Final Report

Industrial and Systems Engineering and Health Care: Critical Areas of Research

Prepared for:
Agency for Healthcare Research and Quality
U.S. Department of Health and Human Services
540 Gaither Road
Rockville, MD 20850
www.ahrq.gov

Contract No. 290-09-00027U

Prepared by:
Rupa Sheth Valdez, Edmond Ramly, and Patricia Flatley Brennan
University of Wisconsin-Madison, Madison, WI

Authors:
Rupa Sheth Valdez
Edmond Ramly
Patricia Flatley Brennan

Agency for Healthcare Research and Quality
Advancing Excellence in Health Care • www.ahrq.gov

HEALTH IT

Suggested Citation:

Valdez RS, Ramly E, Brennan PF. Industrial and Systems Engineering and Health Care: Critical Areas of Research--Final Report. (Prepared by Professional and Scientific Associates under Contract No. 290-09-00027U.) AHRQ Publication No. 10-0079. Rockville, MD: Agency for Healthcare Research and Quality. May 2010.

None of the investigators has any affiliations or financial involvement that conflicts with the material presented in this report.

Acknowledgments

We would like to recognize the sustained help of Teresa Zayas-Cabán, the AHRQ Project Officer. We would also like to thank all reviewers who provided feedback on earlier drafts of this report. In particular, we would like to thank Brian Denton, Assistant Professor, North Carolina State University; Michael M.E. Johns, University Chancellor, Emory University; Michelle L. Rogers, Assistant Professor, Drexel University; William B. Rouse, Professor, Georgia Institute of Technology; James M. Walker, Chief Health Information Officer, Geisinger Health System; José Zayas-Castro, Professor, University of South Florida for their thoughtful feedback.

Contents

Tables

Appendixes

Executive Summary

Background

Industrial and systems engineering (ISyE) has the potential to address many of the challenges faced by the health care delivery system. Mindful of potential synergies between health care and ISyE, the Agency for Healthcare Research and Quality (AHRQ) and the National Science Foundation (NSF) convened a workshop in which experts in both fields were asked to explore the critical areas of research at the intersection of ISyE and health care, with a special emphasis on the supportive role of health information technology (IT).

Objectives

The objectives of the project were to (1) articulate a vision for an ideal health care delivery system, (2) determine why current efforts to apply ISyE knowledge to health care have not resulted in meaningful change, and (3) propose a research and action agenda that should be pursued to enable the field of ISyE to substantially contribute to the realization of an ideal health care delivery system.

Methodology

Background materials included thirteen seminal reports generated in the last decade by various national bodies (National Academy of Sciences, Institute of Medicine, National Academy of Engineering, National Science Foundation), and a background report reviewing and critiquing them. Analysis of background materials led to the formulation of purpose statements for the workshop, guided participant invitations, and helped shape the activities undertaken as part of the workshop and afterwards. The background materials were circulated to all participants prior to the workshop. Presentations and keynote addresses during the workshop contributed to providing a backdrop for discussions.

Small group discussions were used to probe deeply into how specific ISyE specialties could address health care challenges. Five ISyE specialty groups and six health care challenge area groups were constructed. Each participant was assigned to one ISyE group and one crosscutting health care challenge area group. Large group discussions served to identify points of consensus and tension, and to report out conclusions reached by the small groups. Discussions were captured by professional note takers, and small group discussions were professionally facilitated.

This final report synthesizes and discusses the outcomes of the workshop within the context of the knowledge gleaned from the background materials. We emphasize throughout the report that the project objectives call for system-wide breakthrough change, and propose a research agenda and an action agenda.

Vision of an Ideal Health Care Delivery System

Presentations by the workshop chair, two keynote speakers, and six domain specific experts informed the creation of a vision that departs from current realities and explores characteristics of an ideal system. The emphasis is on a system that is *new*, *patient-centered*, and *engineered*: (1) The new, redesigned system is integrated, ubiquitous, distributed, responsive, expansive, flexible, and resilient. (2) Delivery of health care is personalized, facilitated by secure information flow, and mindful of patient privacy. Transparency and open access enable people to make informed choices about their health, with a focus on prevention and health promotion. (3) The delivery system is information-optimized and runs smoothly, efficiently, and safely. All stakeholders leverage ISyE and information and communication technologies to drive both subsystem and system-wide changes. Incentives are aligned to enhance quality of life for all, at the individual and population levels. Evidence-based analytics and mathematical modeling inform standard care processes and biomedical knowledge discovery.

Barriers and Facilitators to Achieving Breakthrough Change with ISyE Knowledge

Nine barriers and four facilitators to achieving breakthrough change to the health care delivery system were identified.

Barriers: (1) Lack of widespread use of ISyE tools, (2) inadequate current ISyE knowledge, (3) insufficient health IT infrastructure, (4) structural and cultural traditions in the health care delivery system emphasizing only subsystem improvement and short-term outcomes and rewards, (5) insufficient pathways which promote use of ISyE knowledge in health care, (6) lack of efficient ways to spread knowledge between ISyE professionals working in health care, (7) no clear funding structures to support development of new ISyE knowledge, (8) current policies constraining level of change possible, and (9) lack of professionals with an adequate understanding of both ISyE and health care.

Facilitators: (1) Increasing recognition of the potential of ISyE to improve health care, (2) progress in both recognition of the need for and the development of new ISyE tools, (3) progress in the use of IT to disseminate ISyE knowledge, and (4) current political climate of health care reform.

Research Agenda

Two main challenges were faced in developing a research agenda focused on new ISyE knowledge: (1) lack of clarity about the scope of ISyE and(2) belief in the adequacy of current ISyE knowledge leading to difficulty thinking “out of the box.” Despite these challenges, research directions were identified and divided into topics. The research agenda is divided into three themes:

- Stimulate innovation in ISyE methods better aligned with the complex, distributed, and stochastic nature of health care (Knowledge Innovation);

- Accelerate knowledge transfer of ISyE methods to solve currently recognized health care challenges (Knowledge Transfer); and
- Integrate over-arching meta-knowledge lessons gleaned from purposefully- targeted research projects (Meta-Knowledge Integration).

To aid agencies and researchers in utilizing the research agenda effectively, a secondary, complementary categorization of key themes of the research agenda items is offered. “Breakthrough” includes items that are essential to realizing the vision of the new health care delivery system. “Sustainability” includes items that are likely to have benefit and improve the health care delivery system, but will not lead to breakthrough changes. “Capacity building” includes items that are necessary to expand the breadth and depth of ISyE knowledge relevant to health care. These categories are conceptualized as complementary, and are all likely to be necessary to achieving the vision of an ideal health care delivery system.

Knowledge Innovation

The majority of the research agenda focused on stimulating ISyE knowledge to address unresolved, unanswered questions posed by the challenges in contemporary health care delivery. The knowledge innovation directions are presented along the lines of system monitoring, system modeling, and system modification. System monitoring research agenda items are required to improve assessment of the system and communication of these assessments to relevant stakeholders. System modeling research agenda items are required to improve understanding of system components and interactions between system components. Finally, system modification research agenda items are required to ensure efficient and effective system transformation.

System monitoring

The agenda items concerning system monitoring are divided into four subtopics: data collection, integration, characterization, and presentation.

Data Collection

(1) (Breakthrough) Consumer-facing health IT solutions that allow patients to self-report their observations, that track and report on trends, and that interact with providers’ annotations; (2) (Sustainability) Efficient and pervasive methods of data capture; (3) (Sustainability) New automatic data collection technologies to capture observations from patients and their environments (e.g., sun exposure and food intake); (4) (Sustainability) Theories and methods beyond natural language processing for the translation of lay person language into structured computable data.

Integration

(1) (Breakthrough)Technologies which enable data to flow quickly and securely through the whole health care delivery system and be available in real-time when and where needed; (2) (Sustainability**)** Efficient methods for integrating large amounts of data from disparate sources; (3) (Sustainability**)** Adequate integration of data collection into workflows in manners that ensure data validity while minimizing interference with clinical workflows; (4) (Sustainability**)** Efficient means of integrating information generated from different perspectives (e.g., different providers, patients, administrators).

Characterization

(1) (Breakthrough**)** Methods to operationalize contextual knowledge to understand generalizability of data; (2) (Sustainability**)** Methods to characterize how the outcomes relate to the processes; (3) (Capacity building**)** Methods to characterize processes, inputs, and outcomes.

Presentation

(1) (Breakthrough**)** Methods to effectively collect and share data in real-time to foster situational awareness of all individuals involved in patient care; (2) (Capacity building**)** Methods to collect and present information that is valuable to diverse stakeholders such as patients, nurses, primary care and specialty physicians, pharmacists, and social workers; (3) (Capacity building**)** Theories and methods for the translation of numerical, analytical, and computational results into understandable and actionable information that multiple stakeholders (e.g., nurses, primary care and specialty care physicians, or pharmacists) and lay people can seamlessly retrieve to ensure the human monitoring of the system.

System Modeling

The agenda items concerning system modeling are divided into four subtopics, covering descriptive, predictive, and prescriptive models, as well as inconvenient realities that models need to be able to handle.

Descriptive models

(1) (Breakthrough**)** Frameworks that explore the integration of many care sources in the production and delivery of care services, and the coordination among these sources (e.g., at end of life care); (2) (Breakthrough**)** Methods to model systems as sets of flows and processes, not just sets of components; (3) (Breakthrough**)** Models that explore the effective use and allocation of different vehicles of health care delivery (e.g., “focused factories” versus integration, such as Mayo Clinics and Kaiser Permanente); (4) (Sustainability**)** Models of trust between patients, providers, and technology.

Predictive models

(1) (Breakthrough**)** Models to evaluate entire systems and large-scale system changes before they are implemented; (2) (Capacity building**)** Models to mitigate uncertainties about the future.

Prescriptive models

(1) (Breakthrough**)** Models of collaboration and competition among health care stakeholders; (2) (Breakthrough**)** Models that consider how health IT can be integrated into decision making processes, how evidence-based knowledge can be integrated into practice; (3) (Sustainability**)** Models that appropriately consider the conflicting objectives of multiple stakeholders and make optimal recommendations for the system overall; (4) (Sustainability**)** Models that provide guidance about when either standardization or customization is necessary; (5) (Capacity building**)** Models to explore the role and consequences of automation, and provide guidance about what can be fully or partially automated; (6) **(**Breakthrough**)** Mathematical programming models.

Models that can handle inconvenient realities

(1) (Breakthrough**)** Methods to build models from incomplete, inaccurate, and unreliable data; (2) (Breakthrough**)** Methods to build models from inconsistent data coming from disparate sources; (3) (Breakthrough**)** Methods to model unstable systems; (4) (Breakthrough**)** Methods to model large-scale, distributed systems where loose coupling occurs; (5) (Breakthrough**)** Models that can integrate qualitative and contextual knowledge (e.g., culture, ethics, law, psychology, social networks, and politics) and be responsive to changes these qualitative and contextual factors; (6) (Sustainability**)** Methods to model the dynamics between micro-changes (at the patient and provider level) and macro-changes (at the population, market and policy levels); (7) (Capacity building**)** Models that incorporate errors and interaction of events.

System Modification

The agenda items concerning system modification are divided into three subtopics: research-practice integration, top-down decomposition, and bottom-up integration.

Research-practice integration

(1) (Sustainability**)** Iterative knowledge development and transfer between research and practice; (2) (Sustainability**)** Improving translation from mathematical and technical languages into lay person terminology; (3) (Capacity building**)** Improving lay people's understanding of analytical results by developing enhanced data visualization techniques.

Top-down decomposition

(1) (Breakthrough**)** Determining ways to modify public and private incentives to influence patients to stay healthy, providers to work in the best interest of their patients, and organizations to be efficient, without unintended negative consequences; (2) (Breakthrough**)** Exploring payment structures that accommodate technologically mediated interactions between providers

and patients (e.g., text messaging, email, visits by teleconference, etc.); (3) (Sustainability**)** Testing of change and implementation theories, and exploration of the tension between pushing for the application of existing knowledge and trying to develop more usable new knowledge; (4) (Capacity building**)** Determining the benefits, limitations, and appropriate use of national, regional, and institutional forcing functions within the health care setting.

Bottom-up integration

(1) (Breakthrough**)** Determining appropriate approaches to stimulating system-wide change, exploring ways to coordinate between bottom-up integration and top-down decomposition; (2) (Sustainability**)** Exploring how social network theories can be used to trigger and facilitate culture change; (3) (Capacity building**)** Determining the role of culture as a necessary element of health care improvement, including the national political conversation and at the level of the patient and provider.

Knowledge Transfer

It is timely to accelerate knowledge transfer of ISyE methods to solve currently recognized health care challenges. Two areas of research for knowledge transfer were identified:(1) (Capacity building**)** Identification of best practices for dissemination and adoption of ISyE knowledge; (2) (Capacity building**)** Identification of best practices for spreading new ISyE knowledge between research and industry and within industry.

Meta-Knowledge Integration

There is a need to integrate over-arching meta-knowledge lessons gleaned from purposefully-targeted research projects. Five areas of research for the development of meta-knowledge were identified:(1) (Sustainability**)** Characterizing health care challenges; (2) (Capacity building**)** Mapping the usefulness of ISyE knowledge to different health care contexts; (3) **(**Breakthrough**)** Exploiting synergies within ISyE knowledge derived from different subdisciplines; (4) (Sustainability**)** Identification of best practices for use of ISyE knowledge; (5) (Capacity building**)** Characterizing research frontiers and directions at the intersection of ISyE and health care.

Action Agenda

Action items in five domains were identified to push the research agenda forward and ensure a timely realization of the vision of an ideal health care delivery system. These domains include collaboration, education and training, funding, dissemination, and administration.

Collaboration

1) Creating consortia of all stakeholders including government, providers, payers, consumers, the insurance industry, and vendors; (2) Promoting multi-stakeholder conversations through interdisciplinary projects; (3) Fostering partnerships among and between agencies, organizations, associations, academia, and industry; (4) Identifying or forming a professional home at the intersection of ISyE and health care.

Education and Training

(1) Creating and enhancing interdisciplinary higher education programs; (2) Expanding professional development and cross-training; (3) Initiating early and mid-career fellowships in health care for ISyE professionals; (4) Compiling a library of case studies.

Funding

(1) Investing in high potential research focusing on the knowledge innovation directions presented in the research agenda; (2) Supporting community-based, low-tech, low cost research; (3) Providing capacity building start-up funding for organizations; (4) Creating centers of excellence; (5) Requiring multidisciplinary grantee teams.

Dissemination

(1) Facilitating publication; (2) Fostering networking; (3) Launching and supporting demonstration projects within real health care organizations.

Administration

(1) Joint solicitations and collaborative funding to drive the research agenda proposed in this report; (2) Accelerating the proposal cycle for grants relevant to the research agenda in this report.

Chapter 1: Introduction

The idea that the United States' health care delivery system must be changed has reached a tipping point. Daily, we are bombarded with health care news at the levels of government, organizations, and individuals. We read about Federal and State efforts to introduce comprehensive health care reform. We listen to local organizations discuss the steps they are taking to try to improve the quality of care while reducing costs. We watch reports about individuals who have poor or no access to health care services. The momentum for change is clearly present.

For over a decade there has been wide-spread recognition of the potential value of applying engineering knowledge to improving health care. Numerous reports document deliberations from consensus conferences and evidence-based practice workshops focused on this topic. However, there has been little uptake of the innovations and improvement strategies advocated in these reports. A specific and actionable research agenda on how to achieve change using engineering knowledge is needed by current and potential funding organizations concerned with improving the health of the country. While many engineering disciplines could contribute to the improvement of the health care delivery system, it is the intent of this project to provide research innovation guidance related to the application of industrial and systems engineering (ISyE) solutions to realizing the vision of an ideal health care delivery system.

The field of industrial and systems engineering (ISyE) has a long history of improving the structure, processes, and outcomes of complex systems in many industries. ISyE leverages information, information technology, information systems and human resources to enable system wide improvement. Although ISyE was originally focused on manufacturing environments, over time, the purview of industrial and systems engineers has expanded to include numerous services (e.g., transportation, hospitality, energy, and finance). Over the last several decades, there has been particular interest in applying the tools and techniques of ISyE to improve the health care delivery system. Organizations such as the Institute of Medicine and the National Academy of Engineering have recently made explicit calls for increased application of ISyE tools to improve the health care delivery system.[8]

A particular challenge of such an endeavor lies in the complexity of the health care delivery system. This complexity is evidenced in multiple ways.

1. Multiple stakeholders, including providers, insurers, payers, regulators, funding authorities, vendors, and consumers each have their own set of objectives, some of which overlap and others of which are in conflict.
2. The health care delivery system is a multi-level system requiring numerous levels of analysis such as those outlined in *Building a Better Delivery System*[8]:
    a. The individual patient;
    b. The care team, which includes professional care providers (e.g., clinicians, pharmacists, and others), the patient, and family members;
    c. The organization (e.g., hospital, clinic, nursing home, etc.) that supports the development and work of care teams by providing infrastructure and complementary resources;

   d. The political and economic environment (e.g., regulatory, financial, payment regimes, and markets), the conditions under which organizations, care teams, individual patients, and individual care providers operate.
3. Each level consists of multiple interacting components (e.g., multiple clinicians within a clinic, multiple clinics within a hospital).
4. The components across and within levels may have very loose organizational ties.
5. The boundaries between components and levels are dynamic and uncertain.
6. The components are not contained within a hierarchical and circumscribed system.

Current approaches to applying ISyE knowledge in health care have been limited to isolated efforts directed towards improving subsystems of the health care delivery system such as a practice, a unit, a clinic, or at the most macro-level, an institution. In addition to focusing on subsystems instead of the system as a whole, such efforts have emphasized incremental as opposed to breakthrough change. The rationale for this focus on incremental change at the subsystem level is two-fold. First, ISyE knowledge was originally developed for use within a clearly bounded system that has a hierarchical structure. Second, the culture and incentive structure of the health care delivery system emphasizes improvement from a provider or organizational perspective (within components) instead of from a patient or societal perspective (across components). Such isolated efforts to incrementally improve subsystems separately, however, have not, and are unlikely to, scale to breakthrough improvement at the level of the entire health care delivery system. Thus, although current knowledge has been essential in bringing about incremental change at the subsystem level, extending the range of application of knowledge will not scale to enable breakthrough change at the system-wide level.

Mindful of potential synergies, the Agency for Healthcare Research and Quality (AHRQ) and the National Science Foundation (NSF) partnered on a project designed to accomplish three objectives:

1. ***Articulate a vision for an ideal health care delivery system;***
2. ***Determine why current efforts to apply ISyE knowledge to health care have not resulted in meaningful change; and***
3. ***Propose a research and action agenda that should be pursued to enable the field of ISyE to substantially contribute to the realization of an ideal health care delivery system.***

At the core of this project is the realization that straightforward application of existing ISyE techniques is insufficient to realize the vision of an ideal health care delivery system. What is needed is a paradigm shift targeted toward determining how to best stimulate breakthrough change and system-wide improvement through innovations in ISyE knowledge, and the ways these can be applied to health care. Special attention was given to developments in health IT necessary to facilitate the ISyE advances. The study focus areas recommended in the research agenda and the initiatives and programs recommended in the action agenda aim to support the realization of the proposed vision for the ideal health care delivery system. Realizing that such a change may also realistically require complementary efforts, however, the research and action agendas also support the development of initiatives to promote knowledge transfer and the integration of ISyE meta-knowledge that will be necessary to sustain the quality of the health care delivery system and to the build capacity ISyE knowledge applicable to health care.

Within the larger ISyE community the terms “model,” “optimize,” and “improvement” are sometimes ambiguous. For example the term “model” may be used to mean a conceptual framework such as Donabedian’s structure-process-outcome framework or to mean an operations research tool such as a simulation or an influence diagram. The term “optimal” is similarly used in multiple ways within the field of ISyE and may refer to a theoretical construct such as the idea that a system functions best when the social and technical subsystems are jointly optimized or to a mathematical construct in which the relevant maximum or minimum is sought. Finally, the term “improvement” is used at different levels of magnitude to mean quality improvement or continuous improvement that occurs in small steps or large-scale initiatives that result in sweeping change. In this report the terms “model” and “optimize” carry, as appropriate, each of these meanings and should be interpreted in context. The term “breakthough improvement” is used to mean the entire process of analysis, design, implementation, and evaluation required to achieve a result fundamentally better than the current state and the term “incremental improvement” is used to mean the entire process of analysis, design, implementation, and evaluation required to achieve a result that is marginally better than the current state.

As detailed in Chapter 2, this project was comprised of three elements:(1) a background report,(2) a workshop, and(3) a final report. Each element of the project was informed by the preceding elements (e.g., the final report was informed by the background report and the workshop). This final report attempts to accurately reflect the deliberations of the workshop participants while simultaneously staying faithful to the knowledge gleaned during the writing of the background report. The outcome of this project will be widely disseminated to both ISyE and health care audiences at meetings of professional organizations. It will also be more widely disseminated to these and other relevant audiences through the project website and social networks.

Chapter 2: Methodology

The objectives of this project were realized by conducting a review of the salient literature and by engaging experts in the fields of ISyE and health care in a critical discussion. A background report containing a summary and critical review of 13 seminal reports and workshops related to the subject matter of this project was produced and disseminated among identified experts in the two fields. During a 2-day workshop held on September 21-22, 2009, in Washington, DC, these experts engaged in intense reflection and discussion about(1) a vision of an ideal health care delivery system,(2) why change using current ISyE methods remains intractable, and (3) the research and action agenda needed to enable ISyE to meaningfully contribute to the realization of an ideal health care delivery system. Upon conclusion of the workshop, participants were asked to provide feedback to help set priorities for the research and action agenda.

Background Report

A background report analyzing selected materials[1-13] appraising the status of health care delivery and opportunities for improvement generated by the National Academy of Science was generated in preparation of the workshop. The purpose of the background report was to provide workshop participants with an overview of the current discourse related to this subject and to stimulate discussion among them during the workshop. As such, the background report contained both a presentation and critique of the progress that has been made to date in achieving the three objectives of this project. The literature included in this report was not intended to be exhaustive; rather, literature was chosen that had made significant contributions to discourse located at the intersection of ISyE and health care and that contained material likely to stimulate discussion among workshop participants.

Three major conclusions emerged from the review of these materials. The first conclusion was that current visions of the health care delivery system suffer from a lack of prescription regarding how the ideal system should respond to the expanding needs for health care in contemporary society. The conclusion was that both the tools of ISyE and the culture of health care are focused on improving the current system through subsystem improvement and not necessarily through fundamental change to the entire system. The third conclusion was that although preliminary steps have been taken toward detailing new ISyE methods that could stimulate real change, the proposed methods remain grounded in today's health care delivery system. A copy of the background report, with pointers to the source reports employed in its development, may be found in Appendix A.

Analysis of background materials led to the formulation of purpose statements for the workshop, guided participant invitations, and helped shape the activities undertaken as part of the workshop and afterwards. The background report and source materials were circulated to all workshop participants and a 2-day workshop was held to further:

1. Explicate a vision of an ideal health care delivery system,
2. Explore why change in the health care delivery system using current ISyE methods remains unachievable and intractable, and
3. Establish the research and action agenda needed to enable ISyE to meaningfully contribute to the realization of an ideal health care delivery system.

Workshop

Workshop Scope

The purpose of the 2-day workshop was to engage a group of experts in the fields of ISyE and health care in addressing the three objectives of this project. Care was taken to ensure that workshop participants included individuals from both academia and industry and individuals at varying stages of the career trajectory. A mix of individuals possessing skills in industrial and systems engineering and/or deep knowledge of the processes and systems of health care was sought. Furthermore, a strong emphasis was placed on inviting individuals who were both embedded in and new to the discourse of improving the health care delivery system. See Appendix B for a full list of workshop participants.

Workshop Format

The goal of the workshop was accomplished through a combination of formal presentations and both large and small group discussions. During a total of nine presentations, the workshop chair, Dr. Patricia Flatley Brennan, and eight invited speakers proposed a vision for an ideal health care delivery system. The two keynote speakers, Dr. Maulik Joshi (President, Health Research & Educational Trust and Senior Vice President of Research, American Hospital Association) and Mr. Aneesh Chopra (United States Chief Technology Officer) provided broad visions for the ideal health care delivery system of the future. The remaining six speakers provided visions that were grounded in their area of industrial and systems engineering expertise as shown below:

1. *Finance and quantitative decisionmaking*
   Brian Denton, PhD
   Assistant Professor, Edward P. Fitts Department of Industrial and Systems Engineering
   North Carolina State University

2. *Information technology*
   James M. Walker, PhD, FACP
   Chief Health Information Officer
   Geisinger Health System

3. *Systems analysis, change, and implementation theory*
   José L. Zayas-Castro, PhD
   Professor and Chair, Department of Industrial and Management Systems Engineering
   University of South Florida

4. *Materials management and production processes*
   Eugene Schneller, PhD
   Professor, School of Health Management & Policy, W. P. Carey School of Business
   Arizona State University

5. *Human factors and sociotechnical systems*
   Stephanie Guerlain, PhD
   Associate Professor, Department of Systems & Information Engineering
   University of Virginia

6. *Quality engineering*
   James Benneyan, PhD
   Associate Professor, Mechanical, Industrial, and Manufacturing Engineering Department
   Northeastern University
   Executive Director, New England VA Healthcare Engineering Partnership

These six speakers also provided insight into why current efforts to improve the health care delivery system using ISyE knowledge have failed to result in significant change.

Large group discussions were primarily used for two purposes: (1) to reflect, as a group, on the information presented by a speaker, and (2) to report out conclusions reached during the small group discussions. Both forms of large group discussion allowed workshop participants to question, clarify, or add to the material presented and to remain engaged in the entire scope of the workshop discussion. The large group discussions were also instrumental in identifying points of consensus and tension between workshop participants.

Small group discussions were used to probe deeply into how specific ISyE specialties could address health care challenges. The field of ISyE is broad in scope; in this report we use the term ISyE liberally to include diverse subdisciplines that may be rooted in applied mathematics, computer science, and psychology. Five ISyE groups and six health care area groups were constructed as shown below.

Each participant was assigned to one ISyE group and one cross-cutting health care challenge area group.

<u>ISyE groups</u>

1. Information technology, finance, and quantitative decisionmaking[1]
2. Systems change, analysis, and implementation theory
3. Materials management and production processes
4. Human factors and sociotechnical systems
5. Quality engineering

[1] The information technology, finance and quantitative decisionmaking groups were originally conceptualized as two separate groups; however because some participants' schedules required late arrival, these groups were combined into one to ensure a lively and productive discussion.

Health care challenge area groups

1. Managing acute illness and disease
2. Creating effective models of health promotion and disease prevention
3. Insuring chronic disease management
4. Enhancing end-of-life experience
5. Facilitating public health
6. Accelerating discovery

During the ISyE small group discussions, participants were asked to consider how the specialty could contribute to the realization of an ideal health care delivery system. Participants were also asked to further discuss challenges to achieving the ideal health care delivery system and ways in which these challenges could be surmounted. Although asked to spend a little time determining what knowledge is currently available to address these challenges, participants were primarily tasked with identifying new ISyE knowledge that must be gained through new research directions within the specialty in order to stimulate breakthrough change at the system level, not incremental change only at the subsystem level. Participants were also asked to determine what programs and initiatives must be put in place for such research to be conducted, disseminated, and sustained.

During the health care challenge area discussions, small group participants were tasked with identifying the difficulties presented by the specific health care challenge areas to stimulate the conceptualization of new ISyE knowledge that should be created in order to address these challenges. Participants were assigned to work with a different set of individuals than those with whom they were matched for the ISyE themed groups to further stimulate innovative ideas.

Multiple methods were used to ensure that both small and large group interactions were productive and captured for later use. All large group discussions were captured using a recording device and by a professional note taker. All small group discussions were professionally facilitated and captured by a professional note taker. Upon completion of the workshop, the lead note taker created a summary of the entire workshop based upon the notes generated from both the large and small group discussions. A copy of the workshop schedule, ISyE small group assignments, and health care challenge area small group assignments are in Appendixes C, D, and E, respectively.

Synthesis

The authors listed on this report created a first draft by synthesizing the background report, the workshop discussions, and the workshop participant feedback. This report was then circulated to all workshop participants and outside reviewers (experts in the fields of ISyE and health care who were not present at the workshop). Based upon the comments received, the final report was revised and submitted to AHRQ and NSF for review and publication.

Chapter 3: Vision of an Ideal Health Care Delivery System

This section synthesizes the vision of the ideal health care delivery system of the future. Some of the points come directly from specific speakers, and those are noted in parentheses. Other ideas that are not attributed to particular individuals were mentioned by participants or came up in the discussions.

A New System

The workshop chair, all six session chairs, and the two keynote speakers articulated the characteristics of the ideal health care delivery system of the future in their vision statements, without drawing the details of its structure. The new system is not merely an extension of the existing system but is fundamentally different.

1. The ideal health care delivery system is an **integrated system** that has improved linkages across multiple access points (Zayas-Castro, Brennan), unlike the current fragmented health care "system."

2. The health care of the future is delivered to a global, multi-cultural, growing, and aging population, and the ideal delivery system needs to be **designed** accordingly, not improved incrementally from the current one (Brennan).

3. It is **ubiquitous, distributed, responsive, expansive, flexible, resilient,** and it incorporates systems engineering concepts (Joshi).

A Patient-Centered System

At the center of the system are the patient and their family (Joshi).

1. Care is **personalized** for them, with consistency throughout the lifespan, and memory of their preferences and particularities.

2. **Information** about their health is secure, digitized, and readily available online at their fingertips for their review and annotation (Chopra). All information, including self-reported observations, sensor data, and provider diagnoses and prescriptions is integrated in separate but interlinked layers.

3. Technologies and policies are in place to ensure their **privacy** is never compromised (Chopra), and configuration options give them the flexibility to personalize how much of what they share with whom and until when, should they choose to (Joshi).

4. Decisions about their health are made collaboratively with their interdisciplinary care team of which they are core. When they need to make a decision, their care team ensures they have the guidance and autonomy they need to make **informed choices**.

5. **Consumer health IT** gives them the data they need when they need it; with the visualization options they prefer (Joshi, Chopra, Guerlain).

6. Their health care is not limited to a few episodes of acute care (Joshi), and emphasizes **prevention** and continuity of care, with a focus on chronic care management. Care is integrated beyond institutional silos and into the community (Brennan).

7. Handoffs and **transitions** of care are understood to be error-prone areas and procedures are in place to prevent or mitigate problems (Joshi).

8. Care teams manage conditions together (e.g., heart disease, depression, diabetes) rather than in silos (Walker). Patients have **open access** to care (Joshi). Resources are wrapped around them when they need them, and retracted seamlessly when they are ready to move on with their life.

9. **Transparency** in the system enhances quality and patient safety, and where appropriate, mandatory public reporting gives patients the power to choose their provider and treatment (Brennan, Joshi)

An Engineered System

Despite the demanding and unpredictable nature of providing personalized care to a large number of patients throughout their life, the delivery system runs smoothly and efficiently.

1. Industrial and systems engineering tools that have produced cost savings, increased responsiveness, and improved quality in other industries (Denton, Benneyan) are leveraged by **all stakeholders** through both bottom-up and top-down approaches (Zayas-Castro). In addition to driving subsystem improvements, ISyE helps guide system-wide policies (Denton).

2. The conflicting objectives of the different players (Zayas-Castro) are coordinated to deliver **quality care** efficiently and **safely** to everyone. The system provides **incentives** to clinicians to keep their patients healthy, to patients to stay healthy, and to providers to be efficient (Denton).

3. Care for common conditions is streamlined with high quality **information technology**, and care for uncommon conditions is supported by state-of-the-art communication technologies (Walker).

4. There is a national concept of **standard care processes** identified with expert-informed evidence-based analytics (Walker, Benneyan) and mathematical modeling (Denton). Best practices are the default practice (Joshi).

5. The system is **information-optimized**. Process outcomes are routinely fed back into the processes for continuous improvement. All parts of the system share generalizable knowledge to learn from each other rather that separately invent the wheel (Walker).

6. The costs of biomedical **knowledge discovery** are reduced by the use of simulation and modeling-assisted randomized controlled trials where operations research techniques are used to narrow the field down to a few good solutions worth trying (Denton).

7. Engineers and clinicians work hand in hand to continuously improve the system (Walker), and all stakeholders are involved in the conversation, including clinicians (Zayas-Castro) and patients. Quality improvement is concentrated on the **quality planning** phase of the Juran trilogy (Benneyan) to maintain high system reliability (Joshi).

8. The health care delivery system treats materials as assets, as they are in other industries, and makes effective use of materials through **dynamic supply chains** and product identification standards (Schneller).

Chapter 4: Barriers and Facilitators to Achieving Breakthrough Change with ISyE Knowledge

This section presents nine barriers that were identified as having prevented current efforts at using ISyE knowledge from resulting in an ideal health care delivery system. As a complement, this section also presents four facilitators that articulate why now is the right time to address these barriers. These facilitators are likely to accelerate the ability of the field of ISyE to make meaningful contributions to the realization of an ideal health care delivery system in the future.

Barriers

Over the course of this project, nine primary barriers were identified as to why current efforts at using ISyE knowledge in health care have not resulted in breakthrough change. Potential means of addressing the barriers outlined below are integrated into the research and action agendas.

1. Lack of wide-spread use of ISyE tools

Perhaps the most common rationale provided for the failure of ISyE knowledge to create breakthrough change to the health care delivery system is that the tools, techniques, and methods of ISyE simply have not been used in a pervasive manner. Lack of resources, awareness, and motivation are all cited as reasons for which current ISyE tools are not prevalent in health care. Multiple publications included in the background report maintain that current ISyE tools have the power to accomplish fundamental change in health care and that dissemination of current knowledge is the key to achieving better results. Workshop participants agreed that lack of use of current ISyE knowledge is one reason why breakthrough change has not been achieved, but cautioned against claiming it was the primary reason.

2. Inadequate ISyE knowledge

ISyE knowledge targets knowable, well-circumscribed elements of a system. Given that ISyE knowledge has traditionally been used primarily in manufacturing settings, ISyE tools, techniques, and methods were often developed for improvement of a small-scale, strictly bounded system such as a production line or a manufacturing company, within which the goal is clearly defined. ISyE knowledge was not purposefully developed for large-scale systems such as a nation's health care delivery system where the boundaries are fuzzy and the goals are constantly in flux.

Consequently, there is a mismatch between the scale for which ISyE knowledge was developed and the scale for which ISyE knowledge is needed to realize a vision of an ideal health care delivery system. If current ISyE knowledge is used at the level for which it was designed, it may result in improvement of subsystems of the health care delivery system (at the level of a physician's practice, a clinic, or perhaps even an organization). This level of improvement is necessary but not sufficient. Furthermore it is unreasonable to conclude that improvement of subcomponents of the system will translate to overall, integrated improvement of the entire system. This is particularly true given that the field of ISyE lacks a sophisticated system of models in which models at the subsystem level integrate with models at a system-wide level.

In addition, much current ISyE knowledge is unlikely to scale to use in a larger system. For example, tools often used for quality improvement at a subsystem level such as rapid cycle testing or value stream mapping are likely to be difficult to apply at the system level of a national health care delivery system. Similarly, current mathematical modeling techniques that rely heavily on robust data and are based on optimizing from a single stakeholder perspective are unlikely to be as useful in a problem space that contains incomplete data from disparate sources and that requires joint optimization of numerous stakeholder perspectives.

Finally, there is a lack of meta-knowledge within ISyE. Specifically there is little understanding of what tools, techniques, and methods are most appropriate for a given problem area and under what circumstances they are most effective. Without such knowledge, ISyE knowledge is likely to be used in a haphazard manner; the choice of tools, techniques, or methods is often informed by the familiarity or preferences of an individual or organization or on the latest trend instead of on evidence of appropriateness and effectiveness.

3. Insufficient health IT infrastructure

The current health IT infrastructure in place to support the effective application of ISyE knowledge within health care is suboptimal. Existing ISyE tools, techniques, and methods rely on the availability of accurate and complete data. At the local level, health IT within health care organizations often does not adequately facilitate output of useable data. There are multiple reasons for this. First, these systems were not created with industrial and systems engineers or other researchers or administrators involved with improving the health care delivery system as the customer of the data generated. Consequently, these IT systems do not always facilitate capture of process data that is salient for ISyE improvement efforts. Second, data from these systems is often provided as a "data dump," with little, if any, meaningful interpretation. At the regional and national level, health IT infrastructure does not facilitate the generation of large, integrated datasets, which are a prerequisite for using ISyE tools on a larger scale.

4. Structural and cultural traditions in the health care delivery system emphasizing only subsystem improvement and short-term outcomes and rewards

At all levels, the structure of the health care delivery system promotes the use of ISyE knowledge that leads to subsystem improvement. Each provider has his/her own panel of patients, each specialty has its own specialized knowledge, and each health care organization has its own market share. There is an incentive to conduct improvement at the level of the subsystem to maintain current competitive advantage. The benefits of coordinated improvement across providers, specialties, and organizations in order to create an ideal health care delivery system are oftentimes less apparent from these perspectives. Existing approaches that reinforce subsystem improvement afford excellent managerial control. However, attending to either patient-specific or aggregate social perspectives requires moving beyond subsystem improvement toward ISyE approaches that guide improved overall system performance.

5. Insufficient pathways which promote use of ISyE knowledge in health care

Organizations such as the Institute for Healthcare Improvement (IHI) and the Leapfrog Group have strongly supported the use of current ISyE knowledge to improve subsystems within the health care delivery system. Their efforts have been instrumental in spreading awareness of current ISyE knowledge; however, they have primarily promoted the use of such knowledge at the level of a practice, clinic, or health care organization. These organizations, which serve as a bridge between ISyE and health care, have assumed that the overall health care delivery system will remain fairly constant and that it is the prerogative of each organization to improve locally. Little attention has been focused on promoting the development of new ISyE knowledge that may be used to improve the health care delivery system as a whole.

6. Lack of efficient ways to spread knowledge between ISyE professionals working in health care

The community of ISyE professionals working in health care is fragmented, precluding effective and efficient diffusion of best practices within the community. A growing number of professional organizations within the field of ISyE – for example the Institute for Operations Research and the Management Sciences (INFORMS), the Human Factors and Ergonomics Society (HFES), and the Institute of Industrial Engineers (IIE) – have created a health section. Additionally, organizations such as the American Medical Informatics Association (AMIA) and the Health Information and Management Systems Society (HIMSS) serve as professional homes for ISyE professionals working at the intersection of IT and health care. As a result ISyE professionals often only maintain a cursory awareness and understanding of the new ISyE knowledge that has been generated and presented to another institution, for example at an annual conference of one society.

7. No clear funding structures to support development of new ISyE knowledge

Research conducted at the intersection of ISyE and health care does not have a funding home. Traditionally, basic engineering research is funded through the National Science Foundation and health services research is funded through the Agency for Healthcare Research and Quality and private foundations such as the Robert Wood Johnson Foundation and the California Healthcare Foundation. This can cause funding sources to determine that a proposed project is within the purview of another organization and can cause researchers to remain uncertain about what funding source to pursue. Thus, research at the intersection of ISyE and health care can be left unfunded because it does not appear to align directly with the priorities of any one particular funder, not because of lack of meritorious ideas and proposals.

8. Current policies constraining level of change possible

Existing policies do not always facilitate realization of an ideal health care delivery system. For example, the realization of a responsive health care delivery system is difficult because of policies that preclude the development of efficient supply chains in areas such as pharmaceuticals. Similarly, development of a completely patient-centered health care delivery system would likely require a realignment of incentives but, unfortunately, such change is slow to come by and unlikely to occur within the next 5 to 7 years. Furthermore, although adoption of health IT is often envisioned as facilitating the development of an ideal health care delivery system, current policies pushing the rapid uptake of meaningful use could result in undesirable unintended consequences. For example, pressure for rapid adoption may inhibit or prohibit the use of appropriate design and implementation strategies, resulting in suboptimal technologies and poor integration into practice. Furthermore, the high cost of health IT systems is likely to prevent institutions from continually investing in new systems, potentially resulting in stagnation of health IT innovation.

9. Lack of professionals with an adequate understanding of both ISyE and health care

This barrier is evidenced in two ways: (1) the lack of health care personnel with sufficient understanding of how to use ISyE solutions, and (2) the lack of ISyE professionals with a good working knowledge of health care. Without an adequate number of professionals with an understanding of both domains, the challenge of achieving an ideal health care delivery system will be insurmountable. Both current and future ISyE tools that can facilitate the realization of an ideal health care delivery system will remain within the domain of only the largest health care organizations. This may result in the improvement of a health care organization, but will impede the realization of a national ideal health care delivery system.

There was a disagreement among workshop participants about whether the low levels of ISyE penetration in health care are due to a low supply of qualified professionals, or if the market demand for them is still too low. Some believe that demand will follow the supply as an increasing number of ISyE professionals in health care demonstrate the benefits of ISyE. Others reminded the group that there has been a growing supply of ISyEs trained to work in health care over the last three decades and that demand has not kept pace.

Table 1 presents a mapping between the barriers identified and the recommendations proposed in this report.

Table 1. Mapping between barriers identified and recommendations proposed

Theme	Barrier	Recommendation Reference
Adoption	Lack of widespread use of ISyE tools	Knowledge Transfer Research Agenda and Education and Training and Dissemination Action Agenda
Knowledge quality	Inadequate current ISyE knowledge	Knowledge Innovation and Meta-Knowledge Integration Research Agenda
IT infrastructure	Insufficient health IT infrastructure	Collaboration and Dissemination Action Agenda
Units of analysis	Structural and cultural traditions in the health care delivery system emphasizing only subsystem improvement and short-term outcomes and rewards	Knowledge Innovation Research Agenda
Private and non-governmental organizational support structures	Insufficient pathways which promote use of ISyE knowledge in health care	Collaboration Action Agenda

Table 1. Mapping between barriers identified and recommendations proposed (continued)

Theme	Barrier	Recommendation Reference
Fragmentation of ISyE and health care communities	Lack of efficient ways to spread knowledge between ISyE professionals working in health care	Collaboration Action Agenda
Government structures	No clear government structures to support development of new ISyE knowledge	Collaboration, Funding, and Administration Action Agenda
Policy constraints	Current policies constraining level of change possible	N/A
Multidisciplinary knowledge	Lack of professionals with an adequate understanding of both ISyE and health care	Education and Training Action Agenda

Facilitators

In contrast to the barriers above, four facilitators likely to promote the use of new ISyE knowledge in realizing the vision of an ideal health care delivery system were identified. A characterization of each facilitator is provided below.

1. Increasing recognition of the potential of ISyE to improve health care

Multiple stakeholders have acknowledged that ISyE knowledge has the potential to make meaningful contributions to realizing the vision of an ideal health care delivery system. This opinion was pervasive throughout the publications reviewed in preparation of the background report and was shared by both ISyE and non-ISyE professionals (e.g., social scientists, clinicians, or administrators) at the workshop. Additionally, the presence of multiple individuals from both AHRQ and NSF at the workshop suggests an acknowledgement of the need to invest in development of ISyE tools, techniques, and methods that can be used to achieve the vision of the ideal health care delivery system. An increasing number of health care institutions advertising ISyE positions and an increasing number of academic programs at the intersection of these two fields provide further evidence of this increased recognition.

2. Progress in both recognition of the need for and the development of new ISyE tools

Both a review of the literature and, to a larger extent, the workshop discussions provided evidence that there has been progress in both recognizing the need for and the development of new ISyE tools to confront the challenges of health care. One publication reviewed in the background report – *Building a Better Delivery System* – recognized the need for new ISyE knowledge to realize a vision of an ideal health care delivery system[8] and suggested a handful of avenues of further research. Workshop participants suggested many more avenues of new ISyE research to facilitate health care transformation. The research agenda presented below reports on avenues of inquiry suggested in previous reports and those generated by workshop participants.

Some progress has been made in developing new ISyE tools, techniques, and methods that may prove useful in creating breakthrough change. For example, new methods of modeling have been developed that account for multiple conflicting objectives and uncertainties. Game theory-based models have also been developed which can account for multiple players whose decisions are contingent upon the actions of others. The creation of this new ISyE knowledge serves as a foundation upon which additional ISyE knowledge may be developed, leading to an increasing sophistication of ISyE solutions for health care.

3. Progress in the use of IT to disseminate ISyE knowledge

Both the Internet and organizational intranets are being used to disseminate ISyE knowledge, increasing awareness of these tools, techniques, and methods within the health care community. Websites of organizations such as IHI and AHRQ now contain ISyE resources that health care professionals may use to facilitate improvement. Intranets of health care organizations have also begun including such tools for use by employees. Such IT infrastructure will be beneficial in spreading new ISyE knowledge that is gained through execution of the proposed research agenda.

4. Current political climate of health care reform

The current political climate has drawn health care reform to a prominent position on the national stage. The emerging political will may lead to strategies that better address some of the barriers identified above. For example, existing policies which impede realization of an ideal health care delivery system may be revisited and new initiatives such as the promotion of a patient-centered health care delivery system or the enhanced development, deployment and acceptance of professionals in science, technology, engineering and math (STEM) may bolster the long-term supply of individuals with an interest in and understanding of both ISyE and health care.

Chapter 5: ISyE and Health Care Research Agenda

This section presents a research agenda that will facilitate realization of the vision of an ideal health care delivery system through the transfer and development of existing and new ISyE knowledge. A discussion of the purpose and scope of the research agenda and the challenges of creating the research agenda is also contained within this section.

Purpose and Scope of the Research Agenda

The primary purpose of the research agenda is to provide guidance related to the type of research that should be prioritized at the intersection of ISyE and health care to realize the vision of an ideal health care delivery system. Completion of this research agenda should lead to improvement in the health of society by improving the performance of the health care sector. Furthermore, completion of this research agenda should lead to creation of new ISyE knowledge that may be used to improve not only the health care industry, but also other manufacturing and service industries. Finally, it is intended that completion of this research agenda will lead to clearer understanding of the health IT resources required to achieve the vision of an ideal health care delivery system.

The scope of this research agenda may be characterized in terms of timeframe and content. This research agenda is intended to be completed in the next 5 to 7 years to yield change in the next 10 to 15 years. At the start of the project, the research agenda was envisioned as only containing content related to the creation of new ISyE knowledge. This initial scope followed from an assumption that current ISyE knowledge, even if adopted across the health care industry, would not lead to breakthrough change. However, during the workshop, it became evident that many participants strongly felt that content related to knowledge transfer should also be contained within the research agenda. These participants opined that current ISyE knowledge has the potential of producing meaningful change when used pervasively and in conjunction with new knowledge. Consequently, the research agenda presented here is intended to provide guidance on the types of investigation required to (1) discover and develop new ISyE knowledge particularly germane to achieving the vision of an ideal health care delivery system, (2) achieve effective knowledge transfer of existing ISyE knowledge within health care, and (3) integrate meta-knowledge about the use of current and new ISyE knowledge.

The original intent was to present the content of the research agenda related to new ISyE knowledge as a grid, with the five ISyE disciplines and the six health care challenge areas used as the basis for the small group discussions as the axes. However, by the end of the workshop, it was clear that such a model would be inappropriate given that the problems identified are relevant across the health care challenge areas and that the contributions of multiple perspectives will be required to develop the necessary ISyE knowledge. Furthermore, it was determined that any attempt to divide the research agenda using this framework was contradictory to the multidisciplinary approach envisioned by workshop participants. As a result, the research agenda for the development of new ISyE knowledge is structured around the monitoring, modeling, and modification of the health care delivery system.

Challenges Encountered in Developing a Research Agenda Focused on New ISyE Methods

Two primary challenges were encountered during the process of articulating the research agenda focused on new ISyE methods. These challenges are identified and characterized below.

1. Lack of clarity about the scope of ISyE

Perhaps the most significant challenge encountered was defining the boundaries of the ISyE discipline. By its very nature, ISyE is multidisciplinary, drawing on traditions as diverse as psychology and organizational behavior (human factors) and mathematics and computer science (operations research). As the application areas of ISyE have expanded, so too have the traditions on which ISyE knowledge and solutions have been based.

During the workshop, the content proposed for the ISyE research agenda often overlapped with content that would be more appropriate for a public policy, business, law, medicine, computer science, psychology research, public health or urban planning research agenda. For example, participants offered research agenda content related to:

a. Creating incentive structures and tax policies (overlap with public policy and business),
b. Implementing an oversight committee analogous to the Institutional Review Board to mitigate unintended consequences of health IT implementation (overlap with law),
c. Prioritizing clinical information for both providers and patients (overlap with medicine),
d. Improving of IT interoperability (overlap with computer science),
e. Increasing patient motivation for behavioral change (overlap with psychology),
f. Designing better nutrition and screening programs (overlap with public health), and
g. Determining appropriate location of clinics, bike paths, community gardens (overlap with urban planning).

Although it was determined that the discipline of ISyE could make research contributions to the issues noted above, content that was determined to be more strongly within the purview of another discipline was excluded from the research agenda.

2. Belief in the adequacy of current ISyE knowledge leading to difficulty thinking “out of the box”

The initial intent of this project was to set the stage for the realization of an ideal health care delivery system either through creation of new ISyE knowledge. This intent was accompanied by the understanding that current ISyE knowledge suffers from limitations that prevent its application from resulting in breakthrough change. The reasons why current ISyE knowledge is limited were detailed in the background report that was disseminated to all workshop participants and was emphasized by the workshop chair, Dr. Patricia Brennan, throughout the 2-day event.

However, despite this attempt to push thinking forward and focus on expanding ISyE knowledge, many participants remained focused on the perceived value of current ISyE knowledge, particularly ISyE knowledge related to their specific research or industrial interests.

Although new research directions were generated, significant portions of the discussion focused on issues of knowledge transfer and bridging the gap between knowledge and action. The reason for this focus is unclear. It may have been that participants did not have an opportunity to read the background report, and, therefore, did not realize the focus of the workshop until later. It may have been that participants wanted to push their own agendas forward. Or it may have been that participants believed in the potential of current ISyE tools to create real change.

Existing ISyE knowledge has seen many successes in manufacturing, aviation, and banking, including improvement of production lines and transportation networks, reduction of waiting times and queue lengths, and achievement of Six Sigma quality in factories. These successes, however, have primarily occurred at the level of a site or organization, not at the level of the entire enterprise or sector. Thus, ISyE knowledge has not succeeded in improving entire industries, as is evidenced by the recent financial crisis and the problems currently faced by airlines and manufacturers.

Rationalization for focusing in the research agenda on transferring existing knowledge stems from a belief among workshop participants that current ISyE knowledge has the power to create breakthrough change and the reasoning that if current methods have not taken hold, the likelihood that new methods will be adopted is low. However, previous discussion in this report demonstrates that even if barriers to adoption were overcome, current ISyE knowledge would result in incremental change at best.

As discussed in the background report and the vision statement, it is unreasonable to expect the current health care delivery system to become an ideal health care delivery system by incremental improvement alone. It is also unreasonable to expect the application of current ISyE knowledge alone to create the needed breakthrough change. In fact, attempts to use ISyE to improve the health care delivery system have been made for the past three decades without significant large-scale impact.

This challenge was tackled by: (1) proposing ways to expand the meaningful adoption of existing and new methods, (2) recognizing that existing methods are insufficient and that even without the barriers to adoption, there is a need for new knowledge to realize an ideal vision of the health care delivery system, (3) determining that meta-knowledge is needed to guide the appropriate and effective use of ISyE tools, techniques, and methods.

Presentation of the Research Agenda

The research agenda is divided along the lines of knowledge innovation, knowledge transfer, and meta-knowledge integration. The knowledge innovation directions are presented under three topic areas: system monitoring, system modeling, and system modification. Whereas research within the domain of knowledge transfer will expedite the use of effective existing ISyE knowledge, research within the domain of knowledge innovation will lead to the creation of new tools, techniques and methods that may be used to improve the health care delivery system. The integration of meta-knowledge is complementary to both these efforts. In this research agenda, greatest emphasis is placed upon knowledge innovation, because it is believed that better long-term value will be gained by investing in innovation rather than by spreading existing knowledge.

To aid agencies and researchers in utilizing the research agenda effectively, an additional categorization of the agenda items is offered:

Breakthrough: These items are essential to realizing the vision of the new health care delivery system
Sustainability: These items are likely to have benefit and improve the health care delivery system, but will not lead to breakthrough changes
Capacity building: These items are necessary to expand the breadth and depth of ISyE knowledge relevant to health care

These categories are conceptualized as complementary, and all likely to be necessary to achieve the vision of an ideal health care delivery system.

Research Agenda: Knowledge Innovation

The majority of the research agenda focused on stimulating ISyE knowledge to address unresolved, unanswered questions posed by the challenges in contemporary health care delivery, as well as anticipated future challenges. New knowledge can result from stimulating innovation in ISyE methods better aligned with the complex, distributed, and stochastic nature of health care. Beyond research that seeks to enhance the use of current ISyE tools, new directions and new knowledge are needed. This section of the research agenda discusses new areas of research at the intersection of ISyE and health care, with a specific focus on how health IT can facilitate the resolution of health care challenges with new ISyE knowledge. The discoveries made through research in these areas of new ISyE knowledge, if successful in health care, are likely to be valuable and applicable to other industries.

The goal of the knowledge innovation directions listed below is to build the ideal health care delivery system described in the vision. Therefore, this section describes the new research directions from a systems perspective, along three lines: system monitoring, system modeling, and system modification. System monitoring research agenda items are required to improve assessment of the system and communication of these assessments to all relevant stakeholders. System modeling research agenda items are required to improve understanding of system components and interactions between system components. Finally, system modification research agenda items are required to ensure efficient and effective system transformation. Since the term "modeling" carries different meanings in different communities and subdisciplines, it should be interpreted in context.

System monitoring

A reoccurring theme throughout the workshop was the absence of clean data for industrial and systems engineers to use. Existing ISyE techniques are data-dependent and current automatic data collection methods in health care are inadequate and lag behind other industries like manufacturing and aviation. They are (1) poorly automated, (2) slow, (3) insensitive to human factors engineering principles, and (4) often deliver non-computable data.

In order to properly leverage existing and future ISyE methods, research is needed to address system-monitoring issues. New methods should have adequate levels of (1) automation, (2) pervasiveness, (3) integration, and (4) usability, and properly address issues of (a) privacy, (b) efficiency, and (c) human factors. Theories and frameworks are needed to characterize and operationalize the tradeoffs between the features listed above. The research agenda should include the development and evaluation of the following.

Data Collection

1. **Consumer-facing health IT solutions that allow patients to self-report their observations, that track and report on trends, and that interact with providers' annotations**
   Motivation: The aviation and banking industries have leveraged IT to push many tasks to the customer, like e-ticketing, boarding pass printing, and online banking. The customer is even a more integral part of the production process in health care, and involving them fosters patient engagement and fits the spirit of patient-centered care, leading to possible benefits like shared decisionmaking and increased adherence.
   Category: *Breakthrough*

2. **Efficient and pervasive methods of data capture**
   Motivation: Much of the ISyE toolkit relies heavily on data and industrial and systems engineers often spend considerable time collecting data (e.g., time studies, run charts, and check sheets) that often could easily be captured by IT systems.
   Category: *Sustainability*

3. **New automatic data collection technologies to capture observations from patients and their environments (e.g., sun exposure and food intake)**
   Motivation: Sensor technologies and others can assist providers in efficiently monitoring changes in patient condition and ensuring patient safety.
   Category: *Sustainability*

4. **Theories and methods beyond natural language processing for the translation of lay person language into structured computable data**
   Motivation: Many data sources in health care are humans, and much of the ISyE techniques rely on computers for large-scale projects. ISyE tools could be more efficiently implemented in the health care setting if those human inputs could be easily made analyzable by computers.
   Category: *Sustainability*

Integration

1. **Technologies which enable data to flow quickly and securely through the whole health care delivery system and be available in real-time when and where needed**
   Motivation: Interoperability is a recognized requirement of ideal health IT, and though it does depend on institutional, State, and Federal regulations, it also presents technical barriers that have yet to be overcome.
   Category: *Breakthrough*

2. **Efficient methods for integrating large amounts of data from disparate sources**
   Motivation: Unless policy changes mandating integration of all health information occur within the time horizon of this research agenda, it can be expected that health care organizations will have to sift through large amounts of data from different health plans and

individuals, with different formats and resolutions. Similar assumptions can be made about individuals and health plans having to deal with information from multiple providers.
Category: *Sustainability*

3. **Adequate integration of data collection into workflows in manners that ensure data validity while minimizing interference with clinical workflows**
   Motivation: Collection of data related to system characteristics is a required means to the end of system improvement. However data collection requiring action on the part of providers may conflict with efficiency and patient safety if it interferes too heavily with clinical workloads and workflows.
   Category: *Sustainability*

4. **Efficient means of integrating information generated from different perspectives (e.g., different providers, patients, and administrators)**
   Motivation: It is important to integrate all perspectives to enable coordination and fully-informed decisions. Beyond interoperability and integration across electronic health records (EHR), there will soon be a need to integrate EHR data with personal health records (PHR) data while keeping them separable, to accommodate integration of patient and provider data. There will also be a need to integrate within EHRs information among providers and with other stakeholders.
   Category: *Sustainability*

Characterization

1. **Methods to operationalize contextual knowledge to understand generalizability of data**
   Motivation: Competition between health care organizations across the country is less relevant than that between manufacturing companies competing for the global market. Therefore, it is conceivable that organizations could make returns on their investments in ISyE by selling their improvement findings and methodologies to non-competing provider organizations in different states. One ingredient to such practice would be the ability to identify generalizable knowledge. This can also provide guidance about the balance between mass customization and standardization based on the context.
   Category: *Breakthrough*

2. **Methods to characterize how the outcomes relate to the processes**
   Motivation: Little is known about the relation between processes and outcomes in health care, and it is not surprising that there is often little relation between cost and quality. ISyE is intuitively well suited to characterize such production functions, but new methods and theories will likely be necessary given the complexity and relative unpredictability of the health care.
   Category: *Sustainability*

3. **Methods to characterize processes, inputs, and outcomes**
   Motivation: A pitfall of computer-based analysis is the reliance on data that is available or can be readily measured, often quantitatively, and made computable. One can see how this

can bias analyses by overlooking less tangible factors. Leveraging analytical methods that require operationalizable data requires the ability to somehow operationalize qualitative data.
Category: *Capacity building*

Presentation

1. **Methods to effectively collect and share data in real-time to foster situational awareness of all individuals involved in patient care**
   Motivation: Problems of coordination and synchronization at points of transition of care from one provider to another constitute patient safety risks, and can lead to redundant or conflicting work (e.g., running an expensive and potentially harmful test that the patient has already had done at another hospital).
   Category: *Breakthrough*

2. **Methods to collect and present information that is valuable to diverse stakeholders such as patients, nurses, primary care and specialty physicians, pharmacists, and social workers**
   Motivation: Current data collection approaches are often single-sided and do not generate information that is usable by all stakeholders without overloading them.
   Category: *Capacity building*

3. **Theories and methods for the translation of numerical, analytical, and computational results into understandable and actionable information that multiple stakeholders (e.g., patients, nurses, primary care and specialty care physicians, or pharmacists) and lay people can seamlessly retrieve to ensure the human monitoring of the system**
   Motivation: Monitoring the system requires the collected data to be accessible and analyzable both by computers and by health care professionals. Those busy humans need timely and concise information to be able to make sure all processes are running as they should, and to handle unanticipated events.
   Category: *Capacity building*

System Modeling

Modeling the health care delivery system could have many aims, including (1) developing a better understanding of the system and the interactions within it, (2) predicting the future behavior of parts of the system or the status of improvement efforts, and (3) recommending actions to be taken by the system. The first three categories below address those aims. The last addresses inconvenient realities that models need to be able to handle.

Descriptive models

1. **Frameworks that explore the integration of many care sources in the production and delivery of care services, and the coordination among these sources (e.g., at end of life care)**
   Motivation: The health care delivery system of the future will cater to increasingly mobile individuals who frequently change employment and residence and seek care in different

states and even globally. Care services are also diversifying and becoming more complex, with more and more sub-specializations and levels of care.
Category: *Breakthrough*

2. **Methods to model systems as set of flows and processes, not just sets of components**
Motivation: Current ISyE tools were created assuming knowable, stable, well-defined systems that are collections of components. Fluctuating complex systems like health care need a different characterization of systems, as sets of processes where information, people, and materials flow between changing and overlapping subsystems.
Category: *Breakthrough*

3. **Models that explore the effective use and allocation of different vehicles of health care delivery (e.g., "focused factories" versus integration, such as Mayo Clinics and Kaiser Permanente)**
Motivation: As the health care industry is becoming more complex, delivery vehicles are diversifying and need to be studied to understand how organizations decide on volume and specialization tradeoffs, and to conduct comparative-effectiveness analyses of the results.
Category: *Breakthrough*

4. **Models of trust between patients, providers, and technology**
Motivation: Interpersonal trust plays a larger role in health care than in manufacturing for which ISyE was initially developed, partly because patients are both an actor in and the recipients of the care processes. With increasing use of technology in health care, especially health IT that interfaces with patients and providers, trust in the technology and in the system as a whole is paramount, and should be better understood.
Category: *Sustainability*

Predictive models

1. **Models to evaluate entire systems and large-scale system changes before they are implemented**
Motivation: Efficient large-scale simulation could save testing costs, prevent safety hazards due to immature designs, and accelerate the system design and implementation process.
Category: *Breakthrough*

2. **Models to mitigate uncertainties about the future**
Motivation: Short-term uncertainties include the demand for beds in a given week, and long-term uncertainties include the type of health conditions that are likely to become prevalent in the future. Examples include models to forecast the demand for health care services, and models to anticipate new diseases (e.g., H1N1, other pandemics).
Category: *Capacity building*

Prescriptive models

1. **Models of collaboration and competition among health care stakeholders**
   Motivation: If organizations allowed patient data to flow freely between organizations and shared generalizable knowledge, the patient experience would be improved and the organizations would save costs by not reinventing the wheel. The system as a whole would be more Pareto efficient. Understanding why health care stakeholders do not collaborate and the circumstances in which they do could help modify policies and incentive structures to foster collaboration for the betterment of the system as a whole.
   Category: *Breakthrough*

2. **Models that consider how health IT can be integrated into decisionmaking processes, how evidence-based knowledge can be integrated into practice**
   Motivation: Health IT is being introduced into practice as a way to ensure that decisionmaking is grounded in evidence. However, the push might lead to unintended consequences if health IT solutions are implemented prematurely. Research about how to better integrate health IT in decisionmaking processes is needed.
   Category: *Breakthrough*

3. **Models that appropriately consider the conflicting objectives of multiple stakeholders and make optimal recommendations for the system overall**
   Motivation: Different stakeholders in the health care delivery system seek to optimize different objectives. All the perspectives need to be systematically taken into account to determine which combination of tradeoffs is best for the overall system and leads to best joint optimization of the multiple objectives.
   Category: *Sustainability*

4. **Models that provide guidance about when either standardization or customization is necessary**
   Motivation: A vision of a personalized patient-centered system requires customization and a vision of an integrated efficient system requires standardization. The vision of the ideal system described in this report makes this a non-trivial tradeoff and a challenging research topic. How can mass customization be achieved while retaining the benefits of standardization?
   Category: *Sustainability*

5. **Models to explore the role and consequences of automation, and provide guidance about what can be fully or partially automated**
   Models to explore the role and consequences of automation, and provide guidance about what can be fully or partially automated
   Motivation: Too much automation might make the system unsafe and impersonal, too little might make it inefficient and unsafe on a different level. Research to model the benefits and pitfalls of automation in different contexts would help address this delicate tradeoff.
   Category: *Capacity building*

6. **Mathematical programming models**
   Motivation: Decades of research have laid the foundation for quantitative models (e.g., hazard rate models) that measure the association between risk factors, treatments, and health outcomes. However, mathematical programming models that use these inputs to determine optimal decisions for individual patients, or treatment policies for populations are in their infancy (e.g., maximizing quality adjusted life span for a patient, minimizing cost to a health system). There are significant opportunities to build optimization models to aid all stakeholders in making complex tradeoffs between the benefit and burden of treatment.
   Category: *Breakthrough*

Models that can handle inconvenient realities

1. **Methods to build models from incomplete, inaccurate, and unreliable data** Motivation: ISyE tools typically rely on complete and accurate data. The current health care delivery system produces data that is incomplete and often inaccurate. Until it is determined how to capture reliable data, an ideal health care delivery system will require tools that can generate value despite unreliable data while informing users about the level of confidence they can have in each of the data elements.
   Category: *Breakthrough*

2. **Methods to build models from inconsistent data coming from disparate sources**
   Motivation: ISyE tools typically rely on consistent and integrated data. The current health care delivery system produces data that is coming more and more from disparate sources and lacks consistency and integrity. Until it is determined how to fully integrate data from disparate sources, or until a single data standard is adopted, an ideal (optimal) health care delivery system will require methods to models huge distributed complex systems like the US health care industry. Such knowledge would evidently be useful for other industries as well.
   Category: *Breakthrough*

3. **Methods to model unstable systems**
   Motivation: ISyE tools typically assume knowable, stable, and well-defined systems. The current health care delivery system is none of the above. Until it is determined how to build such a system, an ideal health care delivery system will require models that are either robust enough or nimble enough to handle the perturbations in the system.
   Category: *Breakthrough*

4. **Methods to model large-scale, distributed systems where loose coupling occurs**
   Motivation: ISyE tools were developed for optimization of well-defined, circumscribed, bounded, knowable systems (e.g., a production line, a factory, a waiting line at a bank) and not to optimize entire industries or sectors. In fact, improving the health care sector is particularly challenging because of its complexity, politicization, fragmentation, and loose coupling. ISyE successes in manufacturing and aviation did not lead to optimal industries. It is unreasonable to believe that current ISyE knowledge is adequate in optimizing the health care sector, or that optimizing microsystems will lead to the optimization of the entire system. An ideal (optimal) health care delivery system will require methods to model large-

scale distributed complex systems. Such knowledge would evidently be useful for other industries as well.
Category: *Breakthrough*

5. **Models that can integrate qualitative and contextual knowledge (e.g., culture, ethics, law, psychology, social networks, and politics) and be responsive to changes in these qualitative and contextual factors**
   Motivation: The development of ISyE tools that focus on unbounded rather than bounded systems necessitates consideration of contextual factors. Examples of contextual factors that must be considered include an increasingly multicultural population, persistent health care disparities, and potential unintended consequences of health IT policies and definitions of meaningful use.
   Category: *Breakthrough*

6. **Methods to model the dynamics between micro-changes (at the patient and provider levels) and macro-changes (at the population, market, and policy levels)**
   Motivation: ISyE approaches to problem solving generally select a single level of analysis when modeling a problem as opposed to an approach that is multi-level. A single level approach works well in highly-bounded, circumscribed systems, but it may not when applied to health care delivery. Market level and policy level changes have traditionally been more within the purview of economics and policy analysis than that of ISyE and systems-thinking. However, if the goal is to optimize the health care industry provider-level optimization cannot suffice, and new ISyE tools are needed that can model the interdependences between the system-wide picture and the microsystems view.
   Category: *Sustainability*

7. **Models that incorporate errors and interaction of events**
   Motivation: ISyE tools were developed for manufacturing, where computer-controlled machines can largely replace human error, and where interactions of events can be anticipated based on the programming of the machines. Until it is determined how to build an entirely automated health care delivery system, and whether that would be advisable, an ideal health care delivery system will require models that can simulate and help prevent errors and interactions of events.
   Category: *Capacity building*

System Modification

Monitoring and modeling the system are only useful if there are efficient ways to modify it. Three system modification angles are discussed: translating research into practice, top-down decomposition, and bottom-up integration. The first addresses research about ways to make knowledge developed by this agenda useful. The second addresses research aimed at guiding administrators and policymakers initiating and sustaining change to the health care delivery system. The third addresses research in organic ways to initiate grassroots change to the health care delivery system.

Research-practice coordination

1. **Iterative knowledge development and transfer between research and practice**
   Motivation: Recent grants have recognized the need for translational research from basic knowledge into practice, however, there is a need to further this process into bilateral and continuous development and refinement between the two domains.
   Category: *Sustainability*

2. **Improving translation from mathematical and technical languages into lay person terminology**
   Motivation: One main system change challenge in health care is that humans are not reprogrammed, but rather trained, and need understandable actionable information consistent with their terminology and context.
   Category: *Sustainability*

3. **Improving lay people's understanding of analytical results by developing enhanced data visualization techniques**
   Motivation: One barrier to understanding numerical and analytical information is often data visualization, and although there is a considerable body of knowledge in that field, it needs to grow to keep up with changing technology.
   Category: *Capacity building*

Top-down decomposition

1. **Determining ways to modify public and private incentives to influence patients to stay healthy, providers to work in the best interest of their patients, and organizations to be efficient, without unintended negative consequences**
   Motivation: A reoccurring theme among the participants was that the main challenge of the health care industry was the perverse incentives. For example, participants noted that patients are given few incentives to stay healthy and that it is providers who may be penalized for having patients who are unwilling to care for themselves. Furthermore, providers are provided greater monetary incentives for services that may not be necessary or have incremental value for patients than they are for preventive services.
   Category: *Breakthrough*

2. **Exploring payment structures that accommodate technologically-mediated interactions between providers and patients (e.g., text messaging, email, or visits by teleconference)**
   Motivation: Providing personalized care to an increasingly growing population will strain the already understaffed system, and technology can help increase the throughput and allow providers to help patients with common conditions faster than in conventional visits. It is important to determine how to pay providers for time spent delivering technologically mediated care, when current reimbursement structures do not accommodate for it.
   Category: *Breakthrough*

3. **Testing of change and implementation theories, and exploration of the tension between pushing for the application of existing knowledge and trying to develop more usable new knowledge**
   Motivation: A primary challenge in this project was the belief within the group that new knowledge should not be pursued while there are no effective channels to facilitate the implementation of even existing knowledge. However, it is possible that low implementation of existing knowledge is due in larger part to its inadequacy than to the low demand for it or the absence of channels for it.
   Category: *Sustainability*

4. **Determining the benefits, limitations, and appropriate use of national, regional, and institutional forcing functions within the health care setting**
   Motivation: Health care "problem owners" may be needed to coordinate improvement efforts, but it is not clear whether regulation is necessary or useful at all levels, or if it might lead to unnecessary bureaucracy.
   Category: *Capacity building*

Bottom-up integration

1. **Determining appropriate approaches to stimulating system-wide change, exploring ways to coordinate between bottom-up integration and top-down decomposition**
   Motivation: Different solutions can be reached when approached from the top-down (e.g., policy driven) or from the bottom-up (e.g., provider, patient driven). Research is needed to determine how to integrate these perspectives to achieve what is best for overall system performance.
   Category: *Breakthrough*

2. **Exploring how social network theories can be used to trigger and facilitate culture change**
   Motivation: Social networks may be modeled by complementing existing and new ISyE related knowledge like graph theory with social sciences and human factors.
   Category: *Sustainability*

3. **Determining the role of culture as a necessary element of health care improvement, including the national political conversation and at the level of the patient and provider**
   Motivation: New sociotechnical systems theories of culture change could be integrated with existing social science theories to provide guidance on how culture change can be systematically initiated and managed.
   Category: *Capacity building*

Research Agenda: Knowledge Transfer

It is timely to accelerate knowledge transfer of ISyE methods to solve currently recognized health care challenges. Both the documents reviewed for the background report and the workshop discussion primarily focused on action agenda items required to effectively disseminate existing ISyE knowledge. For example, recommendations related to knowledge transfer included demonstration projects, training in ISyE knowledge for health care professionals, and centers of excellence and resource centers. In addition to identifying means of effective knowledge transfer, however, two new research directions within the domain of knowledge transfer were also identified:

1. **Identification of best practices for dissemination and adoption of ISyE knowledge**
   Motivation: There is currently a gap between awareness and use of ISyE knowledge, including use of health IT. Research is needed to determine barriers and facilitators to adoption and sustained use of ISyE knowledge at the levels of individual practices, clinics, organizations, and at regional and national levels.
   Category: *Capacity building*

2. **Identification of best practices for spreading new ISyE knowledge between research and industry and within industry**
   Motivation: Development of new ISyE knowledge is only the first step. Effective and efficient pathways must be developed to spread such knowledge between organizations.
   Category: *Capacity building*

Research Agenda: Meta-Knowledge Integration

Research and knowledge building in ISyE has evolved in a viral fashion, serendipitously through projects that address a broad range of health care problems. It is timely to characterize the research space, set priorities strategically, and devise ways to efficiently glean systemic knowledge across disparate resources. Continuous development and refining of the research agenda for ISyE and health care requires meta-research, or research aimed at creating priorities and understanding of best practices within the research agenda.

1. **Characterizing health care challenges**
   Motivation: A systematically derived understanding of health care is needed to identify the most severe problems and the problems that are most easily amenable to change. This is necessary to facilitate a targeted approach to ISyE knowledge creation and use.
   Category: *Sustainability*

2. **Mapping the usefulness of ISyE knowledge to different health care contexts**
   Motivation: ISyE lacks the meta-knowledge needed to map which tools, techniques, and methods are appropriate and effective to address specific health care problems and challenges.
   Category: *Capacity Building*

3. **Exploiting synergies within ISyE knowledge derived from different subdisciplines**
   Motivation: ISyE is composed of multiple methodological subdisciplines, and it is essential to have a plurality of methods to address the complex problems of health care. Investment in one methodological area (e.g., human factors) needs to be complemented with investment other area (e.g., operations research). Meta-knowledge is necessary to identify potential

synergies between and within ISyE subdisciplines, and to tackle specific topical areas with a "systems approach."
Category: *Breakthrough*

4. **Identification of best practices for use of ISyE knowledge**
   Motivation: Currently there is no understanding of what ISyE tools, techniques, or methods are more effective than others in creating change in the health care delivery system. All ISyE knowledge is often disseminated as being equally valuable. Studies comparing the comparative value of diverse types of ISyE knowledge in different problem settings are needed to ensure effective and efficient realization of change.
   Category: *Sustainability*

5. **Characterizing research frontiers and directions at the intersection of ISyE and health care**
   Motivation: A systems understanding of ISyE knowledge and its frontiers is needed to guide new research efforts and continuously evaluate and redefine current priorities. Such efforts will lead to the continuous refinement of the research agenda at the intersection of ISyE and health care.
   Category: *Capacity building*

Summary of Research Agenda

Tables 2-4 list the research agenda items by category, under breakthrough, sustainability, and capacity building.

Table 2. Research Agenda Items That Support Breakthrough

System Monitoring (Knowledge Innovation)	• Consumer-facing health IT solutions that allow patients to self-support their observations, that track and report on trends, and that interact with providers' annotations • Technologies which enable data to flow quickly and securely through the whole health care delivery system and be available in real-time when and where needed • Methods to operationalize contextual knowledge • Methods to effectively collect and share data in real-time to foster situational awareness of all individuals involved in patient care
System Modeling (Knowledge Innovation)	• Frameworks that explore the integration of many care sources in the production and delivery of care services, and the coordination among these sources (e.g., end of life care) • Methods to model systems as set of flows and processes not just sets of components • Models that explore the effective use and allocation of different vehicles of health care delivery (e.g., "focused factories" versus integration, such as Mayo Clinics and Kaiser Permanente) • Models to evaluate entire systems and large-scale system changes before they are implemented • Models of collaboration and competition among health care stakeholders • Models that consider how health IT can be integrated into decisionmaking processes, how evidence-based knowledge can be integrated into practice • Models of collaboration and competition among health care stakeholders • Models that consider how health IT can be integrated into decisionmaking processes, how evidence-based knowledge can be integrated into practice • Methods to build models from incomplete, inaccurate, and unreliable data • Methods to build models from inconsistent data coming from disparate sources • Methods to model unstable systems • Methods to model large-scale distributed systems • Models that can integrate qualitative and contextual knowledge (e.g., culture, ethics, law, psychology, social networks, and politics) and be responsive to its changes
System Modification (Knowledge Innovation)	• Determining ways to modify public and private incentives to influence patients to stay healthy, providers to work in the best interest of their patients, and organizations to be efficient, without unintended negative consequences • Exploring payment structures that accommodate technologically-mediated interactions between providers and patients (e.g., text messaging, email, or visits by teleconference) • Determining appropriate approaches to stimulating system-wide change, exploring ways to coordinate between bottom-up integration and top-down decomposition
Meta-Knowledge Integration	• Exploiting synergies within ISyE knowledge derived from different subdisciplines

Table 3. Research Agenda Items That Support Sustainability

System Monitoring (Knowledge Innovation)	• Identification of best practices for use of ISyE knowledge • Efficient and pervasive methods of data capture • New automatic data collection technologies to capture observations from patients and their environment (e.g., sun exposure and food intake) • Theories and methods beyond natural language processing for the translation of lay person language into structured computable data • Efficient methods for integrating large amounts of data from disparate sources • Adequate integration of data collection into workflows in manners which ensure data validity while minimizing interference with clinical workflows • Efficient means of integrating information generated from different perspectives (e.g., different providers, patients, administrators) • Methods to characterize how the outcomes relate to the processes
System Modeling (Knowledge Innovation)	• Models of trust between patients, providers, and technology • Models that provide guidance about when standardization or customization is necessary • Models that appropriately consider the conflicting objectives of multiple stakeholders and make system-optimal recommendations • Methods to model the dynamics between micro-changes (at the provider level) and macro-changes (at the market and policy levels)
System Modification (Knowledge Innovation)	• Iterative knowledge development and transfer between research and practice. • Improving translation from mathematical and technical languages into lay person terminology • Testing of change and implementation theories, and exploration of the tension between pushing for the application of existing knowledge and trying to develop more usable new knowledge • Exploring how social network theories can be used to trigger and facilitate culture change
Meta-Knowledge Integration	• Characterizing health care challenges • Identification of best practices for use of ISyE knowledge

Table 4. Research Agenda Items That Support Capacity Building

System Monitoring (Knowledge Innovation)	• Identification of best practices for dissemination and adoption of ISyE knowledge • Identification of best practices for spreading new ISyE knowledge between research and industry institutions and among industry institutions • Methods to characterize processes, inputs, and outcomes • Methods to collect and present information that is valuable to diverse stakeholders such as patients, nurses, primary care and specialty physicians, pharmacists, and social workers • Theories and methods for the translation of numerical, analytical, and computational results into understandable and actionable information that multiple stakeholders (nurses, primary and specialty care physicians, pharmacists) and lay people can seamlessly retrieve to ensure the human monitoring of the system
System Modeling (Knowledge Innovation)	• Models to mitigate uncertainties about the future • Models to explore the role and consequences of automation, and providing guidance about what can be fully, partially, or not at all automated • Optimization models • Models that incorporate errors and interaction of events
System Modification (Knowledge Innovation)	• Improving lay people's understanding of analytical results by developing enhanced data visualization techniques • Determining the benefits, limitations, and appropriate use of national, regional, and institutional forcing functions within the health care setting • Determining the role of culture as a necessary element of health care improvement, including the national political conversation and at the level of the patient and provider
Knowledge Transfer	• Identification of best practices for dissemination and adoption of ISyE knowledge • Identification of best practices for spreading new ISyE knowledge between research and industry and within industry
Meta-Knowledge Integration	• Mapping the usefulness of ISyE knowledge to different health care contexts • Characterizing research frontiers and directions at the intersection of ISyE and health care

Discussion of Research Agenda

The proposed research agenda primarily emphasizes knowledge innovation, and discusses the transfer of existing knowledge, as well as the meta-knowledge necessary to improve the effectiveness of ISyE knowledge at the intersection with health care. However, two main obstacles face the success of the research agenda in driving the vision of an ideal health care delivery system.(1) Incentives are currently short-run oriented, and misaligned. As a result, there is no desire for mid-long term analyses to optimize large complex systems.(2) The tenure and promotion processes have emphasized numbers (e.g., papers, publications, and research dollars) without necessarily looking at the potential long-term “real engineering and research impact.” The following action agenda presents recommendations to overcome these and other obstacles identified in Chapter 4.

Chapter 6: ISyE and Health Care Action Agenda

This section presents an action agenda that should be pursued by relevant funding agencies and organizations to accelerate realization of the research agenda. A discussion of the purpose and scope of the action agenda and the challenges of creating the research agenda is also contained within this section.

Purpose and scope of action agenda

Identification of a research agenda at the intersection of ISyE and health care is only the first step to realizing the vision of an ideal health care delivery system. Much support is needed from funders in order to ensure that the research areas identified are pursued in a timely and effective manner and the results of such research disseminated appropriately. The purpose of the action agenda is to identify how such funders can support accomplishment of the research agenda. The scope of the action agenda, therefore, includes programs and initiatives that are directly within the purview of these agencies. As a result, although participants mentioned large-scale policy changes as an important part of an overall action agenda, these are not included in the action agenda. Examples of such policy changes included releasing all public data sets relevant to this research agenda and realigning incentives for provider, patients, and health care institutions.

Presentation of the Action Agenda

The action agenda proposed below is divided into five sections: (1) collaboration, (2) education and training, (3) research, (4) dissemination, and (5) administration. We recommend programs and initiatives in each of these areas in order for the research agenda to be appropriately accomplished and disseminated. Examples of initiatives and programs that should be supported are indentified and characterized within each section of the action agenda.

Collaboration

We recommend support for programs, centers, and initiatives that bring together multiple stakeholders within the health care delivery system to jointly address problems.

1. **Consortia of all stakeholders:** We recommend support for the creation of consortia that include providers, payers, consumers, the insurance industry, and vendors. Inclusion of vendors is particularly important since they are often absent from the conversation but an integral part of any comprehensive solution. Creation of such consortia will stimulate conversations between stakeholders who often have conflicting motivations, likely resulting in more innovative and acceptable solutions to the problems of the health care delivery system.

2. **Multi-stakeholder conversations:** We recommend support for the execution of interdisciplinary projects that bring together all relevant stakeholders mentioned above. Examples include seminars, workshops, and challenge-specific meetings that bring together multidisciplinary groups to address a specific disease process or other bounded problem. Additionally, workshops that focus on the "capacity-building" items identified in the research agenda would likely accelerate the development of new ISyE knowledge.

3. **Partnerships:** We recommend support for the creation and leveraging of working relationships among Federal agencies (e.g., AHRQ, National Institutes of Health (NIH), NSF, Veterans Affairs (VA)) and between Federal agencies and other organizations working on improving the health care delivery system. Partnerships should be pursued with volunteer, governmental, and non-governmental organizations such as those identified below. Through such partnerships, funding agencies can stimulate wider interest in creating an ideal health care delivery system and can engage these diverse individuals knowledgeable about ISyE and health care in creating breakthrough change.

   Examples of partnership organizations (listed alphabetically):

   a. AcademyHealth
   b. American Hospital Association (AHA)
   c. American Medical Association (AMA)
   d. American Society for Quality (ASQ)
   e. Association for Computing Machinery (ACM)
   f. Centers for Disease Control and Prevention (CDC)
   g. Department of Defense (DoD)
   h. Healthcare Information and Management Systems Society (HIMSS)
   i. Human Factors and Ergonomics Society (HFES)
   j. Institute of Electrical and Electronics Engineers (IEEE)
   k. Institute for Healthcare Improvement (IHI)
   l. Institute for Operations Research and the Management Sciences (INFORMS)
   m. Institute of Industrial Engineers (IIE)
   n. Institute of Medicine (IOM)
   o. Joint Commission
   p. Medical Device Manufacturers Association
   q. Medical Group Manufacturer's Association
   r. National Academy of Engineering (NAE)
   s. National Academy of Sciences (NAS)
   t. Production and Operations Management Society (POMS)
   u. Society for Medical Decision Making (SMDM)
   v. Society of General Internal Medicine (SGIM)
   w. World Health Organization (WHO)

In addition to the organizations listed above, there was some debate among workshop participants as to whether or not Federal agencies should partner directly with vendors. Some workshop participants identified vendors such as General Electric and Intel as desirable partners, whereas other participants noted that the conflicting motivations between Federal agencies and such vendors make these forms of partnerships less desirable.

4. **Professional home:** We recommend support for the creation of a common professional association or coordination of existing relevant societies for professionals working at the intersection of ISyE and health care. Creation of a professional home for this intersection (or creation of coordinating mechanisms between multiple professional homes) would facilitate effective and sharing of new knowledge. Such coordination is particularly needed between ISyE and health care organizations.

Education and Training

We recommend support for the creation of programs and initiatives to facilitate the development of professionals with a deep understanding of both ISyE and health care.

1. **Higher education:** We recommend support for the creation of more academic programs and interdisciplinary courses that train undergraduate and graduate ISyE student in health care and health care professionals in ISyE. Creation of these programs will ensure a growing supply of professionals who are working knowledge of both content areas.

2. **Professional development:** We recommend support for the creation of cross-training short courses, seminars, and online trainings to make currently practicing ISyE and health care professionals aware of the knowledge of the other discipline.

3. **Fellowships:** We recommend support for the establishment of early and mid-career awards for ISyE professionals to spend time within a health care environment and for health care professionals to spend time working with ISyE professionals. Such awards would enable professionals from one discipline to obtain fluency in the language and mental models of the other discipline.

4. **Case studies:** We recommend support for the compilation of a library of case studies demonstrating the application of ISyE knowledge to solving problems within the health care delivery system. This library would serve to facilitate teaching of ISyE knowledge to health care professionals and health care knowledge to ISyE professionals. It could also serve to stimulate engineering interest in the problems of health care, resulting in increased recruitment of industrial and systems engineers in health care.

Funding

We recommend direct support for research activities at the intersection of ISyE and health care.

1. **Investigator initiated projects:** We recommend support for investigator initiated projects that are short-term (1 to 2 years) at the intersection of ISyE and health care. Such projects could, for example, focus on testing the appropriateness of an existing method within the context of health care or focus on creating methodological knowledge (e.g., a model) that has applicability within a particular health care domain.

2. **Methodological innovation centers (MICs):** We recommend support for the development of centers that are responsible for the conduct of long-term research (3 years or greater) at the intersection of ISyE and health care. These centers should facilitate alignment of research within health care delivery systems by establishing an enduring relationship with a health care delivery system as a laboratory for testing and refining of new discoveries. This may be accomplished in part by creating partnerships with and capitalizing upon resources of existing centers. MICs should not, however, be focused on existing analytical challenges faced by these centers, but should focus on creating new methodological knowledge at the intersection of ISyE and health care. MICs may be anchored to specific geographical areas or may span several geographical sites.

    a. **An effective way to develop MICs may exist in the identification of "Learning HealthCare Systems."** Envisioned as an enduring research-delivery system alliance, these institutions would integrate basic research in ISyE, a working health care delivery system to serve as a test-bed for new ideas and a demonstration site for ISyE methods integration, and an educational partner (e.g., university, academic health science center) for training the next generation of health-care professionals shaped by ISyE knowledge and ISyE researchers and analysts well-versed in the issues of health care.

3. **Multidisciplinary grantees:** We recommend support for the requirement of grantee teams to be multidisciplinary, bringing together not only ISyE and health care professionals, but also professionals from fields such as social science in order to receive funding. Mutlidisplinary work should be encouraged both for investigator-initiated and center-based projects.

Dissemination

We recommend support for the creation of programs and initiatives that encourage the timely and effective dissemination of research at the intersection of ISyE and health care.

1. **Publication:** We recommend support for the publication of funded research in practice journals and public media in addition to traditional research journals. Furthermore, funders should support the creation of a high-impact research journal designed specifically for publication of research conducted at the intersection of ISyE and health care.

2. **Networking:** We recommend support for the dissemination of research conducted at the intersection of ISyE and health care through IT-enabled social networks to promote rapid transfer of knowledge. Support could take the form of online forums, virtual networks, and virtual conferences.

3. **Demonstration projects** We recommend support for the testing of solutions developed at the intersection of ISyE and health care within physical test beds or real health care organizations. Such testing would help facilitate development of best practices knowledge.

Administration

We recommend support for administrative changes to promote high quality research at the intersection of ISyE and health care.

1. **Joint solicitations and collaborative funding:** We recommend support for joint solicitations and collaborative funding to drive the research agenda proposed in this report. For example, NSF and AHRQ could extend a joint solicitation. NSF could be responsible for the evaluation of the engineering knowledge contained within the proposal and AHRQ could be responsible for the evaluation of the value of the proposal to solving problems within the health care delivery system.

2. **Faster proposal cycle:** We recommend support for the acceleration of the cycle of proposals for grants relevant to the research agenda in this report to ensure a timely realization of the vision of an ideal health care delivery system.

Chapter 7: Conclusion

It is clear that the current U.S. health care delivery system is suboptimal. Lack of efficiency and effectiveness of the system has resulted in health care that is high in cost but not consistently high in quality. Continued operation of such a health care delivery system that is inefficient and costly is unwise, particularly given the unprecedented financial distress being experienced by the country. Solutions are needed which will result not only in incremental change to the health care delivery system (e.g., decreased wait times, more efficient scheduling), but breakthrough changes which will lead to an ideal health care delivery system. Unfortunately, current solutions to the problems of the health care delivery system are often politically motivated, not grounded in systematic development of alternatives, and focused on incremental change at the level of the subsystem.

The field of industrial and systems engineering has the potential to make significant contributions to achieving an ideal health care delivery system through use of tools, techniques, and methods that allow for systematic development of solutions. To date, however, efforts at implementing ISyE knowledge to solving the problems of the health care delivery system have failed to realize breakthrough change.

This project takes an important first step toward determining how the field of ISyE can significantly contribute to breakthrough change in the health care delivery system by:

1. Explicating a vision of an ideal health care delivery system, as new, engineered, and patient-centered,
2. Identifying nine barriers and four facilitators to achieving tractable change in the health care delivery system using current ISyE methods, and
3. Establishing a research agenda focused primarily on knowledge innovation , and to a lesser extent on knowledge transfer and meta-knowledge integration and an action agenda focused on collaboration, education and training, funding, dissemination, and administration needed to enable ISyE to meaningfully contribute to the realization of an ideal health care delivery system.

Much work, however, remains to be accomplished. Three areas warranting further investigation are described below:

1. Policy and incentives. The scope of application of ISyE knowledge is generally confined within a specified policy environment. Consequently, in this project, we treated all policy-related topics, including the topic of incentives as a constraint. Future investigations, however, should explore and address the misaligned incentives that exist, for example, between providers and payers or academia and industry.
2. The role of axiomatic research. The field of health care relies heavily on empiricism. Whereas an empirical approach is grounded in data, an axiomatic approach is grounded in first principles. Such first principles are valuable because they serve as a framework for interpretation of data. The field of ISyE serves as a bridge between fields such as physics and biology that rely heavily on first principles and fields such as the social sciences in which such principles, because of the nature of personalities, politics, and

people do not always hold. Future investigations should explore the tensions between these two approaches and address the role of ISyE in capitalizing upon this tension.

3. Role of health IT. The systematic, purposeful application of health IT will aid in the realization the goal realizing an ideal health care delivery system through the application of ISyE knowledge. Development and implementation of new health IT knowledge will, therefore, play an important role in achieving both the research and action agenda at the intersection of ISyE and health care. Future investigations should focus on creating a research agenda that further explicates the type of health IT knowledge needed.

Both ISyE and health care professionals should work together and team with other stakeholders to accomplish the research agenda outlined in this report. It is recommended that appropriate funding agencies support the successful execution and implementation of the results of the research agenda as outlined in the action agenda. It is also recommended that these communities work together to continue to build upon the research and action agendas by addressing the areas of further investigation outlined above. By solidifying the partnership with health care and by focusing on the development of new tools, techniques, and methods, and how health IT may facilitate development and use of this new knowledge, the field of ISyE can help realize the vision of an ideal health care delivery system.

References

1. Commission on Systemic Interoperability. Ending the document game: Connecting and transforming your healthcare through information technology. Washington, DC: U.S. Government Printing Office; 2005.

2. Donaldson MS, Mohr JJ. Exploring innovation and quality improvement in health care micro-systems: a cross-case analysis. Washington, DC: Institute of Medicine; 2001. A technical report for Institute of Medicine Committee on the Quality of Health Care in America.

3. Institute of Medicine. Crossing the quality chasm: A new health system for the 21st century. Washington, DC: National Academies Press, 2001.

4. Institute of Medicine. Engineering a learning healthcare system: A look at the future/Preliminary draft. Work in progress, 2008.

5. Institute of Medicine. The learning healthcare system: Workshop summary. L Olsen, D Aisner, JM McGinnis, eds. Washington, DC: National Academies Press, 2007.

6. Institute of Medicine. Learning healthcare system concepts v. 2008/Annual report. Washington, DC: National Academies Press, 2008.

7. Institute of Medicine. To err is human: Building a safer health system. LT Kohn, JM Corrigan, MS Donaldson, eds. Washington, DC: National Academies Press, 2000.

8. Institute of Medicine and National Academy of Engineering. Building a better delivery system: A new engineering/health care partnership. PP Reid, WD Compton, JH Grossman, G Fanjiang, eds. Washington, DC: National Academies Press, 2005.

9. McClellan MB, McGinnis JM, Nabel EG, et al. Evidence-based medicine and the changing nature of health care. Washington, DC: Institute of Medicine; 2008.

10. National Research Council. Computational technology for effective health care: Immediate steps and strategic directions. WW Stead & HS Lin, eds. Washington, DC: National Academies Press; 2009.

11. Nelson EC, Batalden, PB, Godfrey MM, et al. Microsystems in health care: The essential building blocks of high performing systems. Princeton (NJ): Robert Wood Johnson Foundation; 2001. RWJ Grant Number 036103.

12. Rardin RL. Research agenda for healthcare systems engineering/Final report. Arlington, VA: National Science Foundation, February, 2007. NSF Grant No. 0613037.

13. Roberts S, Uzsoy R, Ivy J, Denton B. Workshop: Healthcare engineering and health services research: Building bridges, breaking barriers/Final report. Arlington, VA: National Science Foundation, April, 2008. NSF Grant NO. 0817223.

Appendix A: Background Report

Industrial and Systems Engineering and Health Care: Critical Areas of Research

Prepared for:
Agency for Healthcare Research and Quality
U.S. Department of Health and Human Services
540 Gaither Road
Rockville, MD 20850
www.ahrq.gov

Contract No. 290-09-00027U

Prepared by:
University of Wisconsin-Madison, Madison, WI

Authors:
Rupa Sheth Valdez
Industrial and Systems Engineering
University of Wisconsin-Madison

Patricia Flatley Brennan
Professor and Chair
Industrial and Systems Engineering
Professor, School of Nursing
University of Wisconsin-Madison

AHRQ Project Officer:
Teresa Zayas-Caban

This report is also available as a standalone document on the AHRQ NRC Web site at http://healthit.ahrq.gov/engineeringhealthbackgroundreport
(AHRQ Publication No. 09-0094-EF, September 2009)

Contents

Executive Summary

Introduction

There is no question that the current health care delivery system is suboptimal. Problems related to the system's efficiency, effectiveness, accessibility, safety, and other characteristics have been copiously documented in reports issued by both public and private agencies and in numerous journal articles. Acutely aware of the current political climate surrounding health care reform, the popular press daily inundates the public with stories of yet another deficiency in, or failure of, the system. In just one day (September 7, 2009), three prominent news sources reported the following shortcomings:

Chicago Tribune: There is concern that the proposals in Congress for health care reform will threaten the funding and future of the country's safety net hospitals (Johnson, 2009)

Wall Street Journal: A child died from a medical error caused by a lack of communication between physicians (Landro, 2009)

New York Times: Sixty-two percent of bankruptcies this year will be medical. Of those, three-quarters had insurance, at least when they initially got sick (Underwood, 2009)

Leaders in the health care community are deeply aware that change is necessary. Myriad approaches to improving the health care delivery system have been offered and remain at different stages of implementation. Prominent solutions to improving health care delivery include suggestions grounded in education, incentives, research funding, information technology, and systems engineering. Yet, despite consciousness of the problems and the many initiatives targeted at addressing them, the health care delivery system remains replete with flaws.

Purpose of This Meeting and Report

Beginning with the report *Building a Better Delivery System* (Institute of Medicine and National Academy of Engineering, 2005), there has been heightened interest in solving problems in the health care delivery system using industrial and systems engineering tools. Approaches to date envision improvements in the known health care system though the application of industrial and systems engineering approaches. However, the absence of progressive improvement in health care suggests the need to reframe the discussion, beginning first with a vision of an optimal health care system then specifying the industrial and systems engineering methods needed to insure the realization of that future.

The primary purpose of this meeting is to develop a research agenda at the intersection of industrial and systems engineering and health care. To achieve this primary purpose, meeting participants will be asked to engage in three activities:

1. Define a vision of an ideal health care system.
2. Critically examine the reasons for which fundamental change to the health care delivery system, including through the use of industrial and systems engineering tools, remains intractable.
3. Develop a prioritized list of new industrial and systems engineering tools that must be developed to realize the vision of an ideal future.

This background report provides a critical summary of the discourse salient to each element above. Documents generated by conferences, workshops, and working groups sponsored by various national bodies (National Academy of Sciences, Institute of Medicine, National Academy of Engineering, National Science Foundation) serve as the corpus upon which this report rests. By providing an overview of the main themes and identifying points of inconsistency and limitation in the current disquisition, this report seeks to provoke discussion among meeting participants. As such, it seeks not to be exhaustive but stimulating.

There are 13 reports that form the basis for this background report. These reports may be conceptualized as belonging to three categories: (1) reports that "set the stage" for discussions about improving the health care delivery system by drawing national attention to the need for change, (2) reports that directly explore the intersection between industrial and systems engineering and health care delivery, and (3) reports that represent the discourse related to specific mechanisms for improving the health care delivery system. Reports belonging to this final category primarily advocate one of three solutions to the deficiencies of the health care delivery system: (1) information technology, (2) evidence-based medicine, or (3) a "microsystems" approach. We purposely excluded reports that focused on a narrow aspect of the health care delivery system. Thus, for example, we excluded reports that focused solely on documenting specific demand for evidence, adoption challenges related to electronic health records, and a research agenda for consumer health information technology.

This background report has three parts. Chapter 1 presents a brief summary of each of the 13 reports that form the basis of this background report and presents a list of 7 themes common to these reports. Chapters 2-4 present summaries and discussion points related to the three meeting action items. Chapter 5 presents questions that may be used to instigate discussion among meeting participants, and Chapter 6 provides a conclusion.

Key Themes

Review of the 13 reports resulted in identification of seven common themes:

1. The current health care delivery system is both unsustainable in terms of cost and suboptimal in terms of value.
2. The current health care delivery system cannot adequately respond to changes in the larger environment and within the medical sciences.
3. Solving the problems of the health care delivery system is complex and will require approaches that are multidimensional, multileveled, and inclusive of multiple stakeholders.
4. Information technology will play a key role in the future health care delivery system.

5. Incentives are needed to promote change, including the use of systems engineering tools, information technology, and evidence-based medicine.
6. Opportunities are needed for cross-education and collaboration between health care professionals and scientific and technical professionals such as engineers and computer scientists.
7. Research funding is needed to explore the intersections between health care and the use of systems engineering tools, computer science methodologies, and information technology.

Additionally, review of the 13 reports resulted in a short summary and discussion related to each of the three meeting action items:

Define a vision of an ideal health care delivery system: Current visions of an ideal health care delivery system are primarily descriptive rather than prescriptive. When prescriptive guidance is provided, it is partial rather than comprehensive, focusing only on select aspects of an ideal health care delivery system such as the role of evidence-based medicine or information technology. If conceptualized in terms of an engineering design process, the vision or “design” of an ideal health care delivery system must be comprehensively specified prior to realization. Relying on only partial specification may be risky because it constrains the vision and increases the likelihood of unintended and potentially undesirable consequences.

Determine why fundamental change to the health care delivery system remains intractable: Solutions advanced to fixing problems of the health care delivery system are not aligned with the theoretical recognition that solving the problems of the health care delivery system requires a multidimensional solution not grounded in current realities. Furthermore, current approaches to changing the health care delivery system emphasize local optimization rather than system-wide optimization. Systems engineering tools have also been used to promote local optimization. This is reasonable, given the nature of systems engineering tools, the culture of health care, and the systems currently in place to support the use of systems engineering tools.

Determine what new forms of industrial and systems engineering tools are needed to arrive at the vision of an ideal health care delivery system: Although these reports mention several existing industrial and systems engineering tools that would be useful for local optimization, there is only minimal discussion of the new types of industrial and systems engineering tools that will be necessary. Those that are provided are a positive step in the right direction as they push the boundary beyond local optimization. One limitation of the new tools mentioned, however, is that they remain grounded in the current health care delivery system. What is needed is a set of new industrial and systems engineering tools that are grounded not in the current health care delivery system, but in the vision of an ideal health care delivery system.

Chapter 1: Summary of Past Reports and Identification of Common Themes

Report Summaries

In this section, a brief summary is provided of each of the 13 documents that form the foundation of this background report. The corpus is arranged alphabetically for ease of access to the source documents.

Commission on Systemic Interoperability. Ending the document game: Connecting and transforming your healthcare through information technology. Washington, DC: U.S. Government Printing Office; 2005.

This report advances the idea of information technology as a solution to many of the problems present within the current health care delivery system. Specifically, it is noted that increased interconnectivity will facilitate communication, security and confidentiality, and recordkeeping and prevent medical errors. Three steps are presented as a means of creating a nationwide system of health information: adoption, interoperability, and connectivity. The authors note that realization of such a system will involve multiple changes, including reformulated financial incentives, regulatory reform, changes in workforce requirements, data, privacy and authentication standards, a national health information network, and legal protections for consumers.

Donaldson MS, Mohr JJ. Exploring innovation and quality improvement in health care micro-systems: a cross-case analysis. Washington, DC: Institute of Medicine; 2001. A technical report for Institute of Medicine Committee on the Quality of Health Care in America.

This purpose of this report is to define the concept of a microsystem and to determine which characteristics of a microsystem enable it to improve the quality of care received by patients. The authors note that the concept of the microsystem is drawn for the manufacturing and service industry, where it has been successfully applied. In this report, the concept of the microsystem in health care is defined as a consisting of (1) a core team of health care professionals, (2) a defined population they care for, (3) an information environment to support the work of caregivers and patients, and (4) support staff, equipment, and a work environment. Examples of microsystems within health care provided by the report include a dialysis unit, an emergency room in a community hospital, and a hospice. Qualitative interviews with representatives of 43 purposely selected high-performing microsystems yielded eight themes which provide a framework for conceptualizing how microsystems function: (1) integration of information, (2) measurement, (3) interdependence of care team, (4) supportiveness of larger system, (5) constancy of purpose, (6) connection to community, (7) investment in improvement, and (8) alignment of role and training. The authors note that these findings may be used to develop tools, which may be used by other microsystems to replicate and extend the high levels of performance found within this sample.

Institute of Medicine. Crossing the quality chasm: A new health system for the 21st century. Washington, DC: National Academies Press, 2001.

This report serves as a complement to *To Err is Human* (Institute of Medicine, 2000), documenting not only quality concerns caused by errors but by an entire spectrum of causes. The authors acknowledge that although the health care system does, at times, perform admirably, there are large variations in care, and many do not receive the care that they need. Thus, there is recognition that "trying harder" within the current system is not the solution; a new system is needed. Recommendations include a systems approach to creating a health care system that is timely, effective, patient-centered, efficient, equitable, and safe. In advocating a systems approach, the authors acknowledge the need for change at the level of health care providers but also at the level of health care organizations, professional groups, public and private purchasers, and other government bodies. Environmental changes in four areas are proposed as a means of enabling larger system change: infrastructure that supports the dissemination and application of new clinical knowledge and technologies, the information technology infrastructure, payment policies, and preparation of the health care workforce. Funding for recommended to support projects targeted towards achieving the six aims and/or producing substantial improvement in quality for priority conditions.

Institute of Medicine. Engineering a learning healthcare system: A look at the future/Preliminary draft. Work in progress, May, 2008.

The authors of this report note that systems engineering tools have transformed multiple industries and question whether these methods may be useful in creating a learning health care system. Ten common themes are documented in this report: (1) center the system's processes on the right target—the patient experience, (2) system excellence is created by the reliable delivery of established best practice, (3) complexity compels reasoned allowance for tailored adjustments, (4) emphasize interdependence and tend to process interfaces, (5) teamwork and cross-checks trump command and control, (6) performance transparency and feedback serve as engines for improvement, (7) expect errors in the performance of individuals, perfection in the performance of systems, (8) align rewards on key elements of continuous improvement, (9) develop education and research to facilitate understanding and partnerships between engineering and the health professions, and (10) foster a leadership culture, language, and style that reinforces teamwork and results. Finally, the report identifies five points of followup for members of the roundtable including clarifying terms, identifying best practices, exploring changes to health professions education, advancing the science of payment for value, and exploring development of a science of waste and engagement.

Institute of Medicine. The learning healthcare system: Workshop summary. Olsen L, Aisner D, McGinnis JM, eds. Washington, DC: National Academies Press, 2007.

The *learning healthcare system* is a system within which evidence is generated and applied within the decisionmaking process. This report highlights how evidence-based medicine could serve as a rigorous scientific basis for the medical profession and highlights approaches currently used by health care organizations to achieve this aim. Thus, the primary purpose of this report is to document how information could be better generated and applied to improving health care. Twelve needs are identified that must be addressed to move toward a learning healthcare system. These needs include: (1) adaptation to the pace of change, (2) stronger synchrony of efforts, (3) culture of shared responsibility, (4) new clinical research paradigm, (5) clinical decision support systems, (6) universal electronic health records, (7) tools for database linkage, mining, and use, (8) notion of clinical data as public good, (9) incentives aligned for practice-based evidence, (10) public engagement, (11) trusted scientific broker, and (12) leadership. Mechanisms of addressing these needs and current progress towards meeting these needs are presented, including realigned incentives, revised medical education, and building upon current infrastructure and resources. There is also a brief mention of the potential of methodologies such as mathematical modeling, Bayesian statistics, and decision modeling as effective mechanisms for assessing interventions.

Institute of Medicine. Learning healthcare system concepts v. 2008/Annual report. Washington, DC: National Academies Press, 2008.

This report presents a summary of the key issues identified during the first 2 years of work by the Institute of Medicine Roundtable on Evidence-Based Medicine. The authors emphasize that our Nation is failing to deliver the value that should be expected from received care and that the purpose of the roundtable is to accelerate the delivery of such value, particularly in terms of effectiveness and efficiency, by creating a learning health care system. There is mention of the fact that the context within which change to the health care delivery system is needed is daunting, given, for example, constantly changing medical interventions, the increasing complexity of decisions, and geographical variations in spending. A learning health care system within which new evidence is constantly produced and applied through real-time learning and use is presented as a solution to these problems. The report also documents the need to provide incentives for high-performing caregivers, to develop capacity to generate evidence, and to generate and disseminate high-quality data. There is acknowledgment that any effective solution will require the participation of multiple stakeholders, including caregivers, health care organizations, patients, health care product companies, researchers, regulators, and payers and purchasers.

Institute of Medicine. To err is human: Building a safer health system. Kohn LT, Corrigan JM, Donaldson MS, eds. Washington, DC: National Academies Press, 2000.

This report calls attention to the fact that between 48,000 and 96,000 individuals die each year as a result of medical errors in our health care system. Such errors are described as expensive to the system, resulting in rework and opportunity costs as well as intangible ones, such as those related to employee and patient satisfaction and morale. Multiple reasons are provided for the silence that surrounds the issue of medical errors: (1) consumers believe they are protected, (2) providers fear legal repercussions from systematically uncovering and addressing errors, (3) the fragmented system prevents an understanding of root causes, and (4) purchasers have not demanded better quality and safety conditions. This report states that success has been achieved by other industries in reducing errors and that the lessons learned in these industries should be applied to health care. In this report, the problem of medical errors is viewed as a systems problem, and one that can only be solved be implementing a multifaceted, multilevel response. Specifically, the report calls for the number of errors to be reduced through the implementation of regulatory, educational, and engineering mechanisms, and at the level of the provider, health care organization, and national agencies. Funding for a center dedicated to improving patient safety though goal setting, tracking, research, and dissemination is recommended.

Institute of Medicine and National Academy of Engineering. Building a better delivery system: A new engineering/health care partnership. Reid PP, Compton WD, Grossman JH, Fanjiang G, eds. Washington, DC: National Academies Press, 2005.

This report is divided into two sections: the consensus report and a series of individual articles by leaders in the fields of health care delivery or systems engineering. The authors explore the potential of systems engineering tools to the improvement of the health care delivery system. In the consensus report, a framework is presented in which the health care system is conceptualized at consisting of four levels: the patient, the care team, the organization, and the environment. Systems engineering tools are identified that could help the health care system overcome difficulties at each of these four levels. Additionally, action steps are presented which would promote both the awareness and use of systems engineering tools at each of these four levels. These action steps include the dissemination of current systems engineering tools by both governmental and private organizations, development of information and communication technologies, and multidisciplinary research and educational programs. The second half of this report contains short articles by leaders in the fields of health care delivery and systems engineering, each of which focus on a particular area of health or a particular class of systems engineering tools.

McClellan MB, McGinnis JM, Nabel EG, et al. Evidence-based medicine and the changing nature of health care. Washington, DC: Institute of Medicine; 2008.

This report is the 2007 annual report of the Institute of Medicine roundtable on evidence-based medicine. It notes that there is a need for better evidence to guide health care decisions and that a mechanism is needed to both develop and apply evidence naturally during the care process. Nine common themes were identified related to the discussion of evidence-based medicine: (1) increasing complexity of health care, (2) unjustified discrepancies in care patterns, (3) importance of better value from health care, (4) uncertainty exposed by the information environment, (5) pressing need for evidence development, (6) promise of health information technology, (7) need for more practice-based research, (8) shift to a culture of care that learns, (9) new model of patient-provider partnership, and (10) leadership that stems from every quarter. It is noted that a multidimensional approach is needed to implement evidence-based care. Such an approach is described as involving multiple stakeholders such as patients, provider, payers, industry, and policymakers and involving realignment of incentives to support the use of evidence-based care.

National Research Council. Computational technology for effective health care: Immediate steps and strategic directions. Stead WW and Lin HS, eds. Washington, DC: National Academies Press; 2009.

This report centers around two questions: (1) How can today's computer science-based methodologies and approaches be applied more effectively to health care? and (2) What are the limitations of these methodologies? and How can they be overcome through additional research and development? Answers to these questions are obtained through site visits to eight medical centers, literature review, and committee expertise. The authors conclude that the current focus on information technology efforts within health care is insufficient to drive needed change. Recommendations include the implementation of both evolutionary and radical change and to expand research along two dimensions: (1) the extent to which new, fundamental, general-purpose research is needed and (2) the extent to which new research specific to health care and biomedicine is needed. As in other reports, there is acknowledgement that multiple stakeholders, including government, the computer science community, and health care institutions must participate for meaningful change to be realized. There is clear communication that the scope of this report is limited, focusing primarily on the role of clinicians in large health care institutions, and only peripherally touching on the larger economic, political, and cultural context within which health care reform must occur.

Nelson EC, Batalden, PB, Godfrey MM, et al. Microsystems in health care: The essential building blocks of high performing systems. Princeton (NJ): Robert Wood Johnson Foundation; 2001. RWJ Grant Number 036103.

This report presents the concept of the microsystem as an opportunity to think about transforming health care from the front line of service delivery. The authors note that the idea of transforming health care via optimization of the microsystem relies on three primary assumptions about the structure of the health care system: (1) bigger systems (i.e., microsystems) are made of smaller systems, (2) these smaller systems (i.e., microsystems) produce quality, safety, and cost outcomes at the front line of care, and (3) the outcomes of the macrosystems can be no better than the microsystems of which it is a part. Thus, microsystems are conceptualized as the building blocks of the health system. The authors note that the concept of the microsystem has been successfully been used by service organizations such as FedEx®, McDonald's, and Nordstrom. This report then presents the results of a study in which 20 high-performing clinical microsystems were studied to uncover nine characteristics of success: (1) improvement methods, (2) staff focus, (3) performance results, (4) information and information technology, (5) patient focus, (6) leadership, (7) interdependence of care team, (8) culture, and (9) organizational support. The authors conclude that the role of the clinical microsystem has been ignored to date and should be attended to in the future as a means to transform the health care system.

Rardin RL. Research agenda for healthcare systems engineering/Final report. Arlington, VA: National Science Foundation, February, 2007. NSF Grant No. 0613037.

This report serves two primary functions: it (1) proposes a research agenda for health care systems engineering and (2) documents the funding challenges and potential funding solutions for health systems engineering. In this report, the health care system is conceptualized as consisting of six levels: patient, population, team, organization, network, and environment. The field of health care systems engineering is conceptualized as consisting of three domains: technology, model-based, and practice-based. A research agenda is outlined at each health care system level and the potential for advances is evaluated for each of the three health care systems engineering domains. Top research priorities identified include treatment optimization, personalized, preventive care, information rich and configurable operations management, collaboration within networks, and large-scale delivery system design. The report also notes that health care systems engineering has no funding "home" and calls for the establishment of a health care engineering alliance to support such research.

Roberts S, Uzsoy R, Ivy J, Denton B. Workshop: Healthcare engineering and health services research: Building bridges, breaking barriers/Final report. Arlington, VA: National Science Foundation, April, 2008. NSF Grant No. 0817223.

This report in organized around answering four questions at the intersection of health services research and health care systems engineering: (1) What do health services research and health care systems engineering have in common?; (2) What can health care systems engineering learn from health services research?; (3) What can health services research learn from health care systems engineering?; and (4) Why is the VA so important to health care engineering? Commonalities identified include shared understanding of problems, shared common intellectual assets, shared belief in data-driven analysis and decisions, and complementary research methods and tools. Seven recommendations to the National Science Foundation (NSF) are presented, which emphasize the need for NSF to encourage and fund interdisciplinary projects at the intersection of these fields. These recommendations include calls for both educational and research initiatives at the intersection of health care engineering and health services research.

Common Themes

The common themes presented below are not necessarily present in all of the 13 reports included in this background report, but may be found in a large majority of the reports reviewed.

- The current health care delivery system is both unsustainable in terms of cost and suboptimal in terms of value.
- The current health care delivery system cannot adequately respond to changes in the larger environment and within the medical sciences.
- Solving the problems of the health care delivery system is complex and will require approaches that are multidimensional, multi-leveled, and inclusive of multiple stakeholders.
- Information technology will play a key role in the future health care delivery system
- Incentives are needed to promote change, including the use of systems engineering tools, information technology, and evidence-based medicine.
- Opportunities are needed for cross-education and collaboration between health care professionals and scientific and technical professionals such as engineers and computer scientists.
- Research funding is needed to explore the intersections between health care and the use of systems engineering tools, computer science methodologies, and information technology.

Chapter 2: Vision of an Ideal Health Care Delivery System

Summary

In the current discourse, comprehensive visions of an ideal health care delivery system are descriptive rather than prescriptive. For example, in *Crossing the Quality Chasm* (Institute of Medicine, 2001), the ideal health care delivery system is described as embodying six attributes: safety, effectiveness, efficiency, equity, timeliness, and patient-centeredness. Other attributes of an ideal health care delivery system include the capacity to learn and therefore continuously improve (Institute of Medicine, 2007) and cost-effectiveness (Institute of Medicine, 2008a). Finally, an ideal health care system should also be able to accommodate both environmental changes, such as an aging population and the shift in disease burden from acute to chronic illness (National Research Council, 2009) and advances in both technology and medical science, including new medications, devices, diagnostics, biologics, and procedures (Institute of Medicine, 2008b).

Limited attempts have been made to prescriptively specify components of the ideal health care system. Such attempts have primarily focused on detailing the role of information technology in the future. For example, in *Ending the Document Game* (Commission on Systemic Interoperability, 2005), the authors advance a vision of the future in which information technology is used to manage health care information, enabling a medical record to be available wherever and whenever it is needed and authorized. Similarly, reports focusing on evidence-based medicine (e.g., Institute of Medicine, 2007, 2008b; McClellan et al., 2008) detail how a vision of a learning health care system may be achieved by promoting knowledge bases other than randomized controlled trials and by collecting and disseminating data in real-time via information technology.

In *Crossing the Quality Chasm* (Institute of Medicine, 2001), there is an explicit refusal to specify a vision not only of an ideal future health care system, but also of a 21st century health care system. The committee argues that such an exercise would be neither useful nor possible. They further argue that imagination and valuable pluralism abound at the local level and, consequently, offer a set of rules the may be used to implement innovation and achieve improvement at this local level.

Discussion

The potential risk inherent in the current approach of prescriptively specifying only select aspects of a vision of an ideal health care delivery system may be best explored by considering an engineering design process. At the beginning of a design process, a designer establishes an understanding of the functional requirements that a product, service, or system must be meet. This results in a uniquely descriptive vision of this product, service, or system. Endless possibilities exist as to how these functional requirements may be realized.

After exploring the infinite possible design solutions, a designer must create concrete alternatives, evaluate these alternatives, and choose one with which to proceed. Thus, the designer must select the means that will be used to achieve the functional requirements. There is definitive movement from a descriptive solution to a prescriptive solution. No aspect of the design solution is left unspecified.

There is a simple reason for which an engineering design process requires comprehensive specification before advancing to development. Partial specification is unpredictable. Without ensuring that all of the pieces of the final design fit together, there is no assurance that the bridge will not collapse, that circuit will not short. It is not enough to determine what material should be used to build the bridge or build the circuit. Such limited prescriptive specification only serves to constrain the final solution; it does not present a final solution.

The same principles hold for "designing" an ideal health care delivery system. A uniquely descriptive solution is important at the beginning of the process. It allows for application of "imagination and valuable pluralism" (Institute of Medicine, 2001). Yet, this phase of the design process cannot last indefinitely. To realize an ideal health care system, a prescriptive solution must be defined. Precluding a prescriptive solution, it is impossible to determine whether we are moving toward the desired destination. Furthermore, such a solution must be comprehensive. At present, the prescriptive solution is only piece-meal. There are loud calls for the use of evidence-based medicine and information technology and even many details about how these tools may be used to improve health care delivery (e.g., Commission on Systemic Interoperability, 2005; Institute of Medicine, 2007, 2008b; McClellan et al., 2008; National Research Council, 2009). At the same time, however, there is little prescriptive specification as to how other aspects of the health care delivery system will be redesigned, eliminated, or added to fit with these recommended improvements.

One final point should be made about the level at which a prescriptive solution for the health care delivery system is specified. In *Crossing the Quality Chasm* (Institute of Medicine, 2001), the authors imply that such prescriptive specification should take place at the local level. Yet, in other publications such as *Building a Better Delivery System* (Institute of Medicine and National Academy of Engineering, 2005), the ideal health care system is envisioned as something transformed from "an underperforming conglomerate of independent identities 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 (p. 2)."

We are not arguing that a comprehensive prescriptive solution is possible, or even desirable at present. It may be that, as a Nation, we still need time to explore options, to draw lines in the sand. We only wish to draw attention to two realities: (1) there is inherent risk in prescriptively defining only certain dimensions of the ideal health care delivery system, and (2) a comprehensive prescriptive solution is important for ensuring purposeful movement toward an ideal health care delivery system.

Chapter 3: Barriers to Realization of This Vision

Summary

Unquestionably, "solving health care" is viewed as a complex problem. This complexity is recognized in each of the 13 reports that serve as the basis for this background report. Particularly within *To Err is Human* (Institute of Medicine, 2000), *Crossing the Quality Chasm* (Institute of Medicine, 2001), and *Building a Better Delivery System* (Institute of Medicine and National Academy of Engineering, 2005), there is recognition that improving the health care delivery system will require a multifaceted response, involving numerous stakeholders such as providers, health care organizations, public and private purchasers, professional groups, and national agencies. Mechanisms for change advocated in these reports include:

- Financial mechanisms. Create financial incentives, including payment reform, for the use of quality improvement techniques and evidence-based medicine. Implement financial penalties for preventable medical errors. Increase research funding to investigate potential solutions to problems in the health care delivery system.
- Educational mechanisms. Spread knowledge related to tools and techniques that may be used to improve safety, effectiveness, and efficiency. Ensure that all providers are prepared to respond to the changing environment. Create multidisciplinary learning environments to foster innovative solutions to the problems of the current health care delivery system.
- Engineering mechanisms. "Design out" problems that contribute to problems such as medical errors. Create new structures that support evidence-based medicine and the use of information technology.
- Regulatory and market-based mechanisms: Develop performance standards and expectations both for the health care professional and health care organization.
- Provider-based mechanisms: Rely on the intrinsic motivation of providers as a force for improving the health care delivery system.

Thus, philosophically, there is consensus that an ideal health care system will not be realized through incremental improvements of the current system. This sentiment is most directly expressed in *Crossing the Quality Chasm* (Institute of Medicine, 2001): "The current care systems cannot do the job. Trying harder will not work. Changing systems of care will" (p. 4).

A second common theme among the reports is that improving individual components of the health care delivery system will lead to improvement of the overall, or whole, health care delivery system. This theme is most clearly expressed within two reports (Donaldson & Mohr, 2001; Nelson et al., 2001) that detail the microsystem philosophy. In this view, smaller parts of an organization (microsystems) are seen as having semipermeable boundaries with other microsystems, the whole of which is embedded in an environment. This broader environment consists of dimensions such as the payment environment, the regulatory environment, and the cultural–socio-political environment (Nelson et al., 2001). Examples of a microsystem include a dialysis unit, an emergency room within a community hospital, or a hospice care center

(Donaldson & Mohr, 2001). The microsystem philosophy states that (1) bigger systems are made of smaller systems, (2) the smaller systems produce quality, safety, and cost outcomes at the front line of care, and (3) the outcomes of the macrosystems can be no better than the microsystems that comprise it (Nelson et al., 2001). Thus, proponents of this philosophy maintain that improving individual microsystems will lead to improvement of the overall health care delivery system.

Finally, a third common theme among reports is that systems engineering approaches are a novel approach to changing the health care delivery system and should be adopted (e.g., Institute of Medicine, 2000, 2008a; Institute of Medicine and National Academy of Engineering, 2005; Rardin, 2007; Roberts et al., 2008). A common rationale presented for adopting systems engineering tools is that they have been successfully applied within other industries such as banking, manufacturing, and aviation. The reports reviewed suggest that the reason that systems engineering tools have not had a larger impact on changing the health care delivery system is that (1) knowledge of their existence is not widespread, (2) there are no incentives in place for either providers or health care organizations to use these methods, and (3) little funding exists to conduct research on the intersection of health care delivery and systems engineering. As a result, several reports advocate for increased cross-education between health care and engineering professionals (e.g., Institute of Medicine and National Academy of Engineering, 2005; Roberts et al., 2008) and incentives for implementing systems engineering tools within health care organizations (e.g., Institute of Medicine, 2008a; Institute of Medicine and National Academy of Engineering, 2005), and additional research funding (e.g., Institute of Medicine and National Academy of Engineering, 2005; Roberts et al., 2008) to encourage the use of these approaches.

Discussion

There is a contradiction between the philosophical view that solving health care is a complex problem that cannot have a solution grounded in the current system and many of the solutions presented. For example, there is a belief (although not shared by all) that certain solutions will be close to panaceas. In other words, there is a tendency to oversimplify the problem. Such sentiment is found, for example, in *Ending the Document Game* (Commission on Systemic Interoperability, 2005). In this report, the authors argue that many of the problems within health care, for example, problems related to cost, safety, efficiency, and effectiveness, could be solved through the adoption of information technology. The rationale behind this belief is that information technology will enable systems to fundamentally retain their current structure but better perform necessary tasks.

Furthermore, despite acknowledgement that fundamental changes to the delivery system are necessary, many of the changes proposed remain grounded in the current system. Thus, suggestions for increased research funding assume that Federal agencies will remain responsible for disseminating funds. Similarly, suggestions for the use of evidence-based medicine assume that care will primarily continue to be delivered in clinics and solutions for education assume that academic disciplines will, fundamentally, retain their existing boundaries.

A similar problem exists with the idea that implementing change at the level of the microsystem will result in meaningful change at the level of the macrosystem or the overall health care delivery system. Proponents of the microsystem viewpoint maintain that outcomes of the macrosystems can be no better than the microsystems that comprise it (Nelson et al., 2001). Although this is a reasonable statement, modest reflection reveals that its converse is more powerful. In other words, microsystems can be no better than the macrosystem in which they are embedded. It is the macrosystem which constrains what the microsystem is capable of achieving. Thus, the microsystem approach to improving the health care delivery system is also grounded within the current macrosystem reality.

The reflections above highlight that the solutions advocated contradict the understanding that improving the health care delivery system is complex and requires a fundamentally new solution. Answers proposed often either oversimplify the problem and/or remain grounded to current realities. Achieving true reform of the health care delivery system will require solutions that are true to our theoretical understanding of the problem as multidimensional and requiring a paradigm shift.

Unfortunately, the answer of systems engineering has, to date, also failed to yield any fundamental change. Common wisdom suggests that this failure is due to the lack of use, instead of any inherent limitation, of these methods. Failure to use these tools has been attributed to a lack of awareness, resources, or motivation to implement systems engineering knowledge.

There is reason to believe, however, that this failure is also the result of a combination of assumptions about systems engineering tools, of the structures in place to support their use, and of the traditional focus of both systems engineering tools and the health care delivery system. Although each of these factors will be examined in turn, the primary problem seems to be that there has been a focus on local instead of system-wide optimization.

A pervasive assumption exists that systems engineering tools have been useful in solving problems in other fields and will, therefore, be successful in the field of health care. The determination of whether systems engineering tools have been successful in other fields may depend upon the level of examination. Thus, for example, it may be argued that systems engineering tools such as human factors engineering have been useful for the redesign of the cockpit, preventing some pilot errors. Yet, a more microlevel examination may lead to a different conclusion. Aviation, banking, and manufacturing, all industries for which there has been a claim of success for systems engineering tools, are suffering deeply. A more accurate assertion, therefore, may be that systems engineering tools have been successful in solving microlevel problems, but have not been successful at solving many of the microlevel problems pervasive in each of these industries.

The support structures that have been built to support the use of systems engineering tools are similarly focused on local optimization. For example, organizations such as the Institute for Healthcare Improvement and the Leapfrog Group advocate the use of systems engineering tools at the level of a practice or a health care organization. Both the measures and tools presented for use assume that the overall health care delivery system will remain constant, and that it is the prerogative of each individual practice or institution to optimize their performance within this relatively fixed environment.

The culture of health care also promotes local optimization. Silos exist both at the level of the practice, the "microsystem" or subspecialty, and at the level of the health care organization. Each practice has its own panel of patients, each "microsystem" or subspecialty has its own specialized knowledge, and each health care organization has its own market share. At each level, therefore, there is incentive to optimize locally to preserve whatever advantage one currently enjoys. Particularly at the level of the health care organization, there is little incentive to join with another health care organization and to optimize at the level of joint operations. Such a maneuver may be an anathema to profit-driven health care organizations, which, in a market-based health care system, compete with one another for survival.

Finally, by their very nature, systems engineering tools are best suited for local optimization. Although systems engineering tools are meant to provide a means for obtaining a holistic perspective about and solution to a given problem, the "systems" that these methods were originally designed for were relatively small-scale systems such as a manufacturing plant floor or perhaps even an organization. Thus, it could be argued that the use of systems engineering tools at the level of a practice, "microsystem," or even health care organization is sensible. The methods are being used at the level for which they were originally designed.

If this is the case, what is the role of systems engineering tools in creating a vision of the future that is not grounded in the current system? To date, the relationship between systems engineering tools and the health care delivery system has been to use current systems engineering tools to optimize the current health care delivery system. In the future, this relationship will need to change such that new systems engineering tools are developed to facilitate the creation of an ideal health care delivery system.

Chapter 4: New Industrial and Systems Engineering Tools To Realize This Vision

Summary

There is very little discourse related to what new industrial and systems engineering tools must be created to realize a vision of an ideal health care delivery system. Although several reports mention that systems engineering tools must be adopted for use in health care or that new systems engineering tools must be developed for health care (e.g., Institute of Medicine, 2007; Institute of Medicine and National Academy of Engineering, 2005) only one report (Institute of Medicine and National Academy of Engineering) contains an in-depth discussion related to this topic. This report, *Building a Better Delivery System*, is divided into two parts. The first part contains a consensus report and the second, articles written by individuals. Little is mentioned in the consensus report about the need for new systems engineering tools. Only in the individual articles is there some detailed discussion about the new types of systems engineering tools that must be developed to improve the health care delivery system.

Examples of the new industrial and systems engineering tools proposed are presented below. Many of these methods are presented as also necessary to address complex problems within other fields such as manufacturing:

1. Methods of modeling and optimizing supply chains where demand is a function of multiple variables. Within health care, demand is a function of multiple variables including the types of treatment available and the insurance coverage available. Models are needed which can account for demand that does not have a single determinant.
2. Models of modeling and optimizing supply chains within which the actions of one party affect the options available to other parties. The activities of stakeholders in the health care system are interdependent. For example, the coverage decisions made by an insurance company may affect the treatment decisions made by a provider.
3. Methods of analyzing large-scale systems. Industrial and systems engineering tools contain methods such as value-stream mapping and facilities layout tools that may be used to analyze small-scale systems. These tools may be useful for optimizing a clinic or unit but are not as likely to be useful for optimizing an entire system.
4. Methods of modeling which replace the need for clinical trials. Developing knowledge via randomized controlled trials is considered time consuming and costly. Computer modeling techniques may be a useful means of generating the necessary evidence in a more efficient manner.
5. Methods of modeling and optimizing activities of multiple, independent agents. Health care consists of multiple, independent agents such as health care providers, health care systems, health care payers, and regulatory agencies working independently to optimize their position.

Discussion

The methods listed above provide a glimpse into the types of new industrial and systems engineering tools that may be needed to move beyond current improvement efforts. These methodological visions are a step in the right direction to move the tools available beyond local optimization. It should be noted, however, that many of these tools are also grounded in the assumption that the current health care delivery system will retain many of its features such as multiple, independent players and demand that is informed by the actions of insurance companies.

This latter point emphasizes the need also for new industrial and systems engineering tools that are grounded not in the current reality but in the vision of an ideal health care delivery system. The new tools created should be those that will be necessary to both create and optimize this vision. Thus, determining which new industrial and systems engineering tools are necessary must be the last step in the process. Without specifying a vision, it will be unclear what new types of tools will be needed to realize the vision.

Chapter 5: Questions To Stimulate Workshop Discussion

1. Are current systems engineering techniques scalable to be effectively used at levels higher than an organization?

2. Are we asking the right question? Instead of asking how the health care delivery system should respond to environmental changes such as the rising need for chronic care, should we be asking why there is a rising need for chronic care? In an article in the *New York Times* this week, Michael Pollan noted that one reason for rising chronic care is the rise in obesity due to the American diet. Similarly, asthma has increased due to environmental conditions. Instead of placing such emphasis on redesigning the health care delivery system, should we instead focus on preventing these environmental changes?

3. There is a pervasive assumption that providers are intrinsically motivated to deliver the best possible care. There is also an assumption that financial incentives are needed for providers to implement systems engineering tools and to use evidence-based medicine. This suggests that providers are also driven by other motivations. What are the implications of this apparent contradiction?

4. Given that the microlevel system constrains the microlevel systems, is there reason to believe that creating change at lower levels will lead to fundamental change for the entire delivery system?

5. There is a tension between revolutionary and evolutionary change. Historically, systems engineering tools have been used within the field of health care to create evolutionary change. How can systems engineering tools be used to create revolutionary change?

6. Many hold fast to the belief that information technology will solve many of the problems inherent in the current health care delivery system. Why does such an assumption exist? What are the pitfalls of such an assumption?

7. What is the meaning of “best practice”? How should we define “best practice,” given that the definition may differ depending upon the point of view (patient, practitioner, payer)?

8. How do we systematically balance the need for evidence-based care and the individuality of patients?

9. Who will use the newly developed industrial and systems engineering tools? If they are not focused on local optimization, who will be responsible for implementing them in practice?

Chapter 6: Conclusion

There is consensus among the reports reviewed that change to the current health care delivery system is necessary. An understanding exists at a theoretical level that changes to the system must be revolutionary, not simply grounded in current realities. Visions of an ideal health care delivery system are primarily descriptive, although some elements of the vision, such as the role of information technology, have been prescriptively defined.

Efforts at change, including the use of systems engineering methods have, however, remained grounded in current realities. The focus has been on locally optimizing elements of the entire system, such as a practice, unit, or organization. The use of systems engineering tools in this context is understandable given that (1) the culture of health care emphasizes local optimization, (2) existing systems engineering methods were created for local optimization, and (3) structures supporting the use of systems engineering methods promote local optimization.

To create a revolutionary new future, however, there is a need for new industrial and systems engineering tools that have a focus beyond local optimization. The reports reviewed contain a few suggestions of new industrial and systems engineering tools that have this broader focus. Several of these tools, however, are still grounded in the realities of the current health care delivery system. There is a need to create industrial and systems engineering tools that are grounded not in the current reality, but in the vision of an ideal health care delivery system.

References

1. Commission on Systemic Interoperability. Ending the document game: Connecting and transforming your healthcare through information technology. Washington, DC: U.S. Government Printing Office; 2005.

2. Donaldson MS, Mohr JJ. Exploring innovation and quality improvement in health care micro-systems: a cross-case analysis. Washington, DC: Institute of Medicine; 2001. A technical report for Institute of Medicine Committee on the Quality of Health Care in America.

3. Institute of Medicine. Crossing the quality chasm: A new health system for the 21st century. Washington, DC: National Academies Press, 2001.

4. Institute of Medicine. Engineering a learning healthcare system: A look at the future/Preliminary draft. Work in progress, 2008.

5. Institute of Medicine. The learning healthcare system: Workshop summary. Olsen L, Aisner D, McGinnis JM, eds. Washington, DC: National Academies Press, 2007.

6. Institute of Medicine. Learning healthcare system concepts v. 2008/Annual report. Washington, DC: National Academies Press, 2008.

7. Institute of Medicine. To err is human: Building a safer health system. Kohn LT, Corrigan JM, Donaldson MS, eds. Washington, DC: National Academies Press, 2000.

8. Institute of Medicine and National Academy of Engineering. Building a better delivery system: A new engineering/health care partnership. Reid PP, Compton WD, Grossman JH, Fanjiang G, eds. Washington, DC: National Academies Press, 2005.

9. Johnson CK. Will safety net hospitals survive health reform? Chicago Tribune. Available at: http://www.chicagotribune.com/news/chi-ap-us-healthcare-safety,0,5110897.story. Accessed September 7, 2009.

10. Landro L. A fight against fatal error. Wall Street Journal September 7, 2009. Available at: http://online.wsj.com/article/SB10001424052970203706604574378762626910076.html. Accessed September 7, 2009.

11. McClellan MB, McGinnis JM, Nabel EG, et al. Evidence-based medicine and the changing nature of health care. Washington, DC: Institute of Medicine; 2008.

12. National Research Council. Computational technology for effective health care: Immediate steps and strategic directions. Stead WW and Lin HS, eds. Washington, DC: National Academies Press; 2009.

13. Nelson EC, Batalden, PB, Godfrey MM, et al. Microsystems in health care: The essential building blocks of high performing systems. Princeton (NJ): Robert Wood Johnson Foundation; 2001. RWJ Grant Number 036103.

14. Rardin RL. Research agenda for healthcare systems engineering/Final report. Arlington, VA: National Science Foundation, February, 2007. NSF Grant No. 0613037.

15. Roberts S, Uzsoy R, Ivy J, Denton B. Workshop: Healthcare engineering and health services research: Building bridges, breaking barriers/Final report. Arlington, VA: National Science Foundation, April, 2008. NSF Grant No. 0817223.

16. Underwood A. Insured, but bankrupted anyway. New York Times September 7, 2009. Available at: http://prescriptions.blogs.nytimes.com/2009/09/07/insured-but-bankrupted-anyway/?scp=1&sq=medical%20bankruptcy&st=cse. Accessed September 7, 2009.

Appendix B: Workshop Participants

Patricia Flatley Brennan, RN, PhD, FAAN **(Chair)**
Professor and Chair, Industrial & Systems Engineering
College of Engineering
Lillian L. Moehlman Bascom Professor
School of Nursing
University of Wisconsin-Madison
pbrennan@engr.wisc.edu

Maulik S. Joshi, DrPH
(Morning Keynote Speaker)
President, Health Research & Educational Trust
Senior Vice President of Research, American Hospital Association

Aneesh Chopra
(Dinner Keynote Speaker)
United States Chief Technology Officer
Associate Director
Office of Science and Technology Policy

Oguzhan Alagoz, PhD
Assistant Professor
Department of Industrial & Systems College of Engineering
University of Wisconsin-Madison
alagoz@engr.wisc.edu

Nilay Tanik Argon, PhD
Assistant Professor
Department of Statistics & Operations Research
University of North Carolina at Chapel Hill
nilay@email.unc.edu

James Benneyan, PhD
Executive Director, New England VA Healthcare Engineering Partnership
Director, Healthcare Quality & Productivity Lab
Northeastern University
benneyan@coe.neu.edu

Brian Denton, PhD
Assistant Professor
Edward P. Fitts Department of Industrial & Systems Engineering
North Carolina State University
bdenton@ncsu.edu

Robert Dittus, MD, MPH
Albert & Bernard Werthan Professor of Medicine
Chief, Division of General Internal Medicine
Director, Institute for Medicine & Public Health
Director, Center for Health Services Research
Vanderbilt University
robert.dittus@Vanderbilt.Edu

Ilaina Edison, RN, MBA
Vice President for Operations
Visiting Nurse Service of New York
Ilaina.edison@vnsny.org

Seth A. Eisen, MD
Director of Health Services Research & Development
Department of Veterans Affairs
seth.eisen@va.gov

John Fowler, PhD
Editor, IIE Health Systems
Professor of Industrial Engineering
Arizona State University
john.fowler@asu.edu

Charles Friedman, PhD
Deputy National Coordinator for Health IT
U.S. Department of Health & Human Services
charles.friedman@hhs.gov

Stephanie Guerlain, PhD
Associate Professor
Department of Systems & Information Engineering
University of Virginia
guerlain@virginia.edu

Isaac Kohane, MD, PhD
Associate Professor of Pediatrics and Health Sciences & Technology
Director, Children's Hospital Informatics Program
Harvard University
isaac_kohane@harvard.edu

Ross Koppel, PhD
Sociology Department & Center for Epidemiology & Biostatistics
School of Medicine
University of Pennsylvania
rkoppel@sas.upenn.edu

Sally Lundeen, PhD, RN, FAAN
Professor and Dean
College of Nursing
University of Wisconsin - Milwaukee
slundeen@uwm.edu

Sanjay Mehrotra, PhD
Professor
Department of Industrial & Management Systems Engineering
Northwestern University
mehrotra@iems.northwestern.edu

Edmond Ramly
Industrial & Systems Engineering
University of Wisconsin-Madison
edmond.ramly@gmail.com

Marilyn Rantz, PhD, RN, FAAN
Professor, Sinclair School of Nursing
Helen E. Nahm Chair, Sinclair School of Nursing
University Hospitals & Clinics Professor of Nursing
Executive Director, Aging In Place
Associate Director, Interdisciplinary Center on Aging
University of Missouri
rantzm@health.missouri.edu

Michelle Rogers, PhD
Assistant Professor
College of Information Science & Technology
Drexel University
michelle.l.rogers@drexel.edu

Sarah Root, PhD
Assistant Professor of Industrial Engineering
University of Arkansas
seroot@uark.edu

Vinod Sahney, PhD
Senior Vice President and Chief Strategy Officer
Blue Cross Blue Shield of Massachusetts
vinod.sahney@bcbsma.com

Eugene S. Schneller, PhD
Professor
Dean's Council of 100 Distinguished Scholar
Health Sector Supply Chain Initiatives
School of Health Management & Policy
W. P. Carey School of Business
Arizona State University
gene.schneller@asu.edu

Julie Swann, PhD
Associate Professor of Industrial & Systems Engineering
Georgia Institute of Technology
jswann@isye.gatech.edu

James M. Walker, PhD, FACP
Chief Health Information Officer
Geisinger Health System
jmwalker@geisinger.edu

Merry Ward, PhD, MS
Healthcare Informatics Research
Department of Veterans Affairs
merry.ward@va.gov

Steven Witz, PhD, MPH
Director, Regenstrief Center for Healthcare Engineering
Purdue University
witz@purdue.edu

Shinyi Wu, PhD
Assistant Professor
Daniel J. Epstein Department of Industrial & Systems Engineering
University of Southern California
shinyiwu@usc.edu

José L. Zayas-Castro, PhD
Professor and Chair
Department of Industrial & Management Systems Engineering
University of South Florida
josezaya@eng.usf.edu

David Zimmerman, PhD
Professor
Director, Center for Health Systems Research & Analysis
University of Wisconsin-Madison
davidz@chsra.wisc.edu

Appendix C: Agenda

DAY ONE: WHAT ENGINEERING KNOWLEDGE IS NEEDED TO CREATE A DESIRED FUTURE FOR HEALTH CARE?

8:00 am *Registration and Continental Breakfast*

8:30 am **Welcome**
Patricia Flatley Brennan, Lillian L. Moehlman Bascom Professor, School of Nursing and College of Engineering, University of Wisconsin-Madison

8:35 am **Welcome and Comments by AHRQ & NSF**
Teresa Zayas-Cabán, Senior Manager, Health IT, Agency for Healthcare Research and Quality

Cerry Klein, Program Director, Service Enterprise Systems and Manufacturing Enterprise Systems, National Science Foundation

9:00 am **Chair's Presentation**
Patricia Flatley Brennan

9:30 am **Keynote Presenter**
Maulik Joshi, President, Health Research & Educational Trust
SVP of Research, American Hospital Association

10:00 am **Plans for the Day**
Patricia Flatley Brennan

10:10 am *Break*

10:30 am **Vision Statements**

1. Information Technology/Finance and Quantitative Decision Making
2. Systems Analysis, Change and Implementation Theories
3. Materials Management and Production Processes
4. Human Factors and Sociotechnical Systems
5. Quality Engineering

12:00 pm *Lunch*

1:00 pm **Breakout Groups:**

Breakout A: Information Technology/ Finance and Quantitative Decision Making
Session Co-Chairs – James Walker, Chief Health Information Officer, Geisinger Health Systems; *Brian Denton, Assistant Professor, North Carolina State University*

Breakout B: Systems Analysis, Change and Implementation Theories
Session Chair – José L. Zayas-Castro, Professor & Chairperson, University of *South Florida*

Breakout C: Materials Management and Production Processes
Session Chair – Eugene S. Schneller, Ph.D., Professor, School of Health Management and Policy, W. P. Carey School of Business Arizona State University

Breakout D: Human Factors and Sociotechnical Systems
Session Chair – Stephanie Guerlain, Associate Professor, Department of Systems and Information Engineering, University of Virginia

Breakout E: Quality Engineering
Session Chair – James Benneyan, Executive Director, New England VA, Healthcare Engineering Partnership, Director, Quality and Productivity Laboratory, Northeastern University

2:30 pm **Open Discussion**

3:30 pm *Break*

3:45 pm **Cross-cutting Groups:**
Breakout A: Managing acute illness and disease

Breakout B: Creating effective models of health promotion and disease prevention

Breakout C: Insuring chronic disease management

Breakout D: Enhancing the end-of-life experience

Breakout E: Facilitating public health

Breakout F: Accelerating discovery

5:15 pm **Chair's Summary**

Patricia Flatley Brennan

5:30 pm *Adjourn*

6:00 pm **Working Dinner**
Address by Aneesh Chopra, Chief Technology Officer & Associate Director of Technology, Office of Science and Technology Policy, United States

DAY TWO: FROM DISCUSSION TO ACTION: A PLAN FOR MOVING AHEAD

8:00 am *Working breakfast*

Policy Discussion (research in an ever-changing world)
Patricia Flatley Brennan

8:45 am **Plans for the Day**
Patricia Flatley Brennan

9:00 am **Breakout Groups:**

Breakout A: Information Technology/ Finance and Quantitative Decision Making
Session Co-Chairs – *James Walker, Chief Health Information Officer, Geisinger Health Systems*; *Brian Denton, Assistant Professor, North Carolina State University*

Breakout B: Systems Analysis, Change and Implementation Theories
Session Chair – *José L. Zayas-Castro, Professor & Chairperson,* University of *South Florida*

Breakout C: Materials Management and Production Processes
Session Chair – *Eugene S. Schneller, Ph.D., Professor, School of Health Management and Policy, W. P. Carey School of Business Arizona State University*

Breakout D: Human Factors and Sociotechnical Systems
Session Chair – *Stephanie Guerlain, Associate Professor, Department of Systems and Information Engineering, University of Virginia*

Breakout E: Quality Engineering
Session Chair – *James Benneyan, Executive Director, New England VA, Healthcare Engineering Partnership, Director, Quality and Productivity Laboratory, Northeastern University*

10:00 am	*Break*
10:15 am	**Presentation: Research Agenda**
11:30 am	**Update and Revise Research Agenda (Group Work)**
12:15 pm	*Lunch*
1:00 pm	**Roundtable Discussion** *Led by Patricia Flatley Brennan*
3:00 pm	**Concluding Remarks** *Patricia Flatley Brennan*
3:10 pm	**Thanks and Logistics** *Patricia Flatley Brennan*
3:30 pm	*Adjourn*

Appendix D: ISyE Small Group Assignments

Breakout Group Assignments

1:00 PM – 2:30 PM
Monday, September 21, 2009
9:00 AM – 12:15 PM
Tuesday, September 22, 2009

Breakout A – Information Technology/Finance & Quantitative Decisionmaking
Session Co-Chairs – James Walker and Brian Denton
Facilitator - Jacquie Munson-Gaines
Note Taker – Perci Abu

1. Oguzhan Alagoz
2. Ilaina Edison
3. Charles Friedman
4. Isaac Kohane
5. Sarah Root

Breakout B – Systems Analysis, Change and Implementation Theories
Session Chair – José L. Zayas-Castro
Facilitator – Frank Carlos Gihan
Note Taker – Paolo Gonzalez

1. Robert Dittus
2. Sally Lundeen
3. Sanjay Mehrotra
4. Steven Witz

Breakout C – Materials Management and Production Processes
Session Chair – Eugene Schneller
Facilitator – Nhan Tran
Note Taker – Don Cunningham

1. John Fowler
2. Edmond Ramly
3. Julie Swann

Group D – Human Factors and Sociotechnical Systems
Session Chair – Stephanie Guerlain
Facilitator – Jerry Stayton
Note Taker – John Ryan

1. Ross Koppel
2. Marilyn Rantz
3. Michelle Rogers
4. Vinod Sahney

Breakout E – Quality Engineering
Session Chair – James Benneyan
Facilitator – Jennifer Raviv
Note Taker – Sean Fox

1. Nilay Tanik Argon
2. Seth Eisen
3. Merry Ward
4. Shinyi Wu
5. David Zimmerman

Appendix E: Health Care Challenge Area Small Group Assignments

Cross-Cutting Group Assignments

3:45-5:15 PM
Monday, September 21, 2009

Group A - Managing Acute Illness and Disease
Facilitator – Jacquie Munson-Gaines
Note Taker – Perci Abu

1. Oguzhan Alagoz
2. James Benneyan
3. Ross Koppel
4. James Walker
5. Merry Ward

Group B - Creating Effective Models of Health Promotion and Disease Prevention
Facilitator – Pam Wilson
Note Taker – Randi Henderson

1. Edmond Ramly
2. Sarah Root
3. Vinod Sahney
4. Steven Witz

Group C - Insuring Chronic Disease Management
Facilitator – Frank Carlos Gihan
Note Taker – Paolo Gonzalez

1. Brian Denton
2. Eugene Schneller
3. Julie Swann
4. David Zimmerman

Group D - Enhancing the End-of-life Experience
Facilitator – Nhan Tran
Note Taker – Don Cunningham

1. Ilaina Edison
2. Stephanie Guerlain
3. Marilyn Rantz
4. Shinyi Wu

Group E - Facilitating Public Health
Facilitator – Jerry Stayton
Note Taker – John Ryan

1. Seth Eisen
2. Sally Lundeen
3. Sanjay Mehrotra
4. José L. Zayas-Castro

Group F - Accelerating Discovery
Facilitator – Jennifer Raviv
Note Taker – Sean Fox

1. Nilay Tanik Argon
2. Robert Dittus
3. John Fowler
4. Charles Friedman