# Building a Better Delivery System:
# A New Engineering/Health Care Partnership


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and Gary Fanjiang, Editors

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# Preface

In 2000 and 2001, the Institute of Medicine (IOM) issued two reports, *To Err Is Human* and *Crossing the Quality Chasm*, documenting a glaring divergence between the rush of progress in medical science and the deterioration of health care delivery. The first report included an estimate that systems failures in health care delivery (i.e., poorly designed or "broken" care processes) were responsible for at least 90,000 deaths each year. The second report revealed a wide "chasm" between the quality of care the health system should be capable of delivering today, given the astounding advances in medical science and technology in the past half-century, and the quality of care most Americans receive. Documenting deep crises related to the safety, efficacy, efficiency, and patient-centeredness of health care in America, *Crossing the Quality Chasm* set forth a vision for a transformed health care system and challenged system stakeholders to take bold actions to bring about that transformation.

In response to this challenge, the National Academy of Engineering (NAE) and IOM, with support from the National Science Foundation, Robert Wood Johnson Foundation, National Institutes of Health, and the NAE Fund, initiated a project in 2002 to (1) identify engineering applications that could contribute significantly to improvements in health care delivery in the short, medium, and long terms; (2) assess factors that would facilitate or impede the deployment of these applications; and (3) identify areas of research in engineering and other fields that could contribute to rapid improvements in performance. This report, *Building a Better Delivery System*, is the culmination of the joint NAE/IOM study.

The report builds on a growing realization within the health care community of the critical role information/communications technologies, systems engineering tools, and related organizational innovations must play in addressing the interrelated quality and productivity crises facing the health care system. The report provides a framework for change and an action plan for a systems approach to health care delivery based on a partnership between engineers, health care professionals, and health care managers. The goal of the plan is to transform the U.S. health care sector from an underperforming conglomerate of independent entities (individual practitioners, small group practices, clinics, hospitals, pharmacies, community health centers, et al.) into a high-performance "system" in which participating units recognize their interdependence and the implications and repercussions of their actions on the system as a whole. The report describes opportunities and challenges to using systems engineering, information technologies, and other tools to advance a twenty-first century system capable of delivering safe, effective, timely, patient-centered, efficient, equitable health care—a system that embodies the six "quality aims" envisioned in *Crossing the Quality Chasm.*

The committee co-chairs are grateful to the members of the committee, not only for their knowledge, expertise, and commitment to change, but also for their participation in wide-ranging discussions on various aspects of this complex topic. Their collegiality and openness to ideas from many directions enabled the committee as a whole to overcome some of the very communications and cultural barriers described in the report and reach consensus on key recommendations. We also thank the outside experts who contributed their time and efforts to the success of this project, and the NAE and IOM staff for their research, editorial, and administrative support.

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# Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for reviewing this report:

David E. Daniel, University of Texas
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Edward J. Sondik, National Center for Health Statistics
Paul C. Tang, Palo Alto Medical Foundation

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Don E. Detmer, American Medical Informatics Association, and Charles E. Phelps, University of Rochester, appointed by the National Research Council Report Review Committee, who was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

# Contents

# Executive Summary

American medicine defines the cutting edge in most fields of clinical research, training, and practice worldwide, and U.S.-based manufacturers of drugs, medical devices, and medical equipment are among the most innovative and competitive in the world. In large part, the United States has achieved primacy in these areas by focusing public and private resources on research in the life and physical sciences and on the engineering of devices, instruments, and equipment to serve individual patients.

At the same time, relatively little technical talent or material resources have been devoted to improving or optimizing the operations or measuring the quality and productivity of the overall U.S. health care system. The costs of this collective inattention and the failure to take advantage of the tools, knowledge, and infrastructure that have yielded quality and productivity revolutions in many other sectors of the American economy have been enormous. The $1.6 trillion health care sector is now mired in deep crises related to safety, quality, cost, and access that pose serious threats to the health and welfare of many Americans (IOM, 2000, 2001, 2004a,b,c).

One need only note that: (1) more than 98,000 Americans die and more than one million patients suffer injuries each year as a result of broken health care processes and system failures (IOM, 2000; Starfield, 2000); (2) little more than half of U.S. patients receive known "best practice" treatments for their illnesses and less than half of physician practices use recommended processes for care (Casalino et al., 2003; McGlynn et al., 2003); and (3) an estimated thirty to forty cents of every dollar spent on health care, or more than a half-trillion dollars per year, is spent on costs associated with "overuse, underuse, misuse, duplication, system failures, unnecessary repetition, poor communication, and inefficiency" (Lawrence, in this volume). Health care costs have been rising at double-digit rates since the late 1990s—roughly three times the rate of inflation—claiming a growing share of every American's income, inflicting economic hardships on many, and decreasing access to care. At the same time, the number of uninsured has risen to more than 43 million, more than one-sixth of the U.S. population under the age of 65 (IOM, 2004a).

With support from the National Science Foundation (NSF), National Institutes of Health (NIH), and Robert Wood Johnson Foundation, the National Academy of Engineering (NAE) and Institute of Medicine (IOM) of the National Academies convened a committee of 14 engineers and health care professionals to identify engineering tools and technologies that could help the health system overcome these crises and deliver care that is safe, effective, timely, patient-centered, efficient, and equitable—the six quality aims envisioned in the landmark IOM report, *Crossing the Quality Chasm* (Box ES-1).

The committee began with the expectation that systems-engineering tools that have transformed the quality and productivity performance of other large-scale complex systems (e.g., telecommunications, transportation, and manufacturing systems) could also be used to improve health care delivery. The particular charge to the committee was to identify: (1) engineering applications with the potential to improve health care delivery in the short, medium, and long terms; (2) factors that would facilitate or inhibit the deployment of these applications; and (3) priorities for research and education in engineering, the health professions, and related areas that would contribute to rapid improvements in the performance of the health care delivery system. The committee held three intensive workshops with experts from the engineering, health, management, and social science communities. The presentations by these experts can be found in Part 2 of this volume.

## ENGINEERING-HEALTH CARE PARTNERSHIP

This report provides a framework and action plan for a systems approach to health care delivery based on a partner-

**BOX ES-1**
**Six Quality Aims for the 21st Century Health System**

Six aims for improvement to address key dimensions in which today's health care system functions at far lower levels than it can and should. Health care should be:

- Safe—avoiding injuries to patients from the care that is intended to help them.
- Effective—providing services based on scientific knowledge to all who could benefit and refraining from providing services to those not likely to benefit (avoiding underuse and overuse, respectively).
- Patient-centered—providing care that is respectful of and responsive to individual patient preferences, needs, and values and ensuring that patient values guide all clinical decisions.
- Timely—reducing waits and sometimes harmful delays for both those who receive and those who give care.
- Efficient—avoiding waste, including waste of equipment, supplies, ideas, and energy.
- Equitable—providing care that does not vary in quality because of personal characteristics such as gender, ethnicity, geographic location, and socioeconomic status.

Source: IOM, 2001, pp. 5–6.

ship between engineers and health care professionals. The goal of this partnership is to transform the U.S. health care sector from an underperforming conglomerate of independent entities (individual practitioners, small group practices, clinics, hospitals, pharmacies, community health centers, et al.) into a high-performance "system" in which every participating unit recognizes its dependence and influence on every other unit. The report describes the opportunities and challenges to harnessing the power of systems-engineering tools, information technologies, and complementary knowledge in social sciences, cognitive sciences, and business/management to advance the six IOM quality aims for a twenty-first century health care system.

This NAE/IOM study attempts to bridge the knowledge/awareness divide separating health care professionals from their potential partners in systems engineering and related disciplines. After examining the interconnected crises facing the health care system and their proximate causes (Chapter 1), the report presents an overview of the core elements of a systems approach and puts forward a four-level model—patients, care teams, provider organizations, and the broader political-economic environment—of the structure and dynamics of the health care system that suggests the division of labor and interdependencies and identifies levers for change (Chapter 2).

In Chapters 3 and 4, systems-engineering tools and information/communications technologies and their applications to health care delivery are discussed. These complementary tools and technologies have the potential of improving radically the quality and productivity of American health care. Structural, economic, organizational, cultural, and educational barriers to using systems tools and information/communications technologies, and recommendations for overcoming these barriers follow. In Chapter 5, the committee proposes a strategy for building a vigorous partnership between engineering and health care through cross-disciplinary research, education, and outreach.

## SYSTEMS-ENGINEERING TOOLS FOR HEALTH CARE DELIVERY

Systems-engineering tools have been used in a wide variety of applications to achieve major improvements in the quality, efficiency, safety, and/or customer-centeredness of processes, products, and services in a wide range of manufacturing and services industries. The health care sector as a whole has been very slow to embrace them, however, even though they have been shown to yield valuable returns to the small but growing number of health care organizations and clinicians that have applied them (Feistritzer and Keck, 2000; Fone et al., 2000; Leatherman et al., 2003; Murray and Berwick, 2003). Statistical process controls, queuing theory, quality function deployment, failure-mode effects analysis, modeling and simulation, and human-factors engineering have been adapted to applications in health care delivery and used tactically by clinicians, care teams, and administrators in large health care organizations to improve the performance of discrete care processes, units, and departments.

However, the strategic use of these and more information-technology-intensive tools from the fields of enterprise and supply-chain management, financial engineering and risk analysis, and knowledge discovery in databases has been limited. With some adaptations, these tools could be used to measure, characterize, and optimize performance at higher levels of the health care system (e.g., individual health care organizations, regional care systems, the public health system, the health research enterprise, etc.). The most promising systems-engineering tools and areas of associated research identified by the committee are listed in Table ES-1.

Although data and associated information technology needs do not present significant technical or cost barriers to the tactical application of systems-engineering tools, there are significant structural, technical, and cost-related barriers at the organizational, multi-organizational, and environmental levels to the strategic implementation of systems tools. The current organization, management, and regulation of health care delivery provide few incentives for the use or development of systems-engineering tools. Current reimbursement practices, regulatory frameworks, and the lack of support for research have all discouraged the development, adaptation, and use of systems-engineering tools. Cultural, organizational, and policy-related factors (e.g., regulation, licensing, etc.) have contributed to a rigid division of labor in many areas of health care that has also impeded the widespread use of system tools.

In fact, relatively few health care professionals or administrators are equipped to think analytically about health care delivery as a system or to appreciate the relevance of systems-engineering tools. Even fewer are equipped to work with engineers to apply these tools. The widespread use of systems-engineering tools will require determined efforts on the part of health care providers, the engineering community, state and federal governments, private insurers, large employers, and other stakeholders.

TABLE ES-1 Systems Engineering Tools and Research for Health Care Delivery

| | **Levels of Application** | | | |
|---|---|---|---|---|
| **Tools/Research Areas** | **Patient** | **Team** | **Organization** | **Environment** |
| SYSTEMS-DESIGN TOOLS | | | | |
| Concurrent engineering and quality function deployment | | X | X | |
| *Human-factors tools* | X | X | X | X |
| Failure mode effects analysis | | X | X | |
| SYSTEMS-ANALYSIS TOOLS | | | | |
| **Modeling and Simulation** | | | | |
| Queuing methods | X | X | X | |
| Discrete-event simulation | X | X | X | X |
| **Enterprise-Management Tools** | | | | |
| *Supply-chain Management* | | X | X | X |
| *Game theory and contracts* | | X | X | X |
| *Systems-dynamics models* | | X | X | X |
| *Productivity measuring and monitoring* | | X | X | X |
| | **System Levels of Application** | | | |
| **Tools/Research Areas** | **Patient** | **Team** | **Organization** | **Environment** |
| **Financial Engineering and Risk Analysis Tools** | | | | |
| *Stochastic analysis* | | | X | X |
| *Value-at-Risk* | | | X | X |
| *Optimization tools for individual decision making* | | X | X | X |
| *Distributed decision making: market models and agency theory* | | | X | X |
| **Knowledge Discovery in Databases** | | | | |
| *Data mining* | | | X | X |
| *Predictive modeling* | | X | X | X |
| *Neural networks* | | X | X | X |
| SYSTEMS-CONTROL TOOLS | | | | |
| Statistical process control | X | X | X | |
| *Scheduling* | | X | X | |

NOTE: Italics indicate areas with significant research opportunities.

### Chapter 3 Recommendations

**Recommendation 3-1.** Private insurers, large employers, and public payers, including the Federal Center for Medicare and Medicaid Services and state Medicaid programs, should provide more incentives for health care providers to use systems tools to improve the quality of care and the efficiency of care delivery. Reimbursement systems, both private and public, should expand the scope of reimbursement for care episodes or use other bundling techniques (e.g., disease-related groups, severity-adjusted capitation for Medicare Advantage, fixed payment for transplantation, etc.) to encourage the use of systems-engineering tools. Regulatory barriers should also be removed. As a first step, regulatory waivers could be granted for demonstration projects to validate and publicize the utility of systems tools.

**Recommendation 3-2** Outreach and dissemination efforts by public- and private-sector organizations that have used or promoted systems-engineering tools in health care delivery (e.g., Veterans Health Administration, Joint Commission on Accreditation of Healthcare Organizations, Agency for Healthcare Research and Quality, Institute for Healthcare Improvement, Leagfrog Group, U.S. Department of Commerce Baldrige National Quality Program, and others) should be expanded, integrated into existing regulatory and accreditation frameworks, and reviewed to determine whether, and if so how, better coordination might make their collective impact stronger.

**Recommendation 3-3.** The use and diffusion of systems-engineering tools in health care delivery should be promoted by a National Institutes of Health Library of Medicine website that provides patients and clinicians with information about, and access to, systems-engineering tools for health care (a systems-engineering counterpart to the Library of Medicine web-based "clearinghouse" on the status and treatment of diseases and the Agency for Healthcare Research and Quality National Guideline Clearinghouse for evidence-based clinical practice). In addition, federal agencies and private funders should support the development of new curricula, textbooks, instructional software, and other tools to train individual patients and care providers in the use of systems-engineering tools.

**Recommendation 3-4.** The use of any single systems tool or approach should not be put "on hold" until other tools become available. Some systems tools already have extensive tactical or local applications in health care settings. Information-technology-intensive systems tools, however, are just beginning to be used at higher levels of the health care delivery system. Changes must be approached from many directions, with systems engineering tools that are available now and with new tools developed through research. Successes in other industries clearly show that small steps can yield significant results, even while longer term efforts are being pursued.

**Recommendation 3-5.** Federal research and mission agencies should significantly increase their support for research to advance the application and utility of systems engineering in health care delivery, including research on new systems tools and the adaptation, implementation, and improvement of existing tools for all levels of health care delivery. Promising areas for research include human-factors engineering, modeling and simulation, enterprise management, knowledge discovery in databases, and financial engineering and risk analysis. Research on the organizational, economic, and policy-related barriers to implementation of these and other systems tools should be an integral part of the larger research agenda.

## INFORMATION AND COMMUNICATION TECHNOLOGIES FOR HEALTH CARE DELIVERY

Although information collection, processing, communication, and management are at the heart of health care delivery, and considerable evidence links the use of clinical information/communications technologies to improvements in the quality, safety, and patient-centeredness of care, the health care sector remains woefully underinvested in these technologies (Casalino et al., 2003; DOC, 1999; IOM, 2004c; Littlejohns et al., 2003; Pestotnik et al., 1996; Walker et al., 2005; Wang et al., 2003). Factors contributing to this longstanding information/communications technologies deficit include: the atomistic structure of the industry; current payment/reimbursement regimes; the lack of transparency in the market for health care services; weaknesses in health care's managerial culture; the hierarchical structure and rigid division of labor in health professions; and (until very recently) the immaturity of available commercial clinical information/communications systems.

In the past decade, efforts to close the information/communications technologies gap have focused on the need for a comprehensive national health information infrastructure (NHII), that is, the "set of technologies, standards, applications, systems, values, and laws that support all facets of individual health, health care, and public health" (National Committee on Vital and Health Statistics, 2001). Recent progress toward this goal, including the creation of the Office of the National Coordinator for Health Information Technology (ONCHIT), in the U.S. Department of Health and Human Services, and the release of a 10-year plan to build the NHII, is encouraging (Thompson and Brailer, 2004).

A fully implemented NHII could support applications of information/communications technologies that empower individual patients to assume a much more active, controlling role in their own health care; improve access to timely, effective, and convenient care; improve patient compliance with clinician guidance; enable continuous monitoring of patient conditions by care professionals/care teams; and enable care providers to integrate critical information streams to improve patient-centered care, as well as to analyze, control, and optimize the performance of care teams. The NHII could enable health care organizations to integrate their clinical, administrative, and financial information systems internally, as well as link their systems with those of insurers, vendors, regulatory bodies, and other elements of the extended health care delivery enterprise. The NHII could allow provider organizations to make more extensive use of data/information-intensive systems-engineering tools and facilitate the aggregation and exchange of data among health care organizations, public and private payer organizations, regulatory bodies, and the research community. This data pool could support better regulation and oversight of the health care delivery system, population health surveillance, and the continuing development of the clinical knowledge base.

The NHII could also support another family of emerging technologies based on wireless communications and micro-electronic systems with the potential to radically change the structure of the health care delivery system and advance patient-centeredness and quality performance. Wireless integrated microsystems (WIMS) could have an enormous beneficial impact on the quality and cost of health care, especially home health care in the coming decade. Microsystems implemented as wearable and implantable devices connected to clinical information systems through wireless communications could provide diagnostic data and deliver therapeutic agents for the treatment of a variety of chronic conditions, thereby improving the quality of life for senior citizens and chronically ill patients.

Much of the information/communications technology necessary for the realization of NHII exists today and will certainly improve in the decade ahead; however, there will be many challenges to putting it in place. Interoperability and other data standards and serious privacy and reliability concerns must be addressed, as well as training issues at all levels of the health care system. These and many of the same structural, financial, policy-related (reimbursement schemes, regulation), organizational, and cultural barriers that have impeded the use of systems tools will have to be surmounted to close health care's wide information/communications technologies gap..

### Chapter 4 Recommendations

**Recommendation 4-1.** The committee endorses the recommendations made by the Institute of Medicine Committee on Data Standards for Patient Safety, which called for continued development of health care data standards and a significant increase in the technical and material support provided by the federal government for public-private partnerships in this area.

**Recommendation 4-2.** The committee endorses the recommendations of the President's Information Technology Advisory Council that call for: (1) application of lessons learned from advances in other fields (e.g., computer infrastructure, privacy issues, and security issues); and (2) increased coordination of federally supported research and development in these areas through the Networking and Information Technology Research and Development Program.

**Recommendation 4-3.** Research and development in the following areas should be supported:

- human-information/communications technology system interfaces
- voice-recognition systems
- software that improves interoperability and connectivity among systems from different vendors
- systems that spread costs among multiple users
- software dependability in systems critical to health care delivery
- secure, dispersed, multiagent databases that meet the needs of both providers and patients
- measurement of the impact of information/communications systems on the quality and productivity of health care

**Recommendation 4-4.** The committee applauds the U.S. Department of Health and Human Services 10-year plan for the creation of the National Health Information Infrastructure and the high priority given to the creation of standards for the complex network necessary for communications among highly dispersed providers and patients. To ensure that the emerging National Health Information Infrastructure can support current and next-generation clinical information/communications systems and the application of systems tools, research should focus immediately on advanced interface standards and protocols and standards-related issues concerning access, security, and the integration of large-scale wireless communications. Special attention should be given to issues related to large-scale integration. Funding for research in all of these areas will be critical to moving forward.

**Recommendation 4-5.** The committee recommends that public- and private-sector initiatives to reduce or offset current regulatory, accreditation, and reimbursement-related barriers to more extensive use of information/communications technologies in health care be expanded. These initiatives include efforts to reimburse providers for care episodes or use other bundling techniques (e.g., severity-adjusted capitation; disease-related groups, etc.), public and private support of community-based health information network demonstration projects, the Leapfrog Group's purchaser-mediated rewards to providers that use information/communications technologies, and others.

**Recommendation 4-6.** Public- and private-sector support for research on the development of very small, low-power, biocompatible devices will be essential for improving health care delivery

**Recommendation 4-7.** Engineering research should be focused on defining an architecture capable of incorporating data from microsystems into the wider health care network and developing interface standards and protocols to implement this larger network. Microsystems research should be focused on the following areas:

- integration, packaging, and miniaturization (to sizes consistent with implantation in the body)
- tissue interfaces and biocompatibility for long-term implantation
- interfaces and approaches to noninvasive (wearable) devices for measuring a broad range of physiological parameters
- low-power, embedded computing systems and wireless interfaces consistent with *in vivo* use
- systems that can transform data reliably and accurately into information and information into knowledge as a basis for treatment decisions

## A STRATEGY TO ACCELERATE CHANGE

The committee believes that the actions recommended in this report will accelerate the development, adaptation, implementation, and diffusion of systems-engineering tools and information/communications technologies for health care delivery. However, building the partnership between engineering and health care that will accelerate and sustain progress toward the high-performance, patient-centered health care system envisioned by IOM will require bold, intentional, far-reaching changes in the education, research priorities, and practices of health care, engineering, and management. Building on the experiences of recent large-scale, multidisciplinary, research/education/technology-transfer initiatives in engineering and the biological sciences, the committee proposes a strategy for building bridges between the fields of engineering, health care, and management to address the major challenges facing the health care delivery system. An environment in which professionals from all three fields could engage in basic and applied research and translate the results of their research and advances both into the practice arena and the classroom, where students from the three disciplines could interact, would be a powerful catalyst for cultural change.

### Chapter 5 Recommendations

**Recommendation 5-1a.** The federal government, in partnership with the private sector, universities, federal laboratories, and state governments, should establish multidisciplinary centers at institutions of higher learning throughout the country capable of bringing together researchers, practitioners, educators, and students from appropriate fields of engineering, health sciences, management, social and behavioral sciences, and other disciplines to address the quality and productivity challenges facing the nation's health care delivery system. To ensure that the centers have a nationwide impact, they should be geographically distributed. The committee estimates that 30 to 50 centers would be necessary to achieve these goals.

**Recommendation 5-1b.** These multidisciplinary research centers should have a three-fold mission: (1) to conduct basic and applied research on the systems challenges to health care delivery and on the development and use of systems-engineering tools, information/communications technologies, and complementary knowledge from other fields to address them; (2) to demonstrate and diffuse the use of these tools, technologies, and knowledge throughout the health care delivery system (technology transfer); and (3) to educate and train a large cadre of current and future health care, engineering, and management professionals and researchers in the science, practices, and challenges of systems engineering for health care delivery.

**Recommendation 5-2.** Because funding for the multidisciplinary centers will come from a variety of federal agencies, a lead agency should be identified to bring together representatives of public- and private-sector stakeholders to ensure that funding for the centers is stable and adequate and to develop a strategy for overcoming regulatory, reimbursement-related, and other barriers to the widespread application of systems engineering and information/communications technologies in health care delivery.

### *Accelerating Cultural Change through Formal and Continuing Education*

Making systems-engineering tools, information technologies, and complementary knowledge in business/management, social sciences, and cognitive sciences available and training individuals to use them will require the commitment and cooperation of engineers, clinicians, and health care managers, as well as changes in their respective professional cultures. The committee believes that these long-term cultural changes must begin in the formative years of professional education. Individuals in all of these professions should have opportunities to participate in learning and research environments in which they can contribute to a new approach to health care delivery. The training and development of health care, engineering, and management professionals who understand the systems challenges facing health care delivery and the value of using systems tools and technologies to address them should be accelerated and intensified.

**Recommendation 5-3.** Health care providers and educators should ensure that current and future health care professionals have a basic understanding of how systems-engineering tools and information/communications technologies work and their potential benefits. Educators of health professionals should develop curricular materials and programs to train graduate students and practicing professionals in systems approaches to health care delivery and the use of systems tools and information/communications technologies. Accrediting organizations, such as the Liaison Committee on Medical Education and Accreditation Council for Graduate Medical Education, could also require that medical schools and teaching hospitals provide training in the use of systems tools and information/communications technologies. Specialty boards could include training as a requirement for recertification.

**Recommendation 5-4.** Introducing health care issues into the engineering curriculum will require the cooperation of a broad spectrum of engineering educators. Deans of engineering schools and professional societies should take steps to ensure that the relevance of, and opportunities for, engineering to improve health care are integrated into engineering education at the undergraduate, graduate, and continuing education levels. Engineering educators should involve representatives of the health care delivery sector in the development of cases studies and other instructional materials and career tracks for engineers in the health care sector.

**Recommendation 5-5.** The typical MBA curriculum requires that students have fundamental skills in the principal functions of an organization—accounting, finance, economics, marketing, operations, information systems, organizational behavior, and strategy. Examples from health care should be used to illustrate fundamentals in each of these areas. Researchers in operations are encouraged to explore applications of systems tools for health care delivery. Quantitative techniques, such as financial engineering, data mining, and game theory, could significantly improve the financial, marketing, and strategic functions of health care organizations, and incorporating examples from health care into the core MBA curriculum would increase the visibility of health care as a career opportunity. Business and related schools should also be encouraged to develop elective courses and executive education courses focused on various aspects of health care delivery. Finally, students should be provided with information about careers in the health care industry.

**Recommendation 5-6.** Federal mission agencies and private-sector foundations should support the establishment of fellowship programs to educate and train present and future leaders and scholars in health care, engineering, and management in health systems engineering and management. New fellowship programs should build on existing programs, such as the Veterans Administration National Quality Scholars Program (which supports the development of physician/scholars in health care quality improvement), and the Robert Wood Johnson Foundation Health Policy Research and Clinical Scholars Programs (which targets newly minted M.D.s and social science Ph.D.s, to ensure their involvement in health policy research). The new programs should include all relevant fields of engineering and the full spectrum of health professionals.

## CALL TO ACTION

As important as good analytical tools and information/communications systems are, they will ultimately fail to transform the system unless all members of the health care provider community participate and actively support their use. Although individuals "on the ground" (i.e., those doing the work) often know best how to improve things, empowering them to participate in changing the system will require that they understand the overall goals and objectives of the system and subsystem in which they work. Based on this understanding, they can contribute substantively to continuous improvements, as well as to radical advances in processes. The communication of the overall system and subsystem goals to individuals and groups at all levels is a crucial task for the management of the organization, and encouraging and recognizing individuals for their contributions to continuous improvements in operations at every level must be a principal operating goal for management.

Overhauling the health care delivery system will not come quickly or easily. Achieving the long-term goal of improving the health care system will require the ingenuity and commitment of leaders in the health care community, including practitioners in all clinical areas, and leaders in engineering. The committee recognizes the immensity of the task ahead and offers a word of encouragement to all members of the engineering and health care communities. If we take up the challenge to help transform the system now, crises can be abated, costs can be reduced, the number of uninsured can be reduced, and all Americans will have access to the quality care they deserve and that we are capable of delivering.

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