Highlights From the Third Annual Mayo Clinic Conference on Systems Engineering and Operations Research in Health Care

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In August 2010, the Third Annual Mayo Clinic Conference on Systems Engineering and Operations Research in Health Care was held. The continuing mission of the conference is to gather a multidisciplinary group of participants, including health care and operations research (OR) professionals, academic professors, and students to share and discuss the effective translation of systems engineering (SE) concepts, methods, and tools to enhanced delivery of health care. The overall focus of the conference was to showcase and demonstrate the tremendous value of SE/OR in the delivery of high-quality, cost-effective, and patient-focused health care. With substantial changes expected due to health care reform and related legislation, the conference was well received and timely. The topics, workshops, and conference sessions were developed with an emphasis on how research and education can be translated to improved clinical practice. Examples include SE/OR models and implementation experience in cancer screening, medical decision making, delivery of nursing care, patient education and experience, and organizational quality initiatives. The conference also offered participants insight into building an SE/OR infrastructure for health care and enhancing the awareness and education related to these disciplines.

Engineering could be simply defined as the purposeful application of science and mathematics to create valuable and useful solutions. In relation to health care, science and engineering are applied with a deliberate focus on humans—patients, families, and staff—as well as by sharing discoveries and outcomes to continually improve health and patient care. The conference agenda (Figure 1) consisted of sessions that balanced the technical aspects of SE/OR research with the human aspects of health care. Effectively managing this blend was a key to the conference’s success and is addressed in the following highlights from the conference.

PATIENT-CENTERED CARE

Mayo Clinic’s Dean for Practice, Dr. Michel Harper, provided the welcome address for the conference. Dr. Harper highlighted the many challenges facing health care in the United States, including rapid cost escalation and the need to accommodate an additional 30 million new patients due to health care reform. His talk emphasized the important role that health care SE must play in successfully addressing these economic challenges while also improving health outcomes and the experience of patients. In particular, the systems-oriented tools in SE/OR can help to remedy the disjointed nature and narrow focus of existing health care processes.

Continuing the focus on the patient, Dr. Victor Montori of Mayo Clinic highlighted the need to ensure that the voice of the patient is heard in SE efforts. He noted the importance of the “unhurried” patient visit for effective patient care. Efficiencies gained through SE/OR that reduce the administrative burden on health care professionals will enable them to spend more time listening to patients and ensuring quality care.

Understanding the perspective of the patient is key to successful SE/OR implementation in health care. Kathy Kilmer, Director of Industrial Engineering for Walt Disney Parks and Resorts, discussed how her organization integrates the desires of Disney’s patrons into effective SE. Her entertaining address showed the importance of SE to the success of the Walt Disney Parks. Disney anticipates...
the needs of its patrons so that restaurants, restrooms, and other desired facilities are where they should be to maximize patrons’ experience. The engineering magic that Disney integrates into their attractions is “invisible” to visitors but nonetheless is important to their satisfaction. She noted that the effective engineering of patron experiences at Disney had many similarities to effective engineering of patient experiences in health care settings.

Marilyn Carlson Nelson, Chair and former Chief Executive Officer of Carlson Companies and Chair of the Mayo Clinic Board of Trustees, also highlighted the importance of always keeping patients, their families, and health care staff at the center of all health care and SE/OR efforts. Her key messages were the importance of leadership and personal accountability when initiating the kind of changes SE/OR demands of traditional processes. Using many anecdotes from her life and executive leadership experience, she poignantly expressed the need for conference attendees to “make every day count” and “if you don’t like it, fix it.”

These two keynote presentations set the stage for detailed discussion of specific problems, strategies, potential solutions, and exploration of the application of SE/OR methods to the operational and clinical challenges in health care.

SE/OR AT THE POINT OF CARE

Continuing the focus on the patient, several presenters emphasized how SE/OR can assist health care professionals with medical decision making and improving the safety and quality of patient care.

Professor Eva Lee, a well-respected health SE researcher from the Georgia Institute of Technology, discussed her work on the use of SE/OR data analysis techniques for the early detection and treatment of various cancers. These information technology–supported techniques can find patterns in data that are difficult to identify by human brain power alone. A collaborative effort with the Winship Cancer Institute, Dr. Lee’s project uses the vast amount of biological and genetic data currently available in concert with the predictive methods of OR to develop useful decision aids. A rules-based classification method, called discriminant analysis, is used to develop rules for gene silencing and to assist with early cancer detection. Combined with artificial intelligence in a machine-learning framework, the model is providing promising results to identify changes in CpG islands (discrete regions of DNA where cancer is thought to form) that lead to cancer development. Her early work is on breast and lung cancers, but the approach has broad application to many cancers. The research provides early detection and novel treatments by identifying new molecular targets for chemotherapeutic intervention.

In a similar vein, Dr. Karen Kuntz from the University of Minnesota presented research on the application of microsimulation modeling to colorectal cancer screening. Microsimulation models take many fictitious individual life histories and simulate changes to these histories based on different screening approaches. The project is associated with the Cancer Intervention and Surveillance Modeling Network (CISNET), a consortium of 4 research teams started 10 years ago with an initial mandate to identify trends in cancer disease. The mandate evolved to the current focus on informing health policy with the assistance of SE techniques.

The microsimulation model allowed the testing of a variety of screening tests and scenarios, including starting and ending ages. Performance was evaluated by considering the life-years gained per 1000 people vs the total colonoscopies performed. Modeling results showed that flex-
Possible sigmoidoscopy and fecal occult blood testing should be performed at 5-year intervals from age 50 years and at 3-year intervals from age 75 years to increase the efficiency of screening guidelines. Simulation modeling allows the evaluation of such policies before implementation, saving not only money but, more importantly, lives.

Patient disease data can improve diagnostics and treatments, but other types of patient data (wait times, special needs, demographics, volumes) can also be used to continuously improve and design processes and facilities that have higher quality and safety for patients. Dr Shengyong Wang from the University of Akron emphasized the value of SE/OR in hospital and medical facility design. He discussed a structured approach to designing a hospital (Figure 2). This framework is similar to that discussed by McLaughlin and Hays,1 which has been applied at several health care organizations. Such an approach helps to ensure that quality, safety, and efficiency are synergistically designed into health care facilities. Doing so circumvents the problem of creating care delivery processes that must work around facility obstacles that are typically not considered when an SE approach is not used. However, Dr Wang also noted that, as care delivery methods and technologies evolve, facility redesign will be necessary. Again, SE tools (eg, forecasting, optimization, queuing analysis, simulation) can be used to guide the redesign process to balance quality, safety, and cost considerations.

In keeping with the theme of facilities design, Craig Smoldt, Chair, Department of Facilities and Support Services at Mayo Clinic, spoke on the role of technology in health care delivery. He noted the ironic effects of unintended consequences of new technologies on health care organizations. In the 1900s, improved human transportation allowed centralized medical clinics like Mayo to flourish because patients could travel to receive their treatment. New information, video imaging, and health monitoring technologies are now allowing patients to stay at their homes and receive their care. Mr Smoldt highlighted the important role SE/OR can play when designing effective processes and medical decision support tools to ensure that the value of new health care technologies is maximized.

**BUILDING SE/OR INFRASTRUCTURE IN HEALTH CARE**

Many of the concepts and methods of SE/OR are new to health care. Acceptance and integration of SE/OR into health care will require an appropriate infrastructure in health care organizations and educational institutions.

**THE NEED FOR BILINGUAL PHYSICIANS**

As previously noted, one of the purposes of the conference is to bring together SE/OR experts and clinicians interested in addressing the systems problems in their practice. In the panel session entitled “Teaching Systems Engineering to Health Care Professionals and Vice Versa,” one of the presenters was uniquely qualified to speak to the importance...
of this conference objective. Dr Peter Fabri, Professor of Surgery at the University of South Florida, also has a doctorate in industrial engineering, specializing in SE/OR. He asserted that health care in the United States is a cottage industry centered on individual physicians and following hospital practices from the 1950s and 1960s. To improve health care systems, Dr Fabri identified the following requirements: physicians who are bilingual in health care practice and SE, physicians who are “data competent” and understand uncertainty and probability, and engineers who are bilingual and can effectively participate on health systems reengineering teams. Further, Dr Fabri considers the current focus on management and finance to resolve health systems problems to be insufficient. Rather, better engineered systems and processes are also keys to success.

Related to this theme of “bilingual physicians,” Dr Barry Gilbert, Professor of Biomedical Engineering at Mayo Clinic, discussed some of the behavioral issues of engineers and physicians working together to improve health care. He noted that, based on their training, clinicians know little about the physical world and engineers know little about the biological world. Each side tends to think the other’s problems are simple, yet both are very complex. Therefore, engineers often do not understand important clinical constraints when engineering health care systems, and physicians do not understand the potential health system benefits of changing “the way things have always been done.” Learning to appreciate each other’s perspectives and skills will help facilitate the application of SE in health care.

Professor Jim Bennyan from Northeastern University supported Dr Fabri’s perspective with several statistics. According to the 2010 Commonwealth Study, the United States was last in overall ranking of the 7 countries evaluated. The rankings were based on the categories of quality of care, access, efficiency, equity, and life expectancy. The United States was last in all categories except quality of care, in which it was next to last, ahead only of Canada. Particularly disturbing was the fact that US health expenditures per capita ($7290) were nearly twice those of the best overall performer, the Netherlands ($3837). Dr Bennyan thinks that the one way to address the expenditure issue in the United States is to apply SE/OR. Through simulation, optimization, and patient quality and safety modeling, health care outcomes can be raised to a new level with lower costs. Although basic training in quality improvement will move health care part of the way, SE/OR is required to achieve the full potential of systems improvement (Figure 3, adapted from Dr Bennyan’s presentation).

Dr Bennyan has dubbed his prescription to improve health system performance Manhattan II, evoking the Manhattan project to emphasize the importance of the initiative to educate health systems engineers and the need to dedicate appropriate resources to it. Currently, most training in health SE occurs at the graduate level (PhD, 70%; MSc, 20%), with only 10% occurring at the undergraduate level. Dr Bennyan suggests turning the ratio around so that 70% of systems engineers will be undergraduates. His view is that 25,000 applied health systems engineers will be required—about 1 for every 50 hospital beds. Dr Bennyan also identified the types of training needed to be successful. He thinks a significant portion of engineering education must be related to applied projects, with students working in health care organizations. He envisions the creation of “smart sandboxes,” in which engineering academics can “play” together with health care practitioners. Together, they can create better systems through applied research and mutually beneficial training.

**APPLYING ENGINEERING TO HEALTH CARE: HISTORY LESSONS AND FUTURE DIRECTIONS**

A trio of Mayo Clinic staff discussed the history of SE at Mayo Clinic and the current state of SE/OR efforts to enhance capabilities in the discipline. Dr Gary Sieck from the Department of Physiology and Biomedical Engineering discussed the long history of applied engineering at Mayo Clinic. He recounted the important contributions of Dr Henry Plummer, a Mayo physician from 1901 to 1936, and his role in embedding the engineering philosophy into the practice of medicine. In particular, Dr Sieck noted Dr Plummer’s inventions of the standardized medical record, use of pneumatic tubes to distribute records and laboratory specimens, and color-coded lighting systems to support the patient rooming and check-in visit process, all of which remain in use today.

Dr Sieck also discussed the origins of the Division of Systems and Procedures at Mayo Clinic in 1947. He included the following quotation from Dick Cleeremans, former Section Head: “The decision by the Mayo Medical Center to hire industrial engineers in those early years was in keeping with the Mayo commitment to the patient, physician/patient relationship and Dr Plummer’s expectation that the system and the organization of the clinical practice were important and a worthy management activity.” Systems and Procedures continues to be a driving force in the translation of SE at Mayo Clinic.

The next speaker, Ms Jennifer Ferguson of Systems and Procedures, presented the current state of SE/OR work at Mayo Clinic. Ms Ferguson noted that SE efforts and expertise are spread throughout Mayo Clinic but with a concentration in Systems and Procedures. A collaborative Mayo group was formed in 2005 to sponsor seminars and technical workshops and to organize the annual Mayo Clinic Conference on Systems Engineering and Operations Research in Health Care. Several SE projects at Mayo Clinic
were also identified, including successful applications for forecasting outpatient visits and improving sepsis resuscitation processes via simulation.

The final member of the trio, Muhanad Hirzallah of Administrative Services for Research, discussed additional SE projects using Lean methods to improve key research processes at Mayo Clinic and Six Sigma to improve the problem of retained objects in surgery. For the latter project, the defect rate was reduced from 25 defects per million opportunities to 6—very close to the Six Sigma target.

THE SCIENCE OF HEALTH CARE DELIVERY

Certainly, effectively treating patients and managing the resources required for such treatment is an art. However, just as evidence-based medicine has found an appropriate place in clinical processes, so should SE/OR for managing the delivery of health care.

THE “SYSTEM” IS ONE-THIRD OF A PATIENT

In her empirical study of the work life of nurses at several hospitals, Dr Anita Tucker of Harvard University identified that process or systems problems created significant barriers to nurses delivering efficient and effective patient care. These systems problems and the work-arounds nurses used to resolve them equate to a workload of one-third of a patient per nurse and serve to interrupt patient care and create potential safety issues.3

Results from Dr Tucker’s research suggest that efforts to improve systems and processes affecting nursing work need to be thoughtfully managed. Using the measure of perceived improvement, she reported that generating more improvement ideas and identifying the very best idea did not lead to improved performance. Rather, taking action on a broad set of ideas improved processes and systems. Further, the involvement of senior management in process improvement initiatives also led to better performance because systems and process issues often span departmental boundaries and require acceptance, teamwork, and sufficient resources to resolve. Dr Tucker also noted that requiring nurses to extensively report quality and safety issues without having resolution resources in place can lead to cynicism and “improvement burnout.”

Curing the Process May Kill the System

Treatments that cure a specific illness can at times be more harmful to the patient’s overall health than the illness itself. Likewise, the health of systems in medical organizations could inadvertently be jeopardized when attempting process improvements. Sometimes locally oriented efforts that improve efficiency in one process or department actually worsen performance of the overall system. In a session on patient flow modeling, Dr Alexander Kolker from Children’s Hospital of Wisconsin noted that, “a system of local improvements is not the best system; it could be a very inefficient system.” His simulation modeling study was based on linked models of several typical hospital subsystems: an emergency department (ED), an intensive care unit, an operating room, and a hospital ward. In one scenario, process improvements

FIGURE 3. The need for advanced systems engineering (SE). OR = operations research.
were implemented in the ED to reduce the length of stay. The simulation model showed that this reduced the time patients spent waiting for ED beds and ED diversions—a good thing for the ED. However, the full systems model showed that intensive care unit diversions and operating room surgery cancellations increased. Thus, improvements in an upstream subsystem may worsen performance of the overall system—at least for some performance measures. The ability of SE to incorporate a broader, systems-thinking approach is one of its advantages over process-specific improvement methods such as Lean and Plan-Do-Study-Act learning cycles.

In addition to adopting a systems perspective of hospital and patient flows, incorporating the disparate views of the many stakeholders involved in delivering health care is much needed. Dr Sandra Pothoff from the University of Minnesota presented her research on managing capacity in operating rooms that highlighted the need for SE tools to grapple with this multiperspective issue. With her co-investigators Drs Diwakar Gupta and Chris Dickerson, also from the University of Minnesota, Dr Pothoff is working on an SE/OR approach to determine blocks of operating room time to assign to surgical services. This is a politically charged set of decisions at most hospitals and has significant financial and quality implications. Surgical block scheduling affects the lives of patients and their families, surgeons, anesthesiologists, and many other hospital staff. To help balance the competing needs of the various stakeholders, Dr Pothoff presented an SE/OR approach that uses integer goal programming, an OR method that can be applied electronically. One of the advantages of SE/OR applied to this decision is that it removes some of the human “bias” that may occur or be perceived to occur by the stakeholders. Thus, computer solutions are of better quality in terms of meeting the wishes of explicit stakeholders and may be more acceptable to those working in the system because of its perceived fairness.

**CLINICAL APPLICATIONS AND CONCLUDING THOUGHTS**

Systems engineering focuses on coordination, synchronization, and integration of complex systems of personnel, information, materials, processes, facilities, and financial resources. Our contemporary health care systems are exceedingly complex, and their navigation cannot be effectively accomplished without an interdisciplinary and systematic approach, bringing together clinicians and systems engineers. Indeed, the National Academy of Engineering and the Institute of Medicine jointly underscored the importance of applying SE tools to improve health care delivery, although the concept is currently broadly accepted, its practical implementation will require overcoming substantial challenges, which include, but are not limited to, developing a robust information management infrastructure, departing from a culture of division of labor prevalent in health care, surmounting cultural barriers (eg, health care professionals who have difficulty appreciating the contributions that engineering approaches can bring), and redressing the current lack of education in health care delivery for engineering professionals.

The Third Annual Mayo Clinic Conference on Systems Engineering and Operations Research in Health Care underscored the importance of bringing the 2 disciplines together and the need to invest considerable efforts to bridge the gap between clinicians and engineers. Widespread success requires the development of a critical mass of clinicians and engineers who have a common understanding of the value of engineering in health care. Developing this critical mass will require time and resources for cross-training and interdisciplinary collaborations. Further, a robust digital infrastructure is an essential platform for the implementation of the clinician-engineer partnership needed in health care. As engineering principles and models are gradually incorporated into the fabric of health care delivery systems, a deliberate commitment must be made by health care professionals and engineers alike to build nimble yet robust evaluation systems centered on patient choices and preferences for care delivery and outcomes. Given changes expected in the health care landscape as a result of health care reform, Mayo Clinic and other health care organizations must be committed to leveraging and more deliberately applying the vast potential of SE/OR to delivering trusted and affordable health care.

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**REFERENCES**