Health Systems Optimization Workshop

September 12-13, 2014

Northwestern University

Robert H. Lurie Medical Research Center

303 E. Superior Chicago, IL 60611

McCormick Northwestern Engineering

Northwestern University Feinberg School of Medicine
Institute for Public Health and Medicine

Sponsors:

This workshop was sponsored by the National Science Foundation: CMMI Division of Civil, Mechanical, and Manufacturing Innovation, Award Number: 1445448.

A co-sponsor of this workshop is the Center for Prevention Implementation Methodology for Drug Abuse and HIV Sex Risk Behavior (Ce-PIM), which is housed at Northwestern University and supported by the National Institute on Drug Abuse (NIDA/NIH; Grant Number P30DA027828)

Gold sponsor:

Company Fact Sheet

About Cerner

Cerner is the world's largest publicly-traded health information technology company providing leading-edge solutions and services for health care organizations worldwide. Cerner's mission is to contribute to the systemic improvement of health care delivery and the health of communities.

Fast Facts

- Headquarters: North Kansas City, MO, USA
- NASDAQ: CERN
- 2013 revenue: $2.9 billion
- Associates: 15,000 worldwide
- "Cerner" comes from the Latin word meaning "to discern"

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Footprint

Cerner has a presence in 24 countries and our solutions are licensed by more than 14,300 facilities worldwide including more than:

- 3,000 hospitals
- 5,000 physician practices
- 600 ambulatory facilities (laboratories, behavioral health centers, cardiac facilities, radiology clinics, and surgery centers)
- 3,600 extended care facilities
- 150 employer sites

Awards

- Top EHR Vendor Overall – Hospital Chains, Systems, and IDNs and Community Hospitals, *Black Book,* 2014
- 2014 Citi's 50 World Champions, 2014
- #4 Healthiest Workplace in America, Healthiest Employers, LLC, 2014
- #22 Most Innovative Company in the World, *Forbes,* 2014

History

Cerner was founded in 1979 by Neal Patterson, Cliff Illig and Paul Gorup when the three set out to build a software company for an industry where information was mission-critical. The founders quickly realized hospitals were organized internally as silos and needed a method for coordinating care. They also understood that data generated in the silos could improve the quality and safety of health care – if the information was shared on a common platform.

In the 1980s, Cerner created that platform and by the mid-1990s, it would evolve to organize health information by the person – rather than the physician, issue, or payment. This move was unheard of at the time and led to the company's eventual development of a comprehensive medical record that spans a patient's lifetime and can accompany them to different care venues.

Today, Cerner is recognized in the industry for its innovations and ability to securely share data between disparate systems and venues, enabling clinical health information to be available when and where it's needed most.

Philanthropy

First Hand Foundation is the primary philanthropic organization supported by Cerner and its associates. The organization funds individual children's health-related needs when insurance and other financial resources have been exhausted. Learn more at cerner.com/communityimpact.

Welcome From The Organizers

The Affordable Care Act is transforming the dynamics of healthcare delivery in the United States and the ripple effects of this change will be felt worldwide. The health systems optimization community is ideally positioned to provide technical expertise to lead this change. Concurrently, the richness and complexity of many health system challenges have the potential to advance the field of mathematical modeling and optimization. Sponsored by National Science Foundation, this workshop is very timely as healthcare in the United States is undergoing a major change with pressure to reduce costs and improve patient safety and healthcare delivery.

Data, Models, Decisions

Following the success of the 2013 INFORMS Healthcare Conference, this workshop is intended to accelerate the exchange of research ideas in a cross-disciplinary setting. The focus will be on **policies, operations**, and **delivery of care**. We would like to sincerely thank the members organizing committee:

Turgay Ayer	Georgia Institute of Technology
Hari Balasubramanian	University of Massachusetts Amherst
Amarnath Banerjee	Texas A&M University
C. Hendricks Brown	Northwestern University
Satyender Goel	Chicago Health IT Regional Extension Center
Diwakar Gupta	University of Minnesota
Allen Holder	Rose-Hulman Institute of Technology
Nan Kong	Purdue University
Mark P. Van Oyen,	University of Michigan
Burhaneddin Sandikçi	University of Chicago
Karen Smilowitz	Northwestern University
Vikram Tiwari	Vanderbilt University Medical Center
Kai Yang	Wayne State University

for helping to organize sessions and discussions as well as for contributing towards the success of this workshop. The expected clinical practitioners can earn up to eight hours of credit for Continuing Medical Education.[1] [2]

Sanjay Mehrotra & Omid Nohadani
Workshop Co-Chairs

[1] **Accreditation Statement**
The Northwestern University Feinberg School of Medicine is accredited by the Accreditation Council for Continuing Medical Education to provide continuing medical education for physicians.

[2] **Credit Designation Statement**
The Northwestern University Feinberg School of Medicine designates this live activity for a maximum of *8 AMA PRA Category 1 Credit(s)*^{TM}. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

Invited Plenary Speakers

Operations Research and Health Care

Sheldon H. Jacobson, PhD
Director, Sim. & Opt. Lab.
Department of Computer Science
University of Illinois, Urbana Champaign

Optimizing and Transforming the Healthcare System

Eva Lee, PhD
Director, Center for Operations Research in Medicine & HealthCare
Co-Director, NSF I/UCRC Center for Health Organization Transformation
Industrial and Systems Engineering
Georgia Institute of Technology

Systems Engineering in the University of Texas Health System A Multi-Disciplinary, Integrated Model for Improvement

Victoria Jordan, PhD, MBA, MS
Executive Director, Strategic Management & Systems Engineering
Office of Performance Improvement
University of Texas M.D. Anderson Cancer Center

Health Systems Engineering: Lessons from Integration of Systems Engineering within the Veterans Health Administration

Heather Woodward-Hagg, PhD
Director, National Veterans Engineering Resource Center
Director, VA Center for Applied Systems Engineering

Multi-Armed Bandits in Healthcare: Adaptive designs, matching, and admission control

Michael N. Katehakis, PhD
Management Science and Information Systems Department
Rutgers University

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Friday, September 12, 2014

Technical Session 1: Fr. 9:00 am-10:30 am

Location: Gray Seminar Room

Optimal Planning In Healthcare Under Uncertainty

Chair: *Burhaneddin Sandikçi*, University of Chicago **Robust facility location under demand location uncertainty with emergency response applications**

Timothy Chan, Auyon Siddiq

Most classical facility location models assume demand locations are known at the time of facility siting. However, in many applications demand locations are subject to uncertainty. We develop a two-stage robust facility location framework wherein each demand point can be realized with a continuous, bounded uncertainty region, and assignment decisions occur after the demand locations are revealed. We use a conditional value-at-risk objective, which induces a family of location models including robust analogues of the p-median and p-center models. Our approach discretizes each uncertainty region into a set of scenarios that represent possible locations where the demand may be realized. We develop an efficient row-and-column generation solution algorithm. We derive bounds on the error introduced by discretizing the continuous uncertainty regions. Lastly, we demonstrate the value of hedging against demand location uncertainty in two applications related to emergency response.

Chance-Constrained Surgery Planning Under Uncertain or Ambiguous Surgery Durations

Yan Deng, Siqian Shen, Brian Denton

We consider surgery planning problems under uncertain surgery durations. We decide which operating rooms (ORs) to open, allocation of surgeries to ORs, and start time of each surgery. We formulate a binary integer programming model with individual and joint chance constraints to restrict the risk of having surgery delays and OR overtime,

respectively. We further study a distributionally robust variant by assuming ambiguous distributions of random surgery duration, for which we build a confidence set using statistical divergence functions. This variant restricts the maximum risk of surgery delay and overtime for any probability distribution in the confidence set, and is equivalent to a chance-constrained program evaluated on an empirical probability function but with smaller risk tolerances. We compare different models and derive insights about surgery planning under surgery duration uncertainty using problem instances based on data from a hospital-based surgery practice.

Response-guided dosing
Jacob Kotas, Archis Ghate

We will first present a stochastic dynamic programming framework to adapt dosing decisions in biologic treatment of rheumatoid arthritis to the temporal evolution of the 28-joint disease activity scores. The goal is to minimize a weighted combination of the disease score at the end of the treatment course and the total dose delivered. Numerical results and sensitivity analyses based on data available in the clinical literature will be discussed to gain insights into the structure of the dosing policy. A more abstract version of our framework, suitable for other diseases, will then be introduced. Under certain convexity assumptions, we will prove the existence of a monotone dosing policy in this general formulation. This framework will then be extended to the problem of optimally designing clinical trials for adaptive dosing using a cohort of patients. This extension will use a Bayesian approach to learn the cohort's dose-response while simultaneously making dosing decisions.

On spatiotemporal data incorporation in IMRT planning
Arkajyoti Roy, Omid Nohadani

Fractionated radiotherapy is optimized for repeated delivery, assuming invariant geometry. However, spatiotemporal changes may occur and can degrade outcomes. We study the spectrum of spatiotemporal-data-incorporation in treatment planning. The spectrums lower bound is set when the current patients initial data is used due to lack of matching with historic time-resolved data. Conversely, the upper bound is set when the planner relies on a particular past patients time-resolved data due to exact matching. Mid-spectrum, multiple time-resolved datasets of past patients are used to overcome uncertainties in matching. Our observations on two lung cases show that the inclusion of multiple time-resolved datasets, a) improves organ sparing compared to non-time-resolved methods, b) is comparable to the use of an individual dataset when assumptions are met, and c) withstands uncertainties and provides clinically acceptable plans, even in worst-case scenarios.

Technical Session 2: Fr. 9:00 am-10:30 am

Location: Baldwin Auditorium

Applied Healthcare Management

Chair: *Allen Holder*, Rose-Hulman Institute of Technology

Implementing a Medical Screening and Referral Program for Rural Emergency Departments

Murray Côté, Dylan Dacy, Tiffany Radcliff

Emergency Department (ED) overcrowding due to non-emergent use is an ongoing concern. In 2011, a regional health system that primarily serves rural communities in Texas instituted a new program to medically screen and refer non-emergent patients to nearby affiliated rural health clinics (RHCs). This formative evaluation describes the program's goals, process, and early implementation experiences at two sites that adopted the program prior to wider implementation within the rural health system. The program, as implemented, aligned with initial program goals, but was dependent on ED screening staff and RHC availability. Some adjustments to the program were made, and stakeholders reported lessons learned. The system was able to leverage excess capacity of affiliated RHCs to accommodate low acuity patients referred from the ED and may lead to improvements in Triple Aim goals of increased patient satisfaction, better population health and outcomes, and lower per capita costs.

Modeling the Public Health Impacts of Prostate Cancer Biomarkers in a Screening Setting

Christine Barnett, Scott Tomlins, Daniel Underwood, John Wei, Todd Morgan, Selin Merdan, James Montie, Brian Denton

Newly developed prostate cancer biomarker tests have the potential for early detection; however, optimal use of these biomarkers and their impact on long-term health outcomes is unclear. A partially observable Markov chain was validated and used to simulate patients progression through prostate cancer states to all-cause mortality. Patients periodically received one or more biomarker tests according to predefined screening strategies that use combinations of prostate specific antigen (PSA), prostate cancer antigen 3 (PCA3), TMPRSS2:ERG (T2:ERG), and the Mi-Prostate Score (MiPS) models for all cancer and high grade cancer. Monte Carlo simulation was used to estimate quality-adjusted survival and the number of screening biopsies and metastatic cases per 1,000 men. We analyzed how best to use new biomarker tests during screening to tradeoff the benefits of additional life years gained with the harms of new biomarkers.

No Silver Bullet: Identifying Security Vulnerabilities Of Hospital Databases
Liam O'Neill, Nan Zhang, Gautam Das, Heng Huang

Analytical processing was used to identify security vulnerabilities in public hospital databases. Using medical domain knowledge, we recovered the real age of 64 patients, the gender of 796 patients, and the zip codes of 1,219 patients, from a public database of de-identified hospital records. We demonstrate that standard methods to mask personal health information can be reversed, thereby increasing the risk of re-identification of individual patients.

Technical Session 3: Fr. 10:45 am-12:15 pm

Location: Gray Seminar Room

Patient Centered Medical Home

Chair: *Kai Yang*, Wayne State University

Options for managing scarce resource allocation in a Patient Centered Medical Home (PCMH)
Romesh Saigal

In this talk we consider a two stage stochastic allocation problem which assigns resources to teams in a PCMH. We will consider here the number of hours of Primary Care Physician (PCP) needed to meet the patient demand on a team. In the first stage, the planning stage, a preliminary assignment of PCP hours to each team is made. Then after the demand for these hours is observed, in the second stage an adjustment is made by adjusting the preliminary hours assigned to each team and determining, if necessary, the overtime needed to balance the total supply and total demand. We use real options theory to result in a fair and consistent adjustment during the second stage. The concept of fairness involves the pricing of the disruption and then making the adjustments through optimization so that the price of disruption for different teams is the same; and the concept of consistency is obtained by pricing the real options. We discuss several ways we can achieve this consistency.

Designing the patient centered medical home: possible methods and challenges
Hari Balasubramanian, Michael Rossi

The patient centered medical home is a new model of primary care delivery that promotes timely access, patient-clinical team continuity, and coordination of care outside of the office visit. But how should the medical home be designed from a capacity standpoint to achieve these goals? This talk will discuss on methods and challenges in quantifying key features such as the impact of patient case-mix, the dynamic nature of patient requests, the design

of care teams, the care coordination burden outside of office visits, and the impact on patient and cost outcomes.

An Analytics Approach to Designing a Patient Centered Medical Home
Saeede Ajorlou, Issac Shams, Kai Yang

In this talk, we will discuss a two-phase analytics approach to design a Patient Centered Medical Home (PCMH) model. In the first phase, advanced multivariate hierarchical statistical models are developed to predict healthcare demands on various professional lines within a PCMH team. Such models are able to account for dependencies among demands on different providers in a team. In the second phase, we study the patient allocation problem under demand uncertainty. The problem is modeled as two-stage stochastic integer programs with mixed-integer recourse making balance between supply and demand in healthcare. We present a primal-dual scenario decomposition algorithm to solve the problem using 2010-13 National Patient Care Database of Veterans Health Administration. We find that stochastic solutions outperform mean-value solutions in saving costs due to patient assignments and overtime staffing.

Impact of Virtual Encounters on Overall Health Care Use in a Patient Centered Medical Home
Zelda Zabinsky, Paul Fishman, Joseph Heim

Many health systems that introduced patient centered medical homes have used virtual or asynchronous visits through either telephone encounters or secured messaging to increase access and reduce overall health care costs, but there is little evidence regarding whether these new modes of utilization are substitutes for more expensive face to face visits or result in greater overall use and therefore increased cost. We present analyses that examine the impact that secured messages and telephone encounters have on office visits to primary and specialty care physicians among members of a large integrated health care system. We developed a Markov chain model and estimated transitions between visit types using Group Health Cooperative data before and after virtual encounters were implemented. We assess how these new methods of health care impact face-to-face visits by patient age and health status.

Technical Session 4: Fr. 10:45 am-12:15 pm

Location: Baldwin Auditorium

HIV Modeling

Chair: *C. Hendricks Brown*, Northwestern University

HIV Policy Modeling: Linking Research to Decisions in Public Health & Medicine

A. David Paltiel
School of Public Health, School of Management
Yale University

HIV prevention, screening and treatment interventions work. The challenge is to identify program combinations that squeeze the greatest benefit out of every dollar. This challenge does not lend itself readily to traditional forms of health investigation (e.g., clinical trials and observational studies). In 1994, we developed the "Cost-effectiveness of Preventing AIDS Complications" (or CEPAC) Model, a simulation of the clinical management, outcomes, and costs of HIV disease. In this presentation, I will review our use of CEPAC to synthesize information from multiple sources, to extrapolate to longer horizons and new geographic settings, to evaluate the cost-effectiveness and budget impact of specific interventions, and to inform research priorities by measuring the value of information. Examples, drawn from both US and resource-limited settings, will include: expanded HIV screening; antiretroviral treatment as prevention; pre-exposure prophylaxis; and generic antiretrovirals.

Round Table

C. Hendricks Brown (organizer)
Director, Center for Prevention Implementation Methodology
Department of Psychiatry & Behavioral Sciences, Department of Preventive Medicine
Northwestern University

This presentation by Dr. Paltiel will be followed by a roundtable discussion emphasizing what opportunities exist for using simulation modeling for decision making around local HIV policy. While modeling of the transmission of the HIV virus is a complex problem itself, a parallel complexity challenge involves the integration of social systems that need to partner effectively in developing and implementing HIV prevention strategies within defined communities. No amount of modeling by itself will be sufficient, and no amount of modeling at the national level will be as informative as the detailed examination of individual level and social determinants of HIV at the local level. The roundtable discussion brings together the disciplines and organizations required in such a partnership. We include experts in longitudinal, epidemiologic studies of HIV at a community level, biologic and network

factors in HIV transmission and intervention, agent-based modeling, local policy makers, community leaders, scientific policy, and implementation science. A synthesis of these perspectives that integrate research, practice, policy, and community is provided.

Discussant:

- *Benjamin Armbruster*
  Industrial Engineering and Management Sciences
  Northwestern University

- *Nanett Benbow*
  Deputy Commissioner
  Chicago Department of Public Health

- *Richard D'Aquilla*
  Infectious Diseases, Robert H Lurie Medical Research Center
  Northwestern University

- *Chris Gordon*
  Branch Chief, Division of AIDS Research
  National Institute of Mental Health

- *Brian Mustanski*
  Medical Social Sciences
  Northwestern University

- *Daniel Pohl*
  HIV/STD Prevention Department
  Howard Brown Health Center

- *John Schneider*
  Departments of Medicine & Health Studies (Epidemiology)
  University of Chicago

- *Uri Wilenski*
  School of Education and Social Policy;
  Electrical Engineering and Computer Science
  Northwestern University

Lunch: Fr. 12:15 pm-1:15 pm

Location: Ryan Family Atrium

Welcome Address: 1:15 pm 1:30 pm

Location: Hughes Auditorium

Plenary 1: Fr. 1:30 pm-2:30 pm

Location: Hughes Auditorium (CME)

Operations Research and Health Care

Sheldon Jacobson
Director, Sim. & Opt. Lab.
Department of Computer Science
University of Illinois, Urbana Champaign

Operations Research and Health Care: An Opportunity to Make A Difference The operations research community is positioned to impact healthcare across the world. The key asset that we bring to the healthcare field is the manner in which we approach and analyze problems. It is our analytical thinking that provides the greatest opportunity for our efforts to meet the challenges faced by healthcare systems. Our effectiveness in this role will be a function of our willingness to step out of our traditional comfort zones for publication, dissemination, and participation, and boldly immerse ourselves in this domain of study. This talk discusses the issues that are critical for moving operations research modeling and analysis from an interesting technique applied to healthcare into a valuable asset for improving our nations health care system.

Technical Session 5: Fr. 2:45 pm-4:15 pm

Location: Gray Seminar Room

Innovative Mechanisms For Operating Room & Patient Readmission Management

Chair: *Vikram Tiwari*, Vanderbilt University Medical Center

Predicting Day-of-Surgery Case Volume

Vikram Tiwari, Warren Sandberg

Operating Rooms capacity is planned weeks in advance, though the final demand is only known 1-2 days in advance. This time-period is insufficient to adjust staffing and room assignments. Using the developing elective case schedule we build statistical models to predict total daily case volume weeks in advance. Post-implementation, we show the effectiveness of the models predictions in helping identify ORs for closure; however, even this lead time was found to be insufficient to reallocate the released capacity from unutilized surgical services to services that might fill the volume shortfalls. In order to develop forecasts with an even longer lead time, we used surgeons self-reported time-away information to develop probabilistic estimates of surgeons availability to be present clinically in the ORs in the next 6 weeks. Using simulation, we develop daily case volume prediction models at the individual surgical service level that is accurate to within a 2.5% forecast error.

Leveraging Game Theory to Improve Scheduling Accuracy
Bassam Kadry

Frequent underestimates of case durations can lead to costly unanticipated over utilized OR time. Furthermore, an inaccurate schedule can negatively impact patient, physician and nursing satisfaction. Historically, the problem of scheduling accuracy has been approached using mathematics and statistics. We test the impact of gaming mechanics on percent scheduling error where surgeons compete against the computer. A daily reward mechanism was created comparing the surgeons prediction vs. that of the computer. The longitudinal crossover pilot was conducted on ASA 1-3 patients having functional endoscopic sinus surgery. Pre-intervention the percent scheduling error was 58.5% (n=32), post intervention percent scheduling error was 20.2% (n=9, p=0.0022), and when intervention was removed percent scheduling error reverted back to 47.3% (n=12). It is difficult to differentiate if improvements were a result of Hawthorne effect or the application of gaming mechanics.

Patient, Heal Thyself! A Technology Enabled Intervention to Promote Patient Activation
Carrie Queenan, Alan Snell

Chronic disease care consumes a large percentage of US healthcare costs and in many cases, patients have significant control over severity of disease and deterioration. Building on the well known "costs of quality" framework, we argue that prevention costs for chronic disease patients are less expensive than "failure costs" i.e. hospital readmissions. We propose that the strategic use of telemonitoring, with nurse intervention, can improve patient activation and reduce hospitals readmissions. We differentiate our study from many previous telemonitoring efforts as merely "appraisals" as opposed to prevention and show how our telemonitoring helps to prevent patient deterioration. We then present results of a randomized experiment of patients with CHF or COPD and show our telemonitoring enables patients to improve their patient activation measures (PAM), which is associated with better health decisions and fewer hospital readmissions.

Inception and Design of a Randomized Trial to Study the Impact of Case-Specific Operative Time Prediction on Operating Room Productivity
Panos Kougias, Vikram Tiwari, David Berger

In order to maximize operating room (OR) utilization, better estimates of operative case lengths are needed. In most ORs these are calculated based on historical means. This simplistic method fails to account for the influence of operative characteristic on case durations. We statistically modeled the time length of vascular operations. A simulation of the scheduling process was then performed to compare OR throughput when scheduling

using either the developed models or the historical means methodology. This simulation demonstrated that an average annual improvement in throughput of 24% can be anticipated using the regression modeling approach. On the basis of these findings we designed a double blinded randomized controlled trial to assess the performance of the regression-based scheduling in practice. Primary outcome will be the predictive accuracy achieved; secondary outcomes will include OR throughput, OR personnel satisfaction, and postoperative complication rates.

Technical Session 6: Fr. 2:45 pm-4:15 pm

Location: Baldwin Auditorium

Applied Healthcare Management

Chair: *Nan Kong*, Purdue University

Optimal Copayment Restructuring for a Heterogeneous Patient Population
Mariel Lavieri, Greggory Schell

Rising copayments for pharmacotherapy disincentivizes adherence to prescribed medications, which leads to higher incidence rates of preventable disease such as cardiovascular disease. We propose a Markov decision process and nonlinear programming model to determine the optimal copayment levels for each patient class within a heterogeneous population insured by a single insurance provider. The provider is assumed to have a constrained budget for expenditures on reducing out-of-pocket expenses for its patients. The provider is further constrained by a measure of the equity of the copayment coverage across the patient population. In addition to modeling how changes in copayments affects adherence to medication, our model considers the effects of copayment differentials between patient classes and their potential impact on incentivizing lifestyle changes. The model is developed using data from the U.S. Department of Veterans Affairs.

Interventions as an alternative to penalties in preventable readmissions
Jose Zayas-Castro, Andres Garcia

One attempt by the US government to address aspects related to the accessibility, cost, and quality of care, is the Patient Protection and Affordable Care Act. Several years ago, preventable readmissions began to be considered a measure of quality in healthcare. In the fiscal year 2013, the Centers for Medicare and Medicaid Services began imposing financial penalties, through the Inpatient Prospective Payment System, to hospitals that have higher than expected readmission rates in certain diseases. This research studies an alternate policy based on disease-specific interventions to reduce the preventable readmissions. Our

results show that a policy based on implementing disease-specific interventions, instead of penalties, may save result in significant savings.

Optimal Physician Traveling Assignment for Improving Care Access in An Outpatient Care Network
Yan Li, Nan Kong, Qipeng Zheng

In an era of curbing healthcare spending, many patients encounter difficulty in access to care, especially those residing in underserved areas and seeking outpatient specialty care. Many of them are either declined of access or faced with significant travel burden for their appointments. There is a need to address the dire situation with worsening imbalance between provider capacity and care need. In this paper, we develop a mixed integer programming model to optimally assign physicians and patients to outreach care facilities for outpatient care networks to improve patient access to care. We term our model the multi-commodity capacitated traveling facility location problem and develop efficient column generation based heuristic methods. We use mental health in the veterans integrated service networks as case studies. Our studies demonstrate the conditions under which the idea of scheduling sessions at outreach facilities is appealing and show the efficiency of our proposed heuristics.

Technical Session 7: Fr. 2:45 pm-4:15 pm

Location: Hughes Auditorium (CME)

Data-Driven Decision Making

Chair: *Karen Smilowitz*, Northwestern University

Reducing Hospital Readmissions by Integrating Empirical Prediction with Resource Optimization
Jon Stauffer, Jonathan Helm, Adel Alaeddini, Kurt Bretthauer, Ted Skolarus

Hospital readmissions cost $15 billion annually in the US alone. Currently, 17% of Medicare patients are readmitted to a hospital within 30 days of initial discharge. The medical literature conjectures that many readmissions can be avoided or mitigated by post-discharge monitoring. This research develops new methods to empirically generate an individualized estimate of the time to readmission density function and then uses this density to optimize a post-discharge monitoring schedule and staffing plan to support monitoring needs. We transform an intractable monitoring plan optimization with stochastic discharges and health state evolution based on delay-time models into a weakly-coupled network flow model with tractable sub-problems after applying a new pruning method that leverages the problem structure. We show that optimal readmission prediction and monitoring plans

can identify and mitigate 40% - 70% of readmissions before they generate an emergency readmission.

Incorporating new data streams in humanitarian logistics
Irina Dolinskaya, Kezban Yagci Sokat, Alexander Rui Zhou, Karen Smilowitz, Jennifer Chan

In the current age development of communication technology, information can be gathered and shared quickly. This availability can have numerous benefits, especially in the acute phase and post-disaster settings. Using the recent Philippines Typhoon Haiyan as a case study, we analyze how dynamically emerging data can be collected, processed and used in humanitarian logistical decisions. We assess the availability, the benefits and shortcomings of real-time post disaster data related to response logistics. While multiple outlets contain overlapping information, significant gaps are still present in some domain fields, such as the logistical components. The content and format of the data sources create their own set of challenges for integration within logistical operational models to aid quick decisions for operational teams on the ground.

Expanding Medical Preparedness for Mass Gathering Events Through Data Analytics
Karen Smilowitz, George Chiampas, Sanjay Mehrotra, Jennifer Chan, Mike Nishi, Mehmet Basdere

We present findings related to medical preparedness for mass gathering events, focusing on data analytics from the Chicago Marathon, an event of 45,000 runners and an estimated 1.7 million spectators. In response to the extreme temperatures of the 2007 Chicago Marathon, organizers established the Chicago Model, a comprehensive planning and implementation approach integrating organizational structure, information systems, and communication to enhance planning, preparedness and real-time response for mass gathering events. Using 2012 and 2013 medical data from the Chicago Models patient tracking system, we characterize the spatial and temporal distribution of injuries. We present findings on the adoption of the tracking system and use insights to develop a framework for medical studies of mass gathering events. Our goal is to combine this data with data from other events that use the same tracking system to create the most comprehensive medical study of large-scale marathons.

Issues with merging longitudinally collected cohort data from multiple studies
Brittany Bogle, Sanjay Mehrotra

Analyzing data from longitudinal cohort studies can be challenging. While developing

predictive models for cardiovascular outcomes, our team has learned that the organization of longitudinal cohort study data can pose issues before the analysis and modelling can occur. Care should be taken in data cleaning and pre-processing. We discuss issues when developing models that use variable selection techniques, merging exams within the same study, and considerations for merging multiple exams for the same outcome. Our discussion highlights specific examples of issues that we have encountered, focusing on a well known cardiovascular study.

Plenary 2: Fr. 4:30 pm-5:30 pm

Location: Hughes Auditorium (CME)

Optimizing and Transforming the Healthcare System

Eva Lee

Director, Center for Operations Research in Medicine & HealthCare
Co-Director, NSF I/UCRC Center for Health Organization Transformation
Industrial and Systems Engineering
Georgia Institute of Technology

Risk and decision models and predictive analytics have long been cornerstones for advancement of business analytics in industrial, government, and military applications. They are also playing key roles in advancing and transforming the healthcare delivery system. In particular, multi-source data system modeling and big data analytics and technologies play an increasingly important role in modern healthcare enterprise. Many problems can be formulated into mathematical models and can be analyzed using sophisticated optimization, decision analysis, and computational techniques. In this talk, we will share some of our successes in early disease diagnosis, treatment planning design, and healthcare operations through innovation in decision and predictive big data analytics.

Poster Session 7: Fr. 5:45 pm-7:00 pm

Location: Gray Seminar Room

Poster 1: ** Poster Competition **

Race Course Configuration Problem

Mehmet Basdere, Karen Smilowitz, Sanjay Mehrotra

Medical preparedness is an integral part of mass gathering event planning in order to ensure the safety of the participants. In this study, we focus on medical preparedness in marathons from the perspective of marathon course design. For this purpose, we present a new type of tour finding problem, Race Course Configuration Problem (RCCP), which aims to find a valid marathon course that minimizes the average distance to the medical facilities within the region of interest while visiting a predetermined subset of landmark streets. The RCCP differs from classic selective arc routing problems: The medical facilities cannot be 'locked' within the interior region of the tour since public access to these facilities should not be prevented during the race. In a joint work with Chicago Event Management team, we solve the RCCP for Bank of America Chicago Marathon by using a smart enumeration based technique with newly developed valid inequalities.

Poster 2: ** Poster Competition **

Public Health Spending with a focus on Health Outcomes using Simulation

David Cornejo, Maria Mayorga, Stephen Roberts

For colorectal cancer and other chronic diseases, health outcomes may be improved through improved screening of individuals. We wish to optimize the allocation of a limited public health budget to interventions that change individuals choice to screen. The effect of these interventions is dependent on the effort placed into them as well the characteristics of individuals to which they are applied. We develop methods to optimize the allocation of a fixed public health budget across individuals life course and between different demographic groups. To support this optimization, we develop a procedure that allows us to translate unit levels of public health policy efforts into changes in individuals decision making over time. We use a simulation model that incorporates the dynamics of colon cancer natural history and individuals screening agency to test and illustrate the effects of the polices developed by our procedure.

Poster 3: ** Poster Competition **

A Predictive Model for Outpatient Clinic No-Show Behavior

Shannon Harris, Jerrold May, Luis Vargas

Patient no-shows complicate appointment scheduling systems. The accurate prediction of

no-shows can assist a clinic in developing operational mitigation strategies such as overbooking appointments or preemptive calling of patients. We present a new model for predicting no-show behavior based solely on the binary representation of a patients historical attendance history. The model is a parsimonious, pure forecasting model that combines regression modeling and the sum of exponential functions to produce probability estimates. The model can be shown to have good predictive power as compared to established models, and generates parameters that can give insight into how past behavior effects future behavior. Our choice of the exponential function for modeling leads to tractable analysis that can be proved to be optimal and unique, and can be easily applied to other datasets. We illustrate our approach using data from patients attendance and non-attendance at VA outpatient clinics.

Poster 4: ** Poster Competition **

Overdiagnosis and Lifetime Mortality Risk in Cancer Screening while Considering Variation in Patients Adherence Behaviors

Mahboubeh

Overdiagnosis is defined as the diagnosis of screen-detected cancers that would not have presented clinically in a womans lifetime in the absence of screening. Overdiagnosis happens because some cancers never progress or progress slowly enough that the patient dies of another cause before the cancer becomes symptomatic. In this research a nonlinear integer programming model is developed to minimize breast cancer overdiagnosis and lifetime mortality risk while incorporating the heterogeneity in patients adherence to prescribed mammography screening policies. Our results indicate that the efficient policies are significantly different from the current guidelines recommended by health agencies. The screening intervals vary from age to age with more frequent screening mammograms for women in their mid 50s and mid 60s because of the higher incidence rate, longer life expectancy and relatively shorter sojourn time in this age interval.

Poster 5: ** Poster Competition **

On effectiveness of Point-Wise DVH constraints

Arkajyoti Roy, Indra Das, Omid Nohadani

Treatment plan evaluation in radiation therapy are typically conducted using dose-volume histograms (DVH). While specific DVH points are utilized for numerical comparisons of multiple plans, the overall quality is visually inspected. This subjective inspection leads to significant planner bias in treatment planning. We demonstrate the existence of bias on one hundred head-and-neck cancer patients, using three statistical measures: a) the interquartile range of volume, b) the interquartile range of dose, and c) the median and the interquartile range of dose falloff. Furthermore, we observe tendencies to relax constraints in order to satisfy competing objectives, leading to further degradation of plans

at neighboring unconstrained DVH points. This study reveals a need for constraints to be enforced over the entire DVH to diminish planner bias in treatment planning.

Poster 6: ** Poster Competition **

Impacts of room allocation policies on quality of care in an outpatient clinic

Vahab Vahdatzad, Jacqueline Griffin, James Stahl

Overcrowding in hospitals is an increasingly common scenario that affects patient satisfaction, quality of care, staff workloads, and clinical outcomes. In order to address overcrowding in a cardiovascular outpatient clinic, a discrete-event simulation model is constructed which focuses on patient flow, appointment room availability, and staffing. Several Medical Assistants and physician-room allocation policies are compared with respect to patients wait time and length of stay. The impact of implementing a hybrid policy, achieving a balance of both pooled and designated room allocation policies is also examined. In future work, this model may be used to inform real-time room allocation policies that harness the power of real-time location systems in hospitals.

Poster 7:

Optimal Surveillance of Hepatocellular Carcinoma for Patients with Hepatitis C: A Societal Perspective

Turgay Ayer, Qiushi Chen, Jagpreet Chattwal

Hepatocellular carcinoma (HCC), the most common type of liver cancer, is the fastest growing cause of cancer-related death in the United States. Early detection of HCC through regular surveillance can improve survival. However, the optimal surveillance policies are unknown. We propose a novel modeling framework to determine the most cost-effective practical policies from a societal perspective. In contrast to existing policies, our model considers surveillance policies that are stratified by patients' liver condition and age. We carefully calibrate the model parameters based on the best evidence from previously published observational studies. Our results show that our proposed policies are more cost-effective than the recommended one-size-fits-all policies. We further find that, unlike the current practice, expanding surveillance to non-cirrhotic patients has a great potential to improve survival outcomes and cost-effectiveness.

Poster 8:

Robust Post-donation Blood Screening under limited Information on Prevalence Rates

Hadi El Amine, Ebru Bish, Douglas Bish

Blood product safety, in terms of being free of transfusion-transmittable infections, is cru-

cial. Under prevalence rate uncertainty, various objective functions, including minimization of a mean-variance objective and minimization of the maximum regret, were considered in order to determine a "robust" post-donation blood screening strategy that minimizes the risk of releasing an infected unit of blood into the blood supply. Efficient and exact algorithms are provided.

Poster 9:
Uncertainty in clinical data and stochastic model for in-vitro fertilization
Kirti Yenkie, Urmila Diwekar

In-vitro fertilization is the most common technique in assisted reproduction. It has been divided into 4 stages; superovulation, egg retrieval, insemination and embryo transfer. The first stage of superovulation is a drug induced method to enable multiple follicle growth to oocytes in single menstrual cycle. IVF being a medical procedure that aims at manipulating biological functions in human body, is subjected to inherent sources of uncertainty. Also, interplay of hormones with natural functioning of ovaries to stimulate multiple ovulation makes the procedure dependent on several factors like cause of infertility, actual ovarian function, responsiveness to medication, etc. The treatment requires continuous monitoring and testing and this can give rise to observation errors. These uncertainties are in the form of measurement noise in clincial data. The purpose of this work is to come up with a robust model for superovulation cycle to provide a treatment guideline.

Poster 10:
Optimal Issuing Policies for Hospital Blood Inventory
Alireza Sabouri, Tim Huh, Steven Shechter

We propose a model for allocating red blood cells for transfusion to patients, which is motivated by recent findings in medicine that the age of transfused blood can affect health outcomes, with older blood contributing to more complications. Current practice at hospital blood banks is to issue blood in order from oldest to youngest inventory, so as to minimize shortage (and/or wastage). However, the conflicting objective of reducing the age of blood transfused requires a more complicated issuance policy that also depends on the inventory of units of different ages. Since the dynamic programming formulation of this problem suffers from the curse of dimensionality due to the large state and action spaces, we solve the problem using approximate dynamic programming methods. Our numerical results, based on data from a large hospital in British Columbia, suggest we can significantly reduce the age of transfused blood with a relatively small increase in the shortage rate.

Poster 11:

Competitive Healthcare Facility Locations and Capacity Configurations under Stochastic Demand
Xue Han, Wilbert Wilhelm

The stochastic healthcare facility locations and configurations problem is to prescribe each facilitys location and its capacity configuration of each service, including openings, closures, expansions and contractions of capacities over the planning horizon under stochastic patient demands, aiming at maximizing the total expected excess revenue. We model patient demands as random processes based on demographic data and growth projections, and investigate both competition and location-allocation models to assign patient demands. The configuration problem for a single facility is formulated as a resource-constrained shortest path problem (RCSPP). For multiple-facility case, we design a novel column generation algorithm and an approximation method using the RCSPP as building modules. This research conducts case studies to locate and configure primary care centers in mid-Texas scaling form one county to 12 counties, and performs sensitivity analyses for competitive factors.

Poster 12:
Optimizing Distribution of Pandemic Influenza Antivirals
Bismark Singh, Hsin-Chan Huang, David Morton, Gregory Johnson, Alexander Gutfraind, Alison Galvani, Bruce Clements, Lauren Meyers

We propose a method for optimizing the location of distribution points for Strategic National Stockpile (SNS) antivirals within a state. Working with the Texas Department of State Health Services (DSHS), we developed a data-driven facility-location model for designing commercial pharmacy SNS antiviral distribution networks that maximizes access in priority populations. In this work we describe the model which is available to Texas DSHS as a web-based decision-support tool for future pandemics, and we use it to evaluate and optimize the commercial pharmacy distribution network established in Texas during the 2009 H1N1 pandemic.

Poster 13:
The DPI-Dependent Scoring-Scheme for Allocating Cadaver Kidneys
Yichuan Ding, Baris Ata, Stefanos Zenios

In the United States, candidates on the cadaver kidney transplant waitlist are ranked using a scoring scheme that takes into account characteristics of the donor and the candidate. This work undertakes a modeling based analysis of a general class of scoring systems. We consider scoring systems that are DPI-dependent, but also DPI-independent. We use a fluid model to approximate the transplant waitlist, and identify the achievable regions by using both types of scoring policies, respectively. Comparison of the two achievable

regions suggests that the DPI-dependent policy reduces kidney rejections and wastage by strategically rationing the kidneys according to their DPIs.

Poster 14:
Discrete event simulation for primary care redesign
Xiang Zhong, Tingmao Wang, Molly Williams, Jingshan Li, Sally Kraft

In this work, we introduce a discrete event simulation model to characterize the general primary care delivery system, evaluate its design options, and propose recommendations for system improvement. In support of the redesign, discrete-event simulation models are developed to analyze the patient flows in primary care processes with complex interactions among patients, care providers, and other resources. Specifically, different appointment templates are compared and various physician-to-nurse ratios are investigated. Through identifying the optimal scheduling template and staffing model, managerial alternatives and insights of system properties are gained, and reduced patient average length of stay (LOS) and improved staff utilization are achieved.

Poster 15:
Closure Time Out as Predictor for ReOperation to Control Bleeding following CABG Surgery
Terrill Theman, Yu Xin

The need to return patients to surgery to control unremitting bleeding after CABG surgery is associated with increased patient morbidity and mortality. To test the concept of "Closure Time Out" (CTO)and to determine the validity of the 100ml blood-loss parameter as predictor for reoperation to control bleeding, a study was undertaken at 3 unaffiliated cardiac surgery programs. 880 patients were studied over one year with 3.18% requiring reoperation. If patients had ¿100ml in the collection system at time of wound closure, the reoperation rate rose to 13.4%, but it was only 1.58% if initial blood collection was ¡100ml (p¡0.05). By adding CTO to the Surgical Checklist surgeons can improve patient outcomes and reduce the risk of reoperation to control bleeding after CABG surgery.

Poster 16:
Comprehensive Mapping of Injecting Drug Users and their Networks in the Chicago Metropolitan Area
Alexander Gutfraind, Murillo Marco Carvalho Cunha, Basmattee Boodram, Harel Dahari, Marian Major

Persons who inject drugs (PWID) pose a public health concern due to the high morbidity and mortality rates associated with drug use, and infections with pathogens such as HIV

and Hepatitis C. While computational modeling may help to design and simulate intervention programs among PWID, such modeling requires comprehensive characterization of the PWID population, which is not available. In this study we construct a synthetic population (i.e., a statistically representative map) of the PWID population in metropolitan Chicago using a Bayesian approach informed by a unique survey of PWID enrolled in a large needle exchange program. The resulting dataset contains 32,000 individuals and includes their demographics, geolocation, health (HIV and HCV) drug use behaviors and drug sharing network of each individual. Our synthetic population will likely assist planning and optimizing public health intervention programs via computational studies.

Poster 17:
Do hospitals in a large metropolitan area utilize published breast cancer care practices and guidelines?
Christine Weldon, Julia Trosman, Anne Marie Murphy, Melissa Simon, William Gradishar

Insufficient utilization of guideline and evidence based care practices contribute to the cancer crisis (IOM 2013). We examined utilization of published breast cancer (BC) care practices and guidelines at hospitals in a large metro area via an IRB approved survey. 91%, 32/35 sites responded. Care practices utilized by ¡ 50% of sites. Radiation oncologist pre-op consults (53%, 8/15) and offering indicated pre-op chemo (67%, 10/15) is associated with 15 sites with high volume (67+/year, Chen CS 2008) BC surgeons, vs 17 sites without high volume BC surgeons (12%, 2/17) and (24%, 4/17) respectively, p=0.02, p=0.03. Indicated supportive services are more likely at sites with written treatment plans (IOM 2011) (58%, 7/12) than at sites without written treatment plans (10%, 2/20), p=0.006. Low utilization of published care practices and guidelines is concerning and requires attention.

Poster 18:
A Design Process for Patient Safety Solutions: The Active Risk Control Toolkit
Alan Card

Preventable patient harm may be the leading cause of death in the US. To address this, the healthcare industry has adopted operational risk management tools from high-reliability industries. These focus exclusively on risk assessment (problem exploration); none provide direct support for risk control (solutions design/management). The result: Some improvement in the risk assessment process, but no improvement in patient safety outcomes. The Active Risk Control (ARC) Toolkit aims to bridge this gap by providing an analogous, structured approach to risk control design. This presentation will describe a series of studies evaluating the use of the ARC Toolkit across 4 different healthcare settings. Key results: Use of the (free) Toolkit was associated with the design of stronger risk control interventions & increased confidence in the results. Users found the Toolkit useful, easy to use, and

valuable. Most would use the Toolkit again in the same or similar circumstances.

Poster 19:
Workflow Orchestration Cloud Capabilities
David Stumpf, Andrew Schriver, Jesse Shiah

Health care can be engineered as a sequence of events triggering tasks with actors, action scripts, and outcomes. The AgilePoint (AP) cloud enables domain expert curation of workflows which are then compiled into APIs whose capabilities can be accessed by end users. Technologists configure the API for their local environment without writing code. AP workflows contain objects with properties and methods supporting numerous dynamic capabilities: data management, decisions, forms, human tasks, assignments, reporting, simulation and analytics. Park Street Solutions (PSS) provides vocabulary and ontology solutions necessary for aligning workflows across venues. PSS translates API request and response messages with the same content into format requirements of the two venues, thereby addressing ambiguities in standards. AP and PSS collaboration is advantageous for managing messages across venues and expert curation of next generation content required to implement care coordination models.

Poster 20:
Healthcare Scheduling Tools: Customization vs. Convenience
Amy Cohn

Provider and patient scheduling are important challenges in almost any clinical environment. Industrial engineering- and operations research- based decision support tools can be very valuable, not only in reducing the workload of producing these schedules, but in greatly enhancing their quality. This can include improving patient access, quality of care, quality of life for the providers, and educational experience for residents. To be successful, a scheduling tool must capture the unique requirements of the particular clinical environment and the nuances of its unique culture. On the other hand, "starting from scratch" in each new situation is impractical, expensive, and time consuming. We present our experience in developing several different scheduling tools across several different hospitals and healthcare systems, and our attempts to balance the benefits of customization with the convenience of generalization.

Poster 21:
Simultaneous Beam Sampling and Aperture Shape Optimization for Station Parameter Optimized Radiation Therapy (SPORT)
Masoud Zarepisheh, Ruijiang Li, Yinyu Ye, Lei Xing

Station Parameter Optimized Radiation Therapy (SPORT) was recently proposed to fully utilize the technical capability of emerging digital linear accelerators in cancer radiation therapy. In SPORT, the station parameters of a delivery system such as aperture shape and weight, couch position/angle, gantry/collimator angle can be optimized simultaneously. SPORT promises to deliver unprecedented radiation dose distributions in an efficient manner, yet there exist no optimization algorithm for its implementation. The purpose of this work is to develop an algorithm to simultaneously optimize the beam sampling and aperture shapes. To solve the resulting large-scale optimization problem, we devise an effective algorithm by integrating three optimization techniques: column generation, subgradient method, and pattern search. The proposed technique was applied to two previously treated clinical cases: a head and neck, and a prostate case.

Poster 22:
Optimal facility in-network selection for healthcare payers under reference pricing
Victoire Denoyel, Aurelie Thiele, Laurent Alfandari

Healthcare payers are exploring cost-containing policies to steer patients towards providers with the best value proposition. With Reference Pricing (RP), a payer sets a maximum amount for a procedure; patients who select a provider charging more pay the surplus. In a Tiered Network (TN), providers are stratified according to some criteria (quality, cost, location); patients pay a different out-of-pocket price depending on the tier of chosen provider. Motivated by a recent CalPERS program, we design two original MIP models combining both RP and TN for payers, filling the gap of quantitative research on these novel payment policies. Carefully designed constraints provide the decision maker with levers for a trade-off between cost reduction and patients' satisfaction. Numerical experiments provide valuable insights. We argue that this system has strong potential in terms of costs reduction for public or private payers, quality increase for patients and visibility for high-value providers

Poster 23:
Assessing Efficient Frontiers in Emergency Departments and Associated Environmental Factors
Hyojung Kang, Harriet Nembhard

To improve the efficiency of care, hospitals have extensively collected performance measures of emergency department(ED) processes and developed initiatives that focus on reducing waiting times. However, relatively less attention has been given to evaluating the efficiency of resource consumption. This study aims to assess efficient frontiers in EDs and to identify characteristics that contribute to differences in efficiency measures. Using a data envelopment analysis (DEA) method, we evaluate relative efficiencies of 337 EDs. The EDs

are classified into three groups; variable returns to scale DEA models are developed for each group. The nonparametric estimators are associated with sampling variations of the frontiers. To address the bias of the efficiency scores and to obtain statistical inference for the estimators, a bootstrap method is implemented. The adjusted efficiency scores yield a truer picture of the environmental factors that affect efficiency of EDs.

Poster 24:
Rationing Non-Directed Donors in Kidney Exchange
Yichuan Ding, Dongdong Ge, Simai He, Christopher Ryan

Historically, non-directed donors (NDDs) have been allocated to the decreased-donor waitlist. Recently, use of NDDs in exchanges has increased the number of transplants but reduced prospects for patients without donors. We take a non-asymptotic approach to quantify the marginal benefit of NDDs to the exchange pool. When the pool size is not moderately large and the proportion of low sensitized patients is above a threshold, the marginal benefit of NDDs diminishes quickly.

Poster 25:
Towards Cost-Effective Multiple Disease Screening
Sonia Bhaskar, Mohsen Bayati, Andrea Montanari

Recently, in response to the rising costs of healthcare, self-insurance companies who are financially responsible for the medical costs of their employees have been investing in programs to improve the health of their workforce. A main objective of these wellness programs is to reduce the incidence of chronic illnesses which impact future costs. The majority of these wellness programs include an annual screening to detect individuals with a high risk of developing chronic disease. Once these individuals are identified, the company can invest in interventions to reduce the risk of those individuals. However, the overall efficacy of these wellness programs relies on prediction accuracy and cost of the screening. We address this challenge by minimizing the number of biomarkers that need to be captured, while maximizing the predictive ability over a broad spectrum of disease. Our solution uses multi-task learning and group dimensionality reduction from statistical learning.

Poster 26:
Fault tree analysis a system based approach to assessing the risk of surgical complications
Rebeca Khorzad, Lisa McElroy, Zachary Abecassis, Michael Ison, Sanjay Mehrotra, Jane Holl, Daniela Ladner

Background: 25 percent of patients experience some form of preventable harm while hos-

pitalized. Our study assesses the usability of Fault tree analysis (FTA) in three major surgical complications after liver transplant, pneumonia, bacteremia and post-operative hemorrhage.
Method: comprehensive list of faults was generated by Clinicians input and literature review. Branches of the tree were connected with OR or AND gates. Human error, mechanical malfunctions and patient factors were considered and incorporated into the trees.
Results: Less than 10percent of the faults were identified in scientific literature. A lack of redundancy in the system was observed.Clinicians expressed skepticism about the tools ability to capture all the complexities of patient factors involved in surgical complications.
Conclusion: FTA has multiple advantages for clinical use.

Poster 27:
Minimizing Metastatic Risk in Radiotherapy Fractionation Schedules
Kevin Leder, Jagdish Ramakrishnan

Metastasis is the process by which cells from a primary tumor disperse and form new tumors at distant anatomical locations. The treatment and prevention of metastatic cancer remains an extremely challenging problem. In this work, we consider the problem of developing fractionated irradiation schedules that minimize production of metastatic cancer cells. Interestingly we observe that the resulting fractionation schedules are significantly different than those that result from more standard objectives such as minimization of final primary tumor volume. Hypo-fractionation is suggested even in cases when the $\alpha\$/\$\beta$ value of the tumor is large. This work introduces a novel biologically motivated objective function to the radiation optimization community that takes into account metastatic risk instead of the status of the primary tumor.

Poster 28:
Redesigning Transplant Organ Labeling: An Innovative Approach to Improve Patient Safety
Jane Holl, Donna Woods, Daniela Ladner, Enid Montague, Rebeca Khorzad, Anna Nannicelli, Alexandra Brown

Background: As part of a larger HHS Innovation Initiative, we participated in a three phase project to improve the organ labeling and identification process that included: (1) Risk assessment; (2) Testing of a tablet application ("app") and (3) Use of high-fidelity, laboratory-based simulations to assess organ procurement workflow with the new "app".
Study Design: Organ Procurement Organizations (OPOs) and Transplant Centers (TCs) contributed to the creation of a process map. Potential failures for each process step were identified, scored, ranked by criticality, and then used to validate the design of the "app".
Findings: 146 potential failures, critical risks include: Accuracy of donor information on the label; Identification of the laterality of a kidney; and validation of receipt of the right

donor organ for the right recipient.
Conclusion: The "app" impacts 65% of the top ten critical risks and should mitigate labeling errors that lead to loss of organs.

Poster 29:
Writing Custom Queries to Parse Free-Text Pathology Reports and Detect Overdue Colonoscopies
Ajay Haryani, David Liebovitz, Christian Stevoff

Patients with an adenoma detected upon screening colonoscopy are recommended to have a follow-up colonoscopy in five years instead of ten, but often do not adhere. An obstacle in identifying these overdue patients is the free-text nature of colonoscopy pathology reports. Query was generated against the Northwestern Medicine Enterprise Data Warehouse, parsing free-text pathology reports, in order to identify patients overdue for colonoscopy follow-up post adenoma detection from 2007-2008. The results were evaluated against chart review and patient phone call, and patients were directed through their primary care physicians for colonoscopy follow-up. Of 503 eligible patients, 282 were successfully reached with 78% of patients truly overdue for a colonoscopy and 22% having completed colonoscopies elsewhere. This custom query of the Northwestern database seems to be an accurate and cost-effective method of identifying patients overdue for a follow-up colonoscopy post adenoma detection.

Poster 30:
Review of Innovative Packaging technologies for Opioid Abuse Prevention
Onur Babat, Han Gao, Luis Zuluaga

Over the past two decades opioid abuse has escalated within the United States. The misuse of opioids and painkillers has severe effects on users, doctors, and prescribers alike. Solutions to this problem could include: drug development of abuse deterrent formulations, opioid labeling, prescriber and patient education, innovative technological packaging, and encouraging the development of products that treat or prevent abuse and potential overdose. In this paper, current innovative packaging and storing technologies that have the potential to prevent abuse are reviewed. In particular, a categorized description of feasible technology solutions is provided, together with its main characteristics. We also describe the process used to develop the review study, and the main conclusions that can be drawn from it.

Saturday, September 13, 2014

Brunch: 8:00 am-8:30 am

Technical Session 8: Sa. 8:30 am-10:00 am
Location: Gray Seminar Room

Chronic Disease Management
Chair: *Turgay Ayer*, Georgia Institute of Technology

Cost-effectiveness of hepatitis C treatment delivery in U.S. incarcerated populations
Shan Liu, Daena Watcha, Mark Holodiny, Jeremy Goldhaber-Fiebert

The prevalence of chronic hepatitis C virus (HCV) infection is estimated at 12-35% among U.S. incarcerated populations. Availability of highly efficacious antivirals may be beneficial for HCV-infected inmates and expand treatment eligibility for inmates with short sentences. We assessed the cost-effectiveness of newer sofosbuvir-based therapy. We developed a decision-analytic Markov model that included the natural history of chronic HCV and combinations of treatment options both in and out of prisons; and the possibility of reinfection. Sofosbuvir produced the largest absolute reductions in decompensated cirrhosis and hepatocellular carcinoma. We found sofosbuvir-based therapy is cost-effective for long and short-term incarcerated individuals. Very high prison reinfection rates reduce cost-effectiveness for inmares with longer remaining sentences. Given newer drugs, high price, and the large size of the infected incarcerated population, affordability is an important consideration.

Estimating Lipid Management Guidelines' Risk Value Of A Life Year On Treatment

Murat Kurt, Niraj Kumar Pandey, Mark Karwan

Statins reduce the risk of heart attack and stroke with adverse side effects, but except surveys there has not been any emphasis on how to quantify these effects to help physicians make treatment decisions. We gauge these adverse effects for patients with Type 2 diabetes from a central policy makers point of view. We formulate a dynamic decision model in which the objective is to minimize the risk of a first major cardiovascular event where each life year spent on treatment is penalized by a perceived increase in the risk and seek penalty factors that make published lipid management guidelines as close as possible to optimal. Our results show that guidelines penalize males more than females for being on treatment, and among all considered guidelines, Adult Treatment Panel (ATP) III is the most tolerant to treatment with the longest expected treatment durations for both genders. We also observe that almost all guidelines perform close to optimal under their perceived penalty factors. **Evaluation of Breast Cancer Mammography Screening Policies**

Considering Adherence Behavior

Mahboubeh Madadi, Shengfan Zhang, Louise Henderson

Mammography is currently considered the most effective technology for early detection of breast cancer. The efficacy of mammography screening is associated with womens compliance with screening recommendations. However, earlier research indicated that the compliance remained low in recent years. In this study, we develop a randomized discrete-time finite-horizon partially observable Markov chain model to evaluate a wide range of screening mammography policies, incorporating variation in womens adherence behaviors. Policies with varying starting age, ending age and frequency of screening mammograms at different ages are compared in terms of quality adjusted life years (QALYs) and breast cancer lifetime mortality risk. Our results indicate that women with perfect adherence do not always experience higher QALYs. For women with medium and low adherence levels, existing screening guidelines (e.g., American Cancer Society) are not among the efficient policies.

The Impact of Risk Profiling on Mammography Interpretation: Bias in Biopsy Decisions

Mehmet Ayvaci, Mehmet Ahsen, Srinivasan Raghunathan, Zahra Gharibi

Available clinical evidence is inconclusive on the use of profile information when interpreting mammograms. One line of thought suggests that profile information helps radiologists to make better decisions and therefore it should be employed when reading mammograms. In contrast, another line of thought suggests that the profile information could bias the radiologists. We explore the role of profile information and potential bias in mammography

assessment and the subsequent biopsy decisions. Our model aggregates risk distributions due to patient profile and the mammography imaging. We illustrate our findings using clinical data and empirical methods. We find that an unbiased use of profile information with an appropriate weight could reduce the false positives by 3.23% and reduce the number of missed cancers by 3.70% when compared to non-use of profile information. The magnitude of the impact on outcomes depends on the weight assigned to the profile information and the level of bias.

Technical Session 9: Sa. 8:30 am-10:00 am

Location: Hughes Auditorium

Patient Flow In Emergency And Inpatient Care Settings

Chair: *Hari Balasubramanian*, University of Massachusetts Amherst

Using Future Information to Reduce Waiting Times in the Emergency Department

Carri Chan, Kuang Xu

The development of models to predict patient arrivals to the Emergency Department (ED) has been growing. We present a class of proactive policies which utilize future information of potential patient arrivals to manage admissions into the ED while reducing waiting times for patients who are eventually treated. Instead of the standard strategy of waiting for queues to build before diverting patients, the proposed policy utilizes the predictions to identify periods of high congestion and proactively diverts patients before things get too bad. A major challenge is that predictive models provide noisy information. We quantify the noise tolerance of our proposed policies so that they still outperform standard diversion policies. If the quality of the prediction is insufficient, it is better to ignore the future information and simply rely on real-time, current information for the basis of decision making. Using simulation, we find that our proposed policy can reduce delays by up to 15%.

Overflow Policies for Emergency Department Patients Awaiting Inpatient Beds

Pengyi Shi, Jim Dai

Emergency department patients who wait to be admitted to inpatient beds sometimes have to be overflowed to a non-primary ward when they wait too long. We study a queueing system to gain insights into the impact of overflow policies and how bed capacity and discharge timing affect the overflow rate.

Inpatient Discharge Planning at Hospitals
Nicholas Ballester, Pratik Parikh, Nan Kong

We recently completed a study at a local hospital to examine the day-of-discharge process and its effect on upstream patient boarding time. We examined several strategies such as reducing discharge processing time and advancing discharge order writing earlier in the day to reduce boarding. The next logical question is what would be the optimal strategy that minimizes upstream boarding. Assuming that all discharge orders are written by a certain time in the morning, the problem then becomes that of finding a discharge sequence of inpatients that minimizes boarding. We used data from a Trauma Unit at a Midwest US hospital for the year 2012 and developed a simulation-optimization approach to identify near-optimal sequences and compared them with the current strategy. Preliminary findings from this study will be shared and opportunities for further investigation will be discussed.

Technical Session 10: Sa. 8:30 am-10:00 am

Location: Searle Seminar Room

Patient Scheduling And Healthcare Operations

Chair: *Mark Van Oyen*, University of Michigan

Optimizing Timely Access to an Integrated Outpatient Care Network with Throughput and Utilization Metrics
Jivan Deglise-Hawkinson, Jonathan Helm, Todd Huschka, David Kaufman, Mark Van Oyen

Healthcare delivery worldwide is moving toward integrated care models in which services and specialties are coordinated for more comprehensive care. Adopting this new model of care, however, brings a host of operational challenges including the fact that new connectivity means that decisions made in one specialty service can impact other downstream services in the network. This research considers the problem of capacity planning for a network of specialty services in an integrated care organization that serves a heterogeneous patient population. We consider a multi-objective problem of coordinating capacity to reduce patient type-specific waiting times to begin treatment and reduce their time to complete treatment accounting for delays within the patients treatment path, while increasing the volume of new patients seen. Our approach transforms a stochastic optimization problem into a mixed integer program to optimize a booking plan for a network of care resources.

Missed Opportunities in Preventing Hospital Readmissions: Redesigning Post-

discharge Checkup Policies
Jonathan Helm, Michael Hu, Kedi Wu, Xiang Liu, Mariel Lavieri, Ted Skolarus

There are hundreds of thousands hospital readmissions every year, negatively impacting patients and placing a tremendous burden on the national healthcare system. Post-discharge checkup policies can reduce readmissions through early detection of health conditions, however, the methods behind designing effective checkup policies are poorly understood. Under current practice, up to 67% of readmitted patients return to the hospital even before their first scheduled post-discharge checkup. This work focuses on developing effective plans to monitor patients after discharge from a hospital stay based on a variety of monitoring mechanisms including phone calls, telemedicine, and office visits. We develop an analytical model determine the optimal type, number, and timing of checkups to perform as part of a post-discharge monitoring plan. Analyzing the structure of optimal policies, we develop schedules that detect and mitigate at least 32% more readmissions than current practice.

Fast Approximations for Online Scheduling of Outpatient Procedure Centers
Bjorn Berg, Brian Denton

This talk presents a new model for online decision making. Motivated by the health care delivery application of dynamic scheduling in outpatient procedure centers, the online stochastic extensible bin packing problem is described. The objective is to minimize the combined costs of opening procedure rooms and utilizing overtime to complete a day's procedures. The dynamic patient allocation decisions are made in an uncertain environment where the number of patients scheduled and the procedure durations are not known in advance. Approximation methods are presented as well as a special case that is amenable to decomposition-based solution methods. Theoretical performance guarantees are presented for list-based approximation methods as well as an approximation that is common in practice where procedure rooms are reserved for patient groups in advance. Numerical results based on a real outpatient procedure center demonstrate the favorable results of the list-based.

Appointment Scheduling for Multi-service Networks
Ester Wang, Kumar Muthuraman, Doug Morrice

We propose an appointment scheduling mechanism for multi-service networks that provide service points within a care facility. We propose a formulation of a sequential call-in process where a centralized scheduler assigns each patient to a slot of the requested service point that maximizes the network objective. The centralized scheduler optimizes the balance between patient waiting, provider overtime and network revenue. Decision-making accounts for uncertainty in patient attendance, service time and network routing. After

showing the optimal solution to be computationally prohibitive, we compute a myopic policy and numerically show that the optimality gap is small enough to justify the approach. Computational times for the myopic policy are still too expensive to implement the scheduling mechanism in real time. Therefore, we design a series of approximation schemes that trade computational accuracy off time and find an efficient and reasonably accurate approximation method.

Plenary 3: Sa. 10:15 am-11:15 am

Location: Hughes Auditorium (CME)

Systems Engineering in the University of Texas Health System: A Multi-Disciplinary, Integrated Model for Improvement

Victoria Jordan

Executive Director, Strategic Management & Systems Engineering
Office of Performance Improvement
University of Texas M.D. Anderson Cancer Center

The University of Texas (UT) has six health institutions (including MD Anderson Cancer Center) and Industrial and Systems Engineering faculty throughout university locations. These health institutions and academic institutions (along with the UT Medical School) are partnering to implement Systems Engineering in healthcare throughout the UT System. The "systems approach to implementing Systems Engineering" is an opportunity to serve as a world-class model for collaboration across academic and healthcare institutions to implement Systems Engineering and systems thinking in healthcare. By synthesizing the efforts of the UT components, this initiative results in reduced costs, reduced wait times, safer processes, and more efficient and effective care.

Systems Engineering includes front-line tools such as Lean, Six Sigma, PDSA as well as more traditional Industrial Engineering disciplines such as Operations Research including scheduling, simulation, and heuristics; Human Factors; Applied Statistics; and Facility Design Layout. To establish a UT Systems Engineering Initiative, the following actions have been or are being implemented: 1) System-wide Steering Committee and External Advisory Board formed; 2) Industrial and Systems Engineering tools added to the quality improvement toolboxes of the UT system and each component institution via standardized courses and a "train-the-trainer" approach; 3) An over-arching management system that supports an organizational culture that seeks to continuously improve value; 4) An organizational structure across the UT System to support these efforts; 5) Operational support for implementing the Systems Engineering efforts; 6) Grant opportunities for academic and healthcare institutions to partner for "transformational change" using Systems Engineering; 7) Internships and sabbaticals established to teach healthcare to Industrial and Systems Engineering experts and to teach Industrial and Systems Engineering concepts to healthcare providers; 8) Annual conference to share best practice, successes, education

regarding Systems Engineering in Healthcare.
This presentation will explain what has been done so far, describe the current grants underway, outline internship opportunities, and review some projects as examples of specific efforts already underway to use Systems Engineering to deliver healthcare that is safe timely, effective, efficient, equitable, and patient-centered.

Panel Discussion: Sa. 11:30 am-12:30 pm

Location: Hughes Auditorium

Potential Value of Integrated Medical Database

Chair: *Satyender Goel*, Northwestern University

Panelists:

Jay Bhatt, Chief Strategy and Innovation Officer, Chicago Department of Public Health

Abel Kho, Divisions of General Internal Medicine and Biomedical Informatics, Northwestern University; Co-Executive Director: Chicago Health IT Regional Extension Center
Informatics Lead and Co-PI: Chicago Area Patient Centered Outcomes Research Network

Ron Price, Assoc. Vice President, Informatics and Systems Development at Loyola University Chicago - Health Sciences Division

Health systems are creating wealth of data by robust EHR systems and aiming advanced analytics to practice outcomes driven care. In this regime of big data generation, linking health records across sites can improve the effectiveness of epidemiologic studies. Initiatives are in place to connect internal and external operational, clinical, and research data warehouses, one of them is recently announced Patient Centered Outcome Research Institutes (PCORI) Clinical Data Research Networks (CDRNs). In this session expert panelist will discuss how they are envisioning role of health data integration and powerful analytic suites, to improve care at the individual and population level.

Lunch: Sa. 12:30 pm-1:30 pm

Plenary 4: Sa. 1:30 pm-2:30 pm

Location: Hughes Auditorium (CME)

Health Systems Engineering: Lessons from Integration of Systems. Engineering within the Veterans Health Administration

Heather Woodward-Hagg

Director, National Veterans Engineering Resource Center
Director, VA Center for Applied Systems Engineering

Since its initial funding in 2009, Veterans Engineering Resource Centers (VERCs) have successfully supported the translation and integration of Systems Engineering and the new field of Health Systems Engineering (HSE) into Veterans Administration Healthcare Delivery. The four distinct national VERCs, and the supporting National Program Office, have grown into a $31M annual program, facilitating the hiring of over 200 technical HSE staff into the VA and forging affiliations with over 20 academic institutions that provide over 150 technical staff. The next steps for VERC program will include improved field integration, diffusion and dissemination of enterprise-level HSE initiatives. This presentation will provide an overview of the National VERC Program, discuss how the field of Health Systems Engineering is integrated within VHA to optimize clinical and non-clinical systems, as well as identify challenges and summarize lessons learned during the translation of these strategies into an integrated health system. Additionally, the speaker will present specific examples of VHA HSE initiatives.

Technical Session 11: Sa. 2:45 pm-4:15 pm

Location: Gray Seminar Room

Operations Research Applications In Scheduling, Learning, Diagnosis, & Managing

Chair: *Diwakar Gupta*, University of Minnesota

Optimal Advance Scheduling

Van-Ahn Truong

The dynamic assignment of patients to exam days in order to manage daily variations in demand and capacity is a long-standing open research area in appointment scheduling. In particular, the dynamic assignment of advance appointments has been considered to be especially challenging due to its high-dimensionality. We consider a canonical model of dynamic advance scheduling with two patient classes, an urgent demand class, which must be served on the day of arrival, and a regular demand class, which can be served at a future date. Patients take the earliest appointments offered and do not differentiate among providers. We derive a surprising characterization of an optimal policy and an algorithm

to compute the policy exactly and efficiently. These are the first analytical results for the dynamic advance assignment of patients to exam days.

Dynamic Learning of Patient Response Types: An Application to Treating Chronic Diseases
Diana Negoescu, Kotas Bimpikis, Dan Iancu, Margaret Brandeau

For many chronic diseases, available treatments are effective only for a subgroup of patients, and biomarkers that accurately assess the responsiveness of an individual patient do not exist. Physicians then learn about the response through self-reported patient evaluations, as well as from the (non)occurrence of negative health events, such as disease flare-ups. In this paper, we introduce a continuous-time, two-armed bandit framework that balances the trade-off between exploring alternative treatments and exploiting available information. Unlike most multi-armed bandit models, which learn only from observed rewards, our model incorporates information regarding the frequency of health events, and can be analyzed in closed form to derive guidelines for treatment policies. We showcase the effectiveness of our methodology by developing an adaptive policy to treat multiple sclerosis, a chronic autoimmune disease.

Improving HIV early infant diagnosis supply chains in sub-Saharan Africa
Sarang Deo, Jérémie Gallien, Jonas Oddur Jonasson

Early diagnosis of HIV among infants is critical in sub-Saharan Africa as roughly 50% of untreated infected infants die before the age of two years. Yet most of these countries experience significant delays in early infant diagnosis (EID) programs, which comprise of a network of clinics, where samples are drawn from infants, and laboratories, where samples are processed. We develop a two-part modeling framework to generate operational improvements in the EID network. First, we develop an optimization problem whose objective is to maximize the number of HIV infected infants starting treatment. Second, we develop and validate a detailed simulation model to evaluate the performance of solutions obtained from the optimization problem. We apply our methodology to EID program data obtained from Mozambique. We estimate that with an improved operational structure the average sample turnaround time would shorten by 22% and the number of infected infants treated increase by 7%.

Using Matching to Examine Early Warning Systems for ICU Admissions
Wenqi Hu, Carri Chan, Jose Zubizarreta

Unplanned transfers of patients to the Intensive Care Unit (ICU) occur due to rapid physiologic deterioration of patient while in regular wards. Such patients exhibit increased

morbidity and mortality. This work is an empirical study of the potential benefits of early admission to the ICU based on a new warning system. In this work, we utilize a data set of over 100,000 medical patients admitted to one of 21 hospitals over the course of 1 year and a half to estimate whether such preventative admissions may be beneficial. Due to possible endogeneity in ICU admission decisions, we base our identification strategy on an instrumental variable (ICU congestion) and use the recent method of near-far matching method to improve the strength of the instrument and reduce sensitivity to unmeasured biases. We find that preventative admissions have the potential to reduce mortality rates and patient length-of-stay.

Technical Session 12: Sa. 2:45 pm-4:15 pm

Location: Searle Seminar Room (CME)

Patient Centered Modeling

Chair: *Amarnath Banerjee*, Texas A&M University

Patient-Centered Response to Acute Physiological Deterioration
Muge Capan, Julie Ivy, Jeanne Huddleston

Hospitalized patients are at risk of unexpected acute and persistent physiological deterioration (APD), which is identified by disturbance in one or multiple physiological measures. Unanticipated APD may result in respiratory instability, cardiopulmonary arrest and death. Preventable failures during hospitalization accounted for 12% of hospital deaths in 2010 and result in costs of $17-$29 billion per year. Hospitals implement physiological warning scores to identify patients at risk of APD. Exceeding certain thresholds trigger bedside providers rescue actions such as activation of rapid response teams (RRT). There is no consensus on clinical guidelines for selection of these measures and their thresholds to inform acute care decisions. This results in suboptimal utilization of RRT resources, activating RRT unnecessarily, or worse, not activating in case of APD. We develop a semi-Markov Decision Process Model to capture the dynamics of APD and recommend triggers for rescue actions.

Modeling individual heterogeneity in screening choices for colorectal cancer model design impacts outcomes
Maria Mayorga

Colorectal cancer (CRC) screening has been shown to be effective at identifying CRC and early detection greatly reduces mortality risk. Thus, interventions often focus on changing individuals screening behavior. This requires the specification of a baseline model for how individuals make screening choices. We investigate the effects of three different

model specifications for compliance and choice of mode (colonoscopy versus Fecal Occult Blood Stool Test) in CRC screening. First, we ignore individual differences and assume all individuals have homogeneous screening behavior. Then we use two different statistical models, a nested logit model and a multinomial logit model. Claims data from a sample of Blue Cross Blue Shield NC patients is used. The different models for screening are then operationalized as inputs to an individual based simulation model to capture cancer progression and demonstrate how model design impacts long-term life outcomes, costs, and disparities.

Modeling the financial effects of using a Health Information Exchange
Amarnath Banerjee, Yu Fu

The use of a health information exchange (HIE) is a requirement for physicians that are adopting electronic health records. One of the challenges is to establish financial viability of the HIEs. Impact of HIE information on patient visiting frequencies, patient population, and hospitalization ratio are quantified to model the cash flows in a health care system. A polynomial model with a polynomial objective function relating to the amount of information from HIE to hospital and the price of the information service is set to maximize the total cost savings of the health care system. Polynomial constraints are set to coordinate the cost savings among participants. The impact of HIE information on total cost savings, cost savings for each participant as well as operations of hospitals are characterized. Results provide insights on HIE's role on improving financial benefits of health care system and policies to coordinate the financial cooperation between HIE, hospitals and payers.

Capacity Planning for Long-Term Care Networks
Yan Li, Nan Kong, Mark Lawley

Long-term care and community-based services has placed huge economic burden on the US health care system. This study investigates the LTC capacity problem, that is, given a finite homogenous patient population to be served and a finite monetary budget, how should each set of services be capacitated? We propose a migration network model for care recipient flows and a multiproduct newsvendor model for network?wide profit maximization. We explore the structural properties of the problem and identify the most influential factors in the capacity decisions. We present both analytical solutions and numerical results to draw managerial insights. With the model developed, the capacity decision for a long-term care network can be made more systematically with full consideration of different patient flow patterns and budget constraints. The research will be especially useful given the worsening shortage of care providers and the escalating long-term care needs due to population aging.

Plenary 5: Sa. 4:30 pm-5:30 pm

Location: Gray Seminar Room (CME)

Multi-Armed Bandits in Healthcare: Adaptive designs, matching, and admission control

Michael Katehakis

Management Science and Information Systems Department
Rutgers University

First, we provide a survey of the basic multi-armed bandit models and problems with emphasis on modern data-driven healthcare analytics, e.g., allocation of scarce resources, matching patients to treatments, clinical trials, and adaptive licensing.

Then, we present solutions to two key open problems. The first deals with the situation in which a decision to engage a bandit (process) is subject to a commitment of a, possibly stochastic, number or duration of activations before a change to a different process is possible. It is shown that these activation commitments are equivalent to a more general depreciation model for which optimal policies can be constructed using propitiously defined restart in state indices. The second problems deals with the model in which outcomes from different bandits are normally distributed with unknown means and unknown variances, for which the regret increase rate can be minimized by sequential 'upper confidence bounds' based policies.

Lastly, we discuss three new challenging problems involving 'maximizing rewards under multiple simultaneous activation', 'minimizing total deployment costs', and maximizing rewards from 'cumulative payout models'.

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