RESEARCH AGENDA FOR HEALTHCARE SYSTEMS ENGINEERING

Final report from a workshop held June 15-16, 2006

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Executive Summary

Healthcare delivery in the United States is in a crisis of inconsistent and sometimes dismal quality, safety and efficiency, with exploding cost. Paradoxically, while engineering is at the heart of many of the dramatic advances in medical diagnostics and interventions, the engineering that has been done on healthcare delivery processes and operations has had more limited impact, leaving many elements of those delivery systems largely unimproved in half a century. Furthermore, few healthcare professionals are trained to think analytically about delivery systems or even conceive of them as subject to research and engineering.

Workshop. This report derives from a workshop of researchers, sponsors, and graduate students held at NSF headquarters in Arlington, Virginia on June 15-16, 2006. Motivated in part by a recent joint study (*Building a Better Delivery System: A New Engineering/Health Care Partnership*, 2005) of the National Academy of Engineers (NAE) and the Institute of Medicine (IOM), the workshop sought to begin the task of envisioning an agenda for Healthcare Systems Engineering (HcSE) research to confront these yawning delivery challenges. The Service Enterprise Engineering Program of the Design, Manufacture and Innovation Division at National Science Foundation (NSF) was the principal sponsor. Contributions also came from the National Institutes of Health's (NIH's) National Institute of Biomedical Imaging and Bioengineering (NIBIB) and Purdue University's Regenstrief Center for Healthcare Engineering (RCHE). Although informed by the collection of excellent presentations at the workshop and the associated informal discussions, the opinions expressed in this report are those of the author. Many helpful refinements were also suggested by workshop participants in reviewing early drafts of the report.

Taxonomies. The breadth of needed healthcare engineering research is so enormous that it is useful to introduce some organizing taxonomies before turning to specific elements of a research agenda. A first considers the level of the care system to which research is addressed -- whether patient focused on evidence-based choice of interventions for particular cases, population concerned with cost-effective interventions intended for whole populations of patients with like characteristics, team addressed to efforts of frontline care groups, organization concerned with effectiveness and cost of operations and processes within provider facilities, network recognizing the complex mix of organizations and payers who must work together in a decentralizing healthcare delivery system, or environment confronting the regulations, insurance and other payers, consumer and employer interests within which healthcare functions. HcSE research is also classified according to the domain of engineering activity involved – whether technology investigating the tools and components that empower healthcare delivery systems, model-based applying tools of Operations Research, Industrial Engineering, and Operations Management in system design and planning, or practice-based using field trials, survey, and data analysis to improve clinical practice.

Research Priorities. The bulk of the report is a systematic presentation of 27 topics of potential research interest organized within the 6 levels of the patient care taxonomy. Research potential for each is evaluated in all 3 of the engineering domains. Those highlighted for priority consideration within the model-based domain of particular interest for this workshop are as follows:

- Treatment Optimization. Formal optimization can often be employed to explicitly or implicitly optimize a measure of treatment success for the patient over the applicable requirements and treatment details. Examples are optimal delivery of radiation therapy for cancer with its plethora of beam angle and intensity choices, and choice of paths of care for diabetics. The topic has great potential for both new science/methodology innovation and broad healthcare system impact.

- Personalized, Predictive Care. Although its potential is only beginning to even be understood, let alone realized, advances in genomics and proteomics are laying the foundation for transformation in all levels of healthcare by identifying biological markers that both predict health risks and guide the choice of interventions. Modeling and optimization research can have a leading role in how these new protocols for healthcare are delivered if research begins now on how to design, plan and control the new forms of healthcare delivery systems.
- Information Rich and Configurable Operations Management. Operations management research topics centered on the organization level of care have been studied for half a century but remain to realize their full potential. In many cases what is needed is adaptation of fairly well understood methodologies. However, there are special opportunities emerging as widespread information and communications technology finally permeates healthcare delivery facilities. It is also important that more scalable and adjustable forms of operations management models be developed to provide generic tools more easily adapted to widespread application.
- Collaboration Within Networks. Opportunities abound for valuable research targeting collaboration among the many individual provider organizations of modern healthcare networks. The spectrum of attractive topics spans everything from routine provider-to-provider handoffs, to emergency response, to home and telehealth, to patient-care-quality linked supply chain advances. Two decades of supply chain research in other fields can provide many places to start if sufficient attention is addressed to the performance metrics that make healthcare systems different.
- Large-Scale Delivery System Design. Although not limited to any particular level of care, many of the problems discussed in this report present a similar challenge: optimal design of large-scale delivery systems involving information and communication flows, along with dynamically varying patient demands and provider availabilities, while computing value received and costs incurred to assess performance. Deep and highly valuable research may be possible to produce generic, multi-purpose numerical models that can be adapted to a variety of such healthcare delivery system design tasks.

Important challenges for research in the Human Factors engineering were also highlighted at all levels of care. Patient computer interfaces are a major hurdle to expanded use of home and telehealth care. Electronic medical records and the data entry protocols to support them are an active area of research, but far from successfully resolved. Safety engineering investigations and tools need to be standard in reducing medical errors. Clinical reminders can track cost and warn of danger, but important research is needed on both better technology and user interfaces. Team productivity is critical to effective healthcare, although it is far from well understood, and metrics are largely unavailable to quantify progress.

Funding the Agenda. The 2005 NAE/IOM study on a new engineering / healthcare partnership set out a vision for broad new federal investment in academic, engineering-driven research scaled to the dimensions of the critical national need for healthcare delivery transformation in the United States. Unfortunately, that vision is far from realization as this report is written. Instead, HcSE is caught in an inter-agency stalemate, chiefly between the NIH and NSF. NSF is the government's primary home for much of the nation's model-based science and engineering research, but some of its budget-strapped leaders argue that healthcare is NIH's domain, just as energy belongs to the Department of Energy (DOE) and transportation to the Department of Transportation (DOT). However, these analogies are not entirely apt. NIH is indeed the primary home of medical research. But unlike the DOE and DOT cases, systems engineering, especially its model-based healthcare delivery aspects, is not embraced by most parts of NIH and largely incompatible with that agency's organization around medical conditions and demographic groups. Absent major institutional realignment at NIH, NSF appears to be the only federal agency equipped to confront the model-based part of the HcSE challenge.

The limited research which is currently funded has NIBIB and parts of NSF taking the lead in the technology domain of healthcare engineering, NSF with limited help from NIH spearheading model-based research, and primary coverage of the practice-based domain coming from Agency for Healthcare Research and Quality (AHRQ) supported at times by the National Library of Medicine (NLM) and other components of NIH. In the absence of funding appropriate to the research challenge, ways need to be found to maximize the impact of these modest efforts.

- <u>Healthcare Engineering Alliance</u>. Immediate efforts should be made to establish a Healthcare Engineering Alliance among federal sponsors. Modeled after other successful collaborations in manufacturing, nanotechnology and bioengineering, the alliance would hold annual workshops to exchange information on research progress, and coordinate solicitations for grants and contracts. The goal would be to strengthen the working relationships among the agencies that will necessarily be involved in any future acceleration of healthcare engineering research, and to bring more visibility to the field.
- <u>Three-Part Program Leadership</u>. An alliance can provide some degree of strategic leadership in healthcare engineering, but separate focuses of the currently interested agencies will likely sustain for some time. NIBIB should be designated to lead engineering research in the technical domain, NSF should have responsibility for model-based research, and AHRQ should lead on practice-based investigation.
- <u>Partnership Grants</u>. There are numerous challenges where interdisciplinary collaboration among the domains of healthcare engineering is essential. For example, technology advances will have greatest impact if they are utilized in optimally designed delivery systems and planning processes. NSF has experience stimulating collaboration on such interdisciplinary projects with what might be called Partnership Grants. Such grants are joint solicitations from agencies interested in different parts of a problem that are posed with a requirement that all responding teams include one researcher from each domain involved.
- <u>Opportunistic Vigilance</u>**.** Moving forward to strengthen existing sponsor relationships with collaborative infrastructure cannot relieve either the program managers or the research leaders in healthcare engineering from pursuing opportunities for broader funding. For example, partnerships could be assembled to fit HcSE needs into NSF's huge Cyber Infrastructure program, or to structure one of the Engineering Directorate's Emerging Frontiers in Research and Innovation (EFRI) projects. Also, opportunities for significant funding from agencies of the DOD, state governments, and private foundations need to be further explored.

1 Introduction

1.1 The Healthcare Challenge

Healthcare delivery in the United States is in a crisis of inconsistent and sometimes dismal quality, safety, efficiency and access, with exploding cost. It is the largest U.S. industry, currently consuming 15% of the Gross Domestic Product (GDP) and over $6000 per capita. Both these statistics significantly exceed corresponding results for all other developed countries, where healthcare consumes no more than 12% of GDP and $4100 per capita. In addition, U.S. costs are growing at three times inflation because of the rapidly aging population, exploding chronic diseases, and accelerating advances in powerful but expensive medical technology. The resulting financial stress impacts every industry and governments at all levels. At the same time there are serious access shortfalls with over 46 million Americans having no healthcare insurance, many more significantly under-insured, and healthcare constituting the leading cause of personal bankruptcy.

It is paradoxical that while engineering is at the heart of many of the dramatic advances in medical diagnostics and interventions, the engineering that has been done on healthcare delivery processes and operations has had more limited impact, leaving many elements of those delivery systems largely unimproved in half a century. Furthermore, few healthcare professionals are trained to think analytically about delivery systems or even conceive of them as subject to research and engineering. Among the consequences is that lives unnecessarily lost each year in the U.S. due to preventable medical errors are estimated as high as 98,000 and injuries over a million -- higher than losses to auto accidents. An estimated 30-40% of healthcare expenditures go to overuse, underuse, misuse, duplication, system failures, unnecessary repetition, poor communication, and inefficiency. Still, only about half of patients receive best-practice care for their condition. Healthcare is also massively under-invested in information technology, with fewer than 15% of patient records available electronically, and banks spending 4-5 times as much on IT. Coordination and continuity of care are also piecemeal as patients move through a complex of providers, most under separate management with minimal information sharing. The jumble of third party payers funding most of the care, together with distribution of activity across providing institutions and professions, creates perverse economic incentives at every turn.

1.2 Healthcare Systems Engineering Workshop

This report derives from a workshop of researchers, sponsors, and graduate students held at NSF headquarters in Arlington, Virginia on June 15-16, 2006. The goal was to begin the task of envisioning an agenda for Healthcare Systems Engineering (HcSE) research to confront the delivery challenges sketched above. Improvements in medical technology, especially IT and communication can provide building blocks. But the systems task is to fashion replicable, predictive models and other tools for designing engineering-integrated systems of personnel, information and communication technologies, and facilities, together with the planning and control regimes that can together transform the safety, cost, quality, and efficiency of healthcare delivery. Leading researchers in the field offered overviews of topic areas, sponsors discussed funding prospects, and breakout groups evolved agendas for future research. The Service Enterprise Engineering Program of the Design, Manufacture and Innovation Division at National Science Foundation (NSF) was the principal sponsor. Contributions also came from the National Institutes of Health's (NIH's) National Institute of Biomedical Imaging and Bioengineering

(NIBIB) and Purdue University's Regenstrief Center for Healthcare Engineering (RCHE). (See www.purdue.edu/discoverypark/rche/hcse and the Appendices of to this report for workshop materials and presentations.)

This HcSE workshop was conceived as the counterpart to an earlier one on "Improving Health Care Accessibility Through Point-of-Care Technologies" sponsored primarily by the NIBIB at Crystal City, Virginia on April 11-12, 2006. NSF and other parts of NIH cosponsored. That meeting focused on the supporting technologies of healthcare delivery including biosensors, monitors, imaging and informatics, together with their integration into clinical and telehealth needs. (See www.nibib.nih.gov/publicPage.cfm?pageID=4534)

Although informed by the collection of excellent presentations at both these workshops, and the associated informal discussions, the opinions expressed in this report are those of the author. Many helpful refinements were also suggested by workshop participants in reviewing earlier drafts of the report.

1.3 NAE/IOM Study

Both workshops were motivated in part by a recent joint study of the National Academy of Engineers (NAE) and the Institute of Medicine (IOM) entitled *Building a Better Delivery System: A New Engineering/Health Care Partnership* and released in 2005. (Available online at www.iom.edu/CMS/3809/28393.aspx .) The study was funded by NSF, the NIBIB, and the Robert Wood Johnson Foundation.

That NAE/IOM study recommended intensified research on two classes of engineered solutions:

- Delivery facilitating information and communication technology including a comprehensive national health information infrastructure, human-computer interfaces, software for interoperability among vendors, secure and disbursed databases, and microsystems for sensing and monitoring physiological parameters
- Healthcare system engineering modeling, analysis and human factors tools adapted from the systems revolution seen in manufacturing and distribution over recent decades

Both would be energized by a determined effort to cross-educate engineers and healthcare professionals on the value and opportunities for partnership.

Another central recommendation of the report is to establish several multidisciplinary centers at institutions of higher learning, funded over 5-10 years at several million dollars per annum and bringing together appropriate fields of engineering, health sciences, management, and social and behavioral sciences. The report describes the centers mission as "(1) to conduct basic and applied research on the systems challenges to health care delivery and on the development and use of systems engineering tools, information/communications technologies, and complementary knowledge from other fields to address them, (2) to demonstrate and diffuse the use of these tools, technologies and knowledge throughout the health care delivery system (technology transfer); and (3) to educate and train a large cadre of current and future health care, engineering, and management professionals and researchers in the science, practices and challenges of systems engineering for health care delivery." Recognizing that funding for such centers would come from a variety of federal agencies, the report also proposes that a lead agency be identified to take the initiative on establishing and sustaining those vital institutions.

1.4 Current Sponsors

Unfortunately, none of the federal centers envisioned by the NAE/IOM study has materialized, and no agency has stepped forward to take the lead. Still, there is some support.

- NSF has sustained with a very limited budget the government's only generic research on model-based methods of HcSE. Various other parts of NSF also support research on the cyber-infrastructure and enabling information and control technologies of bioengineering that can empower delivery system advances.
- NIBIB is the lead NIH agency for engineering research on imaging and bioengineering tools that can enable HcSE. However, theirs is one of the smallest budgets of all NIH centers and institutes, and almost no work on actually integrating technologies into delivery processes and operations is supported.
- The National Library of Medicine (NLM) maintains a modest research program on information systems aspects of healthcare delivery.
- Other centers and institutes of the NIH, which are primarily organized around medical conditions or demographic groups, have also sponsored HcSE research in particular circumstances such as National Cancer Institute support of cancer therapy delivery optimization research. However, no single unit leads or coordinates these activities.
- The Agency for Healthcare Research and Quality (AHRQ), which is another part of the Department of Health and Human Services, has taken the lead on practice-based clinical implementation research in healthcare delivery systems. Unfortunately, it too has a budget far below the level required to energize the needed research.
- The Department of Veterans Affairs (VA) has pioneered a number of advances in electronic medical records and patient safety for its own clinical networks. However, it has an explicit policy of doing work internally and limiting support to researchers outside the VA.
- The Department of Defense (DOD) also operates a huge network of healthcare facilities as part of the Military Health System and invests significantly in biomedical research. Prospects for DOD support of academic HcSE research have yet to be explored.
- State departments of health are often interested in particular topics, especially those involving policy issues, access and emergency response.
- Private foundations like the Robert Wood Johnson Foundation have long supported research related to HcSE. However, their attention has increasingly been drawn to national and international policy challenges as opposed to operations, processes and technology for healthcare delivery.

1.5 Sources for This Report

The bulk of background information presented in this report is drawn from presentations at the NSF-led workshop in June 2006 and its NIBIB-led counterpart in April 2006, together with material in the NAE/IOM report. Both workshops were introduced in Section 1.2, and full PowerPoint presentations from the June meeting are available online at www.purdue.edu/discoverypark/rche/hcse. Where relevant, these primary sources were supplemented by information in several Institute of Medicine reports: *To Err is Human* (2000), *Crossing the Quality Chasm* (2001), and *Insuring America's Health: Principles and Recommendations* (2004). Some statistics were also drawn from international comparisons of the Organization for Economic Co-operation and Development (OECD, www.oecd.org), and the domestic information in the U.S. Census Bureau's *Income, Poverty, and Health Insurance Coverage in the United States,* www.census.gov/prod/2005pubs/p60-229.pdf . Other useful sources in book form include *Operations Research and Health Care: A Handbook of Methods and Applications,* Kluwer 2004, edited by Margaret Brandeau, Francois Sainfort and William Pierskalla, and the text *Quantitative Methods in Health Care Management: Techniques and Applications,* Jossey-Bass 2005, by Yasar A. Ozcan.

2 Organizing Taxonomies of Healthcare Engineering Research

The breadth of needed healthcare engineering research is so enormous that it is useful to introduce some organizing taxonomies before turning to specific elements of a research agenda. Two are presented here.

2.1 Six Levels of Care

One way to categorize healthcare engineering research is to consider the level of the care system to which it is addressed. The NAE/IOM study adapted an earlier 4-level breakdown. This report adds the refinements of recognizing new Population and provider Network levels to obtain the 6-part scheme depicted in Figure 1.

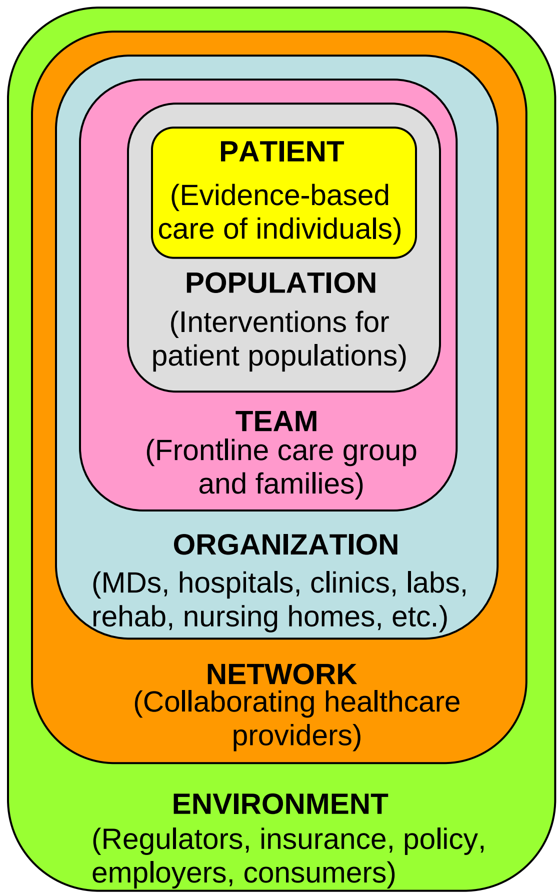


Figure 1. Levels of Care Taxonomy

- Patient. At the core of the system is care of individual patients. Research is addressed to evidence-based choice of interventions.
- Population. The population level of care addresses cost-effective interventions intended for whole populations of patients with like characteristics.
- Team. The team level of analysis focuses on improving the coordinated efforts of the frontline care group, and their collaborations with family and other caregivers.
- Organization. Providers work within the component clinical organizations. Research at that level addresses the quality, effectiveness and cost of operations and processes.
- Network. An increasingly complex network of collaborating organizations and payers, often with separate goals and ownership, must work together to assure proper care in a decentralizing healthcare delivery system. Network level research addresses methods to align goals and processes for effective collaboration among components of the network.
- Environment. All healthcare delivery operations function within an environment of government and professional regulations, insurance and other payers, consumer and employer interests, and more. Research at this level addresses how to better align these policies with effective and cost-efficient healthcare delivery, and how to account for disruptive innovations like the promise of predictive medicine.

2.2 Three Engineering Domains

Noting, among other things, the diverse interests of the sponsors sketched in Section 1.4, it will also be useful to classify healthcare engineering research according to the tools and approaches of investigations undertaken.

- Technology. One domain investigates the technologies and components that empower improvements in healthcare delivery systems. Sensors, imaging, information technology and communication are central issues, but human-computer interfaces to devices and software are also a major target. The NIBIB is the leading government sponsor in this domain, although others, including NSF and AHRQ, have important roles.
- Model-Based. Applications of classic tools of Operations Research, Industrial Engineering, and Operations Management center on model-based design, planning and control of healthcare delivery interventions and operations. Included are optimization, simulation, scheduling, Markov systems, games and equilibria, and quality assessment. The target is generic decision systems transferable across many clinical environments. NSF has been the government's main sponsor of this sort of healthcare engineering research.
- Practice-Based. The practice-based level of healthcare engineering operates closest to providers and clinics. Drawing on field trials within one or more practices, surveys and data analysis, it seeks to discover process advancements and improved standards for clinical practice. The AHRQ leads government sponsor interest in this domain, although various branches of NIH participate on some topics.

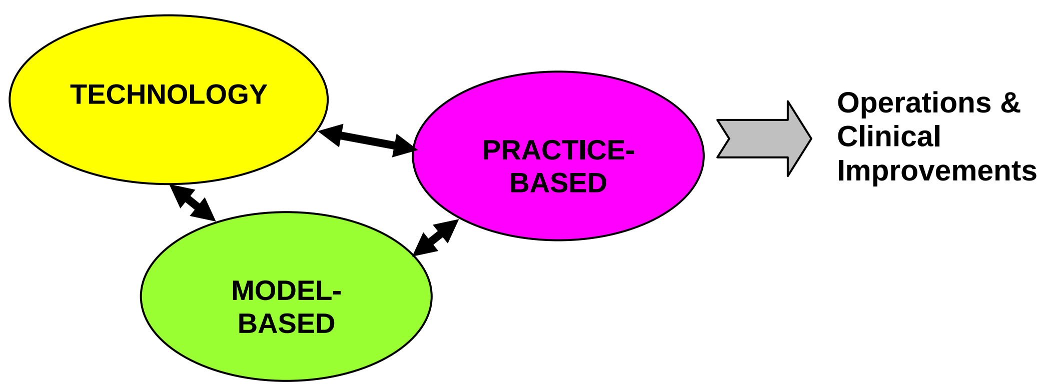


Figure 2. Engineering Domain Taxonomy

The above figure illustrates how these domains of healthcare engineering combine to produce delivery systems improvements. Technology provides critical building blocks. Model-based analysis integrates personnel, facilities, and technology to improve quality, efficiency and cost. Practice-based investigation refines concepts derived from technology and models in a culture of continuous clinical improvement, while also discovering new challenges for the other two domains. Success often requires intense collaboration among all three.

2.3 Essential Role of Practitioner Partnership

This report is about the way forward in Healthcare Systems Engineering (HcSE), and it has been useful to organize the proposed effort according to the six levels of care and the three engineering domains of Sections 2.1 and 2.2. Still, it is important to reaffirm vigorously that almost none of the research to be discussed can be done successfully by engineers and allied technical disciplines alone. No matter how well motivated he/she may be, no engineer can ever understand the challenges in healthcare as well as the professionals who have trained for years and confront the problems every day. Conversely, better understanding and appreciation of HcSE among practitioners is essential for future advances. Success in healthcare engineering research almost always grows out of a solid collaboration with both healthcare professionals and engineering analysts contributing and learning from one another.

3 Assessment of Healthcare Systems Engineering Topics

Using the taxonomies of Section 2, most of the rest of this report will attempt to provide a summary assessment of numerous topics available for investigation in engineering-driven healthcare research. Although the focus is on research in the narrower topic of Healthcare Systems Engineering, which was the center of the June 2006 workshop, broader issues highlighted in the earlier Point-of-Care workshop in April 2006 and elsewhere are also treated as appropriate. As in all assessments, there are bound to be disagreements among the judgments of different research leaders. Still, the evaluations below are intended to reflect the author's understanding of the rough consensus among those participating in the June HcSE workshop.

Discussions to follow are organized by the six levels of care presented in Section 2.1. To provide a concise summary of each, research topics are enumerated and assessed in a table like the one depicted in Figure 3. The potential of each topic to produce high-value research advances if energetically pursued is evaluated as H=high, M=moderate, or L=low for interest in the Technology, Model-Based, and Practice-Based domains of healthcare engineering described in Section 2.2. Potential is intended to reflect both critical need to find solutions in the problem domain and plausible research paths with great promise. Color/shaded-coding is employed as in Figure 4 for emphasis.

	Technology	Model		Practice
Research Topic		Method	Impact	

Figure 3. Table Format for Concise Assessment

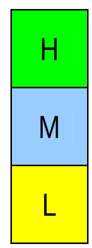


Figure 4. High/Moderate/Low Coding of Topic Potentials

The model-based domain is the most methodologically and mathematically intense of the three. Thus it is possible to distinguish between the methodology interest of research on a topic versus its impact on the healthcare system. For example, some advances in science/methods will have little short term impact but significantly advance the power of associated tools. Other topics require little new science, but application of currently available methods can produce important healthcare delivery advances. It is for that reason that Method and Impact are scored separately in the Model-Based domain.

3.1 Research at the Patient Level of Care

Research Topic	Technology	Model: Method	Model: Impact	Practice
Practitioner Decision Support	M	M	M	H
Patient Decision Support	L	M	M	M
Treatment Optimization	M	H	H	M

The practice of medicine has always focused on one patient at a time. However, tools of systems engineering have recently demonstrated their potential to assist with clinical decisions by helping stakeholders to investigate the ever more complex array of intervention choices and risks for a given patient. In most cases the analysis is from the point of view of the treating clinical professional, but sometimes tools are intended to help patients decide what risks to take with their own health.

Practitioner Decision Support. As the variety of conditions to diagnose and interventions to consider grow at an explosive pace, there is an increasing role for computer-based decision aides intended for practitioners. Such research is unlikely to ever replace the judgment of highly trained physicians and nurses, but it can help to assure important considerations are not overlooked. One example is software to assess risks of proposed pharmaceutical prescriptions including drug interactions and allergies. Improvements in technology are important to continuing advances – especially human computer interactions that explore considerations in a user-friendly manner. Model-based tools can enhance the power of such practitioner aides by implementing agreed decision rules and simulating consequences. Still, most of the knowledge base for practitioner decision support comes from practice-based trials. This is especially true of the rapidly growing base of information on customizing care according to genomic and proteomic distinctions among patients.

Patient Decision Support. In many sorts of medical crises, the patient (and his/her loved ones) needs to take an active role in deciding courses of action. One example is choosing whether to accept an available organ for transplant, taking into account the risks of a poor match now versus likely availability of better choices in the future. Standard methods of interactive decision support can help to structure and inform such weighty decision processes, as well as to facilitate interactions between patient and providers. Technology and model-based aides to such tools are often more readily available and less sophisticated than in the practitioner case. Still, the interactions are certainly informed by insights from practice-based experimentation.

Treatment Optimization. Once a broad course of action has been selected, formal treatment optimization can often be employed to explicitly or implicitly optimize a measure of treatment success for the patient over the applicable requirements and treatment details. Examples are optimal delivery of radiation therapy for cancer with its plethora of beam angle and intensity choices, and choice of paths of care for diabetics. As with any prediction of human physiological change, there is almost always risk and uncertainty in the decision making. Sometimes it can be ignored, but often it must be explicitly modeled to obtain valid results.

Those developing ever more sophisticated treatment technologies must have at least moderate interest in how they can be optimally employed. Practice-based research also devotes attention to implications for clinical processes and feeds back important insights to optimization formulations. But the heart of this research topic lies in the model-based tools used to accomplish the optimizations. The mathematical challenge and size of the models – especially handling of combinatorial phenomena and uncertainty – makes research in this area likely to yield valuable methodological advances. At the same time the wide variety of health conditions that can be addressed implies both the need for a variety of modeling tools and an enormous potential impact on treatment cost and effectiveness.

3.2 Research at the Population Level of Care

Research Topic	Technology	Model		Practice
		Method	Impact	
Patient Screening and Monitoring	H	M	M	H
Wellness and Behavior Change	H	M	M	H
Personalized, Predictive Care	H	H	H	H

Although the ultimate care will be delivered to single patients, population level investigations have long balanced the costs and benefits of interventions being considered for whole classes of individuals. For example, inoculations, laboratory / imaging screening, and similar tools have are core tools of broad public health.

The critical system design issues usually center on what population of individuals are appropriate targets for the intervention, and how it can be delivered to them in the most cost-effective manner. Traditional demographic and condition-based considerations in defining target populations have recently been enriched by growing understanding of bio-chemical markers that differentiate expected responses for different groups.

Patient Screening and Monitoring. Advances in medical technology and results of large population studies yield a continuing stream of opportunities to improve patient outcomes – especially with chronic conditions – by testing physiological parameters. Test-based screening may detect maladies much earlier that waiting for symptoms. Also, monitoring – especially home-based monitoring – can save tremendous cost and keep many patients stable with fewer visits to clinics.

Obviously these methods place a high premium on successful testing and monitoring technologies, and many depend centrally on careful design of patient interactions and processes. There are also important decision problems suitable for model-based research in balancing the costs and health impacts of various mixes of screening and monitoring for particular populations. However, the novelty of tools required and the impact they can have seem moderate compared to those of other domains.

Wellness and Behavior Change. Results of large population studies also yield a continuing stream of opportunities to improve patient outcomes – especially with chronic conditions – my changing such behavior as eating habits, smoking, and substance abuse. Assessment coupled with behavioral modification counseling can be a lost-cost solution with high health impact.

As pharmaceutical and other tools of mental health come to be employed, and evidence of biological propensities and addiction mechanisms is growing, the potential for technology contributions is rich. There is also high value in careful design of patient interactions and processes. As with screening and monitoring, there are also important decision problems suitable for model-based research in balancing the costs and health impacts of various mixes of interventions. However, the novelty of tools required and the impact they can have again seem moderate compared to those of other domains.

Personalized, Predictive Care. Advances in genomics and proteomics are laying the foundation for fundamental advances in all levels of healthcare by identifying biological markers that both predict health risks and guide the choice of interventions based on their likelihood of success in populations of patients. That is, the disease-driven, reactive nature of most current healthcare may be transformed over time into a personalized, proactive, wellness-focused delivery system for the 21st century.

It is clear that these developments require intensive research in the associated technologies. Furthermore, they are likely to require enormous change in the practice-based processes for collaboration between clinical professionals and their patients. Although it is too early to fully envision, they also seem likely to present model-based planning challenges to structure capacities and flows in any transformed systems, and those will require novel methodologies. Such tools are also likely to have broad health impact because they facilitate the transformation to revolutionary new norms.

3.3 Research at the Team Level of Care

Research Topic	Technology	Model: Method	Model: Impact	Practice
Electronic Medical Records	H	L	M	H
Bedside Technology	H	L	M	H
Clinical Reminders	H	L	M	H
Patient Safety	H	L	M	H
Team Productivity	M	M	M	H

Studies at the Team level of care address the small groups of medical professionals, supported by families, who work together on any individual patient case. Information sharing and activity coordination are essential. But they are often hampered by shortages of clinical staff, low morale and work overload, exacerbated by often inadequate supporting information and communication technology.

As demonstrated by the scoring at right, most research in the field requires intense engineering and innovation in technology areas including information and communication systems, and human-computer interaction protocols. Team-level advances are also closely linked with practice-based research on team organization and clinical processes. Model-based research has played a limited role because group processes such as aggregating preferences and avoiding bad outcomes are not well enough understood to support instructive modeling. Impacts that are achieved come mainly from known methodology to find cost-effective mixes of system components.

Electronic Medical Records are fundamental to tracking what was done to/for a patient and how his/her condition was impacted. Although their availability is growing, in part because of the federal government's National Health Information Infrastructure project, data standards and entry protocols are still subjects of intensive research. Furthermore, it is well established that nurses (and other care providers) spend large fractions of their time foraging for records, test results, and other information required to provide care because the location of such materials is not adequately tracked or recorded in databases.

Bedside Technology offers the opportunity to conduct tests and enter data, as well as monitor patient progress without staff running back and forth from other care locations. A major problem is interfacing the variety of new devices being developed into a coordinated records package.

Clinical Reminders are designed to warn staff when something should be done or alert them to possible omissions or threats. However, poorly designed human interfaces frequently lead to annoying burdens and information overload for the team.

Patient Safety has been a key focus of the healthcare community at least since the notable IOM study *To Err is Human* in 2000 with its alarming estimates of the numbers of patients killed or injured as a result of preventable medical errors. All of the team-level technologies discussed above can contribute to increased patient safety. The various forms of root-cause and Failure Modes and Effects analysis (FMEA) have also become a popular and effective tool for process evaluations to identify, predict and prevent situations inviting dangerous delivery system errors.

Team Productivity research investigates how training and other organizational innovations can improve care team effectiveness. Changing roles of different kinds of healthcare professionals must be addressed, as well as how to better incorporate patient friends and loved ones. Exploratory model-based investigations might also help elucidate group processes and evolve useful metrics.

3.4 Research at the Organization Level of Care

Research Topic	Technology	Model: Method	Model: Impact	Practice
Patient Scheduling and Flow	H	H	H	H
Facility and Staff Scheduling	M	H	H	M
Facilities Location and Design	M	H	H	M
Quality Management	M	H	H	M

Research at the health services Organization (e.g. hospital, clinic, physician or other provider) level of care centers around operations management. How should facilities be designed? How should staff and space be used and scheduled? How should patients be scheduled and flowed through the operation? How should the organization's supplies and quality be managed?

These topics are familiar in academic programs in both Industrial Engineering and Operations Management. They have been at the heart of two decades of improvements in the manufacturing and distribution industries.

There has also been a great deal of healthcare engineering research on these operations topics that spans half a century. Still, its impact on healthcare delivery across the nation has been relatively spotty and modest. Disorganization and lack of coordination, quality gaps, safety risks, resource inefficiencies and growing cost are still the norm in most healthcare operations. As a consequence, clinical professionals have little appreciation for the value systems engineering can bring to operations of their facilities, and little motivation to learn more and seek out engineering partners. Indeed, many regard operations engineering as general management rather than any parallel to the engineering of the medical technologies on which they depend routinely. Some of the explanations include the following:

- The transfer of methods from manufacturing and distribution to healthcare is far from straight-forward, and it is easy to suggest solutions glibly without accounting for differences in the environments. One important distinction is that each patient has unique characteristics and risks, in contrast to the standardization of industrial products on which much of manufacturing operations planning is founded. Another is the sometimes life and death risks to patient's associated with healthcare operations issues that in other contexts involve only marginal changes in service cost.
- The pervasive under-investment in information technology for healthcare operations cripples most quantitative or data-hungry planning and control methodologies. For operations, the issue is less patient medical records than tracking location of patients, providers, and associated resources. Slow progress is being made, but most records continue to be in paper files, with limited use of techniques like bar-coding and radio-frequency identification.
- Perhaps most importantly, the lack of standardization or protocols has meant that most studies on healthcare operations have been one-off investigations directed to a specific application site and building from first principles. Far too few involve generic tools that can easily be adapted to different settings.

This predicament leaves research at the organization level in the dilemma reflected in the scoring matrix above. There is moderate potential for productive research on technology to support operations management, especially information technology to track patients, personnel and resources. Similarly, every subtopic poses practice-based research issues that must be addressed before transforming changes can be effected. As it has in other industries, however, model-based analysis should hold the greatest promise for accelerating change by efficiently exploring wide ranges of alternatives, and investigating their consequences, before any is implemented. In many cases it also depends on coordination of operations management solutions for several topics at the same time. For example, progress on patient flow, or facilities design, may be intricately dependent on innovations in staff scheduling.

Patient Scheduling and Flow. Even though it is among of the longest researched, one of the least fully developed areas of healthcare operations management is scheduling of patient visits and managing patient flow through facilities of the clinic. Traditional systems schedule over long time horizons ignoring or discounting volatility about if and when patients actually show up. Opportunities to distinguish scheduling protocols by non-medical characteristics of patients also are rarely exploited. Furthermore, the share of outpatient care is growing rapidly as hospital stays prove too costly. There, same-day and other dynamic scheduling innovations can have great value. Inside large facilities like hospitals, the issue is tracking patient handoffs among departments and assigning rooms and other resources to deal with dynamic demands. Shared facilities like labs and radiation also complicate flows. All these elements lead to important opportunities for technology advances in tracking, and in configurable, dynamic, model-based planning and control innovations, as well as important improvements in clinical processes to exploit better planning.

Facilities and Staff Scheduling. Scheduling of clinical staff such as nurse work shifts, and of critical facilities like operating rooms, are some of the most researched topics in healthcare operations management. Still, much current scheduling is manual, and the challenges of diverse shifts and staffing level requirements are, if anything, growing more complex. As noted earlier, a principal requirement is wider implementation of what is known. Still, there remain opportunities for innovative technology, processes, and configurable modeling tools to address dynamic changes in demands through time and even more complex staffing norms.

Facilities Location and Design. Aging of both the patient population and the large generation of hospitals built in the Hill-Burton era of the 1950's and 1960's has produced a boom in hospital and other clinic construction. This offers a real opportunity for high-impact healthcare engineering addressed to facilities location and design. Model-based tools are available from other domains for the locations questions, but internal design offers many opportunities for innovation. New hospitals must be equipped for ever growing information and bedside technology, and spaces must be flexible enough to respond to variability in demand, often with a smaller number of beds than in older facilities.

Quality Management. Tracking and controlling the quality of medical facility operations is obviously of the highest importance to improvement in healthcare delivery. As on other topics, there is great scope for adapting methods developed for similar challenges in other industries such as Six Sigma. However, all those tools must be modified to confront a fundamental difference in controlling healthcare operations: each patient has different attributes, different risks, and different prospects. Research on risk-adjusted methods and measures remains to be fully explored.

3.5 Research at the Network Level of Care

Research Topic	Technology	Model		Practice
		Method	Impact	
Secure Information Sharing	H	M	M	H
Collaborative Operations	L	H	H	M
Emergency Collaboration	M	H	H	H
Supply Chain Management	M	H	H	M
Home Care	H	H	H	H
Provider-to-Provider Telehealth	H	L	M	H
Perverse Incentives	L	H	H	M

This report has added a Network level of care between individual health providers and the broad environment because of the increasing decentralization of healthcare operations across a variety of different types of providers. Besides hospitals and physicians working alone or in small partnerships, there are ambulatory clinics, diagnostic centers, nursing homes, rehab facilities, pharmacists, home care services, several forms of telecare, and third-party payers. Patients move back and forth among all these providers with their separate goals and management, and minimal information sharing. Indeed, the current state of affairs has been described as a non-system or a cottage industry.

Secure Information Sharing. If patient records are to a shared among providers, with patients and their families, and even with medical informatics researchers, protocols must be developed to protect privacy while at the same time allowing quick and user-friendly data entry and retrieval. Although secure communication has been an active topic of research in computer science for many years, protocols and standards remain far from fully mature. Also, confidentiality in healthcare extends well beyond data encryption. This is especially true when patient data is being interrogated as part of medical research or field trials. Sensitive personal data has to be protected while allowing researchers to attribute causes of disparities seen in outcomes. Research on healthcare sharing and privacy is also intertwined with practice-based development of processes, as well as design of novel human-computer interfaces. Model-based research can contribute in choosing minimum cost and high reliability combinations of available components, but its role is likely to be secondary.

Collaborative Operations. Even after adequate information sharing systems have been devised, there will remain a plethora of problems in coordinating the treatment of patients as they flow through providers with different management, cost incentives, and purposes. Continuity of care is at risk if providers do not properly manage transfers, and in/out flows of one provider can severely impact the capacity management decisions of another. Perhaps most influential are payment and reimbursement structures and how they incentivize or discourage different care protocols. Technology challenges in collaboration other than through IT are relatively modest, but there remain many process targets for practice-based research. Model-based analyses of healthcare collaboration issues are currently rare, but two intense decades of related research in manufacturing supply chains and out-sourced operations is waiting to be adapted to healthcare issues. That work has established through game/equilibrium modeling and computer simulations how value-sharing and incentive arrangements can be structured that align the objectives and yield economic gain for all collaborators.

Emergency Collaboration. Although related, a host of new collaboration issues arise when the healthcare system in a region is confronted by a disease, terrorism, or natural emergency. The new elements are communication technologies for command and control, and protocols for sharing resources and managing their allocation. Besides the collaborative decision-making tools appropriate for regular operations, high-impact model-based research should also evaluate how to place and equip providers for resiliency and rapid reconfigurability in the face of emergencies. It is particularly timely to investigate these issues in the context of the current healthcare facility building boom, and the national emphasis on pandemic and terror threats.

Supply Chain Management. Medical facilities consume vast quantities of sometimes high-value and perishable supplies and equipment. This includes everything for cleaning materials, to pharmaceuticals, to electronics, to implantable devices and joints. The network of manufacturers, group purchasing organizations, third-party logistics firms, and providers themselves that manages these supplies is composed of different players than those of the provider delivery networks discussed so far, but it is subject to all the same requirements for collaboration and alignment of objectives. Furthermore, the rich technologies and lessons of supply chain management research in manufacturing over the past two decades, such as lean and just-in-time procurement, and postponement to facilitate product customization, remain to be broadly mined in many aspects of healthcare. There appears to be substantial opportunity for cost savings while improving availability of materials when they are needed, both of which will make direct contributions to quality and safety of healthcare. However, such advances await important model/method development to adapt tools from other domains to healthcare where performance metrics emphasize quality and safety of patient care above other considerations. In particular, extra attention to risk management may also be critical in model-based approaches because the consequences of stock outs are potentially much greater when human health is involved.

Home Care. Provider outreach and telehealth links in the home span a wide range of systems from home patient visits by nurses, to telecom followup on patients by providers, to remote monitoring of patient physiological parameters. Use of these systems is growing, and they represent a potential opportunity to improve access for rural and other underserved populations, yield significant cost savings, and improve patient satisfaction. However, more widespread application awaits healthcare engineering research of nearly every type. User friendly patient interfaces for persons with little computer literacy are a critical human factors design challenge. Practice-based research is needed on nearly every form of home telehealth to maximize quality and effectiveness of services delivered, while reducing costs. So much is to be decided about the best way to locate facilities, allocate and route staff, provide reliable computer links, and other elements of system design that there should also be a strong opportunity for novel new models that challenge the limits of current model-based methodology.

Provider to Provider Telehealth. Use of telemedicine among spatially distributed providers is another growing dimension of telehealth. It extends from (sometimes global) consultations with specialists not available at the primary care site to remotely controlled robotic procedures. As with the home version of telehealth, they represent a potential opportunity to improve access for rural and other underserved populations, and to reap significant cost savings. Also like the home case, human-computer interfaces are central research issues. But that challenge is somewhat less daunting because those interacting are highly trained medical professionals. On the other hand secure communication of patient documents and images are of greater importance, and advances in practice-based protocols are critical. With the scale of communication networks much smaller and less diverse than those for home care, model-based analysis is likely to center on application of known network-design tools.

Perverse Incentives. An important special set of issues in network collaboration arises when competing incentives for different providers have the effect of risking patient health and/or inflating overall system costs. For example, monitoring patients in their homes may reduce the need for return visits to hospitals. The result is increased revenue to telehealth providers, significantly reduced treatment cost, and improved patient satisfaction, but there may be a significant loss of revenue for hospitals. Again, the model-based tools of supply chains and distributed operations should be adaptable to quantifying effects and structuring collaborative arrangements that align interests with overall system and patient health objectives.

3.6 Research at the Environment Level of Care

Research Topic	Technology	Model		Practice
		Method	Impact	
Capitation vs. Pay for Procedures	L	M	M	H
Pay for Performance	L	M	M	H
Consumer-Based Healthcare	L	M	M	H
Cross Subsidization	L	M	M	H
Predictive Care Transformation	H	H	H	H

Research at the Environment level of care quickly touches the controversies about national healthcare policy that have challenged decision makers for at least the last 60 years. Goals are to realign incentives – especially financial ones – to avoid perverse behavior seen in the present system.

In most cases technology is not a major issue. Instead decisions are informed mostly by high-impact, practice-based studies and demonstration projects across samples of providers. Model-based research – here mostly economic modeling – can do preliminary investigations of possible solutions and estimate their consequences before they receive more field testing. It can also estimate the broad consequences of extending an apparently successful test to wide national implementation.

Capitation vs. Pay for Procedures. One of the most enduring controversies in healthcare policy is whether insurance payers should reimburse providers on a per-patient or capitation basis versus paying for particular procedures as they may be medically indicated. Moving from one to the other clearly has dramatic impacts on the incentives and risks of the payers and the patient. For example, capitation can present providers with enormous financial risk to cases where unexpected but expensive medical complications arise. Conversely, payments for procedures create a bias away from holistic internal medicine in favor of specialists who do expensive interventions.

Pay for Performance. An incentive strategy of more recent origin, termed Pay for Performance, seeks to reward providers based on their history of quality. Reimbursement is fractionally increased for those with good records and/or decreased for those with weaker performance. Development of valid quality measures on which to base such incentives is a challenging topic of research.

Consumer-Based Healthcare. As healthcare costs to employers and government payers accelerate, there is increasing interest in reimbursement schemes where the consumer plays a more active role in treatment choices, and bears more of the financial risk. The intent is to create competitive market pressures for consumers to take their healthcare needs to providers they believe offer the best balance of service quality and price. Such systems also offer the promise of increased leverage to achieve patient-centered care, improved patient compliance with care regimes, and greater patient attention to prevention and wellness as increased responsibility for their care falls on the patient. Major hurdles are that few patients are knowledgeable enough about what healthcare they need to make informed decisions, and fewer still know what providers can offer it, and how they should be compared. Thus, movement to a more consumer-based form of healthcare will require intensive research on how to collect and communicate appropriate care and provider performance data.

Cross Subsidization. The US healthcare market can be subdivided into approximately 27% who have healthcare provided by government, 15% with no healthcare insurance at all, and most of the remainder funded by private employers. Ethical standards and federal law require that providers serve all these populations regardless of the patient's ability to pay. But substantial pressure on reimbursement rates by government payers, and little or no collections from the uninsured, have left providers balancing revenues and costs by increasing charges for privately funded treatment. This cross subsidization is a major and growing burden for private employers that needs to be better quantified and understood if solutions are to be found.

Predictive Care Transformation. The nascent revolution in personalized, predictive care has already been introduced under Population care in Section 3.2. Advances in genomics and proteomics are laying the foundation for fundamental advances in all levels of healthcare by identifying biological markers that both predict health risks and guide the choice of interventions based on their likelihood of success with individual patients. That is, the disease-driven, reactive nature of current healthcare may be transformed over time into a personalized, proactive, wellness-focused delivery system for the 21st century.

Besides offering new challenges in the provision of care -- including technology, practice protocols, and related planning modeling tools -- the prospect of a predictive care transformation will have enormous impact for policy makers at all levels. New institutions and infrastructures will likely be required, and payment/incentives systems are bound to be adjusted. Although it is too early to fully envision, these seem likely to present model-based planning challenges to structure capacities and flows in transformed systems, and those will require novel methodologies with broad health impact.

4 Broad Conclusions and Recommendations

The detailed discussions of Sections 3.1-3.6 offer a host of conclusions about the potential for research on numerous healthcare engineering topics. This final section of the report addresses two broader issues: what topics in the Healthcare Systems Engineering (HcSE) scope of this workshop deserve research priority, and how a partnership among funding agencies can begin addressing the stalemate preventing realization of the academic healthcare engineering vision in the NAE/IOM study.

4.1 Priorities for Model-Based Healthcare Systems Research

Some high potential topics discussed in Section 3 that are most central to the model-based systems engineering part of HcSE deserve priority support – likely under NSF funding leadership.

- Treatment Optimization. Formal optimization can often be employed to explicitly or implicitly optimize a measure of treatment success for the patient over the applicable requirements and treatment details. This category of research has great potential for both new science/methodology and broad system impact because the approach is useful in so many different environments. Each requires different modeling and optimization tools, and each offers a different set of implementation challenges.
- Personalized, Predictive Care. Although its potential is only beginning to even be understood, let alone realized, a revolution in personalized, proactive healthcare seems certain to burst out within the next generation. Modeling and optimization research can have a leading role in how these new protocols for healthcare are delivered if research begins now on how to design, plan and control the new forms of healthcare delivery systems.
- Information Rich and Configurable Operations Management. Operations management research topics centered on the organization level of care have been studied for half a century but remain to realize their full potential. In many cases what is needed is adaptation of fairly well understood methodologies. However, there are special opportunities emerging as widespread information and communications technology finally permeates healthcare delivery facilities. Information-rich forms of delivery systems management supported by readily available data on patient traffic and provider resource loading will both catalyze new methods and offer tremendous system impact. It is also important that more scalable and adjustable forms of operations management models be developed to provide generic tools more easily adapted to widespread application. This includes refining patient scheduling and flow planning tools to address particular patient populations and newer, outpatient-oriented modes of care.
- Collaboration Within Networks. Opportunities abound for valuable research targeting collaboration among the many individual provider organizations of modern healthcare networks. As information systems and sharing become more widespread, new design, planning and control tools will be needed to avoid duplication and perverse incentives, while maintaining high quality continuity of care and providing value to all participants. The spectrum of attractive topics spans everything from routine provider-to-provider handoffs, to emergency response, to home and telehealth, to patient-care-quality linked

supply chain advances. Two decades of supply chain research in other fields can provide many places to start if sufficient attention is addressed to the performance metrics that make healthcare systems different.

- Large-Scale Delivery System Design. Although not limited to any particular level of care, many of the problems discussed in Section 3 present a similar challenge: optimal design of large-scale delivery systems involving information and communication flows, along with dynamically varying patient demands and provider availabilities, while analyzing value received and costs incurred to assess performance. Monte Carlo computer simulations can be used for some such tasks, but their development cost is high, and each is closely linked to a particular setting. Deep and highly valuable research may be possible to produce generic, multi-purpose numerical models that can be adapted to a variety of healthcare delivery system design tasks

4.2 Priorities for Human Factors Healthcare Delivery Research

The focus of the June Workshop which stimulated this report is the NSF-related model-base topics highlighted in Section 4.1. Still, Section 3 notes research needs in the Human Factors field at almost every level of care, and across both the technology and the practice-based engineering domains. Although not likely to be concerns for NSF, the following topics seen to warrant high priority with other sponsors:

- Patient Computer Interfaces. Home and telehealth care offer tremendous opportunities for reducing costs, improving healthcare quality, expanding access, and achieving greater patient satisfaction. But progress is critically hindered by the challenge of having older patients, and ones with limited computer literacy, easily interface with the internet and telecommunication. Accelerated research on both new devices and interchange protocols is urgent.
- Data Entry and Display for Electronic Medical Records. Although the topic has received great attention for more than a decade, the challenge of efficient and reliable data entry and retrieval for electronic medical records systems remains far from fully resolved. How should providers log their treatment and judgments about patients in accessible ways? How can we avoid replacing formal clerical entry processes for data collection by much more expensive and equally burdensome entry by clinical professionals?
- Safety Engineering to Avoid Medical Errors. Application of safety engineering methods developed in the airline and nuclear industries has proved highly valuable in finding safety weaknesses in proposed processes and identifying the root cause of medical errors. Given the critical importance of reducing unnecessary and often costly medical errors, continued investment in research on process and resilient computerized alert systems that extend the power of existing tools is essential.
- Point of Care Clinical Reminders. An important element of human factors research should focus on the computerized systems that support point of care healthcare delivery by communicating progress and warning about dangerous trends. There is a great deal of this sort of technology presently in use or coming, but a balance has not been achieved in the data entry and information load team members are expected to bear in order for the alerts to be effective.
- Team Productivity. At every stage, from delicate surgery to home and rural care, healthcare is a team effort. Research on how to train professionals and shape their roles in enhance productivity is important to improving quality and reducing costs and errors.

An important element is development of metrics to quantify productivity, especially as it relates to outcomes of care.

4.3 Funding the Agenda

As briefly discussed in Sections 1.3, the 2005 NAE/IOM study on a new engineering / healthcare partnership set out a vision for broad new federal investment in academic, engineering-driven research. The effort was to be scaled to the dimensions of the critical national need for healthcare delivery transformation, with one federal agency assuming the lead as a critical step to future progress.

Unfortunately, the review in Section 1.4 highlights how far that vision is from realization as this report is written. Instead, HcSE is caught in an inter-agency stalemate, mainly between NIH and NSF. NSF is the government's primary home for much of the nation's model-based science and engineering research, but some of its budget-strapped leaders argue that healthcare is NIH's domain, just as energy belongs to DOE and transportation to DOT. However, these analogies are not entirely apt. NIH is indeed the primary home of <u>medical</u> research. But unlike the DOE and DOT cases, systems engineering, especially its model-based healthcare delivery aspects, is not embraced by most parts of NIH and largely incompatible with that agency's organization around medical conditions and demographic groups. Absent major institutional realignment at NIH, NSF is the only federal agency equipped to confront the model-based part of the HcSE challenge.

One major challenge of this workshop and report is to find a way forward that begins to deal with this crippling funding stalemate. Relevant research is underway on a limited scale (see Section 1.4), with NIBIB and parts of NSF taking the lead in the technology domain of healthcare engineering, NSF with help from NIH spearheading model-based research, and primary coverage of the practice-based domain coming from AHRQ supported at times by the NLM and other components of NIH. This predicament is far less than acceptable. But it may be all there is to work with for some time, and ways need to be found to maximize its impact.

- Healthcare Engineering Alliance. Immediate efforts should be made to establish a Healthcare Engineering Alliance among federal sponsors. Modeled after other successful collaborations in manufacturing, nanotechnology and bioengineering, the alliance would hold annual workshops to exchange information on research progress, and coordinate solicitations for grants and contracts. The goal would be to strengthen the working relationships among the agencies that will necessarily be involved in any future acceleration of healthcare engineering research, and to bring more visibility to the field.
- Three-Part Program Leadership. An alliance can provide some degree of strategic leadership in healthcare engineering, but separate focuses of the currently interested agencies will likely sustain for some time. NIBIB should be designated to lead engineering research in the technical domain, NSF should have responsibility for model-based research, and AHRQ should lead on practice-based investigation. None of these three would be the only sponsor in their designated domain, but they should be responsible for taking the lead.
- Partnership Grants. There are numerous challenges where interdisciplinary collaboration among the domains of healthcare engineering is essential. For example, technology advances will have greatest impact if they are utilized in optimally designed delivery systems and planning tools. Similarly, economic insights from model-based research can suggest critical technology needs to open the way for high-value gains.

NSF has experience stimulating collaboration on such interdisciplinary projects with various parts of the NIH, the Environmental Protection Agency, the Department of Transportation, the National Aeronautics and Space Administration, and others. An effective tool for stimulating collaboration on such interdisciplinary projects has been what might be called Partnership Grants. Such grants are joint solicitations from agencies interested in different parts of a problem that are posed with a requirement that all responding teams include one researcher from each domain involved. For example the solicitation might call for at least one researcher interested in physiological sensors to collaborate with another interested in optimal facility layout in evolving a new bedside approach to care.

It is undeniably true that all such collaborations are awkward and burdensome for the agencies involved, especially in how they align their peer review processes. But the benefits of truly interdisciplinary research in healthcare engineering and of community building for the whole research effort should outweigh such difficulties.

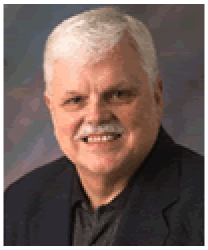
- Opportunistic Vigilance. Moving forward to strengthen existing sponsor relationships with collaborative infrastructure cannot relieve either the program managers or the research leaders in healthcare engineering from pursuing opportunities for broader funding. For example, partnerships could be assembled to fit HcSE needs into NSF's huge Cyber Infrastructure program, or to structure one of the Engineering Directorate's Emerging Frontiers in Research and Innovation (EFRI) projects. Also, opportunities for significant funding from agencies of the DOD, state governments, and private foundations need to be further explored.

APPENDIX 1
WORKSHOP MEETING AGENDA

THURSDAY, JUNE 15			
TIME	**SESSIONS**	**SPEAKER**	**TOPIC**
7:45	Light Breakfast		
8:15	Welcome	R Rardin	Introduction
8:30		W DeVries	NSF/ENG directorate interests
8:45		M Realff	DMI/SEE plans
9:00		P Reid	NAE followup on recent report
9:15	Session 1	F. Sainfort	Challenges and Opportunities
9:30			
9:45		S. Henderson	Simulation in Healthcare Systems Engineering
10:00			
10:15		E. Lee	Optimization in Healthcare Systems Engineering
10:30			
10:45			
11:00	Session 2	J. Benneyan	Quality Management in Healthcare
11:15			
11:30		J. Ivy	Patient Monitoring
11:45			
12:00		P. Carayon	Ergonomics in Healthcare Engineering
12:15			
12:30	Lunch	P Reid	NAE followup on recent report
1:45	Session 3	S. Kim	Sensors & Communication
2:00			
2:15		P. Whitten	Telehealth
2:30			
2:45		J. Sterren	Home Health
3:00			
3:15			
3:30	Breakout 1		
4:30	Report 1		

FRIDAY, JUNE 16			
TIME	**SESSIONS**	**SPEAKER**	**TOPIC**
7:45	Light Breakfast		
8:15	Session 4	M Côté	Patient Flow
8:30			
8:45		D. Gupta	Scheduling
9:00			
9:15		J. Zayas-Castro	Process Design
9:30			
9:45			
10:00	Session 5	M. Rosenman	Data Mining/Informatics
10:15			
10:30		A. Schaefer	Disease Management Modeling and Decision Making
10:45			
11:00		A. Wilson	Screening & Prevention
11:15			
11:30	Lunch	P. Perreiah	Implementation Challenge
12:45	Breakout 2		
1:30	Report 2		
2:30	Sponsors	B Korte	NIBIB interests
2:45			
3:00		J Battles	AHRQ interests
3:15			
3:30		M Corn	NLM interests
3:45			

APPENDIX 2
SPEAKERS



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Jim Benneyan

Healthcare Research Opportunities in Industrial and Quality Engineering

Director: Quality and Productivity Lab at Northeastern University,
Senior Fellow at the Institute for Healthcare Improvement, and
Former senior systems engineer at Harvard Community Health Plan

Pascale Carayon

Ergonomics in Healthcare Delivery

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Department of Industrial and Systems Engineering, and
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Diwakar Gupta

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Shane G. Henderson

Simulation in Health Care,: What's Next?

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Julie Simmons Ivy

Patient Monitoring: Integrated Dynamic Decision Making in Practice

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Sangtae Kim

Emerging Cyberinfrastructure: Implications for Healthcare Systems Engineering

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of Mechanical Engineering, and
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Eva Lee

Optimization in Medicine and Optimization in Medicine and HealthCare

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Peter Perreiah

Implementation Barriers to 'Engineering' Healthcare

Managing Director:
Pittsburgh Regional Healthcare Initiative (PRHI)

Proctor Reid

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

Director:
National Academy of Engineering's
(NAE) Program Office

Marc Rosenman

Indiana Network for Patient Care

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François Sainfort

Transforming Healthcare, Transforming Health: Challenges & Opportunities

Associate Dean for Interdisciplinary Research Programs
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the founder and Director of the Health Systems Institute, and
William W. George Professor of Health Systems in the
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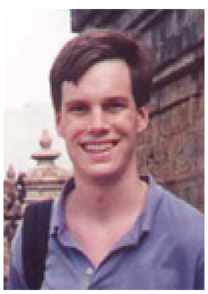

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Therapeutic Optimization

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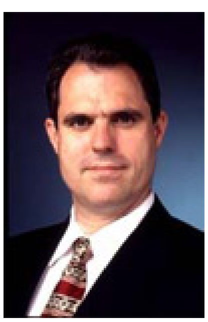

Justin Starren

The Many Faces of Homecare Technology

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Pamela Whitten

Telehealth: Evolution rather than Revolution

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Amy R. Wilson

Ounce of Prevention ?<> Pound of Cure

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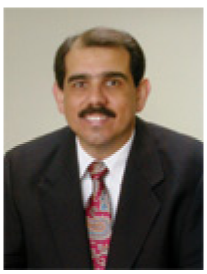

José L. Zayas-Castro

Process Design/Reengineering in Hospital Environments

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James B. Battles

Quality and Safety by Design, How Engineering Can Save Healthcare

Agency for Healthcare Research & Quality
Department of Health & Human Services

Milton Corn

National Library of Medicine & Healthcare Informatics

National Library of Medicine
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Brenda Korte

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