thickness of parts coming through their area (which requires them to be more proactive than they had been before).
- a powdered metal mix (10 percent of total scrap) was eliminated by engineering redesign of machinery and tools.
- tooling that had not been replaced as specifications changed was reduced 40-45 percent by updating all tools on the line.

Bonuses to these scrap reductions have been quality improvements in all downstream departments.

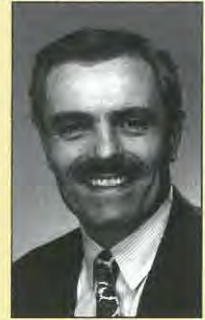
Ginny Maggs '90, 26, is manufacturing technologies coordinator at Johnson & Johnson's Ortho Diagnostics, a manufacturer of blood screening and testing supplies. Her responsibilities involve implementing a new manu-

facturing control system in a 150-worker Raritan, NJ, plant. In 1991, Maggs completed a prototype application of the system for controlling production, automating paperwork flow, and testing and releasing products efficiently. She also served on a multifunctional team that developed a capital funding request, which was approved this past summer. The team is now carrying the project through development and implementation, probably a three-year project.

Maggs reports to the director of Manufacturing and participates in meetings with the manufacturing staff responsible for production teams. "I have the opportunity," she says, "to study problems in the plant and comment on issues. It's a perfect opportunity to be a change agent at a grassroots level. J&J Corporate has made it possible for me to do the kinds of things I want to do." J&J management, she adds, "is an effective communicator to the operating companies about what world-class manufacturing is all about." Such communication has indeed been reaping results: George Thompson, director, Advanced Technologies, Johnson & Johnson and a member of the LFM Operating Committee, agrees that Corporate has noticed "an uplifting of J&J operating companies' and employees' knowledge from LFM involvement. We've just started to reap the benefits."

SHARING IDEAS

U.S. manufacturers are engaged in a fiercely contested battle for global leadership in customer satisfaction and market share. Winning will require a robust and competitive manufacturing base. A



fundamental change in the way we view our manufacturing and engineering systems must occur. We can no longer be satisfied with a piecemeal approach to this business. Tomorrow's leaders will need to integrate engineering with manufacturing into a single, predictable, and stable process that we are beginning to call "Big-M Manufacturing." The MIT Leaders for Manufacturing Program is an opportunity for us to contribute to the development of processes that can guide us into the future and the people to manage them.

We support the concept that industry, academia, and government must all work together to develop and sustain our competitive advantage. The sharing of ideas between similar and like industries, and academia, is key in dealing with this concept. The LFM Program provides the opportunity and construct for such cooperation. We are excited about the prospects of contributing, in partnership with MIT, to the development of this next generation manufacturing process.

OSCAR B. MARX III
VICE PRESIDENT, FORD AUTOMOTIVE
COMPONENTS GROUP
FORD MOTOR COMPANY

THE RESEARCH PROGRAM

Another major facet of LFM is its Research Program, which is discovering and plans to codify what *must* be known to teach manufacturing leadership. Currently under the co-direction of Professors Seering and Welsch, the Leaders Research Program emphasizes teamwork across organizational boundaries and traditional disciplines. The fellows' internship projects serve as a backdrop for the Research Program's longer-term intellectual efforts, most of which are conducted at MIT. Currently, thirty-four such projects are being funded.

The partners link MIT's basic research interests with problems grounded in industry needs. Leaders encourages joint engineering/management faculty supervision of projects; company employees and MIT students and faculty work as teams in MIT laboratories and classrooms and in the plants. (Larger-scale multidisciplinary team projects on major manufacturing issues, with substantial company participation, are planned.) Increasingly, Leaders research will be characterized by company involvement, guidance, and collaboration that "pulls" research into industry.

A few examples of LFM-funded research might help to indicate the breadth of the Research Program. Professor **Julian Szekely** (Materials Science and Engineering) and Research Assistant **Livia Racz** are collaborating on a project originally suggested by Digital Equipment, begun two-and-a-half years ago. The goal: a quantitative framework for predicting the shape and performance of solder joints connecting components to circuit boards. In reflow soldering, solder paste "beads" are deposited onto an empty circuit board. Components are added and the assembly is preheated to volatilize organics, then heated further to melt the solder, joining components to board; the joints' reliability is critical. Through mathematical modeling, the researchers have been able to relate solder bead shape to both volume of solder applied and system process variables, yielding guidelines for optimal solder volume and system geometry to produce reliable joints.

Professor **Emanuel Sachs** (Mechanical Engineering) is collaborating with

INNOVATIVE (LONG-TERM) RESEARCH

- R**obotics, intelligent control; CAD/CAM (ASADA)
- T**ube process planning project; optimal order combination project (BALAKRISHNAN, BROWN)
- S**ystems aspects of manufacturing (BERTSIMAS, TSITSIKLIS)
- U**sing neural networks to determine operational policies for manufacturing systems (CHRYSSOLOURIS)
- M**etal injection molding of metal-matrix composites (CHUN)
- E**nhancing quality function deployment practice (CLAUSING)
- I**nfluence of design details on manufacturing quality (COVERT)
- M**anufacturing/design flexibility and performance (CUSUMANO)
- A**utomated visual inspection for manufacturing process control in electronic assembly (DUBOWSKY)
- A**pplying design structure methods to auto manufacturing (EPPINGER)
- D**esign and implementation of CIM; processing equipment industry study (FINE)
- A** CAD system using shop as the metaphor for design—CAB (FLOWERS)
- P**rogram in manufacturing systems analysis, design, and control (GERSHWIN)
- M**odels for manufacturing process control (HARDT)
- D**evelopment of a computer-based strategic planning system (HAX)
- E**ngineering analysis methodologies to support engine design (HEYWOOD)
- A**utomated assembly and product design (JAKIELA)
- I**nfluence of massively parallel architecture on manufacturability of power electronics (KASSAKIAN)
- A**ssessment of organizational performance (KOCHAN)
- M**ulti-location and multinational manufacturing networks (ROSENFELD)
- R**esearch, development, and application of three-dimensional printing (SACHS)
- E**fficient use and reuse of design knowledge in design activity (SEERING)
- R**apid, precise net-form manufacturing (STAELIN)
- P**attern-induced control and design of self-learning intelligent controllers (STEPHANOPOULOS)
- O**rganizing for effective technology transfer (THOMAS)
- E**ffective introduction and use of new process technologies (TYRE)
- E**xploiting producibility constraints to automate design of structural parts (ULRICH)
- E**ffectively moving new concepts to market (UTTERBACK)
- W**afer screening in semiconductor manufacturing (WEIN, WELSCH)
- D**esign, metrology, and planning of automated fixturing systems (YOUCEF-TOUMI)

Materials Science and Engineering faculty to develop a three-dimensional printing process for producing prototype parts rapidly and flexibly, and for tooling directly from a computer-aided design (CAD) model. Parts are built in layers: a thin layer of powder is spread, and selected particles within this are joined by depositing a binder using a process similar to ink-jet printing; this is repeated until a complete part is built. Loose powder is removed, leaving only the completed part. The process reduces new products' time to market, improves product quality, and lowers tooling costs for low-volume production. Current applications include fabrication of ceramic molds and cores for metal casting, and fabrication of ceramic preforms to metal matrix composites. Potential applications include die fabrication for injection molding and metal forming, and direct fabrication of metal parts.

The Leaders Program supports research in most of Sloan's disciplinary groups, ranging from technological innovation to human resource management. Assistant Professor Tyre, for example, is examining the dynamics of learning and problem solving during new technology introductions. This past year she and her research team have worked with Eastman Kodak to study relationships between developers and users of new process technologies as technology moves from laboratory to plant. "We focus on two questions," Tyre explains. "First, what organizational factors determine the amount and type of joint work between users and developers? Second, what patterns of joint work are most effective to support smooth and timely transfer of improved process equipment, techniques, or concepts?" Research methods employed by the research team include field work (interviewing participants in twenty-five new process-transfer projects and mapping their problems and resolutions) and "quasi-experimental approaches" (soliciting developer and user responses to hypothetical cases that describe frequent problems with such projects).

Other LFM-funded research projects being conducted by Sloan faculty include an integrated engineering-operations approach for medium-term process planning for metal forming (Associate Professor **Anantaram Bala-**

krishnan); development of tools to represent design procedures (Eppinger); a study of customer-supplier relationships and new product development in the processing equipment industries (Fine); effective movement of new concepts to market (Associate Professor **James Utterback**); sequential screening in semiconductor manufacturing—exploiting lot-to-lot variability and spatial dependence (Associate Professor **Lawrence Wein**); and wafer screening and semiconductor manufacturing (Welsch).

Multidimensional sharing

The Leaders Program is developing long-term working relationships between its Engineering and Management faculty and their industry counterparts to generate more company "pull" for the research. Ongoing efforts are expected to speed the movement of manufacturing technology to U.S. plant floors and transform myriad industry experiences into a set of logical principles that can establish manufacturing as an intellectual discipline in its own right, making world-class manufacturing possible both to teach and to practice. At an LFM research retreat held early this past summer, faculty and partner company participants began expanding the concept of *technology transfer from university to industry*, to a broader vision for *multidimensional sharing among partners*.

Partner firms have selected "research liaison faculty" with whom they are conducting cooperative research. (The Leaders Program will hire a research director to coordinate these activities.) For example, Eppinger, in his research liaison role with General Motors Corporation, is working with GM to streamline its product development. He is overseeing a Leaders-supported research assistant, **Kent McCord**, in his study of interactions among GM teams on large projects. McCord's goal is to develop methods for coordinating information transfer within development projects.

Ulrich, research liaison professor for Boeing, is working with industry partners David O'Keefe and David Fitzpatrick on the development of the company's new 777 airplane—specifically, Ulrich says, to determine "how to better organize, communicate, and use information about the production

A LEADING FORCE

The MIT Leaders for Manufacturing Program is an important investment for every manufacturing company in our nation. LFM fellows have made valuable contributions to GM manufacturing operations, as well as to the company's product development process. Both the electric vehicle program and the Saturn production system have benefited from their work.



LFM is a leading force in the movement to change the public perception of manufacturing in America. After looking back at manufacturing's past with its landmark books *Made in America* and *The Machine that Changed the World*, MIT recognized the need for a new vision of manufacturing—a vision of industrial and academic cooperation and of educating tomorrow's leaders so that they can discover, implement, and manage new manufacturing methods, processes, and paradigms.

The Leaders for Manufacturing Program is a symbol of the importance of manufacturing to our quality of life. Our nation's standard of living is directly related to its manufacturing strength. As America's largest manufacturing enterprise, GM is working with universities, U.S. government laboratories, and others to enhance our nation's manufacturing capabilities. Programs such as LFM represent a concrete and vital step in ensuring our nation's wealth and competitiveness for years to come.

ROBERT C. STEMPEL
CHAIRMAN AND CEO
GENERAL MOTORS CORPORATION

A MODEL FOR OTHER UNIVERSITIES

HP's

experience with the Leaders for Manufacturing Program has been enormously positive. First and foremost, the program has served to renew intellectual interest and rigorous research in manufacturing—a focus that, in my opinion, is long overdue. On a more tangible level, we at HP have benefitted from having program participants with us for their six-month internships, as well as from the direct involvement of program faculty in our operations. They've helped us refine some of our manufacturing processes, and in one instance the improvements enabled us to avoid an expensive capital investment. We've also found the program useful in facilitating closer relationships with other member companies. For example, we're sharing environmental data with a couple of them, accelerating our progress on eliminating CFCs from the manufacturing process. It is my hope that the Leaders for Manufacturing Program will serve as a model for other universities, because it is vital to this nation that we maintain a strong manufacturing capability.



JOHN A. YOUNG
PRESIDENT AND CEO
HEWLETT-PACKARD COMPANY

system during the engineering design process." Leaders-supported doctoral student **Jin Oh** and LFM fellow **Troy Smith** are working with Ulrich and Boeing to devise a methodology for choosing design parameters based on both product performance and production process capability. In a related project, doctoral student **Bala Subramaniam** is working to develop process-physics-based computer tools for evaluating part designs for potential fabrication problems.

Alcoa's research liaison faculty, Balakrishnan and Associate Professor **Stuart Brown** (Materials Science and Engineering), have collaborated closely since 1989, visiting and giving talks at several Alcoa facilities, supervising LFM internships there, and initiating a joint research project funded by the Lafayette Works (where Roodvoets is supervisor) that stems from Loucks's 1989 LFM internship, which they advised. The project, which involves Alcoa Technical Center personnel and Lafayette Works managers, supervisors, and planners, seeks to improve manufacturing performance through better process understanding and principled process planning. The researchers have developed a computer-based graphical process planning system and a model to select effective standard extrusion sizes. Their work has led to two LFM theses, an undergraduate Electrical Engineering thesis, and a doctoral dissertation in Operations Research; this collaboration has also inspired a 1993 LFM internship project.

The program encourages and supports thirty-four engineering and twenty-one management faculty to visit partner firms. One result is an increasing number of papers jointly written by faculty, students, and practitioners. Hundreds of practitioners supervise fellows' projects, collaborate on research, and otherwise work with more than fifty MIT faculty, eighty-five fellows, and seventy graduate research assistants. Approximately 250 working papers covering a wide range of research areas are available from the Leaders office (telephone: 617/253-0821).

During the 1991–92 academic year, a member of the LFM research staff, **Ashraf Alkhairey**, worked closely with the partner companies to test his method for optimizing product and

manufacturing process parameters. The Leaders partnership, which partially supported Alkhairey's doctoral work developing the method, created opportunities for him to apply his method and develop it further.

Several projects conducted this year in the electronics, mechanical, materials, and photographic industries empirically support Alkhairey's theoretical work, indicating his method to be broadly applicable, statistically rigorous, robust against false conclusions—and very efficient. Two such projects were LFM internships conducted by **Chip MacDonald '92** (advised by Rosenfield at Sloan and Professor **David Staelin** of the Electrical Engineering department) and **John Glancy '92** (advised by Fine at Sloan and Clausing of the Electrical Engineering & Computer Science department) at Hewlett-Packard, co-supervised by Alkhairey. MacDonald's project (optimizing a fused-silica capillary manufacturing process) required sixteen experiments using the Alkhairey method compared to sixty-four using the Taguchi method. Glancy's project (optimizing a heat-staking process) required eight experiments using the Alkhairey method, forty-four by the Taguchi method, and seventy-five by the multiple response surface method (MRSM). In the MacDonald project, the Taguchi model failed to pass diagnostic tests, resulting in flawed performance predictions; in the Glancy project, the Taguchi and MRSM models resulted in inferior products as well as flawed performance predictions.

Both project teams' recommendations have been implemented. MacDonald's improved product strength 30 percent, saving Hewlett-Packard \$300,000 per year; doubled production capacity, saving an additional \$500,000 in capital investment; and enabled Hewlett-Packard to broaden its product line and resolve critical issues related to vertical integration. Glancy's recommendations have also allowed a 30 percent product improvement, and tripled capacity.

SPREADING THE WORD

Within MIT

Within the Institute, the Leaders Program has strong connections with the Laboratory for Manufacturing and Productivity (LMP), whose faculty

affiliates have been among the program's most active engineering faculty. Similarly committed LFM faculty are connected with the Materials Processing Center (MPC). Leaders also maintains a working relationship with the Laboratory for Electromagnetic and Electronic Systems (LEES) and with the Operations Research (OR) Center; eight OR students, in fact, are supported by the Leaders Program.

Leaders has had more informal interactions with the Center for Coordination Science; the Center for Technology, Policy, and Industrial Development; the International Center for Research on the Management of Technology; the Management of Technology Program; the Sloan Automotive Laboratory; and the Technology and Development Program.

Emerging Institute groups with which the Leaders Program coordinates activities include the MIT Industries Project (launched last spring under the direction of Professor **Richard Lester**), the Manufacturing Institute (being developed by Professor **Nam Suh**), the Organizational Learning Center (directed by Senior Lecturer **Peter Senge**), the Program on the Pharmaceutical Industry (directed by **Thomas Allen**, Gordon Y. Billard Professor of Management, and Professor **Charles Cooney**), the Global Processing Equipment Industries Program (headed by Professors Fine and Eagar), and the Decision Sciences Program (headed by Professor Magnanti).

Beyond the Institute

Leaders faculty and partner companies have collaborated in a "Manufacturing Vision Group" (MVG), an outgrowth of the same vision that drives the Leaders Program. Conceived during an informal discussion between Bowen, Douglas C. Braithwaite (MVG coordinator and recently retired program manager, Research for Manufacturing Leadership, Digital Equipment Corporation), and Professor **Kim Clark** (chairman of the Production and Operations Management area, Harvard Business School) in the fall of 1987—at about the same time as the Leaders Program was taking shape—MVG has fostered collaborations between engineering and management professors at Harvard, MIT, Purdue, and Stanford, and executives at Chaparral Steel, Digi-

tal Equipment Corporation, Eastman Kodak Company, Ford Motor Company, and Hewlett-Packard.

The original members of the group—Gordon Forward, president of Chaparral Steel; Hanson of Digital Equipment; Max Jurosek, senior vice president, North American Auto Operations, Ford; Hal Edmondson, at the time vice president, Hewlett-Packard; Rohn Harmer, director and vice president, Strategic and Quality Planning for Imaging, Kodak; Professor Ferdinand Leimkuhler, Purdue University School of Engineering; Professor Steven Wheelwright, then of Stanford Business School, now at Harvard; and Professors Bowen and Clark—"have reputations for being visionary in manufacturing in their own right and enjoy talking together—'pushing' each other," Braithwaite says.

These "principals" drew up a research agenda to identify broad patterns in new product and process introduction/implementation. Working together on their own time and with their own funding, they compiled information about twenty new product or process introductions. Writing in teams (an engineering and a management faculty member, and a company manager), the MVG expects to publish a book next spring that addresses seven development themes: guiding vision, core capabilities, cross-functional integration, project "ownership," leadership, prototyping, and the pursuit of technological advances. Professors Bowen, Clark, and Wheelwright are editing and, with Professor Charles Holloway of Stanford, coordinating the effort.

Besides generating new understanding about how to lead projects within a firm, the group has learned processes for carrying out multi-institution projects and for extending learning beyond individual organizations. Braithwaite notes that the Vision Group "also needs to find creative ways to share what we've learned with senior corporate officers as well as engineering and management graduate students. The magic isn't in the analysis, however insightful. It's in finding innovative ways to implement and adapt these ideas."

Leaders-affiliated Professor Emeritus and Senior Lecturer **Thomas Lee** is founding president of the Center for Quality Management (CQM). Mod-

BRIGHT YOUNG MINDS

The Leaders for Manufacturing Program is an important academic and industry partnership to Intel as a company and to us as Americans. The program is unique in academia in its recognition that manufacturing should be approached as an interdisciplinary activity that requires the seamless integration of technology, information systems, and human resource leadership. Over the last few decades the preeminence of U.S. manufacturing has been badly eroded by new ideas and management methods from other regions of the world. Leaders for Manufacturing is aimed at returning leadership in manufacturing innovation to the United States, an objective closely aligned with Intel's long-term viability and its continued industry leadership.

We at Intel believe that returning the United States to preeminent stature will be greatly accelerated through research and training focused on successful manufacturing and its associated activities. In this partnership between MIT, Intel, and the program's other participants, we look forward to learning from the bright young minds attracted to the program. We need their fresh ideas, new approaches, and unconventional thinking. In turn, we welcome the opportunity to share our experience and resources in a way that will accelerate their learning, making their academic experience as true to the real world as possible.

We view our participation in the Leaders for Manufacturing Program as a vehicle for increasing the competitiveness of U.S.-based manufacturing. We are proud to participate in the program.

GORDON E. MOORE
CHAIRMAN
INTEL CORPORATION



RECRUITING BENEFIT

The most concrete benefit reaped from Johnson & Johnson's membership in the LFM Program lies in the recruiting area. Johnson & Johnson currently employs eight graduates of the LFM Program.



Each has been assigned challenging tasks that are greatly enhancing our businesses. These tasks include designing and implementing a completely new information technology system to enhance our expanding diagnostics business; working with surgeons' concepts to produce and commercially introduce new endoscopic products rapidly; and implementing new control and information systems at one of our most advanced consumer products manufacturing plants.

A second major benefit involves direct applied research output. For example:

- One LFM research assistant, on-site for a six-month internship, was partnered with an in-house team that modified a tablet coating and printing operation. The result is an annual, reoccurring savings of \$2,000,000.
- Another LFM internship resulted in a 7½ percent increase in process yield and a savings of \$300,000 for one phase of a chemical coating operation.
- Internships have resulted in direct savings to our international sanitary protection business by optimizing web-cutting blade life and reducing waste.

RALPH S. LARSEN
CHAIRMAN AND CEO
JOHNSON & JOHNSON

eled on the Japanese Union of Scientists and Engineers (JUSE), the center is a consortium of twenty-four companies and nine university affiliates (most in New England) organized to improve the practice of total quality management. Shoji Shiba has been key in developing and delivering the Center's educational programs, and CQM is working closely with Shiba to publish his TQM teachings. The center interacts with MIT in many ways: senior management at CQM companies lecture on TQM at MIT, and Institute faculty serve on the center's research and course development committees. The CQM statistics research subgroup has brought together faculty from MIT and Babson College in addition to industry practitioners. This past spring, the center helped MIT organize a conference on total quality management that drew speakers from Japan and Europe as well as the United States. Sloan doctoral student **Gary Burchill**, who has taught classes in TQM facilitated by other MIT students, is yet another CQM/MIT interface: he has targeted four CQM companies, one a Leaders partner, for an in-depth study of concept engineering that applies TQM methodologies to product development.

Paul E. Gray, chairman of the MIT Corporation and a key figure in the founding of LFM while he was president of MIT, served on the Manufacturing Forum, which from November 1989 through December 1991 was a venue for dialogue among industry, government, and academic leaders on issues affecting the performance of U.S. manufacturing industries. The forum, convened by the National Academy of Engineering (NAE) and the National Academy of Sciences at the request of the White House Office of Science & Technology Policy and the National Science Foundation, interacted with the Council on Competitiveness, the National Association of Manufacturers, the National Center for Manufacturing Sciences, and the Manufacturing Studies Board of the National Research Council, among other groups. Its work is being continued by the new National Research Council Board on Science, Technology, and Economic Policy, the Manufacturing Studies Board, and other groups.

Other NAE manufacturing-related

efforts include a study, "Foundations of World-Class Manufacturing," conducted two years ago by the NAE's Committee on Foundations of Manufacturing. Committee members, including Bowen and Harry Cook (formerly a Chrysler representative on the LFM Operating Committee and currently Grayce Wicall Gauthier Professor at the University of Illinois, Urbana-Champaign), identified actions that firms must take to succeed globally. Their findings are collected in a book, *Manufacturing Systems: Foundations of World-Class Practice*, published this year. The volume's preparation inspired a series of six workshops (Bowen hosted one last year at MIT) on removing the barriers to world-class manufacturing. These characterize the process of becoming a world-class manufacturer, identifying effective techniques, approaches, methodologies, and actions; quantifying required resources; and considering optimal action sequences. The workshops bring together experienced executives, managers, and academics who have been directly involved with identifying and removing barriers that traditionally have prevented manufacturers from becoming world-class producers. After the series is completed, a summary of conclusions will be made available to attendees.

The Leaders Program is developing processes and networks to exchange its experiences and findings more broadly and rapidly. In 1991, the program hosted two symposia at MIT, each drawing 400 attendees. The first, in April, shared with leaders from industry and academia what the program has learned through its cooperative research. The second, in October, tapped the insight and experience of partner company practitioners, generating continuing discussions among participants. More symposia are planned.

OTHER MANUFACTURING PROGRAMS

The Leaders Program cannot meet the nation's need for manufacturing leaders on its own; it never intended to do so. In June 1991, the Sloan Foundation and the Leaders Program co-sponsored a conference on curriculum development in manufacturing at MIT, and representatives of more than fifty-five U.S. colleges and universities

Leaders is developing
processes for
exchanging information.

A TRUE AND SUCCESSFUL EXPERIMENT

The Leaders for Manufacturing Program has been a true (and already successful) experiment—a new educational model that MIT's Sloan School of Management, School of Engineering, and more than a dozen major U.S. corporations have pioneered together.

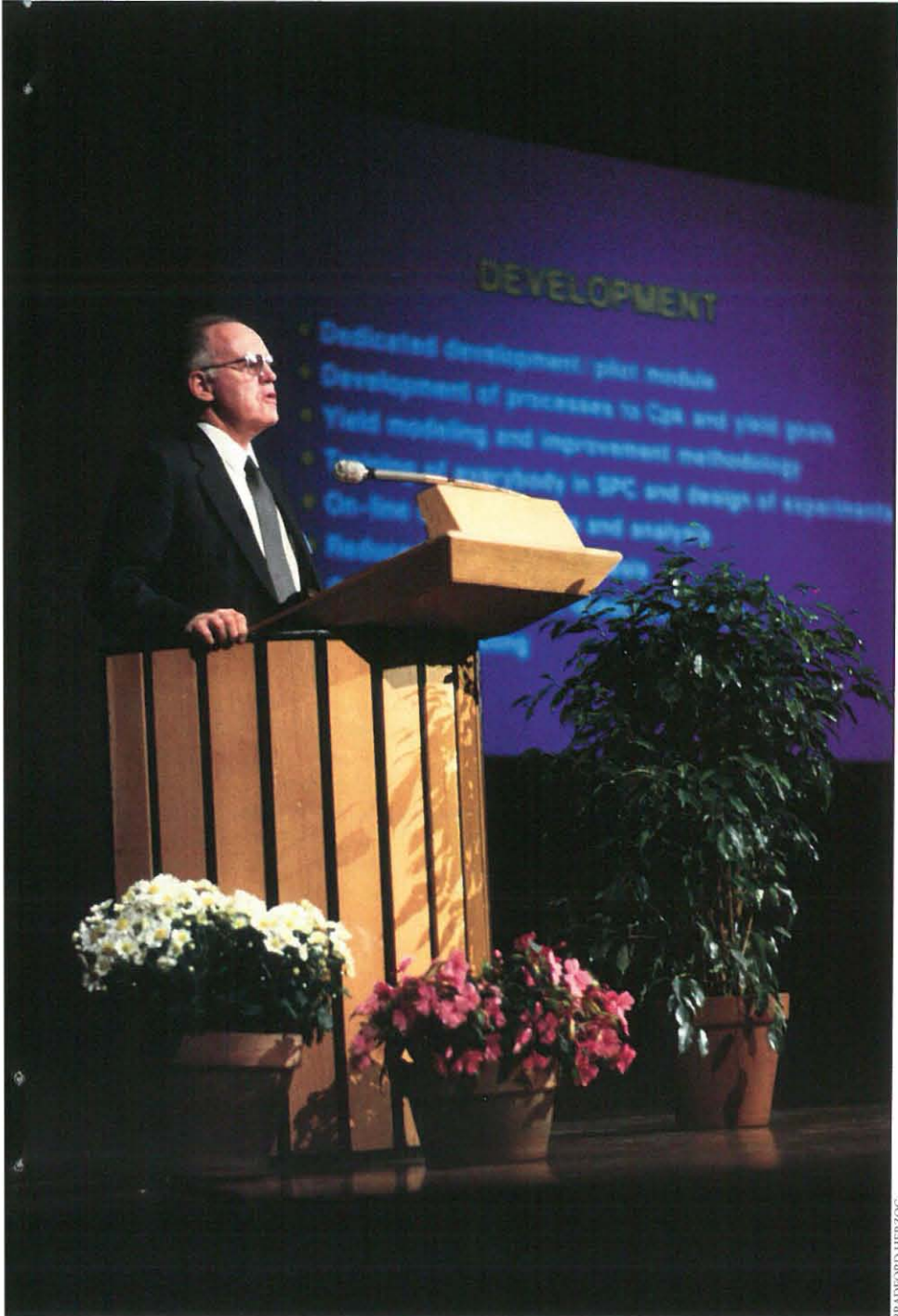


The experiment has been as much one of process as of content. It draws together faculty from both engineering and management and seeks inspiration and expertise from industry as well as academia in creating a new kind of engineering and management education. The goal is a new generation of technical and managerial leaders suited to "Big-M Manufacturing."

This ability to develop educational programs to meet critical needs in an ever-changing world is important for the university as well as the country. It assures MIT's continued relevance "to the times and the nation's need"—one of the founding principles of the Institute as described by our founder, William Barton Rogers. And it is an ability that can only be developed through dynamic, working partnerships between the worlds of research, scholarship, and practice.

We believe the LFM Program has been—and will continue to be—just what its name implies, a leader in every sense of the word. As it expands and spreads to other universities, we expect to see tangible benefits to the nation's economy and productivity—as graduates emerge not only with the traditional self-discipline, analytical skills, and problem-solving abilities of the engineer, but with the preparation and motivation to take leading roles in the management of the manufacturing sector.

CHARLES M. VEST
PRESIDENT
MASSACHUSETTS INSTITUTE OF
TECHNOLOGY



Intel Corporation Chairman Gordon E. Moore addresses the April 1991 Symposium, "Leaders for Manufacturing Program: New Partnerships for Manufacturing Excellence" (co-hosted at the Institute by LFM and MIT's Industrial Liaison Program) on the topic of leadership for the future to effect change.

BRADFORD HERZOG

THE BEST AND THE BRIGHTEST

Of the many benefits derived by Motorola from the LFM Program, perhaps the most significant is access to the best and the brightest entry-level manufacturing professionals.



Some of the more outstanding contributions from LFM fellows include:

- The effort of Thilo Semmelbauer '92 in the design of a cellular telephone test diagnostic system, which has significantly reduced the cycle time for radio problem diagnoses—an important step to a defect-free product.

- The important role played by Julie Johnson '90 in the development and application of advanced printed circuit board technology, which will provide for future high-density interconnection of many of our wireless communication products across the corporation.

- The significant work by Dave Marshall '91 in automated equipment design and programming for our new computer-integrated land mobile multifunctional line.

A second major benefit from the LFM Program has been the research output in important manufacturing fields. Examples include rapid prototyping and tooling, low-temperature diffusion joining, and expert systems for trouble-shooting of complex telecommunications equipment.

Finally, we have derived immeasurable benefit from our interaction with the other LFM member companies who represent a major portion of the U.S. manufacturing industry. The intercompany visits and discussions of important national manufacturing issues and program members' recommendations to the U.S. government on national competitiveness are all examples of the positive output from member interaction.

GEORGE M.C. FISHER
CHAIRMAN AND CEO
MOTOROLA INCORPORATED

attended, as many other schools now offer manufacturing programs. True comparisons of these with LFM, however, are difficult. The Leaders Program seems to be serving as a continuously improving model of manufacturing education, research, and university/industry collaboration—indeed, its mission statement requires that it *not* pursue “business as usual.” Heywood expresses hope “that the new ideas—modes of collaboration, curricula, and integrated research, teaching, and practice—that LFM is developing will be a valuable resource to these and other programs as we all learn to educate manufacturing leaders better.”

Among the best U.S. graduate educational programs in manufacturing:

- **Carnegie Mellon University's** Master of Manufacturing Engineering degree offers qualified engineers and others with technical training a deeper understanding of world-class manufacturing operations and management systems, along with opportunities to develop powerful skills in solving critical manufacturing problems. As the educational counterpart to the university's research efforts, the program draws on broad interdisciplinary resources from the schools of engineering, business, and computer science, and from research centers such as the Robotics Institute, the Engineering Design Research Center, and the Center for Integrated Manufacturing Decision Systems. Advanced courses in these fields support project work in an area of interest to the student and his or her employer. Corporations from a broad range of industries around the nation sponsor students with at least two years of manufacturing experience.

Each of the university's far-ranging efforts in manufacturing builds on Carnegie Mellon's work in computer science and related fields. For instance, the Center for Integrated Manufacturing Decision Systems conducts research in intelligent decision systems to support engineering and manufacturing problem-solving. Staffed with over fifty-five research faculty, technical staff, and graduate students with experience spanning industry, academia, and government, the center's seven integrated laboratories aim to reduce time to market, optimize decisions at each stage of the product manufacturing life cycle, and increase product

quality by incorporating TQM throughout the life cycle. The center is working to develop decision-making software that will enhance U.S. industry's worldwide competitive posture.

- **Cornell University's** Manufacturing Engineering and Productivity Program was established in 1982 to foster manufacturing-related education and research. The cross-disciplinary program involves the College of Engineering, the Graduate School of Management, and the New York State School of Industrial and Labor Relations. In 1991, a cross-disciplinary manufacturing option was added to the one-year master of engineering degree program to include human relations, finance and accounting, processes, logistics, and systems aspects of manufacturing as well as a nine-month cross-disciplinary project with local manufacturing industries. A similar manufacturing option has been added to the MBA program and is planned for the industrial and labor relations master's program.

The MEng degree with the manufacturing option can be earned concurrently with the MBA degree in the Program in Manufacturing Management, sponsored jointly by the engineering college and the school of management.

Cornell's several interdisciplinary manufacturing-related research groups cooperating with industry sponsors include programs in semiconductor manufacturing, injection molding, metal forming, design, and automation. The Industry-Cornell University Alliance for Electronic Packaging, for example, performs basic research in electronic packaging; it encourages participation in research and technology transfer by industry people in residence at Cornell, and offers participants such deliverables as new materials and technology, researchers, and graduates well grounded in electronic packaging.

- **Georgia Institute of Technology's** Computer-Integrated Manufacturing Systems (CIMS) Program, established in 1983 with a grant from IBM, enhances graduate master's and doctoral education in traditional academic disciplines with multidisciplinary coursework and team activities. On a quarter system, students take at least six hours of required coursework outside their enrolled disciplines and

LFM CLASS OF 1992



(First row, left to right:) Tracy L. Harrison, Christine N. Jutte, Parkson Chao, Camilla M. Denison, Michael L. Dorah, Stephanie A. Maggs. (Second row, left to right:) Arthur Keigler, James P. Bonini, Brad L. Kirkwood, Thomas P. Knight, Eva M.H. Csizinszky, Theresa L. Mock, Deishin Lee. (Third row, left to right:) Tidhar D. Shalon, Luciano Spiridiglozzi, Morgan S. Burke, Thilo Semmelbauer, Hollie K. Schmidt, James W. Casamento. (Fourth row, left to right:) Elizabeth J. Altman, Dennis M. Hager, John E. Glancy, Jr., Kathryn L. Whiting, Arthur J. Raymond, Anthony McGettigan, Michael E. Dombrowski. (Back row, left to right:) David K. Lauzun, J. Douglas Field, Eric M. Soederberg, Richard F. Dauch, Timothy J. Copes, Nathan V. Stuart, Francis J. MacDonald, Jr., Bruce D. Lawler. Missing from the photograph is Hans P. Griesser.

twenty-four hours of elective coursework selected from each of four areas. Five to six quarters are generally required to earn a master's degree plus the CIMS certificate. The program awards its certificate to about sixty students (including twelve fellows) each year through the College of Engineering; 411 have been awarded to date. Ten companies currently sponsor the program, involving nearly fifty faculty in nine closely collaborating academic units that have developed courses specially for the program. Georgia Tech's Manufacturing Research Center, established in 1988, complements CIMS's educational function by conducting manufacturing-related research for corporate sponsors.

- **Lehigh University** offers a graduate program in Manufacturing Systems Engineering (MSE), launched in 1984 through a grant from IBM. The program is managed through the university's Center for Manufacturing Systems Engineering, which also interfaces with industry in technology transfer and research. The MSE Program offers full-time (twelve months or, preferably, three semesters) and partial work-release (two years) options. A thirty-

credit-hour minimum leads to an MS degree in Manufacturing Systems Engineering, conferred upon approximately thirty Lehigh students each year by the College of Engineering and Applied Science. The program also offers six- to seven-month internships to candidates who have earned a BS degree in the spring preceding their January entrance into the MSE Program. The engineering and business curricula are tightly coupled and include team projects and industry visits. The program provides a broad-based understanding of integrated manufacturing systems from both engineering and management perspectives, stressing a systems approach and quality by design applied through the whole manufacturing cycle. Fourteen manufacturing companies comprise the program's Industrial Advisory Board.

- **Northwestern University's** J.L. Kellogg Graduate School of Management and Robert R. McCormick School of Engineering and Applied Science launched in 1990 as a joint venture a full-time, two-year Master of Management for Manufacturing (MMM) Program, integrating management and engineering in a single

A NEW BREED OF MANUFACTURING LEADERS

It is exciting to be a part of the development of a new breed of manufacturing leaders through our dedication to the Leaders for Manufacturing Program.



Our enthusiasm at Polaroid shows. Over four hundred Polaroid employees in development and manufacturing have been involved in some aspect of the program. We have found in the Leaders Program, industry and academic partners who share our vision of development and manufacturing, and we've established new levels of collaboration with our industrial partners and our neighbors at MIT.

Our plants have become extensions of the campus laboratories, and the LFM research at our plant sites has stimulated innovative thinking in search of new paradigms for manufacturing.

We are pleased to report that the results of Leaders projects at our plant sites have been integrated into our operations, and we are especially proud of the outstanding graduates who have joined Polaroid.

I. MACALLISTER BOOTH
CHAIRMAN, PRESIDENT, & CEO
POLAROID CORPORATION

A UNIQUE SOLUTION

Whatever the technology involved, manufacturing is still at the heart of an industry's success.

This is a truism, but one that has been overlooked all too often in the recent past as young MBAs arrived at the job with a wealth of knowledge and ideas but little interest or practical experience in the real world of manufacturing.

The Leaders for Manufacturing Program is a unique solution that incorporates an unprecedented degree of partnership. MIT's School of Engineering and Sloan School of Management, along with the corporate sponsors and, most importantly, the highly talented LFM fellows, all work together in a spirit of cooperation and teamwork that benefits everyone involved. This is not the kind of program in which the sponsoring company drops a check in the mail and visits the school once a year to see how the money is being spent. In our case, our people at all levels have been involved in virtually every phase of the program.

The advantages to LFM graduates obviously are great, and from a sponsor's own point of view, so are the benefits that we receive. As a result of our participation in the Leaders for Manufacturing Program, some of MIT's, and the nation's, brightest young people have come to work at United Technologies, and we have begun enrolling our own employees.

So far the number of graduates is small, but the impact of the program on both academia and industry is large. All of us expect great things from this program and its graduates.

ROBERT F. DANIELL
CHAIRMAN AND CEO
UNITED TECHNOLOGIES
CORPORATION



degree. Students with significant industrial experience take fourteen required courses (seven each in general management and manufacturing cores) and nine electives, and perform an industry internship during the summer between their two academic years. The interdisciplinary approach involves five management and four engineering departments, and is capped by a two-course sequence in product and process management taught by a faculty/industry team, in which student teams conduct a product development project. An industrial advisory board participates in developing individual courses as well as the overall curriculum. The first forty-nine students graduated in June 1992.

Since 1983 Northwestern has also offered a full-time, nine-month Master's in Manufacturing Engineering Program through four departments of its McCormick School of Engineering and Applied Science. The program emphasizes technologies and processes for discrete parts manufacturing and graduates approximately fifteen students each year.

- **Purdue University** awards degrees in manufacturing engineering and management at all levels. A degree option first offered in 1991 permits students working for their master's degree in any traditional engineering field (aeronautical, chemical, civil, electrical, industrial, materials, mechanical, and nuclear) a specialization in manufacturing. Students in this program enroll in three interdisciplinary core courses and three special summer seminar courses, generally meeting all requirements within the same time period as needed to obtain a traditional degree; dual master's degrees in engineering and management can conceivably be earned in two years. Resources of the Engineering Research Center (ERC) for Intelligent Manufacturing Systems, established in 1985, support the program. Sixty companies participate as partners and affiliates in the ERC, which supports research projects and internships involving forty faculty and approximately 200 students.

- **Stanford University's** Stanford Integrated Manufacturing Association (SIMA), an affiliation with thirteen industrial companies that ensure program quality and relevance, offers three graduate-level educational programs

involving forty-five faculty. The Manufacturing Systems Engineering (MSE) master's program was established in 1984 through a grant from IBM. Organized by the Industrial Engineering/Engineering Management Department and the Mechanical Engineering Department, it offers students the opportunity to earn the MSE degree within three to five academic quarters. The program attracts engineers interested in design, technology, and management to a curriculum that integrates engineering design and manufacturing-focused management. Each year it graduates thirty students.

The MSE/MBA program, introduced in 1990, brings together the Schools of Engineering and Business to offer a dual master's degree (in engineering and business administration) within seven or eight quarters to ten students each year.

Stanford has also developed a doctoral program in manufacturing that involves all ten departments in the School of Engineering and the Graduate School of Business. The program, which seeks to attract industry people into full-time teaching about world-class manufacturing, enrolls its first class this fall.

Leaders Program participants in no way consider the LFM job done, just well on the way—steadily growing in terms of the kinds of initiatives deemed important now and in the future. Magnanti cautions that “though we are proud of our accomplishments, we realize there is still a long way to go, and welcome the opportunity to learn more from our industrial colleagues and bring our own ‘functional silos’ closer together.”

Now looking well beyond the fifth year of the Leaders Program's startup phase, the partners expect not only to continue addressing manufacturing education and research, and influencing other universities and companies, but eventually to involve other university-based manufacturing programs and the U.S. government in the partnership.

Leaders for Manufacturing serves as a dynamic new paradigm for manufacturing partnerships, facilitating the evolution of university-industry collaborations and manufacturing principles and leaders. ■