

# inferms HEALTHCARE 2019 CAMBRIDGEOMA

Cambridge, Massachusetts / July 27–29, 2019



This Technical Session listing, which provides the most detailed information. The listing is presented chronologically by day/time, showing each session and the papers/abstracts/authors within each session.

# **The Session Codes**



## **Time Blocks**

### Saturday

- **A** 8:00am 9:30am
- **B** 11:10am 12:40pm
- **C** 2:00pm 3:30pm

Poster - 3:30pm - 4:30pm

**D** - 4:30pm - 6:00pm

### Sunday

- **A** 8:00am 9:30am
- **B** 11:10am 12:40pm
- **C** 2:00pm 3:30pm
- **D** 4:00pm 5:30pm

### Monday

- **A** 8:00am 9:30am
- **B** 9:45am 11:15am
- **C** 11:30am 1:00pm

# Saturday, 8:00AM - 9:30AM

## SA01

E52 Samberg - Dining Room 6

### Improving Patient Access and Flow in Outpatient Clinical Settings

Emerging Topic: Healthcare Delivery

Chair: Jakob Kiel-Locey, University of Michigan, Ann Arbor, MI,

 Using Stochastic Programming for Outpatient Appointment Scheduling with Random Service and Arrival Times Karmel S. Shehadeh, University of Michigan, Ann Arbor, MI, United States, Amy Cohn, Ruiwei Jiang

We present two-stage stochastic mixed-integer approximations and Monte Carlo approach for outpatient appointment scheduling with stochastic arrival times, random service durations, and adaptive rescheduling. In a series of numerical experiments, we demonstrate the near-optimality of the (easily implementable) appointment order (AO) policy, which requires that patients are served in the order of their scheduled appointments, in a wide range of parameter settings. We also identify parameter settings under which the AO policy is suboptimal and propose an alternative and near-optimal policy.

### 2 - Optimizing Make-ahead Chemotherapy Drug Policies at an Outpatient Infusion Center

Donald B. Richardson, PhD Candidate, University of Michigan, Ann Arbor, MI, 48109-2117, United States, Amy Cohn

With increasing demand at outpatient chemotherapy infusions centers, the need to improve operational performance ensuring the safety and satisfaction of the patients becomes more essential. One major opportunity for improvement is by pre-mixing drugs (i.e. making drugs before the patient arrives) at the pharmacy. This, however, requires careful consideration of the trade-off between time savings versus the potential cost of wasting a drug if the patient is deemed ineligible for treatment or if a drug expires before an eligible patient arrives to use it. We present an optimization model that evaluates this tradeoff to support make-ahead drug policies at outpatient chemotherapy infusion centers.

#### 3 - Evaluating Veteran Access to Eye Care Services Using Facility Location Models

Guyi Chen, University of Michigan, Ann Arbor, MI, United States, Adam VanDeusen, April Maa, Amy Cohn

Many patients, including United States veterans, face barriers to accessing appropriate, affordable healthcare. These barriers can be addressed by optimizing clinic locations while delivering care that effectively utilizes providers' practice responsibilities. We present a model to evaluate veterans' eye care facility location options with consideration for overall system access. We further present a case study in which trained technicians perform visual disease screenings typically conducted by ophthalmologists. We are also exploring the stochastic formulation of this problem. Our work may guide decision-makers in locating and staffing clinics to improve patient access.

#### 4 - Simulating and Evaluating Scheduling Policies for Colonoscopy Patients with Stochastic Procedure Durations

Jakob Kiel-Locey, University of Michigan, Ann Arbor, MI, United States, Amy Cohn

Like many clinical procedures, colonoscopies and other endoscopic procedures have stochastic procedure duration. The impact of a high-quality bowel prep before the procedure, and the variability in patient prep, makes the problem of scheduling patients of this type even more challenging. We present a simulation tool for analyzing different scheduling policies to take into account this variability and its impact on both the creation and the execution of schedules under these policies. The framework is designed to enable not only provider idle time, clinical overtime, and patient delays, but also patient preference and the impact on clinical outcomes to be considered as well.

# SA02

### E52 Samberg - Dining Room 5

### **Data Analytics and Dynamic Decision-Making**

Emerging Topic: Healthcare Supply Chains

Chair: Ilbin Lee, University of Alberta, Edmonton, AB, T6G 2R6, Canada

### 1 - Modeling Natural Progression of ALS

F. Safa Erenay, University of Waterloo, Kitchener, ON, N2N 0A2, Canada, Mustafa Y. Sir, Ozden Onur Dalgic, Kalyan Pasupathy, Osman Ozaltin, Brian Crum

ALS causes loss of breathing, speaking, eating, and moving their abilities to due to motor neuron degeneration and muscle atrophy. ALS progression varies over time significantly. We first developed the Tollgate-based ALS Staging System (TASS) to capture ALS progression. Then, using descriptive analytics and 500 patients' data from Mayo Clinic, we analyzed ALS progression pathways. We showed that TASS can efficiently capture ALS progression and timing of needed critical disabilities and medical interventions in short run. Next, using classification, we converted 3,000 patients' data into tollgate information; and analyzed the timing of ALS progression tollgates in the long run. We are currently developing prescriptive analytics tools to analyze the optimal timing of the assistive medical interventions.

### 2 - Is Separately Modeling Sub-Populations Beneficial for Sequential Decision-Making?

Ilbin Lee, University of Alberta, Edmonton, AB, T6G 2R6, Canada

In recent applications of Markov decision processes, transition probabilities and rewards are often estimated from large-scale sequential data. In health applications, sequential data are collected from a population where each sequence corresponds to a person. Thus, there may be sub-populations that exhibit heterogeneous transition patterns. In this work, we study the benefit of making optimal decisions separately for different subpopulations and derive a theoretical bound on the benefit. We also suggest a method to estimate the benefit and empirically illustrate it. Lastly, we discuss several intuitions derived from the theoretical and empirical analyses.

### 3 - Resource Allocation Strategies under Dynamically Changing Patient Health Conditions

Siddhartha Nambiar, North Carolina State University, Raleigh, NC, United States

Consider patients being treated for a disease, whose condition changes over time. Resources allocated toa patient influence disease progression and outcomes. Our goal is to allocate a limited number of resources to patients, depending on their health status, to maximize outcomes. We formulate the model as a Markov Decision Process (MDP) to allocate floating resources in such a setting and tested the optimal dynamic policy against various heuristics that are easier to implement on account of practicality. Our experimental studies show that dynamic allocation policies perform better than their static counterparts. We also show that the optimal policy lacks a monotone structure and discuss the implications related to this.

### 4 - Home Health Care Nurse Scheduling and Routing

Jonathan Patrick, University of Ottawa, Ottawa, ON, K1N 6N5, Canada, Danial Khorasanian, Onur Ozturk

We develop an MDP model for the home care nurse scheduling and routing problem. We incorporate the uncertainty around the patient care plan, the number of patient visits and new arrivals. Decision involves the whether or not to accept a new patient and if accepted how to route the nurse(s) in order to optimally meet demand. Given the size of the state space we employ the linear programming approach to approximate dynamic programming in order to find a feasible solution to the problem that we then test in a simulation.

## SA03

E52 Samberg - Dining Room 4

# Disease Dynamics and Treatment Policy: Applications of Optimization

Emerging Topic: Public Health and Health Policy

Chair: Naveed Chehrazi, McCombs School of Business, Austin, TX, 78712, United States

Co-Chair: Lauren Cipriano, Ivey Business School, London, ON, N6G 0N1, Canada

### 1 - Cholesterol Follow-up Policy in the Context of Preventive Treatment of Cardiovascular Disease

Daniel F. Otero Leon, PhD Student, University of Michigan, Ann Arbor, MI, United States, Brian T. Denton, Mariel Sofia Lavieri

Preventing chronic diseases is an essential aspect of medical care for healthy patients, but deciding when to collect information, such as the patient's cholesterol levels, is difficult. Measuring too frequently may be unnecessary and costly; on the other hand, measuring too infrequently means the patient may forgo needed treatment and experience adverse events related to the disease. We present results from estimating a stochastic model based on longitudinal data for cholesterol in a large cohort of patients seen in the national Veterans Alfairs health system. We further use this model to study policies for when to collect measurements to assess the need for cholesterol lowering medications.

### 2 - Search in the Selection of Model Parameters for Medical Decision Making

Michael J. Hintlian, University of Southern California, Los Angeles, CA, 90006, United States, Julia Lynne Higle

The search for model parameters, sometimes called calibration, is an important step in the creation of models for medical decision-making. A collection of wellcalibrated models can provide insight into the uncertainty surrounding model parameters and the sensitivity of the outcome of an analysis. We introduce improved search methods for model calibration, which can be leveraged to facilitate sensitivity analysis cost-effectiveness and other model-based analyses. Implications and computations will be discussed.

#### 3 - Prediction and Management of Infectious Diseases in Finescale Spatial Contexts

Yuan Zhou, University of Texas at Arlington, Arlington, TX, 76019, United States

Despite much effort, communicable diseases continue to be one of the leading causes of death worldwide. To stimulate further advancement of disease management capabilities, it is a key to inform public health policymakers of accurate, sufficient, and timely information on disease dynamics, and tailor intervention strategies to mitigate disease dispersion effectively. This presentation will discuss applications of a generalizable, agent-based framework for modeling transmission dynamics of communicable diseases in two fine-scale spatial contexts: shopping mall and university campus, with the hope to develop localized and targeted interventions to respond diseases more effectively.

#### 4 - Optimal Control of an Infectious Disease with Drug Resistance Naveed Chehrazi, McCombs School of Business, Austin, TX, 78712, United States, Lauren Cipriano, Eva A. Enns

We identify the optimal treatment policy for an SIS infectious disease model incorporating drug resistance. The social planner's problem is formulated as an optimal control problem with two continuous state variables: disease prevalence and drug "quality" (fraction of drug-susceptible infections). We prove the optimal treatment policy is a bang-bang policy with a single switching time. Relaxing the standard assumption of constant disease transmission fundamentally changes the shape of the action region, adds a singular arc to the optimal control, and makes preserving the drug for a serious outbreak optimal. We apply our framework to the case of antibiotic resistant gonorrhea.

## SA04

E52 Samberg - Dining Room 3

### Medical Decision Making

Emerging Topic: Personalized Medicine and Disease Modeling

Chair: Steven Shechter, University of British Columbia, Vancouver, BC, V6T 1Z2, Canada

1 - Optimal Decision Making in a Markov Model with Parameter Uncertainty: The Case of Chronic Kidney

M. Reza Skandari, Imperial College Business School, London, W3 8SX, United Kingdom, Steven Shechter

We investigate a Markov decision process whose unknown transition parameters are revealed partially through state observation. Decisions are made as the state evolves. We use the model to study the optimal time to start preparing a type of vascular access for chronic kidney disease patients who will need dialysis.

 2 - Optimizing Adjuvant Treatment for Stage II Colon Cancer: A Biomarker-based Cost-effectiveness Analysis
 Fernando Alarid-Escudero, Assistant Professor, Center for Research and Teaching in Economics (CIDE) - CONACyT, Aguascalientes, Mexico, Deborah Schrag, Karen M. Kuntz

Adjuvant chemotherapy is not recommended for patients with average-risk stage II colon cancer. Patients lacking CDX2 biomarker expression (CDX2-) face a higher rate of developing recurrence compared to CDX2+ patients. Adjuvant chemotherapy only benefits CDX2- patients. We determined the optimal adjuvant treatment for different test-and-treat strategies in average-risk stage II colon cancer patients using a dynamic decision model. Testing for the absence of CDX2 expression followed by adjuvant chemotherapy for those without biomarker expression is cost-saving under a range of assumptions and a wide range of parameter values tested on sensitivity analyses for cost of the test, prevalence of CDX2- patients and effectiveness of adjuvant chemotherapy. Identifying a small subgroup of average risk stage II colon cancer CDX2- patients for targeted chemotherapy is effective and cost saving.

### 3 - Optimizing Personalized Treatment Selection for Partially Observable Chronic Conditions

Shan Liu, University of Washington, University of Washington, Seattle, WA, 98195-2650, United States, Jue Gong

Developing a personalized treatment plan is a difficult sequential decision-making problem. The main challenges include accurately capturing the disease progression dynamics and designing adaptive treatment selection strategies. We propose the Partially Observable Collaborative Model (POCM) to learn the individual disease progression model under multiple treatment options when the true health state is hidden to the decision maker. We show how treatment strategies can be optimized for individuals using the Partially Observable Markov Decision Process (POMDP) by utilizing disease models learned with the POCM. We also discuss approaches for modeling uncertainties in estimating the disease progression to find robust POMDP policies.

# SA05

E52 Samberg - Dining Room 2

### Catalyzing Quality and Productivity Improvements: Empirical Evidence

Emerging Topic: Healthcare Economics

Chair: Kamalini Ramdas, London Business School, London, NW1 4SA, United Kingdom

Co-Chair: Nazli Sonmez, London Business School, London, NW1SN, United Kingdom

1 - Recovering from Critical Incidents: Evidence from Paramedic Performance

Jónas Oddur Jónasson, MIT Sloan School of Management, Cambridge, MA, 02142, United States, Hessam Bavafa

We examine operational performance in settings where workers can encounter critical incidents (CIs)—jobs which are sufficiently disturbing to challenge workers' coping mechanisms. Using data on 902,002 ambulance activations we find that Crews who have encountered one prior CI (two prior CIs) spend on average 2.6% (7.5%) more time completing each remaining ambulance activation in the shift. The largest effects come from the sub-processes which are least standardized and where paramedics cannot rely on standard operating procedures.

#### 2 - Working Smarter: The Effects of Performance Pay on Discretionary Task Sequence, Learning and Performance

Maria R. Ibanez, Kellogg School of Management at Northwestern University, Evanston, IL, 60208, United States

Analyzing records of millions of radiological diagnoses from doctors working across the US, we investigate how performance pay induces workers to work not only harder but also smarter—learning how to be more productive and to sequence their work better.

#### 3 - Increasing Patient Engagement through Shared Medical Appointments

Kamalini Ramdas, London Business School, London, NW1 4SA, United Kingdom

In a shared medical appointment (SMA), a group of patients with similar chronic conditions meet with a doctor simultaneously and each receives one-on-one care. Through a randomized control trial, we examine the impact of SMAs on levels of patient engagement. Relative to traditional one-on-one care models, we study how SMAs affect engagement levels, both during the appointment (such as making eye contact with the physician, engaging in the proceedings, and asking questions) and after (such as complying with prescribed medications in the home). Although SMAs hold obvious promise for improving the efficiency of healthcare, to the extent that they may lead to increased patient engagement, they may result in improved outcomes as well.

# **SA06**

E52 Samberg - Salon West

# Prediction, Modeling, and Design for Improving Health Care Delivery

Emerging Topic: Public Health and Health Policy

Chair: Xiang Zhong, University of Florida, Gainesville, FL

Co-Chair: Hyo Kyung Lee, University of Wisconsin-Madison, Madison, WI, 53703, United States

#### Evaluation of E-Consults in Healthcare Delivery Xiang Zhong, Univ. of Florida, Gainesville, FL, 32611, United States, Aditya Mahadev Prakash, Qiao-Chu He

E-consults offer a digital platform whereby primary care providers (PCP) can consult the specialists and obtain feedback or offer a direct specialty referral to the patients. It is believed that e-consults help in matching patients to the right care provider (PCP or Specialist) and reduce delays for patients. We abstract away from the e-consult operations and offer an analytic framework that quantifies the benefit of e-consults in the context of efficient matching in a flexible service system. We consider heterogeneous patients who lack information regarding their severity. A Bayesian framework is developed to estimate the true severity, parametrized by the level of e-consult efficiency, measured as the efforts of PCPs and specialists' communication and information sharing. E-consults when implemented with increasing perfection, were analytically shown to improve the operational and economic performance of the healthcare subsystem by improving the matching and thereby streamlining the patient flow while reducing redundancies.

### 2 - Development of a Bayesian Network Based MDP Model for Dynamic COPD Intervention Planning

Sujee Lee, University of Wisconsin-Madison, Madison, WI, 53705, United States, Philip Bain, Christine Baker, Jingshan Li

Approximately 10% to 20% of patients hospitalized for COPD exacerbations are readmitted within 30 days after discharge. Proper post-discharge interventions can lead to a reduced rate of COPD rehopitalization. However, the current interventions are not yet customized and tailored to a patient's characteristics and are not adjusted dynamically based on the patient's status change. To achieve more effective intervention, personalized care is needed. Therefore, in this talk, we propose a new framework to evaluate the intervention's effectiveness for each patient periodically and obtain the optimal intervention strategy. The framework integrates a dynamic causal network into Markov decision process (MDP) model to consider the COPD patient's detailed status and make the optimal decision to reduce readmissions. The framework can be applied to other diseases to make personalized and more effective intervention plans.

#### 3 - Pricing and Management of Video Conferencing Visits with Nurse Assistance for Chronic Disease Patients Xiaojie Wang, University of Florida, Gainesville, FL, 32608,

United States, Xiang Zhong, Yongpei Guan

Video-conferencing (VC) meeting with nurse assistance is emerging. Such virtual care services provide convenience and reduce travel burden of patients; however, costs are incurred by coordinating nurses to assist patients at home. In this paper, we consider a medical institution offering both in-person and VC visits to community patients. Communities are characterized by distance and population density. A revenue-maximizing problem is formulated to identify the best pricing and patient diversion strategy that is also incentive compatible for patients, and the results are compared with that from a social welfare perspective. Our results show that under certain cost structures, both patients and the medical institution will be strictly better off with VC visits, and the social planner would like more patients to be served at home than the medical institution does. The insights support the design and implementation of VC visits that maximize the potential of telehealth to improve patient access.

### 4 - AKI Risk Prediction Models in Intensive Care

Kaiye Yu, Tsinghua University, Beijing, BJ100084, China and University of Wisconsin-Madison, Madison, WI, United States, Hyo Kyung Lee, Xiaolei Xie, Jingshan Li

Acute Kidney Injury (AKI) is a common complication of critical illnesses, which is often associated with high mortality rate. Delayed diagnoses of AKI may lead to poor patient outcomes. Therefore, early prediction of AKI risk can avoid further injurious practice and improve its outcome. In this talk, we will introduce machine learning based prediction model for AKI risk in intensive care. About 20,000 patient records from MIMIC III database are processed, analyzed, and used to generate the prediction models. More than 40 factors are used to train and validate the models. Acceptable accuracy has been obtained in the prediction models, which can provide support for clinical interventions.

# SA07

E52 Samberg - Ballroom T

# Disease Modeling and Pattern Mining Using Electronic Health Record Data

Emerging Topic: Personalized Medicine and Disease Modeling

Chair: Yiye Zhang, Cornell University, Mountain View, CA, 94043, United States

1 - Using Machine Learning with Health Care Data to Improve Early Identification of Elder Abuse

Tony Rosen, Weill Cornell Medical College, New York, NY, United States, Yuhua Bao, Sunday Clark, Alyssa Elman, Katherine Wen, Philip Jeng, Mark Lachs, Yiye Zhang

Elder abuse is common and has serious health consequences but is underrecognized by health care providers, suggesting a missed opportunity. We apply machine learning to insurance claims and electronic health record (EHR) data to identify potential victims. The model will leverage valuable information on a patient from claims and the EHR using techniques like sequential pattern mining and will generate a score indicating level of risk for being a victim, thus prompting additional evaluation. This informatics tool can transform approaches to elder abuse, help our ability to identify vulnerable older adults and improve their health and safety.

### 2 - Scheduling Patient-centric Dialysis Services

Daniel Gartner, Cardiff University, Cardiff, 76327, United Kingdom, Rosie Fleming, Rema Padman, Dafydd James

The increasing prevalence of end stage renal disease requires efficient use of scarce dialysis resources. We develop a scheduling model that assigns patients' dialysis pathways to machines and staff. Also, patients' drop-off and pick-up time windows at/from the dialysis unit are considered. The objective is to minimize patient waiting times before the treatment and, if necessary, synchronizes the treatment finish time with the actual pick up by relatives or local transportation. Using an open source solver and data from a dialysis unit in the UK, we demonstrate the model's effectiveness.

# 3 - Multi-Trajectory Modeling to Assess Risk of

### Postoperative Complications

Rema Padman, Carnegie Mellon University, The H. John Heinz III College, Pittsburgh, PA, 15213, United States, Urmila Ravichandran, Jennifer Grant, Philip Prosapio, Aparajita Sahoo, Yi Xu, Nirav Shah

Identifying patients at increased risk of postoperative complications can limit unnecessary testing and antibiotic prescribing. Multi-trajectory modeling and evaluation of 589 elective colectomy patients from 2007-2013 who follow similar progression of inpatient stay indicate several distinct trajectories and their frequencies with differing rates of complications to facilitate early identification of at-risk patients. 4 - Smartphones to Address Health Equity

Sriram Iyengar, Texas A&M Health Science Center, Houston, TX, United States

Abstract is not available at this time.

### 5 - Automated Prediction of Postpartum Depression Using Electronic Health Records

Yiye Zhang, Weill Cornell Medicine, 1300 York Avenue, New York, NY, 10065, United States

Postpartum depression (PPD) is considered to be one of the most frequent maternal morbidities after delivery with serious implications on the mother and children. The ability to predict PPD in women could enable the implementation of effective mental and behavioral health interventions. We aim to leverage machine learning(ML) to predict PPD using routinely collected clinical data from electronic health records (EHRs).

# SA08

E52 Samberg - Ballroom I

### Models to Manage and Prevent Disease

Emerging Topic: Personalized Medicine and Disease Modeling

Chair: Sze-chuan Suen, University of Southern California, Los Angeles, CA, 90089-0193, United States

1 - Branch-and-bound Algorithm for Dynamic Resource Allocation in Population Disease Management

Shan Liu, University of Washington, Seattle, WA, 98195-2650, United States, TingYu Ho, Zelda B. Zabinsky

Resource allocation problems in population disease management are commonly formulated using Markov decision processes, which are challenging to solve due to large state-space and action- and time-dependent transition probabilities. We embed an approximate dynamic program into a branch-and-bound framework to solve sequential budget allocation problems to implement healthcare interventions. The algorithm is capable of providing an optimality guarantee and getting bounds on the optimality gap of the interventions. We present updated results from a numerical simulation study on screening and treatment policies regarding to chronic hepatitis C elimination among baby boomers in the US.

### 2 - The Price of Simplicity in Personalized Prostate Cancer Screening Strategies

John Silberholz, University of Michigan, Ann Arbor, MI, United States

Patient preferences for different health states can significantly impact their best course of action in screening for diseases like prostate cancer. Patients with a relatively small disutility for treatment side effects might benefit from aggressive screening or no screening at all. In this work, we use a mathematical model to quantify the benefit of fully personalized prostate cancer screening versus a one-size-fits-all strategy. Further, we identify simpler, more interpretable personalized screening strategies that could be easier to implement in practice, and we quantify the price of this simplicity in strategies.

### 3 - When and What to Test for: A Cost-effectiveness Analysis of Test-and-treat Strategies for Undifferentiated Febrile Illness in the Era of Responsible Antibiotic Use

Zhenhuan Zhang, University of Minnesota, Minneapolis, MN, United States, Diana Maria Negoescu, Claudia Munoz-Zanzi

Febrile illness caused by viral and bacterial infectious diseases have similar symptoms and are difficult to differentiate without diagnostic tests. If not treated appropriately, patients may experience serious complications. The question of what diagnostic tests to make available to providers to inform treatment remains an open problem for health services facing limited resources. We constructed Markov models to capture febrile illness progression and formulated the problem of minimizing the weighted average of antibiotic underuse and overuse to inform optimal test-and-treat strategies in two settings in Thailand with contrasting bacterial versus viral disease prevalence.

### 4 - Demonstration of Potential Threats to Health Privacy from Artificial Intelligence

Cong Yang, University of California, Berkeley, Berkeley, CA, United States, Liangyuan Na, Chi-Cheng Lo, Fangyuan Zhao, Yoshimi Fukuoka, Anil Aswani

This cross-sectional study evaluates the feasibility of reidentifying accelerometermeasured physical activity data from the National Health and Nutrition Examination Surveys, which have had geographic and protected health information removed, using support vector machines (SVMs) and random forest methods from machine learning. Among 14451 individuals, the demographic and 20-minute aggregated physical activity data of approximately 80% of children and 95% of adults was successfully reidentified. Such result, which was further validated by hypothesis testing and sensitivity analysis, suggests that partial data aggregation and removal of certain information may be insufficient to ensure privacy. Julie Higle, University of Southern California, Jing Voon Chen

We present a model of ovarian cancer that incorporates recent discoveries in ovarian carcinogenesis. Our model is differentiated in terms of both patient risk (e.g., genetic mutation status) and cancer sub-type (e.g., serous v. non-serous). Using this model, we develop estimates of various disease attributes (e.g., sojourn times for various disease states) and assess the potential impact of emerging prophylactic strategies.

# SA09

E52 Samberg - Ballroom M Practice Oriented Session

# Implementation of Data-Driven Solutions in AMCs: Sample Projects

Chair: Ana Cecilia Zenteno, Massachusetts General Hospital, Boston, MA, 02142, United States

In this session, members from top Academic Medical Centers will present specific examples of how operations research and analytics are being actively applied in their institutions to effect change in clinical operations. In a subsequent session (SB07), members from the same hospitals will discuss the necessary processes and conditions under which they make this happen.

### 1 - Priority-Driven Patient Access Management

Mustafa Y. Sir, Mayo Clinic, Rochester, MN, 55905, United States, Kalyan Pasupathy, Esma Gel, Derya Kilinc, Narges Shahraki

We developed a software platform referred to as Priority-Driven Patient Access Tool (PDPAT). PDPAT allows clinical departments to define their patient prioritization schema based on medical indication and other patient characteristics and makes various appointment itinerary suggestions to appointment coordinators for optimal scheduling. PDPAT dynamically reserves capacity for high-priority patients while delaying lower-priority patient through so-called scheduling time windows optimized for each priority group. A pilot study at a surgical division reduced access time and increased throughput, due to better coordination of clinic and surgical calendars.

#### 2 - Machine and Deep Learning Hospital Improvement Projects; Lessons from Failures and Successes

David Scheinker, Stanford - Lucile Packard Children's Hospital, Huang Engineering Center, Stanford, CA, 94305, United States

In order to deliver value a project based on machine learning or deep learning must succeed in three stages: technical performance, implementation, and sustained use. We describe how each of three projects failed or succeeded in each of these stages. The projects were aimed to reduce chronic kidney disease, central line associated blood stream infections, and severe clinical decline. We focus on lessons generalizable across medical institutions.

### 3 - Optimizing Hospital-Wide Bed Allocation

Martin S. Copenhaver, Massachusetts General Hospital, Boston, MA, 02139, United States, Bethany Daily, Peter Dunn, Retsef Levi, Andrew Vanden Berg, A. Cecilia Zenteno

Hospital units or floors are typically assigned to specific medical and surgical services in order to localize and optimize clinical care. Since patient demand for beds can be highly variable, the physical capacity allocated to a given clinical service is frequently not sufficient to accommodate all requests. In this talk, we will discuss the use of optimization and simulation models to design and implement a new bed allocation that aims to minimize off-service placements at Massachusetts General Hospital. The proposed allocation is currently being implemented, with two out of three phases already completed.

# SA10

E52 Samberg - Salon East

### **Health Policy**

Contributed Session

Chair: Justin Kistler, University of South Carolina, Columbia, SC, 29212, United States

1 - Optimizing HIV Interventions for Multiplex Social Networks via Partition-Based Random Search

Qingpeng Zhang, Assistant Professor, City University of Hong Kong, Kowloon, Hong Kong, Lu Zhong, Siyang Gao, Xiaoming Li

There are multiple modes for human immunodeficiency virus (HIV) transmissions, each of which is usually associated with a certain key population (e.g., needle sharing among people who inject drugs). In this paper, we aim to address this challenge by developing a multiplex social network framework to

capture the multimode transmission across two key populations. Based on the multiplex social network framework, we propose a new random search method, named partition-based random search with network and memory prior- itization (PRS-NMP), to identify the optimal subset of high-value individuals in the social network for interventions.

### 2 - Provider Specialty and Prevalence of Opioids

Anushka Bhaskar, Student, Harvard University, Cambridge, MA, United States, Anchal Bhaskar

The opioid epidemic persists in 2019, with medical clinics slashing prescriptions in half to reduce access to these addictive substances, hospitals calling for volunteers to cuddle babies suffering from withdrawal, and families of victims of substance abuse calling for action against Big Pharma. Using descriptive analytics, we give view into the current situation and seek to gain an understanding of the major regions and specialties who prescribe opioids to those individuals who overdose. By this way of predictive modeling analysis, we've identified doctors who prescribe these high-risk drugs, which can help prevent easy access to drugs and provides checks on unethical activity by the physician.

### 3 - Association of EHR Use and Opioid Prescribing Rates Among Providers in the United States

Ajit Appari, Worcester Polytechnic Institute, Worcester, MA, United States

The rising growth of certified electronic health record (EHR) systems by providers may help to stem the Opioid crisis as they could make informed decisions. In this cross-sectional study design, I examined the association of provider-level Opioid prescribing rates with their use of EHR systems by estimating mixed-effects generalized linear model regression, adjusting for provider characteristics and area-level socioeconomic factors. Data on 892,664 providers participating in Medicare Part-D (prescription) program and their EHR use for year 2016 was obtained from data.cms.gov site. Results suggest that providers using EHR systems are less likely to prescribe Opioids to their patients.

# 4 - The Unintended Consequences of Health Policy:

An Empirical Analysis of Opioid Prescribing Behavior Justin Kistler, University of South Carolina, Columbia, SC, United States, Luv Sharma

The Value Based Purchasing program (VBP) was designed to incentivize healthcare organizations and providers to improve the safety and quality of patient care. While considerable improvement has been made in a number of performance domains, our empirical analysis of opioid prescription rates over a seven year period indicates an unintended increase in opioid prescribing immediately following the implementation of the VBP program. Our findings also indicate the moderating impact of prescriber workload and specialty training on opioid prescription rates.

# SA11

E52 Samberg - Room 164

### **Patient Provider Behavior and Patient Flow**

Emerging Topic: Healthcare Economics

Chair: Jillian Berry Jaeker, Boston University, Boston, MA, 02215, United States

Co-Chair: Arshya Feizi, Allston, MA, 02134, United States

# 1 - Mixing it Up: Operational Impact of Hospitalist Workload

Alex Mills, Baruch College, City University of New York, New York, NY, 10010, United States, Masoud Kamalahmadi, Jonathan Helm, Kurt M. Bretthauer

We develop an operational model of hospitalist-patient interaction, optimizing hospitalist case mix and workload to achieve the maximal reduction in patient length of stay (LOS). We show that hospitalists are effective at reducing LOS for patients with complex conditions, which matches clinicians' intuition that medically complicated patients would benefit most from hospitalist care. However, we show that the optimal hospitalist service mix also includes simple patients with few interventions and short length of stay, which is contrary to clinical expectation. Although these patients do not have complicated medical problems, their short LOS leads to proportionally long discharge delays when not attended by a hospitalist are most effective operationally when attending a mix of simple and complex patients. We illustrate our approach by analyzing data for inpatients with 25 common conditions from the California State Inpatient Database.

### 2 - Priority and Predictability

Jillian Berry Jaeker, Boston University, Boston, MA, 02215, United States

We use a laboratory experiment to explore surgeon admission decisions under different conditions. We find that both predictability and own patient prioritization affect admission decisions independent of clinical need. We propose and test multiple managerial solutions.

#### 3 - The Impact of Non-Human Interfaces on Misinformation: An Experimental Approach in the Patient-Doctor Relationship Arshya Feizi, Boston University, Boston, MA, 02134, United States, Anita L Tucker

Nowadays many care-giving facilities employ electronic questionnaires or data collection tools for increased operational efficiency. We explore whether the use of such non-human interfaces may increase the risk of patient misinformation with their caregiver.

### 4 - Outpatient Appointment Scheduling with a Risk-Averse Decision Maker

Kenneth J. Klassen, Brock University, Goodman School of Business, Dept, of Finance Operations & IS, St. Catharines, ON, L2S 3A1, Canada, Amir Ahmadi-Javid, Zahra Jalali

Outpatient appointment scheduling has been studied from many perspectives, but most prior work has assumed risk-neutrality of the decision maker. This research develops schedules that work well when risk measures are included in the objective. We show how prior reported findings for optimal appointment-scheduling policies can be adjusted if the scheduler wants to avoid risk.

# SA12

E62 Sloan - Room 221

## **Resource Allocation**

Contributed Session

Chair: Mohammad Dehghanimohammadabadi, Northeastern University, Boston, MA, 02115, United States

### 1 - Resource Optimization of Neurology Outpatient Clinic Through Discrete Event Simulation

Akiva D. Blickstein, Intermediate Modeler, Geisinger, Danville, PA, United States, Eric S. Reich, Jason S. Puckey, Poorani Selvaraj

In Geisinger's Neurology Outpatient Clinic, providers have varied schedules and patient demand with select appointment slots double booked. One weekday accounts for 40% of patient demand which leads to increases in both patient wait times that day and resource utilization the remaining weekdays. A discrete event simulation model was built to test alternative appointment schedules, staffing levels, and weekly patient distribution. Results showed that level loading the patient volume throughout the week resulted in a 25% reduction in patient waiting times. Neurology leadership now has a model it can use to determine the impact of changes to the clinic on patient wait times and resource utilization.

#### 2 - Determining Ideal Resident to Physician Ratios in an Outpatient Dermatology Clinic using Discrete-Event Simulation

Ann Suhaimi, Northeastern University, Boston, MA, United States, Jacqueline Griffin, Vahab Vahdatzad

Residents are a key component of healthcare operations since they provide medical services while also receiving educational training. Despite their critical role and effect on the workflows, minimal studies examine the relationship between residents' participation and efficiencies of clinic processes especially with regard to patients' waiting time and length of stay. We develop a discrete-event simulation model to evaluate the process flows in a dermatology clinic and the impact on these metrics. We also analyze the effects of varying resident to physician ratios in the current system to identify the ideal ratio that maximizes provider productivity while improving timeliness of care.

### 3 - Optimal Allocation of Defibrillator Drones in Mountainous Regions

Christian Truden, Alpen-Adria-Universität Klagenfurt, Klagenfurt, Austria, Christian Wankmüller, Christopher Korzen, Philipp Hungerländer, Ewald Kolesnik, Gerald Reiner

Responding to sudden cardiac arrests (SCA) in mountainous regions is quite challenging as as air ambulances and mountain rescue services are often confronted with logistics challenges and adverse weather conditions that extend the response times. Drones equipped with automated external defibrillators (AED) allow to overcome the time criticality by reducing the time between SCA and early defibrillation. We present an ILP model to determine the optimal allocation of drone base stations in a given geographical region while minimizing the response times to SCAs. Considering empirical data, we test the model and demonstrate the capability of drones to fasten the delivery of AEDs to SCA patients.  4 - A Multi-objective Outpatient Appointment Scheduling: A Data-Table Input Simulation-Optimization Approach Mohammad Dehghanimohammadabadi, Northeastern University, Boston, MA, 02115, United States, Javad Seif, Mandana Rezaeiahari

Appointment scheduling (AS) is one of the key factors to enhance patient satisfaction in healthcare services. A practical and robust appointment scheduling pattern allows clinics to utilize medical assets, equipment, and resources in an efficient manner. In this study, a multi-objective simulation-optimization (MSO) approach is applied to determine the most preferred appointment scheduling pattern for an outpatient clinic system with multiple patients types and procedures. The developed MSO model is using the concept of the table-input experiment (appointments table) in a simulation environment which is improved using an iterative multi-objective metaheuristic algorithm (NSGA-II). The proposed model optimizes the performance measure by determining (i) patients arrival pattern, and (ii) the inter-arrival time between patients.

# SA13

E62 Sloan - Room 223

### Applications of OR and Analytics in Healthcare

Sponsored: MSOM/Healthcare

Chair: Vedat Verter, McGill University, Montreal, QC, H3A 1G5, Canada

#### How Does Workload Affect Test Ordering Behavior of Physicians? An Empirical Investigation Evrim D. Gunes, Koc University, Rumeli Feneri Yolu, Sariyer,

Istanbul, 34450, Turkey, Busra Ergun Sahin, Ayse Kocabiyikoglu, Ahmet Keskin

We investigate the relationship between workload and the test ordering behavior of physicians, in an operational context where test ordering may act as a substitute for service process time. We define workload in two forms: the unfinished workload, that is, the number of patients waiting to be examined, and the finished workload, that is, the number of patients examined before a given patient in a work day. We hypothesize that physicians order more diagnostic tests at higher unfinished workload levels, and order fewer diagnostic tests at higher finished workload levels. Analysis of data from a public training and research hospital provides strong evidence supporting both hypotheses. We also report the results of several robustness tests.

### 2 - Optimal Genetic Screening for Cystic Fibrosis

Hussein El Hajj, Virginia Tech, Blacksburg, VA, United States, Ebru Korular Bish, Douglas R. Bish

Cystic fibrosis (CF) is among the most prevalent life-threatening genetic disorders. Early diagnosis can improve quality of life and reduce healthcare expenditures. There are 312 CF-causing variants, but genetic screening is costly. Therefore, most CF newborn screening processes start with a bio-marker test; followed by a genetic test, ending with diagnostic testing for those with mutations detected, which corrects false-positive screening results. On the other hand, a false-negative represents a missed CF diagnosis. Therefore, an important decision is which CFcausing variants to include in the screening panel to reduce the false-negative probability under a CF testing budget. We develop novel stochastic optimization models, and identify key structural properties of optimal mutation panels, and use these properties to develop efficient algorithms. Our case study underscores the value of our optimization-based approaches compared to current practices. Our findings have important implications for public policy.

### 3 - Preventing Schizophrenia Patients from Hospitalization: The Impact of Court Treatment Orders

Vedat Verter, McGill University, Faculty of Mgm, Montreal, QC, H3A 1G5, Canada, Fan E., Angelos Georghiou, Daniel Frank

Community treatment orders (CTOs) for schizophrenia patients are controversial due their coercive nature. We study the relationship between the date that the CTO was awarded by the court with the subsequent increase in the frequency of long acting injections received. We find that, for a specific sub-group of patients, CTOs are associated with increased freedom to live in the community.

#### 4 - Machine Learning based Risk Stratification for Early Detection of Diabetes and Hypertension in Resource-limited Settings Justin J. Boutilier, University of Wisconsin - Madison, Madison, WI, United States, Timothy Chan, Manish Ranjan, Sarang Deo

The impending scale up of non-communicable disease screening programs coupled with limited health resources require that such programs are as efficient as possible. To achieve maximal efficiency, risk stratification algorithms need to be tailored to the population, especially in low-and middle-income countries where the at-risk populations differ significantly on social, lifestyle, and genetic aspects. We demonstrate that machine learning risk stratification algorithms that are tailored for community-based screening programs in low-resource settings with limited screening data can significantly improve risk stratification accuracy, program yield, and cost-effectiveness. Implementing our models into India's nationwide NCD screening program could save approximately \$1.19 billion USD for diabetes and \$960 million USD for hypertension by reducing missed diagnoses.

# SA14

E62 Sloan - Room 250

### Transforming Health with OR and Data

Sponsored: Healthcare Applications

Chair: Michelle M. Alvarado, University of Florida, Gainesville, FL, 32611-6595, United States

Co-Chair: Behshad Lahijanian, University of Florida, Gainesville, FL, 32611, United States

1 - Rapid Review: Application of Optimization in the Supply Chain of Vaccines

Michelle M. Alvarado, University of Florida, Gainesville, FL, 32611-6595, United States, Juliano Marçal Lopes, Vidal Augusto Zapparoli Castro Melo, Eduardo Mario Dias

Our goal was to understand how optimization has been applied to improve vaccine distribution and inventory management worldwide. For this, we used a rapid review methodology, searching for peer-reviewed articles, published between 2009 and 2019, in 4 scientific databases. The search for terms such as optimization, vaccine, distribution, supply chain, and logistics resulted in 388 articles, of which 21 were selected for full-text screening. Among several characteristics of the manuscripts, our analysis focused on the identification of their objective values, which portion of the supply chain, which type of optimization model was used, and whether outbreak scenarios were considered.

#### 2 - Frequent Temporal Pattern Mining from Multivariate Time Series Data

Meserret Karaca, University of Florida, Gainesville, FL, 32607, United States, Michelle M. Alvarado, Panayote (Panos) M. Pardalos

Frequent temporal pattern mining (FTPM) is the problem of detecting frequently appearing events from multivariate time series data. This is a recently emerging problem with applications in medical event detection, equipment malfunction detection, environmental monitoring, etc. This study proposes a hybrid pattern mining approach for the FTPM problem. The FTPM problem has two steps: (i) generating patterns known as candidates, (ii) identifying the frequently occurring patterns. The goal of the study is to create a faster FTPM algorithm by preventing the generation of the redundant candidates. The proposed hybrid approach uses FP tree approach to obtain frequent candidates and uses novel pruning techniques to find the sequential events among frequent unordered patterns.

### 3 - Appointment Scheduling of Skin Cancer Surgeries with Patient Re-entrance

Coralys Colon, University of Florida, Gainesville, FL, United States

Mohs is a surgical procedure for the treatment of skin cancer. It removes one layer at a time to be examined for the presence of cancer. Due to the stochastic nature of patient re-entrance, poorly structured schedules cause clinic overtime and long patient wait times. The goal of this project is to propose a stochastic programming model that provides clinic appointment schedules for Mohs procedures considering stochastic behaviors such as number of layers per patient and processing time variance and patient no shows. The objective is to minimize clinic overtime and patient wait times while maximizing clinic revenues. We use simulation modeling to compare our optimal schedule to MMS current practice.

#### 4 - Machine Learning Applied to Walk-in Demand Prediction of University Counseling Center

Erin Magee, Undergraduate Student, University of Florida, Gainesville, FL, 32611-6595, United States, Meserret

Karaca, Ernesto Escoto, Alvin Lawrence, Michelle M. Alvarado The University of Florida Counseling and Wellness Center (UCWC) implemented

walk-in appointment policy for emergency student needs. UCWC walk-in appointment policy for emergency student needs. UCWC walk-in appointment traffic has been increasing, averaging a 7% increase in patient visits yearly. Hourly, daily or weekly demand for walk-in services is highly uncertain. This creates challenges in staffing to meet emergency student needs. Demand prediction is an important aspect to schedule counselors to handle unexpected demand scenarios. This project utilized data visualization and applied machine learning using the Gradient Boosting algorithm. This model predicted demand with a mean of 4.2 patients per hour and a mean square error of 1.75.

### 5 - Chance-constrained Stochastic Programming for Reducing Hospital Readmission

Behshad Lahijanian, University of Florida, Herbert Wertheim College of Engineering, Industrial and Systems Engineer, Gainesville, FL, 32611, United States, Michelle M. Alvarado

The Hospital Readmission Reduction Program (HRRP) aims to reduce hospital readmissions by applying a financial penalty to hospitals whose readmission rates are worse than their peers. We develop a stochastic program to obtain the hospital's optimal care strategy for avoiding HRRP penalties. The model minimizes the hospital's costs without sacrificing quality of care and utilizes probabilistic

constraints to control uncertain readmission probabilities across all patients for each condition, with the goal of achieving targeted readmission rates with a given confidence level. The trade-o between the cost of care, reduced readmission rates, and confidence levels will be explored.

# SA15

E62 Sloan - Room 262

### **Transforming Health Care with Analytics**

Emerging Topic: Healthcare Information Technology and Management

Chair: Hemant K. Bhargava, University of California, Davis, CA, 95616, United States

Co-Chair: Yegin Genc, Pace University, New York, NY

#### 1 - Gamified Challenges in Online Weight-loss Communities Behnaz Bojd, University of Washington, Seattle, WA, United States

Gamified challenges, one of the most popular features of online weight-loss communities, enable users to pursue a short-term goal, and compare their weight-loss progress with other challenge participants using gamification elements such as leaderboards. In this paper, using the data from a leading online weight-loss community, we study the effect of gamified challenges on weight-loss progress. We utilize the system GMM and Inverse Probability Weighting (IPW) approach to address endogeneity issues. Our findings indicate that participation in gamified challenges has a positive and significant short-term effect on weight-loss. The long-term effect of participation in challenges suggests that participation on a regular basis is required to achieve and maintain larger weight-loss goals. We also show heterogeneous effects across challenges based on the objective of the challenge. The results suggest that participating in challenges with a numeric weight-loss target has a larger effect on weight-loss than challenges without a target.

#### 2 - Modeling Government Policy for Protecting User Privacy on Healthcare Websites

Sule Nur Kutlu, University of Connecticut, Storrs, CT, United States, Ram Gopal, Hooman Hidaji, Raymond A. Patterson, Niam Yaraghi

Abuse of user privacy on websites has brought governmental policy-level issues with it including how best to protect user privacy. Using economic modeling, we investigate various government intervention policies that can help policy-makers and governments to improve different metrics such as user surplus, websites' profits, the combination of users surplus and websites' profits, and social welfare (which also includes the profit of third-parties). Comparing intervention policies, we find that the best policy depends on the metric, the level of privacy concern, and the quality level for government website alternatives.

#### 3 - Augmenting Crowd Intelligence for Radiology Data Annotations Yegin Genc, Pace University, New York City, NY, United States

Artificial intelligence (AI) can help automate the annotation of unstructured healthcare data which is more than medical experts can manually annotate due to the increase in electronic healthcare records. Recent research has shown that a crowd of non-experts can be as accurate in annotation tasks requiring domain knowledge as medical experts. This crowd-annotated data is then used to train supervised AI models which can be as effective as models that are trained by expert data. In this study, we explore combining human and artificial intelligence by providing AI based inputs for non-experts to annotate healthcare records. In particular, we investigate how and to what extent the model performance and the annotation task. We use noisy crowd-annotated data in radiology to train a supervised AI model, and expert annotated data for validation. We conducted an online experiment in Mechanical Turk (MT) and tested the effect of two levels of system transparency and model performance.

# 4 - Reciprocity or Self-Interest? Leveraging Digital Social Connections for Healthy Behavior.

Che-wei Liu, Indiana University, Bloomington, IN, United States, Guodong (Gordon) Gao, Ritu Agarwal

We examine the role of reciprocity enabled by digital social platforms for offline healthy behavior. We conduct a large randomized field experiment with over 1,700 pairs of users on a mobile platform. We find that on average, reciprocity outperforms self-interest in motivating individuals to exercise more. Furthermore, our results reveal that the magnitude of the reciprocity effect is contingent on the social closeness between senders and receivers. Interestingly, social closeness has an inverted U-shaped influence on the reciprocity effect. This mechanism can be implemented cost-effectively with improved precision using today's ubiquitous digital social connections and wearable devices.

# SA16

E62 Sloan - Room 276

# The Economics of Healthcare Delivery: Patient Demand, Provider Behavior, and Payment Models

Emerging Topic: Healthcare Economics

Chair: Lesley Meng, The Wharton School, University of Pennsylvania, Philadelphia, PA, 19104, United States

### 1 - Stirring the Pot: Switching from Blended Fee-for-Service to Blended Capitation in Ontario, Canada

Nibene Habib Some, PhD, Western University, London, ON, Canada, Rose Anne Devlin, Nirav Mehta, Greg Zaric, Sisira Sarma

In Canada's most populous province, Ontario, family physicians choose between the blended fee-for-service (FHG) and blended capitation (FHO) payment models. We develop a theoretical model to predict physicians' behavior under FHG and FHO and test our predictions empirically. We use Ontario health administrative data to evaluate the impact of switching physicians from FHG to FHO on healthcare services using a two-stage estimation strategy: propensity score matching with panel data regressions. The results show that switching from FHG to FHO reduces capitated services and services to non-enrolled patients by 16% and 5%, and increases after-hours and non-incentivized services by 8% and 14%.

### 2 - Magnitude, Persistence, and Sources of Spending Deviations among Accountable Care Organizations in the Medicare Shared Savings Program

Michael Anne Kyle, Harvard Business School, Boston, MA, United States

Understanding variation in spending across organizations, as opposed to across geography, is important because care is delivered by organizations and interventions increasingly focused on organizations. Organizations with the incentives to reduce spending, such as accountable care organizations (ACOs), are particularly important and analysis of variation may help identify cost savings opportunities. We examined the persistence, magnitude, and sources of spending variation among ACOs over four years (2013-16). In each year, within-market adjusted total spending for the highest-spending quartile of ACOs was 14-15% higher than ACOs in the lowest quartile. In percentage terms, variation between high- and low-spending ACOs was greatest in post-acute care, but inpatient care was the largest driver of the absolute difference in dollar terms, accounting for 32-39% of the spread in total spending.

### 3 - Estimating the Prevalence of Undiagnosed Coronary Heart Disease Using the Terror Queue Model

Jingyuan Wang, Yale University, New Haven, CT, United States, Edward H Kaplan

Coronary heart disease (CHD) is the leading cause of death worldwide. However, the total prevalence of CHD (symptomatic and asymptomatic) in the United States is unknown. We estimate the prevalence of undiagnosed coronary heart disease in the United States using the mortality, incidence and the prevalence of diagnosed CHD by adapting the Terror Queue Model to CHD diagnosis. We find that there are an estimated 30.94M [95% CI, 30.86M to 31.02M] people with undiagnosed coronary heart disease in the United States, which is 9.5% of the U.S. population. For every diagnosed CHD patient in the U.S., there are about 1.76 people with CHD who have not been diagnosed. Our results suggest great opportunities for CHD prevention by better identifying people with undiagnosed CHD.

### 4 - The Impact of Medication Delays on Patient Health in the ICU: Estimating Marginal Effects Under Endogenous Delays

Lesley Meng, The Wharton School, University of Pennsylvania, JMHH, Philadelphia, PA, 19104, United States,

Krzysztof Laudanski, Ann Huffenberger, Christian Terwiesch

We study the hospital intensive care unit (ICU) to investigate the impact of exogenous medication delays, introduced by shift changes, on granular patient health outcomes. Using patient vital sign data electronically archived every few minutes, merged with the electronic medical record and the medication order database, we are able to estimate the marginal impact of a minute of medication delay on patient vital status following the late medication.

# Saturday, 10:00am- 10:50am

### Plenary

E52 Samberg – Ballroom, 7th Floor

### **Health System Innovation through Data & Analytics** Emerging Topic: Plenary

### 1 - Health System Innovation through Data & Analytics

Retsef Levi, MIT, Cambridge, MA & Peter Dunn, Massachusetts General Hospital, Boston, MA

This talk will discuss several examples of how analytics and operations research approaches could enable system level changes in large academic medical centers. Modeling, analytical and implementation challenges and considerations will be discussed. The examples cover both inpatient and outpatient settings. The talk will highlight both technical and organizational key success drivers in collaboration between operations research academics and experts in large health systems.

# Saturday, 11:10AM - 12:40PM

# ■ SB01

E52 Samberg - Dining Room 6

### **Disease Modeling: From Data to Insights**

Emerging Topic: Personalized Medicine and Disease Modeling

Chair: Tinglong Dai, Johns Hopkins University, Baltimore, MD, 21202, United States

Co-Chair: Kimia Ghobadi, Johns Hopkins University, Baltimore, MD, 21218, United States

### 1 - Personalized Treatment for Opioid Use Disorder

Jingyi (Kyra) Gan, Tepper School of Business, Pittsburgh, PA, 15213, United States, Alan Scheller-Wolf, Sridhar R. Tayur

In order to be cost effective, an opioid use disorder (OUD) treatment must collect and utilize information on how a patient responds to different treatment regimens. Traditional methods of evaluating patient response—urine tests and self-reports—have not been effective. In contrast, wearable devices can potentially help detect patient craving episodes and health status in real-time. A variety of wearable devices with different features and costs are available; whether such devices are practical in OUD treatments, and if so how they should be used, are critical questions. We build a sequence of partially observable Markov decision processes (POMDPs) and a Markov decision process with budget constraints to address these questions. We provide a fast solution method for the POMDP models: a novel heuristic algorithm with an analytic error bound. We perform a numerical study to investigate the value of incorporating different wearables in OUD treatments under various scenarios of budget, wearable precision, and patient treatment adherence.

#### 2 - Radiation Therapy Treatment Planning for Brain Cancer Kimia Ghobadi, Johns Hopkins University, Baltimore, MD, United States

In this talk, we present optimization methods for brain cancer patients who undergo radiation therapy treatment using Leksell Gamma Knife. A significant tradeoff in such patients in the plan quality and the treatment time. We propose integer optimization models to capture the tradeoff and find the focal points of the radiation. The primary goal of the optimization is to spare the healthy tissue as much as possible while delivering enough dose to the target tissue and reducing the treatment time.

### 3 - Pride and Prejudice: The Human Side of Interventional Cardiology

Tinglong Dai, Johns Hopkins University, Baltimore, MD, 21202, United States

Few issues in the healthcare ecosystem are more salient than the utilization of medical tests. By some estimates, up to 30% of medical-testing decisions are deemed inappropriate, which may entail either over- or under-testing. All too frequently, the public attention has centered on over-testing. By comparison, under-testing has received little media coverage, but frequently appears in the medical literature. In addition, contrary to popular belief, the US trails most OECD countries in terms of the utilization of medical tests. In this talk, I discuss several recent modeling efforts aimed at understanding physician decision-making leading to over- and under-testing. These efforts, motivated by ophthalmology and interventional cardiology practices, reflect clinical, financial, and operational incentives. I will also highlight implications for policymakers and healthcare executives.

E52 Samberg - Dining Room 5

### **Healthcare Operations**

Emerging Topic: Healthcare Supply Chains

Chair: Huiyin Ouyang, The University of Hong Kong

 Dynamic Server Assignment in Multiclass Queues, with Application to Nurse Staffing in Emergency Departments Vahid Sarhangian, PhD, Dept. of Mechanical & Industrial Engineering, University of Toronto, Toronto, ON, Canada, Carri Chan

Nurse staffing decisions in emergency departments (EDs) are typically assigned weeks in advance, which can create staffing imbalances as patient demand fluctuates. In this work, we consider the potential benefits of assigning nurses to different areas within an ED at the beginning of each shift. We study the problem of optimal reassignment of nurses to areas by considering a multiclass queueing model of the system and studying its associated fluid control problem. We find this additional flexibility can substantially reduce waiting times for patients. Preliminary results from a pilot implemented at our partner ED also support the numerical observations.

### 2 - Optimizing Colorectal Cancer Screening Policies Using a Combination of Fecal Immunochemical Test and Colonoscopy

Zhichao Zheng, Singapore Management University, Singapore,

Jing Li, Mabel Chou, Ming Dong Many countries have adopted a combination of fecal immunochemical test (FIT) and colonoscopy as the preferred protocol for colorectal cancer (CRC) screening and surveillance. Current guidelines typically recommend two consecutive FITs annually after age 50 and immediate colonoscopy if there is at least one positive FIT outcome. The guidelines have not been followed closely in practice, however, and patient compliance with this recommendation is very low. Furthermore, it is unclear from literature about the values of having the FIT as a pre-screening method before colonoscopy. We propose a partially observable Markov decision process (POMDP) model to optimize the CRC screening protocol that combines FIT and colonoscopy considering information from prior screening history and individual risk factors. Compared to the screening protocol that uses colonoscopy alone, we demonstrate that when FIT sensitivity is not too low, adding FITs can

# help identify CRC in a timely manner, while at the same time reduce the number of colonoscopies required.

#### 3 - Who is Next: Dynamic Patient Prioritization in an Emergency Department

Zhankun Sun, City University of Hong Kong, Kowloon, Hong Kong, Wenhao Li, Jeff Hong

In the emergency department (ED), priority scores are assigned to patients at triage based on their acuity levels. However, using operational data from more than 150,000 patient visits, we find that doctors may deviate from this priority sequence, and within each priority class, patients may not be served in a first-come-first-serve manner. Our analysis shows that when selecting the next patient to treat, doctors prioritize patients who are more likely to be discharged after treatment at ED when many ED beds are occupied by boarding patients, in an effort to avoid further access block to the ED.

### 4 - Allocation of Intensive Care Unit Beds with Patient Readmissions

Huiyin Ouyang, the University of Hong Kong, Pok Fo Lam, Hong Kong, Zhankun Sun

This work aims to use mathematical modeling and analysis to develop insights into and policies for making priority decisions in Intensive Care Units (ICUs) with patient readmissions. We assume patients' health conditions may change over time, and patients who are early discharged from ICU due to capacity constraint might get readmitted to ICU when beds become available later. We propose a stylized mathematical model in which patients' health conditions change over time according to a Markov chain. The ICU has limited bed availability and therefore when a patient arrives to a full ICU, a decision needs to be made as to whether the patient should be admitted to the ICU and if so which patient in the ICU should be early discharged to the general ward. Patients waiting in the general ward could get readmitted to ICU when a bed becomes available, in which case a decision needs to be made as to which patient should be readmitted. We formulate this decision problem as a Markov decision process and provide some analysis of the structure of the optimal policy.

## SB03

E52 Samberg - Dining Room 4

### Predictive Applications for Personalized Care Delivery

Emerging Topic: Healthcare Supply Chains

Chair: David Anderson, Villanova University, Villanova, PA

Co-Chair: Sean Barnes, University of Maryland-College Park, College Park, MD, 20742, United States

### An Analytics-driven Approach to Developing (individualized) Optimal Screening Guidelines for Diabetes Patients Vishal Ahuja, SMU, Hossein Kamalzadeh, Michael Hahsler, Michael Bowen

Diabetes Mellitus, a chronic disease, is a leading cause of many complications and major section of medical care expenditures. Identifying people at the highest risk of developing diabetes (e.g. those with prediabetes) is thus an important clinical and policy problem. The two key stages in the natural progression of diabetes are "prediabetes" and "diabetes". We develop a Partially Observable Markov Decision Process (POMDP) model that captures various stages of diabetes natural progression and provides decision makers answers to two key questions: "whom to screen?" and "when to screen?" The parameters of the model are obtained using proprietary data from a large safety-net hospital. The framework of this research incorporates both prescriptive and predictive/prescriptive tools as well as Hidden Markov Models to develop policies for diabetes screening at both individual and population-level. The results indicate that our proposed policy outperforms all existing guidelines.

### 2 - A Data-Driven Framework for Identifying Intensive Care Unit Admissions Colonized with Multidrug-Resistant Organisms Caglar Caglayan, Georgia Institute of Technology, Atlanta, GA, 30332, United States, Sean Barnes, Lisa Pineles, Eili Klein, Anthony Harris

Multi-drug resistant organisms, such as Methicillin-resistant Staphylococcus Aureus (MRSA), Vancomycin-resistant Enterococci (VRE), Carbapenem-resistant Enterobacteriaceae (CRE), are difficult to treat with existing medications. The increasing colonization rate of such organisms is concerning especially in healthcare settings, as they pose a significant threat to the patient population. In this study, we conduct a data-driven analysis based on prediction models to (1) identify the factors associated with MRSA, VRE, CRE colonization upon intensive care unit admission and (2) predict the admission outcome based on the sociodemographic and clinical factors.

### 3 - Can Consumers Use Online Reviews to Avoid Unsuitable Doctors?

David Anderson, Villanova University, Villanova, PA, 07030, United States

It is difficult to assess a doctor's quality. According to theory, doctors provide a classic credence service, where the quality of the service is difficult or impossible to determine even after its consumption. We challenge the notion that doctors are pure credence goods by analyzing the power of online reviews to predict whether a doctor is unsuitable for medical practice. We use doctor ratings as inputs to our model despite strong debate regarding their informational value in healthcare. We use state medical board sanctions as a signal of doctors' suitability to practice. We find predictive power in our models: there is indeed a signal of underlying doctor suitability in online ratings. Implications for consumer choice, regulatory surveillance, economic theory, and the usefulness of predictive modeling are discussed.

### E52 Samberg - Dining Room 3

### **Incentives and Hospital Choice**

Contributed Session

Chair: Jingrong Zhu, Beijing Institute of Technology, South Zhongguancun Street, Beijing, China

### 1 - Optimal Subsidies for Early Access to Rare Disease Therapeutics

Wendy Olsder, Eindhoven University of Technology, Eindhoven, Netherlands, Tugce G. Martagan, Christopher S. Tang

There are more than 7000 known rare diseases but treatments are available only for 300 of them. For patients with a life-threatening condition, orphan drugs in clinical trials can be made available through the Expanded Access Program (EAPs). To encourage the launch of EAPs, the government offers subsidies to patients, manufactures, or both. We present a three-stage Stackelberg game to determine the optimal allocation of the limited subsidy budget (i.e., subsidize patients only, manufacturers only or both). We derive the optimal subsidy allocation for different pricing settings and characterize the optimal unit selling price and manufacturer's R&D effort.

### 2 - Choice and Preference for Health Provider Choice in China

Jingrong Zhu, Beijing Institute of Technology, Beijing, China, Jinlin Li

In China, public hospitals contribute to most of the health care services for a long time. However, private hospitals are experiencing a rapid development. The aim of the work was to explore whether the public in China prefer seeking outpatient care in public hospitals or private clinic. Our work takes advantage of a labeled discrete choice experiment. Mixed logit model was used to analyse the data. The results show that for outpatient care patients consider provider's type to be the most important determinant, and also value the different attributes. The study also reports on the preference of heterogeneous. Our results will have implications for policy makers aiming at putting a new policy into effect.

# ■ SB05

E52 Samberg - Dining Room 2

### **Global Health and Health Policy**

Contributed Session

Chair: Li Hao, Beijing Inst. of Technology, Beijing, China.

- 1 A New Epidemics-logistics Model: Insights into Controlling the Ebola Virus Disease in West Africa
  - Esra Buyuktahtakin Toy, New Jersey Institute of Technology, Newark, NJ, United States, Eyyub Yunus Kibis, Emmanuel des-Bordes, Xuecheng Yin

In this study, we address a core limitation of existing epidemiological models by introducing a new epidemics-logistics mixed-integer programming (MIP) formulation to determine the optimal amount, timing and location of resources that are allocated for controlling an epidemic. The present study is the first spatially explicit optimization approach that considers geographically varying rates for disease transmission, migration of infected individuals over different regions, and varying treatment rates due to the limited capacity of treatment centers. We illustrate the performance of the MIP model using the case of the 2014-2015 Ebola outbreak in Guinea, Liberia, and Sierra Leone.

### 2 - Intervention Mechanism of Healthcare Service Goods Based on Social Welfare Maximization in China

Li Hao, Beijing Institute of Technology, Beijing, China

We explore a healthcare service goods supply chain problem for a setting composed of an administrative sector and a product provider. The main objective of the administrative sector is to establish an intervention mechanism that is beneficial to society. Two intervention strategies are applied to the intervention mechanism jointly, one is demand-growth strategy that influences the stochastic demand, and the other is subsidy strategy that affects profit for the product provider, then two benchmark approaches are introduced. Finally, the result indicates that our joint healthcare service goods intervention mechanism is helpful to achieve the target and increase social welfare.

### SB06

E52 Samberg - Salon West

### **Evaluation of Healthcare Interventions**

Emerging Topic: Public Health and Health Policy

Chair: Pinar Keskinocak, Georgia Institute of Technology, Atlanta, GA, 30332, United States

Co-Chair: Melike Yildirim, Georgia Institute of Technology, Atlanta, GA

### 1 - Cost-Effectiveness of Adjuvanted Subunit Vaccination for Herpes Zoster

David W Hutton, University of Michigan, Ann Arbor, MI, 48105, United States, Christopher Carpenter, Annas Aljassem, Jerry Stassinopoulos, Giovanni Pisacreta

Herpes zoster (HZ) develops in up to 50% of unvaccinated individuals, accounting for more than 1 million cases annually in the United States. A new two-dose adjuvanted HZ subunit vaccine (SUV) has better initial efficacy than the existing live attenuated HZ vaccine (LAV). Using Markov models to simulate long-term impacts, we determine vaccination with SUV was more cost-effective than LAV at all age groups studied and that vaccination with SUV may be cost-effective in younger age groups.

#### 2 - Methodology for Parameterization of Cancer Progression Model for Data Limited Settings

Xinmeng Zhao, University of Massachusetts, Amherst, MA, United States, Chaitra Gopalappa, Jiachen Guo, Buyannemekh Munkhbat, Prashant Meckoni, Jeremy Lauer, Andre Ilbawi, Carel Pretorius

We present a mathematical methodology for parameterization of natural cancer onset and progression specifically for settings that do not have longitudinal data, such as in low and middle income countries. This could help inform countryspecific guidelines for cancer screening. The methodology was applied to cancers of the breast, cervical, and colorectal for informing the World Health Organization's 'Best Buys' for updating the Appendix 3 of the Global Action Plan for Prevention of Noncommunicable Diseases

#### 3 - Estimating the Impact of Asthma Interventions on Health Utilization and Expenditures for Medicaid-Enrolled Children Fatma Melike Yildirim, Georgia Institute of Technology, North Ave NW, Atlanta, GA, 30332, United States, Pinar Keskinocak, Julie L. Swann, Paul Griffin

Since the effect of intervention programs are not obvious, we aim to quantify the effect of pediatric asthma interventions on the healthcare utilization and medication costs. We analyze four interventions: influenza vaccine, spacer, self-management education, and nebulizer. We further investigate the probability reductions of related emergency department, primary care physician and inpatient visit with interventions. Although all the interventions are cost effective, the estimated affects varied by the state and intervention program.

### 4 - Pandemic Influenza Vaccine Allocation with Equity Shakiba Enayati, State University of New York, Plattsburgh, Plattsburgh, NY, 12901, United States, Osman Ozaltin

We develop an age-structured influenza epidemic model with isolation. We then formulate a mathematical program to find an allocation policy that minimizes the vaccine stockpile needed to avoid a widespread infection. The proposed approach returns the optimal age-structured vaccine allocation rather than comparing the efficacy of just a few specific vaccination policies. Furthermore, we propose an equity constraint to help public health authorities integrate fairness in their vaccine allocation decisions.

#### 5 - Evaluating the Impact of ProACT Interventions on Reducing Malaria Transmission in Sub-Saharan African Countries Yifan Wang, Georgia Institute of Technology, Atlanta, GA, United States, Pinar Keskinocak, Brian Gurbaxani, Julie Gutman, Julie Thwing

Malaria causes substantial burden in sub-Saharan Africa. ProACT is a new method of malaria control, in which a community health worker regularly visits households to find and test people with malaria symptoms, and treats those testing positive. Initial data suggest that this strategy has substantial impact, but no data exist on the optimal duration or frequency of visits. Using an agent-based simulation model of malaria transmission, we predict that 3 rounds of visits (start, middle, and end of peak season) or 21 weekly visits during peak season lead to 14% and 41% reduction in malaria cases, respectively. Using modelling, we describe how to achieve the optimal balance between case reduction and cost.

E52 Samberg - Ballroom T Practice Oriented Session

### Implementation of Data-Driven Solutions in AMCs: A Panel Discussion

Practice Oriented Session

In this panel session, leaders from top Academic Medical Centers across the United States will describe their experience in using operations research methods and analytics to drive successful process-redesign projects in large hospitals. Discussants will talk about necessary conditions for success, list common challenges, and cite lessons learned. The session will include time for questions from the audience.

### Moderators:

Kyan Safavi, Massachusetts General Physicians Organization, Boston, MA, United States

Ana Cecilia Zenteno, Massachusetts General Hospital, 55 Fruit Street, White 400, Boston, MA, 02142, United States

### Panelists:

Bethany Daily, Massachusetts General Hospital, Boston, MA, United States

David Scheinker, Stanford - Lucile Packard Children's Hospital, Huang Engineering Center, Stanford, CA, 94305, United States Mustafa Y. Sir, Mayo Clinic, Rochester, MN, 55905, United States

### SB08

E52 Samberg - Ballroom I

# Examples of Machine Learning Applications in Healthcare Management

Emerging Topic: Personalized Medicine and Disease Modeling

Chair: Mohsen Bayati, Stanford University, Stanford, CA, 94305, United States

### 1 - Augmenting Radiologists' Decision Making Based on Mammography Using Deep Learning

Mehmet Eren Ahsen, PhD, Mount Sinai, New York City, NY, 10029, United States, Mehmet U.S. Ayvaci

Despite their increasing ubiquity, we are yet to understand when and how machine learning algorithms best augment human intelligence. Motivated by the difference between cognitive powers of machine learning methods and human beings in solving prediction problems of heterogeneous difficulty, we propose an algorithm that optimally combines algorithmic predictions with expert judgments. We apply our algorithm on a data in breast cancer based on mammograms. The data includes deep learning models trained on mammograms. Our results empirically demonstrate conditions when and how radiologists' decision making is enhanced.

### 2 - Precision Medicine in Multiple Myeloma Treatment

Ujjal Kumar Mukherjee, University of Illinois, Urbana-Champaign, Champaign, IL, 61820, United States, Amit Mitra

In this paper, we propose a data driven method for implementation of precision medicine using gene expression information for Multiple Myeloma patients. Using gene expression and other clinical data from a large panel of Gene expression data we demonstrate that prescription of proteasome inhibitors to multiple myeloma patients can be made targeted and more precise so as to improve the effectiveness of cancer treatment. We also conduct laboratory experiments to demonstrate the application of our proposed method.

### 3 - Matrix Completion Methods for Causal Panel Data Models in Healthcare

Khashayar Khosravi, Stanford University, Stanford, CA, 94305, United States, Mohsen Bayati, Guido Imbens, Susan Athey, Nikolay Doudchenko

A central problem in healthcare decision-making is estimating treatment effects using observational data. We investigate treatment effect estimation for the panel data model (matrix), where a subset of patients (rows) are exposed to the treatment during a subset of time periods (columns). We suggest a low-rank estimator that minimizes the estimation error and prove its consistency. We then demonstrate the performance of our method in estimating the effect of a glucose inhibitor drug (metformin) for pre-diabetic treatment.

### 4 - Wait Time Information and Patients Waiting Experience in the Emergency Department

Danqi Luo, Stanford Graduate School of Business, Stanford, CA, 94305, United States, Mohsen Bayati, Erica Plambeck

A field experiment on providing wait time information to patients in a hospital emergency department is carried out to look at how different forms of wait time information affect patients' waiting experience, behavior, and long-run quality of care, cost of care.

# SB09

E52 Samberg - Ballroom M Practice Oriented Session

# Improving the Allocation of Livers for Liver Transplantation

Practice Oriented Session

Chair: Zachary Leung, City University of Hong Kong, Hong Kong, China

Co-Chair: Nikolaos Trichakis, MIT, Cambridge, MA, 02143, United States

**Panelists:** Heidi Yeh, MGH, Boston, MA, hyeh@mgh.harvard.edu Charles Gerard Rickert, Massachusetts General Hospital, Boston, MA

Despite numerous efforts to improve liver transplant allocation, the liver transplant community has remained divided over the discussions surrounding broader distribution of deceased-donor liver grafts, patient prioritization based on medical urgency, and other allocation criteria. The geographic disparity in access to organs, for example, remains a contentious topic that has progressed from a debate among medical professionals to now resulting in a litigious intersection with law, politics, and policy. In this session, Dr. Heidi Yeh, MD, and Dr. Charles Gerard Rickert, MD, from the Massachusetts General Hospital Department of Surgery, will provide an overview of challenges facing liver allocation, followed by 4 research presentations on policy recommendations.

### 1 - REACH: A New Strategy for Prioritizing Hepatocellular Carcinoma Patients on the Liver Transplant Waitlist

Charles G. Rickert, Massachusetts General Hospital, Boston, MA, United States, Zachary Leung, Mustafa Akan, James F. Markmann, Sridhar R. Tayur, Huan Zhao, Heidi Yeh

Adult HCC patients are prioritized for liver transplantation by receiving MELD exception points, determined by time on waitlist, unlike lab MELD, which prognosticates risk of death in 3 months. We, therefore, developed a scoring algorithm based on tumor characteristics to predict the risk of drop out or exceeding of allocation criteria within 3 months for HCC patients. This REACH-score (Risk of Exceeding Allocation Criteria for HCC), provides a tool for prioritizing liver allocation among HCC patients by accurately identifying HCC patients most likely to drop off the waitlist. This score can be used in conjunction with the standard MELD system to co-prioritize HCC patients with ELSD patients.

### 2 - Efficiency and Equity in a Liver Allocation System with Two Patient Classes

Zachary Leung, City University of Hong Kong, Kowloon, Hong Kong, Mustafa Akan, Huan Zhao, Sridhar R. Tayur, Heidi Yeh

In the United States, the majority of the patients on the liver transplantation waiting list have either end-stage liver disease (ESLD) and/or hepatocellular carcinoma (HCC). One of the challenges in liver allocation is the differences between ESLD and HCC disease progression. In the first part of this work, we applied a fluid model framework to study the liver allocation system. Our model allows us to characterize the structure of the optimal allocation policy as well as the tradeoff in allocating more livers to ESLD patients at the expense of HCC patients. In the second part of this work, we developed a simulation model, which allows us to evaluate our proposed alternative liver allocation policies.

3 - Development and Validation of an Optimized Prediction of Mortality for Candidates Awaiting Liver Transplantation Nikolaos Trichakis, Massachusetts Institute of Technology, Cambridge, MA, 02142, United States, Dimitris Bertsimas, Jerry Kung, Yuchen Wang, Ryutaro Hirose, Parsia Vagefi

MELD allocation does not allow for equitable access to all waitlisted candidates. An optimized prediction of mortality (OPOM) was developed (http://www.opom.online) utilizing machine learning optimal classification tree models trained to predict a candidate's 3 month waitlist mortality or removal utilizing the Standard Transplant Analysis and Research (STAR) dataset. The Liver Simulated Allocation Model (LSAM) was then used to compare OPOM to MELD based allocation. Out of sample area under the curve (AUC) was also calculated for candidate groups of increasing disease severity. OPOM allocation, when compared to MELD, reduced mortality on average by 417.96 (406.8 428.4) deaths every year in LSAM analysis. Improved survival was noted across all candidate demographics, diagnoses, and geographic regions. OPOM delivered a substantially higher AUC across all disease severity groups. These data demonstrate the potential of machine learning technology to help guide clinical practice, and poten tially guide national policy.

4 - Balancing Efficiency and Fairness in Liver Transplant Access: Optimizing Organ Distribution with Implications for National Transplant Policy

Theodore Papalexopoulos, MIT, Cambridge, MA, United States, Dimitris Bertsimas, Nikolaos Trichakis, Yuchen Wang, Ryutaro Hirose, Parsia Vagefi

Current distribution policies have resulted in persistent geographic disparity in access to donated livers for waitlisted candidates. Using optimization and simulation, the current policy, proposed alternative models, and a novel continuous distribution model were assessed. A number of scenarios for each policy distribution concept were generated through efficiency-fairness tradeoff curves. Continuous distribution allowed both for the greatest reduction in patient deaths and for the most equitable geographic distribution across comparable organ transportation burden. When applied with an Optimized Prediction of Mortality, continuous distribution allowed for a significant reduction in number of deaths—as large as 566 lives saved annually. Development and implementation of continuous distribution models for all solid organ transplants may allow for minimization of the geographic disparity in organ distribution, and allow for efficient and fair access to a limited national resource for all candidates.

# SB10

E52 Samberg - Salon East

### Scheduling / Staffing

Contributed Session

Chair: Mahesh Nagarajan, University of British Columbia, Vancouver, BC, V6T 1Z2, Canada

1 - Physician Staffing in Emergency Rooms: Opening the Blackbox of ER Care via a Multi-class Multi-stage Network Caglar Caglayan, Georgia Institute of Technology, Atlanta, GA, United States, Yunan Liu, Turgay Ayer, Kalyan Pasupathy, David Nestler, Mustafa Y. Sir

Emergency Rooms (ERs) are complex healthcare delivery systems characterized by time-varying unscheduled arrivals, medium-to-long service times, high patient volumes, multiple patient classes, and multiple treatment stages. In such a complex system, optimizing staffing levels of physicians, the most critical resources in ERs, is a major challenge. In this paper, in collaboration with Mayo Clinic, we study the ER physician staffing problem under tail probability of delay (TPoD) type service targets. We capture the patient flow in the ER with a multiclass multi-stage queuing network and propose a new staffing algorithm to determine the staffing levels for the queues that physicians serve.

### 2 - Positional Flexibility and Consistent Assignment in Long-Term Care Staffing

Vincent Slaugh, Cornell University, Ithaca, NY, United States, Alan Scheller-Wolf

We study the shift-level worker-to-unit assignment problem for long-term care with random worker availability. Nursing homes seek to minimize inconsistency of care, which we observe to be driven by the part-time workforce in some facilities. We use a hindsight optimization model with real schedule data, a stochastic model of the repeated assignment problem, and a trace-based simulation of assignment schemes. While various priority list schemes can improve upon actual schedules, a policy that gives home-unit assignment priority to part-time workers outperforms a policy that gives priority to full-time workers.

### 3 - Home Healthcare Integrated Staffing and Scheduling

Louis-Martin Rousseau, Professor, Polythechnique Montreal, Montreal, QC, Canada, Maria Restrepo, Jonathan Vallée

Workforce planning for home healthcare represents an important and challenging task involving complex factors associated with labor regulations, caregivers' preferences, and demand uncertainties. We present a two-stage stochastic programming model for employee staffing and scheduling in home healthcare. where first-stage decisions correspond to the staffing and scheduling and second stage decisions are related to the temporary reallocation of caregivers to neighboring districts, to contact caregivers to work on a day-off, and to allow under- and over-covering of demand. The proposed model is tested on real-world instances.

### 4 - Capacity Planning at B.C. Children's Hospital

Mahesh Nagarajan, University of British Columbia, Vancouver, BC, V6T 1Z2, Canada, S. Carew, S. Shechter, E. Skaarsgaard, J. Armeja

Given the variety of urgency levels in highly utilized operating rooms, capacity allocation decisions can have a major impact on how wait times are rationed. We examine a longer-term, sequential capacity planning problem, in which a hospital allocates operating room time to different surgical specialties. We seek to minimize an urgency-weighted wait time metric. Our problem is a variant of a well known NP-HARD inventory problem and we propose heuristics that outperforms the existing capacity allocation software used in many Canadian hospitals.

# SB11

E52 Samberg - Room 164

### **Behavioral OM in Health Care**

Emerging Topic: Healthcare Economics

Chair: Hummy Song, Philadelphia, PA, 19104, United States

1 - Empowering Patients as Providers of Self-Care: Evidence from a Randomized Control Trial

Shannon Harris, The Ohio State University, Columbus, Aravind Chandrasekaran

This study presents insights from a randomized control trial that investigates how people-centric programs in professional service industries affect operational outcomes. Specifically, we study the implementation of a patient empowerment program after hospital discharge, and its relationship with patient outcomes namely, patient anxiety and readmissions. We examine these outcomes by conducting a 13-month randomized control trial (RCT) involving 80 kidney transplant patients and 25 care providers from a major health system. This result suggests that incorporating a people-centric program, such as patient empowerment through mentoring, reduces patient anxiety, an operational outcome of interest to a transplant clinic. However, we also find a counterintuitive result that initial readmissions are 17% greater for empowered patients than patients in the control group. However, early readmissions help hospitals prevent long term illness.

### 2 - Shared Medical Appointments - An Innovative Approach to Healthcare Delivery

Nazli Sonmez, London Business School, Regent's Park, London, NW1SN, United Kingdom, Kamalini Ramdas, Ryan Buell

We examine shared medical appointments (SMAs) as a substitute for regular oneon-one appointments. Under this innovative approach, a group of patients with similar chronic conditions meet with a doctor simultaneously and receive one-onone care. We conduct a randomized controlled trial at the Aravind Eye Hospital's Glaucoma Clinic, in Pondicherry, India to assess the effectiveness of shared medical appointments versus traditional one-on-one appointments for glaucoma. Preliminary results obtained with the data suggest that the knowledge and satisfaction level of patients who attend shared medical appointments is significantly higher than that of patients who attend one-on-one appointments.

#### 3 - Evaluating the Efficacy of Connected Healthcare: An Empirical Examination of the Impact of Patient Engagement and Feedback Systems

Tan Lekwijit, University of Pennsylvania-Wharton School, Philadelphia, PA, 19104, United States, Christian Terwiesch, Kevin Volpp

Connected Health (CH) is a form of telehealth in which patients and doctors are connected by means of timely information sharing. The benefits of CH are oftentimes ambiguous. We study CH in a setting where patients received electronic pill bottles and social support that involved different types of feedback. Our work aims to investigate the efficacy of feedback systems in promoting medication adherence, and to establish the relationship between medication adherence and readmission. Our findings suggest that spontaneous manual interventions can effectively turn nonadherence into adherence. Moreover, we also find that better adherence substantially reduces the risk of readmission.

E62 Sloan - Room 221

# Scheduling of Operating Rooms and Equipment

Contributed Session

### Chair: Alexander Tesch, Zuse Institute Berlin, Berlin, Germany.

1 - Operating Room Scheduling with Parallel Surgery Processing Cansin Cagan Acarer, Brock University, St. Catharines, ON,

Canada, Reena Yoogalingam

We study the operating room scheduling problem and the operational impact of overlapping surgeries where non-critical portions of surgeries can be scheduled in parallel. A simulation optimization approach is used to determine the conditions under which this practice can be implemented in a viable way in terms of resource utilization and service quality.

### 2 - Optimization and Approximate Dynamic Programming for Adaptive Operating Room Scheduling

Alexander Tesch, Zuse Institute Berlin, Berlin, Germany

We consider the problem of scheduling an operating room on a daily basis. This includes the generation of a baseline schedule and dynamic rescheduling decisions throughout the planning day due to stochastic surgery durations. Our goal is to optimize the static baseline schedule and the associated dynamic rescheduling policy that together yield minimum expected cost. We approach this highly complex problem by using different approximators for the cost of the dynamic rescheduling problem that, in turn, serve as approximations on the 'real' cost of the baseline schedule which is finally computed by branch-and-bound techniques. Our method is tested on real data of a major hospital in Germany.

# SB13

E62 Sloan - Room 223

### **Healthcare Analytics**

Sponsored: MSOM/Healthcare

Chair: Hessam Bavafa, Wisconsin School of Business, Madison, WI, 53706, United States

### 1 - Drivers of Emergency Department Boarding

Arshya Feizi, Boston University, Boston, MA, 02134, United States, Jillian Berry Jaeker, William E. Baker

Emergency department (ED) overcrowding occurs primarily due to patients who are admitted to an inpatient unit but must wait in the ED pending their departure, which is called "boarding". Long boarding times have been associated with lower quality of care such as an increased risk of readmission and mortality. In this paper we aim to find the drivers of boarding and their relative impact.

### 2 - Continuity of Care and Risk of Readmission: An Investigation into the Healthcare Journey of Heart Failure Patients Claire Senot, Tulane University, New Orleans, LA, 70118, United States

I investigate the association between continuity of care mechanisms and a patient's risk of readmission in the context of one chronic condition, heart failure. Continuity of care is defined as the level of consistency across patient care episodes. I dynamically measure continuity of individual referring provider; continuity of physical location; and continuity of Accountable Care Organization (ACO). The final sample covers 44,129 episodes of care for 3,263 patients. Using a competitive-risks survival model, I find that all three continuity mechanisms are associated with a patient's lower risk of readmission. This exploratory study contributes to operations management literature by identifying effective integration mechanisms in the setting of healthcare delivery. In addition, by providing the first quantitative evidence for the critical role of multiple simultaneous mechanisms in resuring continuity of care, this study offers important preliminary insights for public policy efforts.

### 3 - Being on the Productivity Frontier:

Identifying "Triple Aim Performance" Hospitals Sriram Venkataraman, University of South Carolina, Department of Management Science, Moore School of Business, Columbia, SC, 29208, United States, Aleda Roth, Anita L. Tucker, Jon A. Chilingerian

Hospital decision-makers face trade-offs that make it difficult to obtain the trifecta of high performance on clinical quality, patient experience, and technical efficiency. We use the term "triple aim performance" (TAP) to refer to the simultaneous achievement of these three goals. Using datasets from 2010 and 2012 and data envelopment analysis, we identify about 20 triple aim performance hospitals in each year among U.S. acute care hospitals with at least 200 beds. We also examine factors that influence the probability of being a TAP hospital. We find that the percentage of physicians employed by the hospital has a positive and significant relationship with TAP, and that bed utilization rate has a positive relationship with technical efficiency, but a negative relationship with clinical quality and patient experience performance.

### 4 - Impact of Pharmaceutical Supply Chain Disruptions on Patient Safety

Minje Park, Boston University, Boston, MA, United States, Jillian Berry Jaeker, Anita L. Tucker

In the pharmaceutical industry, supply chain disruptions could pose harm to not only firms' performance but also to patients' safety. Yet, supply chain disruptions are very common in the U.S. drug market where 306 drugs were in shortage in 2018. This paper examines the impact of pharmaceutical supply chains disruptions to patient safety by analyzing the case of Heparin shortage in 2017 and proposes some operational measures to mitigate the impact on patient safety.

# ■ SB14

E62 Sloan - Room 250

## Applied Health Research by Bonder Scholars

Sponsored: Healthcare Applications

Chair: Justin J. Boutilier, University of Wisconsin, Madison, WI, 53706, United States

#### Doing More with Less: Applying Modern Predictive Modeling Methods to Improve Acute Concussion Assessment Gian-Gabriel P. Garcia, University of Michigan, Ann Arbor, MI, 48105, United States, Jing Yang, Mariel Sofia Lavieri,

Thomas McAllister, Michael McCrea, Steven Broglio

Accurate and timely diagnosis is critical for improving patient outcomes. Yet, few studies aim to identify subsets of commonly used concussion assessment batteries (e.g., the SCAT) which can be administered more quickly than the whole battery without losing accuracy. Thus, we created logistic regression models using mixed integer programming for variable selection to identify maximally accurate subsets of the SCAT. These subsets actually outperform the whole SCAT, indicating that components of the battery add "noise" to acute concussion assessment.

### 2 - Multi-modality Optimal Radiation Therapy

Roman Levin, University of Washington, Seattle, WA, 98105, United States, Aleksandr Y. Aravkin, Minsun Kim

Radiotherapy is used to treat cancer patients using ionizing radiation to damage the tumor. X-rays are the most widely used radiation modality, however, there is a growing interest in using other radiation types, e.g. protons, due to their unique dosimetric and biological properties. Current attempts to determine an optimal radiation modality or a combination of modalities are mostly empirical. We propose a novel mathematical framework to maximize the damage to the tumor while sparing normal tissue in the multi-modality setup. We develop algorithms to efficiently solve the underlying non-convex optimization problem and find the optimal radiation dose distributions with the number of fractions.

#### 3 - Response Time Optimization with Queuing Constraints for Drone Delivered Defibrillators Justin J. Boutilier, University of Wisconsin, Madison, WI, 53706, United States, Timothy Chan

Out-of-hospital cardiac arrest (OHCA) is a time-sensitive medical emergency claiming over 400,000 lives each year and an automated external defibrillator (AED) is one of the only effective methods for treating OHCA. In this paper, we propose an integrated location-queuing model to minimize the total number of drones required to meet an average response time goal while guaranteeing a sufficient number of drones are located at each base. We develop a novel reformulation technique that allows us to solve real-world instances and determine the optimal deployment of AED-enabled drone resources using eight years of data covering 26,000 square kilometers around Toronto, Canada.

E62 Sloan - Room 262

### **Healthcare Delivery Operations**

Emerging Topic: Healthcare Information Technology and Management

Chair: Sandeep Rath, University of North Carolina at Chapel Hill -Kenan Flagler, Chapel Hill, NC, 27599, United States

1 - Episode-based Payment Models: An Analysis of Affine Contracts for Hospital-Physician Gainsharing

Mili Mehrotra, University of Minnesota, Minneapolis, MN, 55455, United States, Diwakar Gupta, Xiaoxu Tang

The Centers for Medicare and Medicaid Services (CMS) has introduced several Episode-based Payment Models (EPMs). CMS pays the hospital and physicians participating in that EPM on a fee-for-service basis. These payments are reconciled against a target price, resulting in either a gain or loss to the hospital. The hospital may also have gains or losses from its internal operations. It may incentivize physicians to select a treatment option that will improve quality and reduce costs by offering to share gains and losses. CMS has placed restrictions on what gains or losses may be shared and implemented stop loss and gain provisions (SLSG) for the hospital and the physicians, which affect the physicians' choice of treatment options. In this paper, we consider a class of linear gainsharing functions and study the impact of the SLSG provisions, the maximum savings potential, and the risk preferences of the hospital and physicians on gainsharing and the choice of treatment options.

### 2 - Expanding the Donor Pool: Incentivizing the Use of Marginal Organs for Transplantation

Sait Tunc, The University of Chicago Booth School of Business, Chicago, IL, 60615, United States, Burhaneddin Sandikci, Bekir Tanriover

The standard of care for organ failure is transplantation. Despite the growing need for donor organs as demand outpaces supply, a significant fraction of organs harvested for transplantation are rejected and discarded. To alleviate the burden of shortages, we study incentive mechanisms that may increase organ utilization using a queueing-theoretic framework. We investigate socially efficient and equilibrium utilization of donor organs, and introduce an incentive mechanism that helps increase the utilization while also improving overall social welfare. We also present detailed simulation results quantifying the magnitude of impact of this incentive mechanism for the U.S. kidney transplant system.

#### 3 - Managing Outpatient Care Services with Strategic Walk-in Patients

Nan Liu, Boston College, Chestnut Hill, MA, 02467, United States, Willem van Jaarsveld, Shan Wang, Guanlian Xiao

In addition to serving patients with scheduled appointments, outpatient care providers often set aside some time to see walk-in patients, who arrive without making an appointment in advance. Facing these two channels of accessing care, patients make choices based on their health conditions and the utilities of these two options. In this talk, we discuss how an outpatient care provider should manage her capacity, taking into account such strategic behavior of patients.

### 4 - Efficient Transition to Post-Acute Care

Alex Mills, Baruch College, City University of New York, New York, NY, 10010, United States, Jonathan Helm, Pengyi Shi

Lack of skilled nursing capacity is a major contributor to discharge delays. We show that value-based payments with gainsharing can lead to efficient distribution of skilled nursing capacity and subsequent cost reductions in markets with a dominant hospital, by reserving capacity for short-stay patients. However, when a market has multiple competing hospitals, value-based payments can lead to a prisoners' dilemma where all hospitals are worse off. We argue that understanding how capacity is shared in a market is key to designing value-based payments that improve the healthcare system.

# Saturday, 2:00PM - 3:30PM

# SC01

E52 Samberg - Dining Room 6

# Recent Advancement in Healthcare Scheduling and Capacity Management

Emerging Topic: Healthcare Delivery

Chair: Nan Liu, Boston College, Chestnut Hill, MA, 02467, United States

1 - Optimal Scheduling of Proactive Care with Patient Deterioration Yue Hu, Columbia Business School, New York, NY, 10027, United States, Carri Chan, Jing Dong

Healthcare is a limited resource environment where the most severe patients are typically prioritized. However, there has been a growing interest in preventative care. While providing care for patients when they are less critical could mean that fewer resources are necessary to return them to a healthy state, utilizing limited capacity for patients who may never need it also takes the capacity away from other more critical patients. To understand this tension, we propose a two-class queueing model where a moderate class patient who does not receive treatment may recover or deteriorate to an urgent class. In this setting, we characterize how moderate and urgent patients should be prioritized for care.

#### 2 - Online Contextual Learning and Resource Allocation with Perishable Resources

Jingtong Zhao, Columbia University, New York, NY, 10027, United States

We formulate a novel class of online matching problems with learning. In these problems, randomly arriving customers must be matched to perishable resources so as to maximize a total expected reward. The matching accounts for variations in rewards among different customer-resource pairings. It also accounts for the perishability of the resources. For concreteness, we focus on healthcare platforms, but our work can be easily extended to other service applications.

### 3 - Stochastic Dynamic Inter-day and Intra-day Appointment Scheduling

Christos Zacharias, University of Miami Business School, Coral Gables, FL, 33146, United States

The simultaneous consideration of appointment day (inter-day) and time of day (intra-day) in stochastic dynamic scheduling decisions has not been addressed adequately in the Operations Research literature due to its large dimensionality and computational complexity. The scope of this research is to provide an optimization platform that solves this problem effectively and efficiently in a stochastic environment. We leverage the multimodularity property of the static intra-day problem and its propagation through dynamic programming recursion.

### 4 - On Scheduling Appointments in Tandem Service Systems

Nan Liu, Boston College, Chestnut Hill, MA, 02467, United States, Guohua Wan, Shan Wang

In many healthcare settings, patients come for a series of services instead of a single one. Each of these service stages may require a substantial amount of time with significant variability. For instance, in an infusion center, patients usually go through three main stages of services—blood draw, physician exam (to finalize/verify the treatment plan), and finally, infusion; in an orthopedic clinic, a common care path involves an X-ray exam, followed by a physician consultation, and finally, the service by orthopedic technicians. We study how to manage appointment scheduling in such tandem service systems.

# SC02

E52 Samberg - Dining Room 5

### Healthcare Supply Chain

Emerging Topic: Healthcare Supply Chains

Chair: Emily L. Tucker, University of Michigan, Ann Arbor, MI, 48109, United States

### 1 - Dynamic Pharmaceutical Supply Chain Design under Disruption and Effects on Drug Shortages

Emily L. Tucker, University of Michigan, Ann Arbor, MI, 48109, United States, Mark Stephen Daskin, Burgunda V. Sweet, Wallace J. Hopp

Drug shortages continue to be a public health crisis in the United States. There are hundreds of active shortages each year, and they persist for an average of 14 months. Shortages are often caused by supply chain disruptions. In this work, we present a multi-stage stochastic program that optimizes a pharmaceutical company's supply chain design over time under uncertainty in disruption and recovery. Components include suppliers of active pharmaceutical ingredients (APIs), manufacturing plants, and lines. We study the effects of policies proposed to reduce shortages on supply chains of example oncology drugs. We discuss the impacts on expected profit and shortages.

#### 2 - Optimal Group Testing: Structural Properties and Robust Solutions, with Application to Public Health Screening

Hrayer Aprahamian, Texas A&M, College Station, TX, 77840, United States, Douglas R. Bish, Ebru Korular Bish

We provide a novel robust formulation of the Dorfman group size problem considering the realistic setting in which prevalence rates are uncertain. We establish key structural properties of the optimal solution, and provide an exact algorithm. Our analysis also leads to exact closed-form expressions for the optimal Dorfman group size under a deterministic prevalence rate, which is the problem studied in the extant literature. Our structural results unify existing, and mostly empirical, results on the Dorfman group size problem, and, more importantly, enable us to efficiently solve the robust version of this problem to optimality. We demonstrate the value of robust testing schemes with a case study on disease screening with time-varying characteristics using realistic data. Our case study indicates that robust testing schemes can significantly outperform their deterministic counterparts, by not only substantially reducing the maximum regret value, but, in the majority of the cases, reducing testing costs as well.

### 3 - Optimizing A UAV-based Emergency Medical Service Network for Trauma Injury Patients

Ruijiu Mao, Purdue University, West Lafayette, IN, United States, Nan Kong, Bin Du, Dengfeng Sun

Emergency medical service must be time sensitive. However, in many cases, satisfactory service cannot be ensured due to inconvenient logistics. For its easily deployable and widely accessible nature, unmanned aerial vehicles (UAVs) have the potential to improve the service, especially in areas that are traditionally under-served. In this paper, we develop a service network optimization problem for locating UAV bases, staffing a UAV fleet at each constructed base, and zoning demand nodes. We formulate a location-allocation optimization model with numerically simulated waiting times for the service zones as the objective. We adapt a genetic algorithm to solve the optimization model. We test our network optimization approach on instances of traumatic injury cases. By comparing our approach to a two-phase method in Boutilier et al. [1], we suggest an up to 60% reduction in mean waiting time.

# SC03

E52 Samberg - Dining Room 4

# Vaccines - Operational Challenges and Beyond

Emerging Topic: Public Health and Health Policy

Chair: Margaret Bjarnadottir, PhD, University of Maryland, College Park, MD, 20742, United States

1 - Enhancing Affordability and Profitability in the Global Vaccine Market via Market Coordination

Ruben A. Proano, Associate Professor, Rochester Institute of Technology, Gleason College of Engineering, Rochester, NY, 14623, United States

This talk discusses the effect of market segmentation for vaccine pricing purposes on a hypothetically coordinated vaccine market to enhance affordability and profitability. This study assumes that vaccine procurement for countries grouped in market segments is coordinated by decision makers who aim to ensure a sustainable vaccine market. We show the effect of having multiple uncooperative decision makers, as well as the effect of having a different portfolio of market segments per decision maker. We show that affordability for the lowest income countries is enhanced by increasing the number of market segments coordinated by each decision maker.

### 2 - Cost-Effectiveness of a Potential Norovirus Vaccine

David Hutton, PhD, University of Michigan, Ann Arbor, MI, United States

Norovirus vaccines are under development. If and when they become available, payers and providers will be looking for guidance about which populations (if any) should receive the vaccine. We have developed a mathematical model of norovirus transmission and disease to evaluate the cost-effectiveness of vaccination in various populations. We examine the best populations to receive the vaccine and evaluate under what conditions (vaccine price and efficacy) at which the vaccine would be considered cost-effective.

### 3 - Vaccine Distribution Supply Chains in Low- and

### Middle-Income Countries

Kim De Boeck, KU Leuven, Leuven, Belgium, Catherine Jenny Decouttere, Nico Vandaele

Access to immunization varies greatly across the world. In order to increase vaccine coverage, the required vaccines need to be able to reach the targeted population. However, in developing countries, this often turns out to be a challenging task. This talk elaborates on the characteristics and challenges inherent to such distribution supply chains. Next, a comparison is made between issues reported in practice and those investigated in operations research and operations management literature.

# **SC04**

E52 Samberg - Dining Room 3

### Sample-Efficient Data-Driven Decision Making

Emerging Topic: Personalized Medicine and Disease Modeling

Chair: Stefan Wager, Stanford GSB, Stanford, CA, 94305, United States

### 1 - Robust Policies for Proactive ICU Transfers

Julien Grand-Clement, Columbia University, New York, NY, United States, Carri Chan, Vineet Goyal

Patients admitted to the ICU after a sudden health deterioration have a higher mortality rate and in-hospital length-of-stay than those who were admitted proactively. The medical community has been exploring proactive ICU admission decisions based on patient risk scores. We study the impact of proactive transfer policies on the clinical outcomes. We develop an approximation of the hospital system and show that under some mild assumptions, an optimal strategy is threshold: it sends every patient whose health condition is more severe than a certain risk score. We study the robustness of our model to parameters mispecification and show that an optimal robust transfer strategy can be found among threshold policies too. Using data from real hospitals, we estimate the parameter uncertainty in our model and present numerical experiments where the performances of the hospital deteriorates even for small deviations in the estimated parameters. As such, we emphasize the impact of data uncertainty when developing robust versus naive strategies.

### 2 - Learning When-to-Treat Policies

Xinkun Nie, Stanford University, Stanford, CA, United States, Emma Brunskill, Stefan Wager

Many applied decision making problems have a dynamic component: The policy maker needs not only to choose whom to treat, but also when to start which treatment. For example, a medical doctor may see a patient many times and, at each visit, need to choose between prescribing either an invasive or a non-invasive procedure and postponing the decision to the next visit. In this paper, we develop an "advantage double robust" estimator for learning such dynamic treatment rules using observational data. We prove welfare regret bounds that generalize results for doubly robust learning in the single-step setting, and show promising empirical performance in several different contexts. Our approach is practical for policy optimization, and does not need any structural (e.g., Markovian) assumptions.

#### **3 - The Risk of Being Fit: Trade-Offs in Empirical Risk Minimization** Jann Spiess, Post-Doctoral Researcher, Microsoft Research, Cambridge, MA, United States, Guillaume Pouliot

We study the statistical efficiency of the selection of predictive models from finite samples. Specifically, we consider assumptions on loss functions and sample distributions under which in-sample empirical risk minimization is an inadmissible selection criterion for out-of-sample risk minimization, and propose alternatives based on Bayesian decision rules. We apply the results to treatment assignment from experimental data and prediction problems in inventory management.

### 4 - Parametrized Exploration in Reinforcement Learning

Eric B. Laber, North Carolina State University, Raleigh, NC, 27518, United States

We introduce Parameterized Exploration (PE), a simple family of methods for model-based tuning of the exploration schedule in sequential decision problems. Unlike common heuristics for exploration, our method accounts for the time horizon of the decision problem as well as the agent's current state of knowledge of the dynamics of the decision problem. We show our method as applied to several common exploration techniques has superior performance relative to untuned counterparts in Bernoulli and Gaussian multi-armed bandits, contextual bandits, and a Markov decision process based on a mobile health (mHealth) study. We also examine the effects of the accuracy of the estimated dynamics model on the performance of PE.

## **SC05**

E52 Samberg - Dining Room 2

### **Data-driven Decision-making for Physicians**

Emerging Topic: Personalized Medicine and Disease Modeling

Chair: Vishal Ahuja, Southern Methodist University, Southern Methodist University, Dallas, TX, 75275, United States

### 1 - Quantifying Joint Prevalence of Chronic Conditions and Patterns of Specialty Care

Hari Balasubramanian, University of Massachusetts, Amherst, MA, 01003, United States

More than half of the US population has at least one chronic condition and over 30% have two or more chronic conditions. Patients with 2 more chronic conditions account for 70% of the US healthcare expenditures and experience highly fragmented care. In this talk, we discuss methodologies for identifying the combinations of chronic conditions that are most prevalent in a population data set and quantifying patterns of specialty care associated with the conditions.

### 2 - Predicting Colorectal Cancer Mortality: Models to Facilitate Patient-Physician Conversations

David Anderson, Villanova School of Business, Villanova, PA, 07030, United States

Having accurate, unbiased prognosis information can help patients and providers make better decisions about what course of treatment to take. Using a comprehensive dataset of all colorectal cancer patients in California, we generate predictive models that estimate short-term and medium-term survival probabilities for patients based on their clinical and demographic information. Our study addresses some of the contradictions in the literature about survival rates and significantly improves predictive power over the performance of any model in previously published papers.

#### 3 - Accounting for the Patient in Data-Driven Physician Decision Support Systems

Kellas Ross Cameron, University of South Florida, Tampa, FL, 33624, United States, Deepti Singh, Jayakanth Srinivasan

Due to the ever-increasing complexity of the situations faced by physicians, there is a need for decision support systems. There have been two assumptions for these models: that patients with similar medical diagnoses should be treated identically, and physician decisions are made rationally according to standard medical practices. However, we know that acknowledgment of patient uniqueness is required for an optimal outcome, and with each interaction, a physician has the opportunity to update their medical decisions based on different patient characteristics. We posit that socio-economic conditions also play a role in a physician's decision-making process. Therefore, to make appropriate medical treatment suggestions, a DSS needs to adapt for both patient demographics and medical diagnoses. The goal of this work is to understand if physicians do adapt their decision-making strategies for different patient types, as this would allow us to create a more accurate data-driven model by accounting for prior patient encounters.

### **SC06**

E52 Samberg - Salon West

### **Decision Analytic Models in Public Health Policy**

Emerging Topic: Public Health and Health Policy

Chair: Chaitra Gopalappa, University of Massachusetts, Amherst, MA, 01003, United States

Co-Chair: Seyedeh Nazanin Khatami, University of Massachusetts, Amherst, MA, 01002, United States

#### Models for Equitable Allocation of Organs in Transplantation Sanjay Mehrotra, Northwestern University, Dept of I E / M S C246 Tech Inst, Evanston, IL, 60208-3119, United States

We will present alternative fractional optimization models for equitable organ allocation in transplantation. Computational results from liver and kidney allocation will indicate the robustness of these models, and the possibility of developing allocation strategies that are consistent with the current discussions at UNOS.

#### 2 - Active Surveillance

Weiyu Li, IOE department, University of Michigan, Ann Arbor, MI, 48105, United States, Brian T. Denton

Active surveillance (AS) is a strategy that involves regular clinical examinations, biomarker tests, and biopsies to monitor patients diagnosed with low-risk prostate cancer. The ideal strategy must strike a balance between the burden of testing and the benefit of early detection of progression to high-risk prostate cancer. We propose a hidden Markov model (HMM) to estimate the progression rate of cancer, and the sensitivity and specificity of the biomarker tests using longitudinal data from a large surveillance study. We use the HMM as the basis for a partially observable Markov decision process (POMDP) and present results for optimal strategies.

### 3 - Factor Selection for Influenza Epidemic Mitigation Using Bi-objective Optimization

Hanisha Tatapudi, University of South Florida, Tampa, FL, United States, Aigerim Bogyrbayeva, Hadi Charkhgard, Walter Silva Sotillo

Implementation of non-pharmaceutical interventions is a cost-effective approach to curb the dissemination of virus during an influenza pandemic. The work presented in study [3] utilized a statistical analysis of variance and regression model to compute an optimal NPI strategy to mitigate influenza spread. In our study, we propose a bi-objective mixed integer linear program model to identify the significant factors and propose an optimal NPI strategy to reduce disease burden. Our procedure employs an existing agent based simulation model presented in [3] to generate the disease outcomes, which are provided as input to the BOMILP model. The two objectives of the BOMILP are to minimize the number of predictors and the bias, simultaneously. Under the proposed method, our computational results yield an optimal policy that reduces the influenza attack rate of an outbreak from 33% to 0.6% with 85% accuracy. Our results significantly outperform existing results presented in [3] that estimate the IAR to be 1.83% under their proposed policy.

#### 4 - How to Reach Zero HIV Incidence in the Us? A Reinforcement Learning Algorithm to Inform Optimal Decision Paths Seyedeh Nazanin Khatami, University of Massachusetts, Amherst, MA, 01002, United States

In this study, we address the question of how to reduce new HIV infections to zero in the US by formulating the problem as a Markov decision process with decision-making steps at 5-year intervals over a finite time period and solved using reinforcement learning algorithm. The objective of the model is to identify an intervention strategy that maximizes the expected total reward, i.e., the difference in the total quality-adjusted life-years saved multiplied with the gross domestic product per capita in the US and the associated costs of the strategy for heterosexuals, men who have sex with men, and persons who inject drugs. For informing the next 5-year strategic plan, commonly used models in the HIV literature evaluate a few pre-selected strategies for comparative analysis. The methodology presented here identifies an optimal 5-year strategy by considering future dynamic changes in not only the epidemic but also the decisions to be made to optimally reach zero new infections.

# SC07

E52 Samberg - Ballroom T Practice Oriented Session

# Putting Theory to Work: Insights from Recent Implementation Efforts (Panel)

Practice Oriented Session

Chair: Nan Liu, Boston College, Chestnut Hill, MA, 02467, United States

Co-Chair: Diwakar Gupta, University of Texas, Austin, TX, 78712, United States

### Moderator

Diwakar Gupta, University of Texas, Austin, TX, 78712, United States

This session consists of four case studies that feature advanced modeling and analysis, and active participation of practitioners. On the one hand, practitioner involvement complicates model formulation. On the other hand, it leads to novel model formulations and opportunities to contribute to the operations management literature. Increasingly, it is also important to leverage data and present the results of the analysis in a manner that enhances practitioner decision-making. All four case studies also describe how the authors overcame such challenges. The session will start with these four case study presentations, followed by a moderated panel discussion led by co-chairs Diwakar Gupta and Nan Liu with the speakers on the opportunities and challenges of implementing operations models in healthcare practice.

#### 1 - Implementing Provider Scheduling Decision Support Tools in Clinical Practice

Amy Cohn, University of Michigan, 1205 Beal Avenue, Department of IOE, Ann Arbor, MI, 48109, United States

Mathematical programming techniques can be very useful in solving complex combinatorial optimization problems such as those found in provider scheduling. In order to solve practical, real-world problems, however, it is often not sufficient to formulate and solve an integer program. It can be quite challenging to develop a true understanding of the nuanced constraints that must be met to ensure a feasible solution; the clinicians providing this contextual knowledge often have a very different vocabulary and way of communicating ideas. In addition, such problems often do not have one single, well-defined "cost" function. Rather, there are multiple objective criteria that must be traded off, typically in a very qualitative and subjective way. We present our experience developing and implementing decision support tools for several provider scheduling problems at Michigan Medicine and other institutions.

### 2 - Improving the Perceived Fairness of ED Physician

**Time Allocation** 

Craig Froehle, University of Cincinnati, Cincinnati, OH, 45221-0130, United States, David Rea, Suzanne Masterson, Brian Stettler, Greg Fermann, Art Pancioli

Management models can affect employees' well-being in complex ways. Satisfaction with decision-making is influenced by how fair employees perceive the system to be. We conceptualize fairness in terms of two competing aspects motivated by organizational justice theory: equity (greater individual contributions yield beneficial outcomes) and equality (identical outcomes for all). We incorporate this tradeoff in a bi-objective optimization model that assigns clinical time at multiple ED locations to physicians. The model significantly improves the match between allocations and physician preferences while also rewarding departmental contributions, and most physicians are happier as a result. Pre-/post-implementation survey data revealed statistically significant improvements in satisfaction with the decision-making process, including transparency and perceived fairness.

### 3 - Implementing Readmission Solutions in Hospitals

Jonathan Helm, Indiana University, Kelley School of Business, Bloomington, IN, 47401, United States, Pengyi Shi, Julian Pan, Jivan Deglise-Hawkinson

This talk will focus on the implementation of academic research in a partner hospital. The talk will discuss the technology and why it appealed to the partner hospital, gaining initial buy-in from hospital management, working with the hospital to customize and improve the research to fit their practical needs, development of a product, working with different members of the organization to implement the research in practice, and initial results of the implementation. I will also describe challenges and pitfalls faced along the way and how to leverage an initial implementation to attract new hospitals.

#### 4 - Operating Rooms Cleaning Staff Capacity Planning using Queuing Models

Vikram Tiwari, Vanderbilt University Medical Center, Nashville, TN, 37221, United States

Stationary independent period-by-period G/G/s queuing model helped determine staffing levels for operating rooms cleaning crews to ensure that no OR waits longer than 10 minutes before a staff shows up. The model helped restructure support staff roles and create a hierarchy between lower and higher valued roles, leading to increased efficiencies and staff satisfaction.

# SC08

E52 Samberg - Ballroom I

### Analytical Tools to Support Personalized Care; Designing for Implementation

Emerging Topic: Personalized Medicine and Disease Modeling

Chair: David Scheinker, Stanford - Lucile Packard Children's Hospital, Stanford, Stanford, CA, 94305, United States

#### Lessons from Failed And Successful Uses of the Electronic Health Record Data to Personalize and Optimize Surgical Care Kristin Petersen, MBA, Lucile Packard Children's Hospital Stanford, Palo Alto, CA, United States

We describe three projects to personalize and optimize surgical patient care using machine learning and optimization. We highlight the practical considerations necessary for the design and implementation of such models and illustrate with two projects that did not translate into measurable value and one that did. For the successful project, we present the results of a case-control study evaluating the use of a fully data-driven tool for optimizing surgical preference cards in order to reduce direct surgical costs. Surgical nurses accepted, rejected, or modified changes to preference cards suggested by an optimization tool built using data from the Electronic Health Record. In contrast to previous studies, this work did not require forming cost-reduction committees, incentivizing surgeon participation, or significant individual surgeon effort.

### 2 - Target Based Care: Reducing Length of Stay Using Electronic Health Record Derived Benchmarks

Andrew Shin, MD, Stanford University, Palo Alto, CA, United States

Changing behaviors across large systems to adopt standardized practices requires data-driven culture change. Target Based Care is an award-winning program that leverages achievable benchmarks derived from the Electronic Health Record to reduce the variability and improve the predictability of patient hospital length of stay. The original phase was based on manual review of patient charts by healthcare providers. We describe how engineers partnered with providers to develop machine learning and congestion-based models to support the expansion of the program. Automation of patient chorts used to establish care milestones helped sustain and expand the program to multiple healthcare sectors.

### 3 - Operationalizing Risk Prediction Algorithms in Healthcare Settings

Alton Russell, Stanford School of Engineering, CA, United States

Numerous machine learning models generate personalized risk estimates for adverse health outcomes, but relatively few have been implemented. For risk prediction decision-support tools to be operationalized, the trade-offs and limitations of the decision context must be considered during the development of the model. I will present methods to develop risk prediction algorithms that are suitable for guiding clinical resource allocation decisions, where a decision maker must prescribe interventions to patients in resource constrained settings. I will illustrate with two case studies. In the first, we work with the directors of blood center to determine how frequently a repeat blood donor should be allowed to give blood. The second focuses on implementing in EPIC an algorithm to identify pediatric patients at high-risk of developing kidney disease post-hospitalization.

#### 4 - The Design and Implementation of Quantitative Tools for Personalized Type 1 Diabetes Care David Scheinker, Stanford Unviersity, Huang Engineering Center, Stanford, CA, 94305, United States

Despite the high incidence and significant morbidity and mortality associated with type 1 diabetes (T1D), quantitative tools to personalize care are not available and deteriorating glucose control is often detected only retrospectively in quarterly visits. The recent increase in the adoption of continuous glucose monitors (CGMs), which record blood glucose levels once every 5 minutes, offers an opportunity to personalize care, identify or predict deteriorating glucose control, and standardize care delivery. We present preliminary results on the design and implementation tools designed to do so. We emphasize how our approach, based on signal processing and machine learning, was designed to satisfy the constraints of the hospital IT infrastructure, the bandwidth of the clinical care team, and empirical evidence on the limitations of patient and family participation.

# **SC09**

E52 Samberg - Ballroom M

### Engaging with Health Care Technology Companies and Foundations: Opportunities for Collaboration (Panel)

Practice Oriented Session

**Moderator:** Hummy Song, Philadelphia, PA, 19104, United States

How might researchers most effectively engage in research collaborations with health care technology companies and foundations? What types of innovations are taking place in the industry? How are data analytics and predictive modeling used commercially? Join us for a discussion with panelists from Optum Analytics, athenahealth Inc., and the Robert Wood Johnson Foundation to answer these questions and learn about potential collaboration opportunities with industry.

### Panelists

Bethany Sheridan, PhD, Athenahealth, Watertown, MA, United States

Ashley-Kay Fryer, PhD, Optum Analytics, Boston, MA, United States

Katherine Hempstead, Robert Wood Johnson Foundation, Princeton, NJ, United States

# SC10

E52 Samberg - Salon East

### **Emergency Department Operations**

Contributed Session

Chair: Eman Almehdawe, University of Regina, Regina, SK, Canada.

1 - Reducing Overcrowding in Emergency Department by Facilitating Better Discharge Planning Md Asaduzzaman, Senior Lecturer in Stat and Operational Research, Staffordshire University, Stoke on Trent, United Kingdom, Andrew Davy, Keira Watts, Uchitha Jayawickrama, Helen Wright-White, Guy Smallman

The NHS England sets out the target that 95% of people attending Accident & Emergency Departments are seen within four hours. The delay in discharge is often, not due to a lack of beds, but an inability of the system to flex to the peaks in demand and to be proactive in organising home care for patients in advance of discharge. Using a modified Glasgow Admission Prediction Score with a five-point triage scale at UHNM, the paper attempts to predict admissions and length of stay to allow better planning of patients' admission and discharges and accommodate peaks in demand for care and community beds, thereby, reducing the bottlenecks of patient flow through the hospital and as a result reduce overcrowding in A&E.

### 2 - Impact of Congestion at the ED on Patient Length of Stay and Quality of Care: The Case of Regina General Hospital

Eman Almehdawe, University of Regina, Regina, SK, Canada

Using data from a local hospital emergency department in Saskatchewan, we analyze the relationship between congestion, patient Length of Stay (LOS) and some quality of care measures, namely: the chance of a return visit to the ED, the likelihood of mortality, and the chance of leaving the ED without being seen. We use regression analysis to construct relationships between different variables of interest.

# ■ SC11

E52 Samberg - Room 164

# Health and Healthcare Systems: Collaboration and Connection

Emerging Topic: Healthcare Economics

Chair: Nicholas Soulakis, Northwestern University Feinberg School of Medicine, Chicago, IL

 Managing Complexity in Collaborative Healthcare Processes Nicholas Soulakis, Northwestern University, Chicago, IL, United States

We present a quantitative measure of provider relationships that independently predicts stroke patient outcomes. After prospectively ascertaining severity, complications, and outcomes, we retrospectively retrieved team member activities as documented in the electronic health record, then created a bipartite provider-

patient network to identify healthcare providers who jointly participated in patient encounters. An objective, risk-adjusted composite performance measure was then calculated. Our findings reveal significant differences in patient complications and outcomes between provider groups.

### 2 - Transparency of Data Use: Implications for Consent and Notification

Jodyn Platt, PhD, University of Michigan, M. Grace Trinidad

Rapid adoption of health information technologies and the expansion of health information exchanges (HIE) holds promise for improved coordination of care and teamwork. Public and patient perspectives on how their personal health information is shared suggest reservations about the secondary use of healthcare information use. In this presentation we consider the public's willingness to share different types of health information with providers, researchers, and commercial entities (survey, n=420 US adults), and consider the implications for improved processes for consent and notification.

#### 3 - Evaluating the Impact of Clinical Teams and Care Activities on Patient Health Outcomes: An Edge-Weighted Multilayer Network Approach

Ariel E Chandler, Northwestern University, Chicago, IL, United States

As American healthcare shifts toward value-based incentives, there is a pressing need for scalable methods that evaluate the effect of inpatient hospital care on health outcomes. A multilayer network model was developed to evaluate the impact of teams and care on outcomes, by quantifying the interconnectivity of specific care providers, activities, and patients using a risk-adjusted outcome weighted edge schema. This model was applied to activity logs and outcomes data of intracerebral hemorrhage patients. Quantified connections, generated using the network framework, identified team members associated with variant outcomes and care activities that were highly predictive of outcomes.

### 4 - Assessing Team Dynamics in Antimicrobial Stewardship Programs for Vulnerable Populations

Ashley Hughes, University of Illinois at Chicago, Chicago, IL, United States, Katie J. Suda, Margaret Fitzpatrick, Cara Ray, Amanda Vivo, Marissa Gutkowski, Ayokunle Olagoke, Swetha Ramanthan, Charlesnika Evans

Patient with spinal cord injury (SCI) have a 2-3 times higher rate of infection than other inpatients. For these reasons, SCI patients have unique needs, including but not limited to antimicrobial stewardship (AS). AS is mandated within the Veterans Health Administration (VHA); however, little guidance is provided for specialized populations. For this reason, we sought to explore the unique needs for SCI patients by examining multi-level team needs to guide future implementation. To do this, we conducted interviews with AS leaders and SCI providers from 23 SCI care centers in the VHA. Qualitative techniques target multi-level needs for fostering improved team process in AS, particular to the needs of SCI. This approach produces contextually valid recommendations for implementing and improving allocation of business resources for AS in a specialized population.

# SC12

E62 Sloan - Room 221

## Pharmaceuticals: Supply Chains, Inventory, Prescriptions

Contributed Session

Chair: Ajit Appari, Worcester Polytechnic Institute, Worcester, MA, 01609, United States

 Determinants of Process Innovation in Pharmaceutical Industry Ivan Lugovoi, HEC Paris, Jouy-en-Josas, France, Dimitrios Andritsos, Claire Senot

Utilizing a unique dataset of the process patent expert evaluations merged with the sales of generic pharmaceutical products over a 10 year period, we explore in depth the link between technological diversification in related/unrelated products and process innovation including its dimensions: novelty and scope. We find that diversification in related products negatively affects process innovation, novelty, and scope. Likewise, diversification in unrelated products has a negative association with process innovation and scope but positive effect on novelty. However, experience with focal product positively influence process innovation and scope but has a negative association with novelty.

#### 2 - Polypharmacy Risk for Adults Patients with Different Combinations of Multiple Chronic Condition Patterns Aiit Appari, Wargester Polytechnic Institute, Wargester

Ajit Appari, Worcester Polytechnic Institute, Worcester, MA, United States, Maria Ukhanova

Our knowledge of polypharmacy regimen (using multiple medications) among working-age adults with multiple chronic conditions (MCC) is limited. Using exploratory factor analysis on 6years (2008-13) claims data of 452,834 working-age adults in Texas, we determined four MCC patterns for each gender. By applying established algorithm, we estimated polypharmacy levels for 172,226 adults during 2012-13 from outpatient claims. Finally, we estimated polypharmacy risk by using mixed effect logistic model adjusting for socioeconomic and healthcare factors. Polypharmacy risk for men and women grows by 3 to 23-fold as MCC pattern combinations increases compared to people with one chronic condition.

# SC13

E62 Sloan - Room 223

### **Healthcare Payment Models and Incentives**

Sponsored: MSOM/Healthcare

Chair: Elodie Adida, University of California, Riverside, CA, 92521, United States

### 1 - Reference Pricing for Healthcare Services

Shima Nassiri, University of Michigan, Ross School of Business, Ann Arbor, MI, 48109, United States, Elodie Adida, Hamed Mamani

The traditional payment system between an insurer and providers does not incentivize providers to limit their prices nor patients to choose less expensive providers, hence contributing to high insurer expenditures. Reference pricing has been proposed as a way to better align incentives and control the rising costs of healthcare. In this payment system, the insurer determines the maximum amount that can be reimbursed for a procedure (reference price). If a patient selects a provider charging more than the reference price, the patient is responsible for the portion above it. We propose a model to analyze the reference pricing payment scheme. Our model incorporates an insurer who chooses the reference price, multiple competing price-setting providers, and patients who select a provider based on a multinomial logit choice model. Our goal is to understand how reference pricing compares with payment systems where patients pay a fixed or a variable amount.

### 2 - Modeling Patients' Illness Perception and Equilibrium Analysis of Patients' Doctor Shopping Behavior

Pengfei Guo, Hong Kong Polytechnic University, Department of Logistics and Maritime Studies, Hung Hom, Hong Kong, Yulan Wang, Fengfeng Huang

In this paper, we investigate the patient' doctor shopping behavior when they seek diagnostic service. When a patient' belief about her health status is inconsistent with a doctor's diagnosis, cognitive dissonance may arise. The patient then may seek more doctoral opinions to mitigate such dissonance, a behavior called doctor shopping. We derive the patient' optimal doctor shopping times by adopting the simple `one-stage look-ahead' rule and Bayesian updating.

### 3 - Can Big Data Cure Risk Selection in Healthcare Capitation Programs?

Zhaowei She, Georgia Institute of Technology, Atlanta, GA, 30067, United States, Turgay Ayer, Daniel Montanera

We analyze the risk selection problem in Medicare Advantage (MA), the largest capitation payment program in the U.S. healthcare market. In practice and current literature, the observed risk selection in MA market is primarily attributed to data limitations and low explanatory power (e.g. low R^2) of the current risk adjustment design. However, our study shows that MA cannot eliminate risk selection even if its risk adjustment design becomes informationally perfect (e.g. R^2 = 1) in the age of big data. To address risk selection in capitation programs, practitioners and policy makers should not solely rely on big data and advanced ML algorithms, and and need to consider mechanisms other than pure statistical risk adjustment designs.

### 4 - Outcome-based Pricing for Pharmaceuticals via Rebates Elodie Adida, University of California, School of Business

Administration, Riverside, CA, 92521, United States

We study the effect of outcome-based pricing for new pharmaceuticals via rebates. Under this payment scheme, the pharmaceutical firm is paid only when the drug treatment achieves a pre-specified goal. We consider heterogenous, price-sensitive, risk-averse patients, a payer, and a pharmaceutical firm producing a drug with uncertain effectiveness. We find that outcome-based pricing is unlikely to solve the issues of high drug prices and high payer expenditures. However, supplementing outcome-based pricing with a transfer payment between firm and payer can make patients, payer and firm better off than under uniform pricing.

## ■ SC14

E62 Sloan - Room 250

### **Empirical Research in Healthcare Operations**

Sponsored: Healthcare Applications

Chair: Maria Ibanez, Kellogg School of Management at Northwestern University, Evanston, IL, United States

### 1 - Physician Peer Effects on Speed and Quality: Evidence from the Emergency Department

Raha Imanirad, Harvard Business School, Cambridge, MA, 02472, United States, Soroush Saghafian, Stephen Traub

In this study, we estimate peer effects in the context of an Emergency Department (ED) setting by addressing the question of whether peer physicians' characteristics including relative performance, experience, type of medical degree, and gender affect a physician's performance. Our findings provide strong evidence on the existence of peer effects in this setting. Our results have important practical implications for improving the operations of EDs. These include superior physician scheduling where one needs to decide which providers should be scheduled during the same shift as well as in physician training where one needs to provide guidance to physicians with ways to improve their performance.

### 2 - The Impact of Facility Layout on Service Worker Behavior: An Empirical Study of Nurses in the Emergency Department Lesley Meng, The Wharton School, University of Pennsylvania, Philadelphia, PA, 19104, United States, Bob Batt, Christian Terwiesch

We study how the facility layout of ED patient rooms impacts nurse workflow decisions. Specifically, linking our infrared nurse location tracking data to the electronic medical record, we are able to investigate the impact of facility layout variables such as patient room distance from the nurses' station on ED care provision.

### 3 - Improving MRI Hospital Waiting Times using Geographical Partial Pooling: An Empirical Analysis of 72 Hospitals in Canada Yangzi Jiang, PhD Student, Kellogg School of Management, Northwestern University, Evanston, IL, United States, Jan A. Van Mieghem, Hossein Abouee Mehrizi

Significant mismatches between demand and capacity in MRI hospitals in Ontario, Canada leads to prolonged waiting time which inspired our research of when and to what extend to implement pooling. Using patient-level data gathered from 72 MRI hospitals over 5 years, we conducted an empirical analysis using regional pooling to achieve over 37% wait-time reduction. This research contributed to our understanding of how resource pooling can be applied to effectively reduce the waiting time in MRI hospitals with high scanner utilization.

### 4 - Is Good Research Worth It? The Effect of Research Methods on Research Conclusions and Diffusion

Maryaline Catillon, Harvard Business School, Wyss Doctoral Office, Boston, MA, 02163, United States

Randomized clinical trials (RCTs) are the gold standard treatment evaluation, as their design potentially reduces some biases of non-randomized studies. However, when they fail to reduce risks of bias appropriately, RCTs can yield mistaken conclusions, inflated treatment effects or greater variability. Due to data and methodological challenges, empirical evidence on the relationship between research methods and research outcomes remains limited. This study utilizes a new large database of clinical trials to map the full text, methodological assessments, and study conclusions, to detailed bibliometric and funding information. This paper estimates the effect of higher quality research methods on research conclusions and diffusion of medical knowledge.

## ■ SC15

E62 Sloan - Room 262

### **Technology-Enabled Operations in Healthcare**

Emerging Topic: Healthcare Information Technology and Management

Chair: Mehmet U.S. Ayvaci, University of Texas at Dallas

1 - Does Telemedicine Reduce Emergency Department Congestion? Evidence from New York State

Shujing Sun, University of Rochester, Rochester, NY, United States, Susan F. Lu, Huaxia Rui

Overcrowding in emergency departments (EDs) is a common yet nagging problem. It not only is costly for hospitals but also compromises care quality and patient experience. Using a large dataset covering all ED patients of New York State, we investigate the role of telemedicine in enhancing ED e ciency. We show that on average, ED telemedicine adoption significantly reduces patients' length of stay, and the effect is larger when an ED becomes more congested. More importantly, we show that such an e ect is not a byproduct of other widely adopted health IT applications, and the e ciency improvement does not come at the expense of care quality or patient cost. We also replicate the analysis using a hospital-year panel including all the EDs throughout the U.S. Our finding parallels the individual level analysis: ED telemedicine adoption significantly reduces average patients' waiting time, and the effect is larger for more congested Eds.

### 2 - The Role of Decision Support Systems in Attenuating Racial Biases in Healthcare Delivery

Hilal Atasoy, Temple University, Fox School of Business, Phialdelphia, PA, 19122, United States, Kartik Ganju, Brad N. Greenwood, Jeff McCullough

In this study, we analyze the effect of electronic health record (EHR) systems on moderating a known systematic bias that results in African-American patients receiving more limb amputations vs. revascularization, relative to white patients. We use machine-learning techniques to develop a method to predict the likelihood of amputation based on medical codes at the patient-visit level. Controlling for this prediction, EHR adoption lowers the rates of amputations for black patients but does not significantly alter the rates of amputations for white patients. Further, the decrease in the rates of amputations is highest among black patients with more severe conditions.

#### 3 - Spoiled for Choice? Personalized Recommendation for Healthcare Decisions: A Multi-armed Bandit Approach with a Dynamic Discrete-choice Scheme

. Tongxin Zhou, University of Washington, Seattle, WA, 98105, United States, Yingfei Wang, Lu Yan, Yong Tan

Patient engagement is considered a critical element of patient-centered care. In terms of healthcare, however, patients are laymen who do not have medical knowledge or expertise. To better prepare patients for health management, in this study, we propose a personalized recommendation approach to help patients to reduce uncertainty in their decision making. Taking into account that making effective healthcare recommendations requires decision makers to consider individuals' unique characteristics and to adjust their recommendations dynamically along with individuals' evolving conditions/behaviors, we employ a multi-armed bandit (MAB) model to develop our recommendation framework. To determine the empirical performance of this MAB-driven recommendation approach, we combine it with a structural model, i.e., a single-agent model, to help us to rationalize individuals' behavior schemes under healthcare recommendations. Our results provide valuable insight into patients' health management and healthcare platform design.

### 4 - Saving Lives with Algorithm-enabled Process Innovation: The Case of Sepsis

Mehmet U.S. Ayvaci, University of Texas at Dallas, Richardson, TX, 75080-3021, United States, Idris Adjerid, Ozalp Ozer

We study whether and how algorithm-enabled process innovation (AEPI) creates value in the context of an AEPI effort focused on early identification and treatment of a deadly clinical condition known as sepsis. Using a rich set of clinical and nonclinical data from a hospital system, we examine the relationship between sepsis AEPI and patient mortality. Overall, we demonstrate that sepsis AEPI is effective in reducing mortality and it does so through timely diagnostic (i.e., lactates) and therapeutic (i.e., antibiotics) interventions. As time goes by, however, the timeliness of these interventions partially lapses and so does the sepsis AEPI's reduction impact on mortality.

# SC16

E62 Sloan - Room 276

### **Empirical Healthcare Operations**

Emerging Topic: Healthcare Economics

Chair: Hessam Bavafa, Wisconsin School of Business, Madison, WI, 53706, United States

### Utilizing Data-Driven Decision Support Systems to Reduce Readmission Rates for Patients with Congestive Heart Failure Kellas Ross Cameron, University of South Florida, Tampa, FL, 33624, United States, Jayakanth Srinivasan, Janelle Heineke

Physicians currently attempt to identify CHF patients that are likely to be readmitted within 30 days. However, the readmission rate for these patients remains over 20%. Data-driven decision support systems can provide an additional tool to understand which patients are at high-risk of readmission. We create a statistical model to utilize patient-specific information to not only more accurately identify the patients most likely to be readmitted, but also why - whether for condition-related reasons or not. This allows physicians to suggest patient-specific readmission prevention strategies.

### 2 - Competitive Markets Associated with Hospital Adoption of Advanced Electronic Health Record Functionality

A. Jay Holmgren, Harvard Business School, Robert Huckman

Hospitals in the US have undergone a dramatic shift toward digitizing health care records. Despite widespread adoption, many of the theorized cost and quality benefits of EHRs have not been realized. Concurrent with the adoption of EHRs is the ongoing debate regarding the impact of competition in hospital markets. A key argument in favor of consolidation centers around the ability of hospitals to leverage economies of scale to adopt more advanced IT. Using national hospital data from 2014 - 2017, we find hospitals located in more-competitive markets adopt more advanced EHR functionalities. This difference is driven primarily by patient-facing convenience functionalities.

### 3 - Does What Happens in ED Stay in ED? The Effects of Workload in Emergency Department on Post-ed Care

Mohamad Soltani, University of Wisconsin-Madison, Madison, WI, 53706, United States, Robert Batt, Hessam Bavafa, Brian Patterson

We study the effects of workload in Emergency Department (ED) on post-ED care. First, using an ED patient-level data, we show that attending physicians admit more patients to the hospital when their workload increases. Second, combining the ED data with an integrated health system billing data, we find different effects of physician workload on number of follow-up visits. As workload increases, even after controlling for the changes in the admission decision, the number of follow-up visits increases for the discharged patients but does not change significantly for the admitted patients. We also explore the changes in care provided during the ED visit as the possible drivers of these effects.

### 4 - Can Change of Facility Layout Impact Efficiency of Care?

Shima Nassiri, University of Michigan, Ross School of Business, Ann Arbor, MI, 48109, United States, Maria Shunko, Hamed Mamani

We study an outpatient clinic that transformed some of its traditional exam rooms to flexible suites such that each suite consists of two consultation rooms and a shared examination space with a bed and other examining equipment. Our goal is to investigate the impact of the new design on the efficiency of care. We find a significant 13.5\% decrease in the difference in average Physician Time for treatment and control group of rooms after the implementation of the layout change. Additionally, we observe that the average length of stay (LOS) has an 11.3\% reduction between the treatment and control group of rooms after the intervention. Finally, we show that there is a longer LOS for non-external referral visits in the flexible suites compared to the traditional exam rooms. This means that it is more beneficial to schedule external visits in the flexible suites to reduce the length of stay of patients and its associated cost.

# Saturday, 3:30PM - 4:30PM

## SP01

Sloan - 1st Floor

### Poster Session

Poster Session

### 1 - Stochastic Capacity Planning for Chronic Disease Operations Management

Mohammad Hessam Olya, Wayne State University, Detroit, MI, United States, Kai Yang

Chronic diseases are among the most common and costly health conditions in the United States. In this presentation we propose a stochastic optimization method to reduce the overall cost of the healthcare service. After predicting the required workload of each patient, we use the proposed stochastic optimization model to minimize the overall number of healthcare teams plus the expected overloading cost of healthcare providers in each team. We also assign each patient to teams such that the overall workload of the teams are balanced. The results show that considering uncertainty into the model leads to reducing the cost of provided care.

#### 2 - Light Coded Language (LCL): Infrared Thermography based Interactive Touch Sensing 3D Display for Medical Applications\* Vijay A. Kanade, Senior Patent Associate, Intellectual Property Research Firm, Pune, India

The paper proposes a healthcare system that harnesses IR properties of human body radiation for allowing surgeons to perform surgeries remotely through a 3D interactive display. The system supports in-volume interactions with integrated touch sensing mechanism where IR cameras detect human hand interactions within the floating 3D display volume through 'Infrared Thermography'. Thus, as the surgeon interacts with the 3D display at a remote location, the actions are reproduced by the medical device at the patient's location. The proposed system is explicitly outlined for conducting medical emergencies.

### 3 - Bone Marrow Transplant Predictive Model for Patient and Hospital Staffing Requirements: Virginia Commonwealth University, Massey Cancer Center

R. Jerome Dixon, Senior Operations Research Analyst, Virginia Commonwealth University, Richmond, VA, United States

Virginia Commonwealth University's Massey Cancer Center Bone Marrow Transplant Center requested an analysis of historical patient data to help forecast future staffing requirements. This analysis uses a myriad of machine learning and analysis tools (SAS Enterprise Miner, Tableau, and R/RStudio) with System Dynamics to formulate a staffing forecast model.

#### 4 - A Cloud-based, Ontology-driven Dementia Care Information Service

Ping Yu, Group Lead, Digital Health and Digital Aged Care, University of Wollongong, Wollongong, NSW, Australia

Many governments and non-profit organisations have established web sites to publish information about dementia, guidelines and training materials on dementia care. These make the Web a gigantic source of information and knowledge about dementia and dementia care. Enabling effective retrieval of the best available information is one of the most cost effective strategies to advancing dementia care training and standards. This project aims to design a dementia and dementia care information on web.

#### 5 - Translating Lean: The Evolution from Automotive to Healthcare Kathryn A. Thompson, Senior Performance Improvement Consultant, Barnes Jewish Hospital, St. Louis, MO, United States, Raymond Brand

Hospitals nationwide are faced with rising demands. To meet the demand it is imperative to apply lean methodologies and data-driven decisions to improve patient safety, reduce inefficiencies, and decrease costs. While traditional lean thinking identifies and eliminates waste, the tools tend to speak to engineers. There is a distinct advantage in translating manufacturing tools to a hospital environment so they are useful at every level of the organization. By translating tools you make them easy to read and understand which allows clinical and operational leadership, as well as front line staff, able to engage in the improvement process expediting the rate of improvement.

#### 6 - Optimizing Emergency Department (ED) Physician Staffing Across the Day and the Number of Shifts

Jordan Bai, Ministry of Health, Singapore, Wai Leng Leong, Gary Choa

We present a mixed-integer nonlinear optimization model to determine the number of ED physician man-hours for each 8-hour shift and the number of shifts. Most studies have sought to optimize the manpower required to achieve operational targets. Instead, we constrain the total staffing level and seek to balance the workload across shifts. Workload was defined by both the number of new arrivals and patients requiring ongoing attention. The model determines the number of shifts and the number of physicians per shift by minimizing the standard deviation of the hourly workload per physician. This reduced variability by 58% and the required manpower by up to 1 man-day as compared to manual allocation.

#### 7 - The National Emergency Department Overcrowding Scale and Perceived Staff Workload: Evidence for Construct Validity in a Pediatric Setting

Kenneth W. McKinley, Children's National Health System, Washington, DC, United States, Rimma Perotte, Megan Nye, Maria Y. Kwok, Joan S. Bregstein, Daniel B. Fenster, F. Meridith Sonnett, David O. Kessler

Our objective was to determine if a correlation, as defined by the R2≥0.4 on univariate linear regression, exists between NASA Task Load Index (TLX) as a measure of perceived staff workload and the National Emergency Department Overcrowding Scale (NEDOCS). We summed 401 responses to each of 6 TLX subscales to correlate with most recent NEDOCS. R2=0.096 for our primary outcome. Mean TLX across staff within a given hour had correlation with NEDOCS of R2=0.638. On logistic regression, summed TLX subfields predicted NEDOCS corresponding to "severely overcrowded" or greater with an AUC of 0.731. Summed TLX correlates better with NEDOCS categories than it does with exact NEDOCS scores.

### 8 - A Limited Application of Queue Theory for Physician Rostering in an Emergency Department

Gary Choa, Attending Emergency Physician, Ng Teng Fong General Hospital, Singapore, Poh Choong Soh, Joyce Loke

Formal queue theory can be difficult to apply in the ED. Patient arrival is not randomly distributed but displays known patterns of variations. Patient process time by the physician is also often interrupted rather than continuous. A limited application of queue theory is still useful to understand the demand and supply patterns in the ED for physician rostering. In this study, patient arrival is analysed hourly and by day of the week. Process time is estimated by the average physician productivity. The minimum number of physicians required such that expected time in queue < 60 min for each hour is then calculated. This is then used to guide allocation of actual physician manpower available.

#### 9 - Reducing Unnecessary Phlebotomy and Blood Bank Testing using a Clinical Decision Support System

Valerie Strockbine, Transfusion Safety Officer, The Johns Hopkins Hospital, Baltimore, MD, United States, Cathie Guzzetta, Eric Gehrie, Qiuping (Pearl) Zhou

We aimed to determine the effectiveness of a clinical decision support system on reducing unnecessarily ordered type and screen tests, assess ordering practices by provider type, and estimate the cost saved from CDSS implementation. We reduced unnecessary tests by 16.7% and estimate an annual cost savings of \$142,611. The bulk of tests were ordered by physicians compared to advanced practice nurses and physician assistants. Our study shows that CDSS can reach all provider types, reduce unnecessary phlebotomy tests, and achieve cost savings. Aligning with precision medicine, the upshot of ordering the right test, at the right time, for the right reason can cut cost, reduce waste, and improve quality.

### 10 - A Mobile Health Coaching Program to Improve Fitness for Surgery in Patients with Obesity

Ping Yu, Associate Professor, University of Wollongong, Wollongong, NSW 2516, Australia, Siyu Qian, Natalie Anne Smith, Vida Bliokas, Gregory Peoples, Yasmine Probst, Pascal Perez, Tingru Cui, Mehrdad Amirghasemi, Ting Song

Over half of the patients undergoing elective surgery in an Australian tertiary hospital are obese. Mobile coach program delivered via a smartphone can provide an accessible, low-cost solution to improve these patients' fitness before surgery. Therefore, we form a multi-disciplinary research team including a clinicalanaesthetist, psychologist, dietician, exercise physiologist, e-health and software engineers to developing this mobile coach program. We apply social cognitive theory to guide the design of the persuasive message. Three-round consumer consultation will be conducted to adequately capture the consumer input to theprogram. This poster will present our work in progress.

### 11 - A Multi-criteria Decision Making Model for Dynamic Patient-to-hospital Allocation

Phongchai Jittamai, Suranaree University of Technology, Nakhon Ratchasima, 30000, Thailand, Wijai Boonyanusith

In the EMS system, the dispatcher may face the problem in retransferring the patient elsewhere because delivering the patient to the nearest hospital does not guarantee the right definitive care. This is a result of lacking explicit information and decision tool to select the proper hospital to allocate the patient without retransferring. Thus, we apply an MCDM, using Fuzzy TOPSIS method, to develop the patient-to-hospital allocation model incorporating 14 criteria. A case study is proposed, and the simulation method is conducted for the numerical example based on the dynamic system framework. The results are discussed on improving the patient care and prehospital service level in the EMS system.

### 12 - Using Discrete Event Simulation to Quantify the Impact of Universal Suicide Screening on Pediatric Emergency Department Resources

Kelly N. Rickard, Graduate Student, George Washington University, Washington, DC, United States, Kenneth McKinley, Finza Latif, Theresa Wavra, Julie Berg, Sephora Morrison, James Chamberlain, Shilpa J. Patel

Suicide is a leading cause of death among children. In anticipation of new regulations we used DES to test two interventions: (1) universal screening for all pediatric emergency department (PED) patients  $\geq$  10 years old, and (2) universal screening for outpatients  $\geq$  12 years old, with referral to the PED for any screening positive. These interventions would on average increase behavioral health complaint patient volume by 39% and 171%, respectively. We found negligible changes to length of stay post-implementation. However, our model predicts that screening would more than double the number of days each year patient census will exceed secure capacity, impacting the PED's situational readiness.

### 13 - Operating Rooms Scheduling with Uncertain Durations of Surgeries

Mari Ito, Tokyo University of Science, Chiba, Japan, Kinju Hoshino, Ryuta Takashima, Manabu Hashimoto, Hiroyuki Yamamoto, Hirofumi Fujii

We introduce a stochastic programming model for scheduling operating rooms using the conditional value-at-risk (CVaR). The CVaR expresses the risk-averse attitude of the scheduler to the risk event that the expected end time of a surgery can be considerably delayed. One of the important advantages of the CVaR is that the stochastic programming problem can be treated as a linear programming problem. In this study, we evaluate the effectiveness of the proposed model by applying it to data obtained at National Cancer Center Hospital East, Japan.

#### 14 - Evaluation of Reaction and Learning in the Analytics and Modelling Academy of the United Kingdom's National Health Service

Daniel Gartner, Cardiff University, Cardiff, United Kingdom, Doris Behrens, Tracey England, Izabela Spernaes

Recent research has highlighted the need to invest in the development of healthcare analytics capability. However, the contents of such programmes and how they should be delivered to maximise the learning outcome are unclear. In this poster, we provide insights of the learning within the first two cohorts of modelling fellows successfully trained in the Welsh National Health Service (NHS): The analytics and modelling academy. The participants took part in 2017 and 2018 following a taught healthcare analytics and mathematical modelling programme. We build our learning evaluation framework on Kirkpatrick's training evaluation model.

#### 15 - Patient Flow Optimization at an Orthopedic Outpatient Clinic Using Lean Engineering and Discrete Event Simulation Applications

Amy Lorincz, Concordia University, Montreal, ON, Canada, Michelle Nague, Adriana Sahyoun, Tarek Al Assaad, Stephen Thavarajah, Gregory K. Berry, Linda Bendavid, Ali Akgunduz

Outpatient clinics driven by appointment scheduling systems face challenges in efficiently aligning capacity in response to patient demand for care services. High patient throughput and long wait times lead to patient dissatisfaction increasing the need for strategies to optimize patient flow. Lean tools were used to identify areas of improvements and discrete event simulation modeling was constructed to test alternative scheduling strategies to reduce patient waiting time and physician's idle time. Optimal solutions have the potential to improve the patient experience by reducing wait time by up to 66.5% and the total time spent at the clinic by up to 46%.

### 16 - Improving Community Paramedicine via Data Driven Optimization. Selective, Proactive Management of Emergency Department Patients

Shima Azizi, Worcester Polytechnic Institute, Worcester, MA, United States, Andrew C. Trapp, Renata Konrad, Sharon Johnson, Brenton Faber

Community paramedicine is a recent healthcare innovation that enables proactive visitation of patients at home, often shortly after Emergency Department and hospital discharge. We develop patient visitation priorities based on disease acuity using data from Canton-Potsdam Hospital, and present an optimization model to both select patients and route healthcare providers to visit them in a manner that maximizes overall patient welfare. We conclude by discussing computational findings.

### 17 - Predicting Patients' Severity Scores of Lymphoma Based on Clinical Impression from FDG-PET Scans

Junho Yoon, University of Iowa, Iowa City, IA, United States

Lymph systems are one of the critical nodes and vessels that transfer lymph fluid across our body. It has been constantly reported that lymphoma, a severe disease that develops from lymphocytes and is detrimental to its patients, causes serious damage to human beings and even put their lives at risk. Using the text data from radiologists' comments on 'PET' scan, in this project, word embedding using word2vector was implemented for a visualization and input vector. Also, deep learning methods were utilized to classify and predict the severity of scan image. Our suggested model shows an acceptable level of performance in predicting severity in spite of its room for further improvements.

### 18 - Modeling an Al Voice Assisted Physical Activity Virtual Coach for Older Cancer Survivors

Prashant Duhoon, Data Scientist and Research Associate, University of South Carolina, College of Engineering and Computing, Columbia, SC, United States, Madison DeMello Kindred, Gauri Sathe, Benjamin Schooley, Neset Hikmet, Bernardine M. Pinto

Physical activity (PA) has been recommended by the American Cancer Society and the American College of Sports Medicine to help cancer survivors recover physical functioning, improve quality of life, reduce fatigue and provide other psychosocial benefits 1,2. Yet, becoming physically active is especially challenging for older cancer survivors, given the effects of cancer treatment, late and longterm sequelae, age-related declines and co-morbidities 3,4. Artificial intelligence (AI) devices, such as an Alexa, have grown in popularity within the home. The capabilities of voice assisted AI devices have just recently been applied in research to promote behavior change, including an Alexa AI device to promote PA among overweight/obese cancer survivors9 where a 3-arm randomized trial is underway. AI devices within the home can be used to promote PA since they are interactive, can provide an array of informational tools, and provide support for what, when, where, and how PA can be accomplished. Support provided by an AIconversational device can facilitate participant engagement due to its perceived anonymity and non-judgmental nature.

### 19 - Improving the Efficiency of an Emergency Department Based on Activity-relationship Diagram and Radio Frequency Identification Technology

Shao-Jen Weng, Tunghai University, Taichung City, Taiwan

How to reduce the movement waste of patients and medical manpower is critical to hospitals. In this research, the average time in system of patients and the moment distance of nurses can be evaluated and improved by using activity-relationship diagram, radio frequency identification technology, and system simulation. Therefore, experiment results show that the reduction of nurse's walking is equivalent to a workload saving of around 240 minutes daily. The reduction of nurse walking time in the emergency department (ED) can used to serve nearly 600 beds more a year, which can increase the National Health Insurance reimbursement about 0.2 million.

### 20 - Impact of Respiratory Issues on Inpatient Length of Stay: A Prediction Model Using Random Forest Algorithm Shilpa Balan, Assistant Professor, California State University-Los Angeles, Los Angeles, CA, United States, Vrunda Shah

Since the inpatient stay of individuals suffering from respiratory diseases have increased remarkably, we applied the Random Forest algorithm to predict the length of their stay. With a prediction accuracy of over 90%, the key reasons we found are exceedingly high income, increased age and patient location. Moreover, male patients and those with Medicare coverage influence the length of stay.

21 - Predicting Cerebral Aneurysm Rupture By Machine Learning Using Clinical, Morphological, And Hemodynamic Information Masaaki Suzuki, Tokyo University of Science, Chiba, Japan, Toshiyuki Haruhara, Niken Prasasti Martono, Hiroyuki Takao, Takashi Suzuki, Soichiro Fujimura, Soichiro Fujimura, Toshihiro Ishibashi, Makoto Yamamoto, Yuichi Murayama, Hayato Ohwada

A classifier constructed by machine learning using combined medical and cerebral blood-flow-simulation data was used for prediction of cerebral aneurysm rupture in a total of 338 cerebral aneurysm data samples (35 ruptured, 303 unruptured). Using logistic regression as a classification model, we found the sensitivity of 0.64 and the specificity of 0.85. The results showed the possibility of highly accurate prediction of cerebral aneurysm rupture by machine learning using engineering information obtained from simulations.

#### 22 - Relationship between and Causal Verification of Intentional and Unintentional Medication Non-adherence Hidehiko Sakurai, Hokkaido University of Science, Sapporo, Japan; Chihiro Morito, Keiko Kishimoto

We performed a verification study to analyze intentional and unintentional medication non-adherence. We surveyed about 30,000 patients aged 40 plus in acute and chronic phases on the Internet and used structural equation modeling. Among acute patients, the effect from unintentional on intentional non-adherence was significant, but among chronic patients, the effect was recursive. Although there were differences between affecting factors, there is a need to investigate varying support measures for chronic and acute phase patients.

# Saturday, 4:30PM - 6:00PM

# SD01

E52 Samberg - Dining Room 6

### **Global Health**

Emerging Topic: Healthcare Delivery

Chair: Justin J. Boutilier, University of Wisconsin - Madison, University of Wisconsin, Madison, WI, 53706, United States

#### 1 - A Mechanism Design Approach for Medical Surplus Product Allocation

Can Zhang, Duke University, Durham, NC, 27708, United States, Atalay Atasu, Turgay Ayer, Beril L. Toktay

In this paper, we analyze a resource allocation problem faced by Medical Surplus Recovery Organizations (MSROs) that recover medical surplus to fulfill the needs of under-served healthcare facilities in developing countries. A key challenge in this setting is that recipient needs information is usually not known to the MSRO. To address this challenge, we propose a mechanism design approach to help MSROs elicit recipient needs information and determine which recipient to serve at each shipping opportunity based on recipients' reported preference rankings of different products. Thanks to its simplicity and competitive performance, our proposed approach has led to a change in the practice of an award-winning MSRO, MedShare, for their allocation of biomedical equipment. I will briefly talk about the implementation of our proposed mechanism in this presentation.

### 2 - Optimal Motorcycle Routing in Sample Transportation for Diagnostic Networks

Emma L. Gibson, MIT, Cambridge, MA, 02142, United States, Sarang Deo, Jonas Oddur Jonasson, Mphatso Kachule, Kara Palamountain

Due to limited resources, diagnostic and disease monitoring services in sub-Saharan Africa are delivered through a network of clinics and laboratories. An ongoing challenge is to develop cost-effective sample transportation systems to ensure short turnaround times of results. Using data from Riders for Health in Malawi we develop an algorithm for the daily route optimization of couriers in a diagnostic network and evaluate its impact on turnaround times and distance driven. Our method maintains current service levels while requiring approximately 90,000 km less distance travelled per year.

### 3 - Incentivizing Adherence for Treatment of Infectious Diseases Sze-chuan Suen, University of Southern California, Los Angeles,

CA, 90089-0193, United States, Diana Maria Negoescu, Joel Goh

Premature cessation of antibiotic therapy (non-adherence) is common in long treatment regimens and can severely compromise health outcomes. In this work, we investigate the problem of designing a schedule of incentive payments to induce socially-optimal treatment adherence levels with heterogeneous patient preferences for treatment adherence that are unobservable to a health provider. Unlike past contract-theoretic models, a unique challenge in this problem is that any prior commitment that a patient makes to a given level of treatment adherence typically cannot be enforced and contracted upon in practice. We show that the optimal payment schedule can be constructed through the solution of a single convex optimization problem and conduct a numerical study using representative data in the context of the tuberculosis epidemic in India.

### 4 - Ambulance Emergency Response Optimization in Developing Urban Centers

Justin J. Boutilier, University of Wisconsin - Madison, Madison, WI, 53706, United States, Timothy Chan

The lack of emergency medical transportation is viewed as the main barrier to the access and availability of emergency medical care in low and middle-income countries (LMICs). In this paper, we combine machine learning models with a robust optimization approach to determine both the location and routing of emergency response vehicles, accounting for uncertainty in travel times and spatial demand characteristic of LMICs. We then evaluate our solutions and provide an in-depth investigation into policy-related questions using a simulation model based on real data from Dhaka, Bangladesh.

## SD02

E52 Samberg - Dining Room 5

### Managing Demand in a Healthcare Setting

Emerging Topic: Healthcare Supply Chains

Chair: Vanitha Virudachalam, Wharton School, OID, Philadelphia, PA, 19104, United States

Co-Chair: Hessam Bavafa, Wisconsin School of Business, Madison, WI, 53706, United States

#### 1 - Surgical Case-Mix and Discharge Decisions: Does Within-Hospital Coordination Matter

Vanitha Virudachalam, The Wharton School, Philadelphia, PA, 19104, United States, Hessam Bavafa, Lerzan E. Ormeci, Sergei Savin

We study the problem faced by a hospital that controls patient inflows by designing a case-mix of its elective procedures and patient outflows via patient discharges. Our model analyzes the impact of patient flow management decisions on the utilization of two main classes of hospital resources, "front-end" (such as operating rooms), and "backroom" (such as recovery beds). We assess the benefits associated with the hospital employing a coordinated decision-making process, in which both portfolio and discharge decisions are made in tandem, when compared to two decentralized approaches: a "front-end" approach, under which both decisions are made based exclusively on the front-end costs, and a "siloed" approach, where discharge decisions are made based on backroom costs, and the case-mix is determined as the optimal match for the discharge policy.

### 2 - The Interplay between Online Reviews and Physician Demand: An Empirical Investigation

Yuqian Xu, University of Illinois at Urbana-Champaign, Champaign, IL, 61820, United States, Mor Armony, Anindya Ghose

Social media platforms for healthcare services are changing how patients choose physicians. The digitization of healthcare reviews has been providing additional information to patients when choosing their physicians. In this paper, we derive various service-quality proxies from online reviews and study the relationship between these quality proxies and physician demand. To do so, we study a unique data set from one of the leading appointment booking websites in the United States, that contains online physicians' appointments made over a five-month period, along with other online information. We propose a random coefficient choice model to characterize patient heterogeneity in physician choices, taking into account both numeric and textual user-generated content with text mining techniques. We derive from the text reviews the seven most frequently mentioned topics among patients, namely, bedside manner, diagnosis, waiting time, service time, insurance process, physician knowledge, and office environment.

#### 3 - The Impact of Freelancers on Cost Performance in Hospitals Yingchao Lan, University of Nebraska-Lincoln, Lincoln, NE, 68506, United States, Deepa Wani, Aravind Chandrasekaran

In recent years, the share of hospitals with integrated physicians has been increasing. The implicit assumption is that integrated physicians can bring in more patient volume, improve efficiency, reduce costs and enable close collaboration through established familiarity. However, the cost implications of such a trend is not clear. We assemble a unique patient-level 3 year panel data to empirically explore the following questions: 1. To what degree do freelancers (physicians) explain the cost performance of hospitals? 2. Do any physician-level characteristics such as tenure, non-medical degree, etc. impact the cost performance? 3. Does a hospital's participation in an accountable care organization moderate the impact of freelancers on cost performance of hospitals? Our preliminary results suggest that freelancers can bring down cost in terms of radiology and pharmacy cost.

### 4 - Factors Influencing the Mortality Outcomes in Patients Waiting for New Specialty Cardiology Consultation in Chile, South America

Diana Prieto Santa, Johns Hopkins University, Baltimore, MD, United States, Bolanle Akinyele, Diego A. Martinez, Rodrigo Martinez

Between January and June of 2018, 9724 people died while waiting for public healthcare services in Chile, where 27.1% of the deaths were due to diseases in the circulatory system. Using data from one of the largest public health services in Chile, we aim to assess the relationship between socio-demographic, medical-center factors, and waiting time in the mortality risk. The results would inform the need of specific interventions aimed at reducing the waiting time for new specialty cardiology consultation.

## SD03

E52 Samberg - Dining Room 4

### Systems Modeling for Health Policy

Emerging Topic: Public Health and Health Policy

Chair: Qiushi Chen, Penn State University, University Park, PA, 16802, United States

#### Modeling the Trajectories of Opioid Use Disorder in the US Mohammad S. Jalali, PhD, Harvard Medical School, Boston, MA, United States

The alarming rise in opioid misuse over the past two decades has resulted in a public health crisis, characterized most prominently by a dramatic increase in drug overdose deaths. In this research, we present our results of modeling the trajectories of opioid use disorder in the US and discuss the effects of major prevention and treatment strategies.

### 2 - The Potential Impact of a Sugar-Sweetened Beverage Tax in New York City—A Cost-Effectiveness Analysis

Yan Li, Icahn School of Medicine at Mount Sinai, New York, NY, United States, Daniel Bu, Rienna Russo, Stella Yi

The consumption of sugar sweetened beverages (SSB) is associated with many chronic diseases such as diabetes and cardiovascular disease. An SSB tax has demonstrated consistent effectiveness in reducing SSB consumption in several cities and countries. SSB consumption remains a public health challenge in New York City (NYC). Despite prior attempts, NYC has yet to enact an SSB tax. Using a validated microsimulation model of cardiovascular disease, we aim to assess the cost-effectiveness of an SSB tax in NYC. Findings from our study will provide evidence of the impact and costs associated with an SSB tax and may prompt policymakers and key stakeholders to revisit the idea of implementing a tax in NYC.

### 3 - An Agent-based Algorithm for Studying the Dynamics of Transmission Clusters for HIV

Sonza Singh, University of Massachusetts, Amherst, MA, 01003, United States, Anne Marie France, Yao-Hsuan Chen, Zihao Li, Paul Farnham, Stephanie Sansom, Alexandra Oster, Chaitra Gopalappa

We test the capacity of an evolving contact network algorithm to generate HIV transmission clusters of different sizes in a hypothetical population, and we examine the sensitivity of behavioral and care parameters on the cluster properties. Identifying a methodology to generate the dynamics related to transmission clusters can help develop a simulation model for HIV transmissions in the US and inform intervention strategies.

### 4 - Resource Allocation for Hepatitis C Elimination

Qiushi Chen, Penn State University, University Park, PA, 16802, United States, Turgay Ayer, Jagpreet Chhatwal

More than 70 million people are chronically infected with hepatitis C virus (HCV) globally. With the recent availability of new treatments, the World Health Organization (WHO) set an ambitious target to eliminate HCV by 2030. However, high treatment cost and unawareness of infection remain major barriers to elimination. In this study, we develop an HCV transmission model that aids in optimal allocation of resources to scale-up HCV screening and treatment that can lead to HCV elimination. We present optimal allocation policies in different health care settings and target population profiles.

# ■ SD04

E52 Samberg - Dining Room 3

### Panel: Predictive Modeling to Improve Healthcare Delivery

Emerging Topic: Personalized Medicine and Disease Modeling

Moderators: Mohammed Saeed, Zeeshan H. Syed

1 - Predictive Analytics in Readmission Reduction and Care Management

Jason Wasfy, MD, Massachusetts General Hospital and Harvard Medical School, MA, United States

### 2 - Panelist

Zahoor Elahi, SVP, Optum, Eden Prarie, MN, United States

Optum is a leading information and technology-enabled health services business dedicated to helping make the health system work better for everyone. With more than 160,000 people worldwide, Optum delivers intelligent, integrated solutions infused with OptumIQTM, our unique combination of curated data, advanced analytics and applied health care expertise, that help modernize the health system and improve overall population health. Optum is part of UnitedHealth Group (NYSE: UNH). For more information, visit www.optum.com/iq.

### 3 - Panelist: Development of Real-time Mortality Predictor Using Clinical Data Trajectory in Intensive Care Units

Junchao Ma, Yale SOM, New Haven, CT, United States, Edieal J Pinker, Donald Lee

We are going to talk about a real-time statistical learning model we developed for forecasting near-term mortality in ICU patients. The tool made use of full trajectories of patients' physiologic data and achieved one of the best predictive performances in current literature with a relatively small dataset. The tool can be integrated into a Electronic Health Records system to generate predictions in a periodic basis.

# **SD05**

E52 Samberg - Dining Room 2

### **EHR Analytics and Health Statistics**

Contributed Session

Chair: Andreas Brieden, UniBW Munchen, Werner-Heisenberg-Weg 39, Neubiberg, 85579, Germany

1 - Harmonic Mean Point Processes for Proportional Rate Minimization Across Time

Jeremy C. Weiss, Assistant Professor of Health Informatics, Carnegie Mellon University, Pittsburgh, PA, United States

Point processes and deep learning are popular modeling techniques for the analysis of the temporal event sequences in electronic health records (EHR) data with applications in risk stratification and risk score systems. The standard optimization of point processes with a log-likelihood function gives disproportionate attention to high risk individuals. We propose an adjusted log-likelihood formulation as a new objective for point process neural networks. We show that the proposed formulation is a weighted sum of segmented likelihood contributions that allows proportionate attention and show its characteristics in identifying neurologic decline in intracerebral hemorrhage.

### 2 - Treatment Effect Inference with Imputation of Potential Missing Responses in Longitudinal Data

Hai-Yan Yu, Penn State University, State College, PA, United States

As missing data are almost always present in real datasets, one fundamental issue is that effects of interest are typically not identified in multiple-order array. With the known entries of the nonignorable missing data, the conventional average treatment effect (ATE)models did not have the capacity of estimation in multipleorder array. Our proposed approach estimated the treatment effect of the three slices of responses with both potential missing and drops. A novel algorithm was proposed to inference the treatment-effect for the responses with drops in the longitudinal data.

# 3 - Response Prediction: Detecting Reliable Insight in Case of Small Data

Andreas Brieden, UniBW Munchen, Neubiberg, Germany

One goal of a recent non-interventional clinical study with schizophrenia patients was to determine whether outcome prediction of medication can be done depending on the characteristics of baseline variables like BMI, age etc. Despite a relative small number of patients Clopper Pearson confidence intervals could be computed for the response of prototypical subgroups of patients that show the relevance of key variables. The main ingredient for the presented approach is an algorithmic idea that was developed within the EURO 2013 excellence in practice award winning project. Using convex optimization subgroups of homogeneous patients are identified whose response rates significantly differ.

# ■ SD11

E52 Samberg - Room 164

# Health Commodity Disruptions

Emerging Topic: Healthcare Economics

Chair: Iva Petrova Rashkova, Washington University-St Louis, St Louis, MO, 63130, United States

1 - Supply Chain Interventions to Mitigate Health Commodity Stock-outs: An Empirical Study

Amir Karimi, University of Minnesota, Minneapolis, MN, 55408, United States, Karthik V. Natarajan, Kingshuk K Sinha

Public health supply chains in developing countries commonly use two types of distribution channels in order to deliver health commodities from upstream warehouses to health facilities in the last-mile, namely pull and push distribution channels. We use data from the field to develop contingencies of pull-push strategies.

#### 2 - A Portfolio Optimization Approach to Pharmaceutical Capacity Allocations

Iva P. Rashkova, Washington University-St Louis, St Louis, MO, 63130, United States, Panos Kouvelis

Insufficient manufacturing capacity results in nationwide drug shortages. We study the drug capacity allocation problem using a portfolio optimization approach. A manufacturer's drug portfolio changes over time as new drugs are approved and existing drugs are discontinued. We present three hypotheses about the relationship between new and existing drugs in a portfolio. We examine the strength of these relationships using time series data of drug shortages, approvals and discontinuations. Furthermore, we build predictive models of aggregate drug shortages based on linear regression and random forest forecast methods. The latter performs better on out-of-sample data.

### 3 - Does Competition Help Product Recovery? Evidence from U.S. Drug Shortages

Junghee Lee, Tulane University, New Orleans, LA, 70118, United States, Hyun Seok Lee, Hyoduk Shin, Vish Krishnan

The ongoing shortages of pharmaceutical drugs in the U.S. have threatened public health. As the drug manufacturing industry becomes consolidated, one manufacturing disruption can lead to a nationwide shortage. Resolving drug shortages largely depends on the disrupted firm's recovery driven by economic incentives for recovery and operational challenges of recovery, which arise from the drug's various features such as market, product, and process. We examine how such features affect a drug's time-to-recovery (TTR) in conjunction with the Food and Drug Administration intervention in 2012. By analyzing drug shortage recoveries between 2010 and 2015, we find subtle effects of the drug features on TTR. For example, TTR exhibits a non-monotonic pattern of increasing-then-decreasing in competition. Unexpectedly, this pattern changes into a monotonically decreasing pattern after the intervention due to the differential intervention effects across competition levels. Besides, TTR of drugs with greater economic incentives decreased more.

# SD12

E62 Sloan - Room 221

### **Transplantation**

Contributed Session

Chair: Sommer Gentry, US Naval Academy, Mathematics Department, Annapolis, MD, 21402, United States

1 - Fair Liver Transplant Allocation: A Scalable Optimization Model Subramanian Raghavan, University of Maryland-College Park, College Park, MD, United States, Shubham Akshat, Sommer Gentry

U.S. Department of Health and Human Services is interested in increasing geographic equity in liver transplants. We develop an optimization model to improve the allocation system. It reduces the supply to demand variations among proposed geographies and is scalable to zip-code level. We compare our allocations against others via simulation.

### 2 - Skipping Centers and Simultaneous Offers: Evaluating Novel Strategies to Accelerate Kidney Allocation

Michal Mankowski, King Abdullah University of Science and Technology, Jeddah, Saudi Arabia, Sommer Gentry

To decrease kidney discards, we propose two schemes that accelerate organ allocation: Simultaneously Expiring Offers (SEO) - offers are made to multiple centers in batches and Skipping Centers (SC) -centers with the lowest score are not receiving an offer. We build a discrete event simulation of 3,146 kidneys allocation, where the organ acceptance probability decreases with time. We looked at how timing of offers affects kidney placement. Comparing to the baseline of 87%/58% kidneys placed by the tenth hour for low/high KDPI, the SEO scheme placed 98%/89% kidneys while the SC scheme allocated 95%/83% kidneys. Both methods increased the number of kidney transplants across the quality spectrum.

#### 3 - Reducing Geographic Disparity in Liver Allocation with Population-density Adjusted Circular Distribution Sommer E Gentry, Professor, US Naval Academy, Annapolis, MD, United States, Tanveen Ishaque, Abel Sapirstein, Alex Cauneac, Dorry Segev, Christine Haugen

The Organ Procurement and Transplantation Network plans to address geographic disparity in organ allocation with circular distribution boundaries. We studied variance in hospital level supply/demand ratios for 27,334 livers donated and 44,652 patients, comparing fixed distance circles (150 or 400 mile radius) and population-adjusted (12 or 50 million) circles to the current allocation. Smaller circles did not reduce geographic disparity compared to current allocation, but larger fixed distance and larger population-adjusted circles did reduce geographic disparity. Counterintuitively to some, population-adjusted circles are not superior to fixed distance circles.

## ■ SD13

E62 Sloan - Room 223

### **Data-Driven Models in Healthcare**

Sponsored: MSOM/Healthcare

Chair: Eline Tsai, University of Twente, 7522 NB Enschede, Netherlands.

### 1 - The Making of Practice Guidelines: Dynamics of Selection Criteria in Population Screening

Ozge Karanfil, Koc University, Istanbul, Turkey

Clinical practice guidelines (CPGs) for routine screening are contentious and often fluctuate over time. We develop the first broad boundary feedback theory and formal model to explain dynamics of screening policy formation. Our behaviourally realistic model of detection and selection for screening explains oscillations in CPGs as decision makers weigh harms and benefits. The model endogenously generates fluctuations in policy thresholds leading suboptimal guidelines. We use cancer screening as a motivating example, but the model is generic and applicable to other diseases such as Alzheimers or to nonmedical contexts such as airport screening, background checks or automotive emission tests

# 2 - Optimal Assignment of Clinical Chemistry Samples to Analyzers to Reduce Sojourn Times

Eline Tsai, University of Twente

In this study, we consider clinical chemistry laboratories using an automated preanalysis unit for sample preparation and several automated analyzer lines for sample testing. In these systems, individual samples are already assigned to an analyzer at the start of pre-analysis. Prediction of the workload of the analyzers upon arrival of the samples in the analytical phase may improve analyzer selection with respect to sample sojourn times. To optimize analyzer selection, we have developed a queueing model that enables prediction of the sojourn time of samples in the pre-analytical and analytical phase.

# SD14

E62 Sloan - Room 250

### Staffing in Healthcare – Antecedents and Consequences

Sponsored: Healthcare Applications

Chair: Sandra Sülz, Erasmus University, Rotterdam, Netherlands

1 - Continuity of Care vs a Second Medical Opinion: The Effect of Healthcare Delivery Design on Long-Term Opioid Usage Katherine Bobroske, University of Cambridge, Cambridge, United Kingdom, Lawrence Huan, Michael Freeman, Anita Cattrell, Stefan Scholtes

Many patients are initially prescribed opioids in the primary care setting. While clinical guidelines promote continuity of care for managing opioids, little is known about whether this recommendation is effective in the early stages of a patient's opioid journey. We analyzed the medical claims of opioid-naive patients who received their first opioid prescription in a primary care office setting. Using data mining and econometric methods, we found that exposing patients to a second medical opinion early in their opioid journey may significantly curb rates of long-term opioid use.

### 2 - Nursing Team Continuity and its Influence on Medical Outcomes: Evidence from a Multicenter Study

Eilermann Kerstin, University of Cologne, Cologne, Germany, Ludwig M. Kuntz, Stefan Scholtes

Low staffing levels are known to be a risk factor for medical outcomes. It is, however, important to not only consider nurse staffing levels but also the allocation of available nursing staff to shifts. Based on data from a prospective multicenter study with 66 neonatal intensive care units in Germany, we analyze the association between nursing team continuity and patient outcomes.

### 3 - Applying Markov Modelling to Predict Capacity for Colonoscopies Sylvia Elkhuizen, Erasmus School of Health Policy & Management,

Sylvia Elkhuizen, Erasmus School of Health Policy & Management, Rotterdam, Netherlands

Colon cancer is one of the most common cancers in the Netherlands with 15,400 new illnesses per year. In 2014 a colon cancer screening program was implemented in the Netherlands. The central question in this study is what the influence is of the screening program on required capacity for colonoscopies at national and hospital level. We used Markov modelling to analyse this. We derived transition probabilities from literature, historical data, and guidelines & protocols. We applied the model for a national level and for on specific hospital. We also used the model for scenario analyses to test the influence of possible changes in factors on the number of colonoscopies.

## SD15

E62 Sloan - Room 262

### Implementing Data Driven Technology

Emerging Topic: Healthcare Information Technology and Management

Chair: Craig Froehle, University of Cincinnati, Cincinnati, OH, 45221-0130, United States

Co-Chair: David Rea, University of Cincinnati, Cincinnati, OH, 45220, United States

### 1 - The Impact of Data Breach Remediation on Care Quality

Eric Johnson, Vanderbilt University, Nashville, TN, United States, Sung Choi

Health data breaches have significant consequences for patients, providers, and payers. While improving security, post breach remediation activity may introduce process changes that delay, complicate, or disrupt patient care. We examine changes in hospital care quality subsequent to a breach for patients with symptoms suggestive of ST-segment elevation myocardial infarction.

### 2 - Government Ideology and Responses from Hospitals to the Affordable Care Act Legislation

Justin Kistler, University of South Carolina, Columbia, SC, 29212, United States, Luv Sharma

Following the passage of the Patient Protection and Affordable Care Act, hospitals were financially incentivized to improve patient experiences. Efforts to improve experiences, however, require significant resources. Using real options theory, we argue that the legislation's future was uncertain, which created value for firms to wait to invest in compliance. We investigate how local government ideology influenced the value of organizations' options to wait to invest in compliance. We further investigate the impact of local competitive and organizational factors on the option's value. We test our hypotheses by leveraging United States hospital performance data from 2009 to 2014. Results indicate that the ideology of the local government has a significant impact on how and when hospitals invest in compliance with the new legislation.

### 3 - Coordinated Scheduling for In-clinic and Virtual Medicine Patients in an Integrated Practice Unit

Douglas Morrice, University of Texas-Austin, IROM Department, Austin, TX, 78712-1750, United States, Jingyao Huang

Coordinated services and virtual medicine are two innovative concepts being employed in value-based, patient-centered care. In this paper, we consider coordinated scheduling for both in-clinic and virtual medicine patients in an Integrated Practice Units (IPU). An IPU is a co-located, multi-disciplinary team of providers that delivers a full care cycle.

#### 4 - Optimizing Fairness in a Multi-Site Emergency Department Staff Allocation Model

- David Rea, PhD Candidate, University of Cincinnati, Cincinnati,
- OH, United States, Craig Froehle, Suzanne Masterson,
- Brian Stettler, Greg Fermann, Art Pancioli

The importance of fairness in allocation decisions has been broadly recognized in the operations literature, yielding various mathematical formulations. Drawing upon the organizational-justice literature, we express fairness in terms of two competing aspects: equity (greater individual contributions yield beneficial outcomes) and equality (identical outcomes for all). We exploit this insight to formulate a bi-objective (equity vs. equality) optimization model that assigns clinical hours at multiple locations to physicians. The model attempts to minimize dissatisfying time (deviations from physicians' preferences) while accounting for individual contributions. Solutions upon a Pareto frontier reduce dissatisfying time by over 50%. We found that dissatisfying time becomes more concentrated on a smaller set of physicians at higher levels of equity, but lower levels of equity result in more broadly distributed dissatisfaction. Survey data suggest physician satisfaction improved significantly after model implementation.

# **SD16**

E62 Sloan - Room 276

### Incentive and Policy Design in Healthcare

Emerging Topic: Healthcare Economics

Chair: Fernanda Bravo, UCLA Anderson School of Management, Los Angeles, CA, 90024, United States

Co-Chair: Tinglong Dai, Johns Hopkins University, Baltimore, MD, 21202, United States

Risk-Sharing Agreements for New Medical Treatments
 Ozge Yapar, Indiana University Kelley School of Business,
 Wharton School of Business, Bloomington, IN, 19103,
 United States, Stephen E. Chick, Noah Gans

Any estimate of a new treatment's value that relies only on clinical-trial data can have significant residual uncertainty. Post-marketing data, captured after the treatment has entered the market, can augment clinical-trial data to better validate the safety, efficacy, and economic value of the treatment. In fact, new risk-sharing contracts, in which a treatment's price is a function of post-marketing data, are under consideration around the world. We analyze several related types of agreements that update the price according to a range of contract terms. An understanding of the equilibrium outcomes of different agreements is valuable to payers as they decide which contract forms to offer.

### 2 - Analysis of Comprehensive Primary Care Plus (CPC+) Initiative

Fernanda Bravo, UCLA Anderson School of Management, Los Angeles, CA, 90024, United States, Elodie Adida

The Centers for Medicare and Medicaid Services have recently launched the Comprehensive Primary Care Plus (CPC+) initiative, aiming at improving primary care delivery by changing the way providers are paid for their services. CPC+ includes a capitation payment, a reduced fee per visit, as well as a performancebased payment incentive. Under this program, physicians are encouraged to use alternative care delivery methods (phone calls, e-visit, in-home nurse visits, etc.). We study how this payment system impacts providers' care delivery decisions, patient welfare and payer cost.

### 3 - Optimizing Simultaneous-Offering Mechanism of Marginal Cadaveric Organs

Tinglong Dai, Johns Hopkins University, Baltimore, MD, 21202, United States, Ronghuo Zheng

In the US, when an organ from a deceased donor becomes available, an organ procurement organizations (OPO) will offer the organ to multiple transplant centers using an online, automated offering system called DonorNet. Surgeons conduct research into the details of the offer and decide whether to accept or reject it. Ultimately, the organ is offered to the patient with the highest priority first, then second highest priority, and so on. In this study, motivated by an OPO's problem of determining the optimal batch size of simultaneous offers made to transplantation centers, we model the strategic interaction among transplant centers both within and across batches, leading to structural properties and computational insights in terms of (1) the relationship between the number of simultaneous offers and a surgeon's decision to conduct research into the quality of the organ, (2) the optimal size of each batch, and (3) the optimal information environment in the placement process of offers from marginal donors.

# Sunday, 8:00AM - 9:30AM

# SuA01

E52 Samberg - Dining Room 6

### Empirical Methods and Applications in Personalized Medicine and Disease Modeling

Emerging Topic: Personalized Medicine and Disease Modeling

Chair: Song-Hee Kim, University of Southern California, Los Angeles, CA, 90089, United States

1 - A Robust Approach to Study Multiple Treatments: Hierarchical Contrast-Specific Propensity Score

Shasha Han, NUS Business School, NUS Business School, Singapore, Joel Goh, Fanwen Meng, Donald B. Rubin

To prevent or delay the onset of the complications for diabetics is challenging, in part because healthcare providers lack treatment guideline at clinic operational level. A scientific and practical solution to this problem would be localizing an evidence-based medication guideline, namely, taking into account evidence from observational data specific to a given country or region. However, existing methods for causal inference with observational data have limitations that hinder them from being used in this purpose. In this study, we are motivated by this setting, specifically, a provider has to decide among three treatment options: nomedication and two classes of medications (statins and fibrates) to control cholesterol for a newly-diagnosed diabetic. We develop a new approach that obtains causal effects of multiple treatments from observational data. We discuss how our approach overcomes several limitations with existing methods; in particular, the approach enjoys robustness to some model mis-specifications.

### 2 - Learning Interpretable Policies for Medical Treatment Assignments

Zhengyuan Zhou, Stanford, CA, 94305, United States

In many settings, a decision-maker wishes to learn a rule, or policy, that maps from observable characteristics of an individual to an action. An important application domain, for example, is personalized medicine, where it is desirable to learn a medical treatment rule that prescribes medications to patients using electronic medical records. Here, we study the offline multi-action policy learning problem with observational data and where the policy may need to respect budget constraints or belong to a restricted policy class such as decision trees. We build on the theory of efficient semi-parametric inference in order to propose and implement a policy learning algorithm that achieves asymptotically minimaxoptimal regret. To the best of our knowledge, this is the first result of this type in the multi-action setup, and it provides a substantial performance improvement over the existing learning algorithms.

#### 3 - An Instrumental Variable Tree Approach for Detecting Heterogeneous Treatment Effects in Observational Studies Guihua Wang, Ross School of Business, University of Michigan, Ann Arbor, MI, 48105, United States, Jun Li, Wallace J. Hopp

We develop a new Instrumental Variable (IV) tree approach for detecting heterogeneous treatment effects in observational studies. We show that the IV tree approach effectively corrects for endogeneity issues and partitions subjects into groups such that those in the same group have similar treatment effects and those in different groups have different treatment effects. We demonstrate the practical application of the IV tree approach by using colectomy as the clinical setting to compare teaching (treatment) and non-teaching (control) hospitals and find that the outcome differences between teaching and non-teaching hospitals are heterogeneous across patient types.

## SuA02

E52 Samberg - Dining Room 5

### **Hospital Operations**

Emerging Topic: Healthcare Supply Chains

Chair: Wanyi Chen, Harard Medical School, Boston, MA

1 - Analysis of Hybrid Patient Prioritization in Outpatient Clinics using Continuous-time Markov Chain Approximation Model Vahab Vahdat, Harvard Medical School, Boston, MA, 02114, United States, Jacqueline Griffin, Nurul Suhaimi

In the last decade, the use of ambulatory care services has consistently increased in comparison to inpatient hospitalization in the United States. This increase in demand has resulted outpatient clinics investigating ways to improve their processes and operations. One of the less studied area of research is hybrid patient prioritization where the prioritization scheme can alter depending on the state of the outpatient clinic. In this presentation, we investigate the characteristics of patient prioritization using continuous-time Markov chain model for two groups of patients in an orthopedic outpatient center. Our results demonstrate that full prioritization will not always benefit the timeliness of patient care and the prioritization should be based on patient group characteristics and clinic utilization.

2 - Improving Patient Flow at Emergency Department Through Predicting Hospital Admissions at Triage and Requesting Hospital Beds Early On

Wanyi Chen, Harvard Medical School, Boston, MA, 27514, United States, Nilay Argon, Serhan Ziya, Tommy Bohrmann, Kenneth Lopiano, Debbie Travers, Benjamin Linthicum, Abhi Mehrotra

We present a scheme to speed up service in an emergency department (ED) setting through predicting hospital admissions at time of triage and making early (hospital) bed request (BeRT) for patients with high predicted admission probabilities. We constructed a Markov decision model that recapitulated the service flow at the ED to inform us the structural properties of the optimal BeRT policy. The policy is optimal in the sense of minimizing a cost of holding patients in the ED and false positive early BeRTs. We then evaluated the performance of several heuristic policies using a simulation model tailored to the ED at University of North Carolina at Chapel Hill.

### 3 - Improving Patient Flow at an Orthopedic Outpatient Clinic Usinga Systems Engineering Approach: A Lean Engineering and Discrete System Simulation Application

Linda Bendavid, McGill University Health Centre, Montreal, QC, Canada, Amy Lorinca, Michelle Nague, Adriana Sahyoun, Stephen Thavarajah, Tarek Al-Assaad, Ali Akgunduz, Greg Berry

Outpatient clinics face challenges to efficiently align its capacity to respond to patient's demand for care services. Long wait times, clinicians' idle time, and delays to access care are driving patient flow optimization initiatives. Lean tools were used to identify improvements in the patient flow. A discrete event

simulation modeling was constructed to test alternative booking strategies to reduce patient waiting times and physician's idle time, and improve patient throughput and patient experience. Optimization through simulation studies shows that optimal solutions could reduce wait time by up to 66.5% and the total time spent at the clinic by up to 46%.

### 4 - Balancing of Load (Operational, Emotional, Cognitive) in Healthcare Systems

Nitzan Carmeli, Technion Israel Institute of Technology, Haifa, Israel, Galit B. Yom-Tov, Avishai Mandelbaum

Operational offered-load, calculated through queueing models, is the basis for design, staffing and routing in congestion-prone service systems. In healthcare systems, however, service providers experience additional significant features of load such as emotional and cognitive - these could cause stress and fatigue even when the operational offered-load is low. How can one then balance multi-featured load among service providers? In our research, we develop a novel theoretical framework that supports answers to this question. We apply the framework to the case of two maternity wards, within which we optimally and fairly balance a multi-feature load.

# SuA03

E52 Samberg - Dining Room 4

### The Interplay of Policy and Operational Decision Making in Healthcare

Emerging Topic: Public Health and Health Policy

Chair: Bjorn Berg, University of Minnesota, Minneapolis, MN, 55455, United States

1 - The Effect of Health Policy Induced Hospital Nudging on Imaging Decisions

Christian Wernz, Virginia Commonwealth University, Richmond, VA, 23298, United States, Yongjia Song, Aditya Umesh Kulkarni, Danny R. Hughes

To be revised/placeholder: Public reporting of hospital quality data intends to help patients make better consumer choices. We develop a multiscale decision theory model to analyze the decision responses by patients, hospitals and physicians, and explore whether hospitals should incentivize physicians.

### 2 - Priority Based Templating for Outpatient Specialty Practices

Miao Bai, University of Connecticut, Storrs, CT, 55904, United States, Bjorn Berg, Esra Sisikoglu Sir, Mustafa Y Sir

Patient scheduling within an outpatient specialty practice presents unique challenges. Capacity allocation policies are often multi-dimensional in their need to balance competing criteria including clinical urgency, alignment with provider expertise, geographical access, and case mix targets. Further, as timely access requirements are evaluated within health policy and plan management decisions, the need to schedule certain patients within a pre-determined time frame provides further motivation for priority-based scheduling templates. We propose a priority-based scheduling approach motivated by real appointment data from a specialty clinic within a large academic medical center. The problem is formulated as a two-stage stochastic program. The problem's structure is used to attain results to guide allocating patient groups into a tiered priority scheme.

### 3 - Modeling the Effects of Positive Incentives on Outpatient Care Efficiency

Bjorn Berg, University of Minnesota, Minneapolis, MN, 55455, United States

The research presented seeks to evaluate viable positive incentive-based interventions to improve healthcare delivery system efficiency. The design of the incentive-based model is premised on reimbursing patients who are at high risk of no-show when they attend their scheduled appointments thereby improving provider efficiency and increasing access measures and outcomes for the high risk patients. The underlying question we seek to answer in developing models in this research is: How do we change the behavior of patients who are imposing a negative externality on other patients in a way that improves the health of everyone and the efficiency of the system overall? This research aims to address the current gap between positive incentive-based operational design and efficient outpatient access management.

## ■ SuA04

E52 Samberg - Dining Room 3

# Data-Driven Decision Making, using Techniques from Machine Learning and Optimization

Emerging Topic: Personalized Medicine and Disease Modeling

Chair: Emisa Nategh, University of Washington, Seattle, WA, 98105, United States

1 - Automated Radiation Therapy Treatment Planning using Ensemble Learning and Inverse Optimization

Rafid Mahmood, University of Toronto, Mississauga, ON, L5M 7Y6, Canada, Aaron Babier, Taewoo Lee, Daria Terekhov, Timothy Chan

Knowledge-based automated planning (KBAP) is a two-stage pipeline that designs personalized radiation therapy plans for treating patients with cancer. In KBAP, a machine learning model first predicts desirable treatments, which are refashioned into deliverable plans via inverse optimization (IO). Treatment plans are often evaluated over a set of competing clinical criteria and depending on the machine learning model used, a KBAP pipeline often overfits to a subset of the metrics. In this work, we introduce a novel IO approach that uses an ensemble of predictions from different machine learning models to construct a single deliverable plan that better balances all clinical trade-offs. Our final KBAP pipeline uses a subset of the individually best performing machine learning models to produce plans that are on average superior to all plans produced using individual predictions.

### 2 - Personalized Lung Cancer Screening Policies using a Partially Observable Markov Decision Process

Lakovos Toumazis, Stanford University, CA, United States, Oguzhan Alagoz, Ann Leung, Sylvia Plevritis

The US Preventive Services Task Force recommends lung cancer screening for high risk individuals aged between 55-80 years, with at least 30 pack-years, and no more than 15 years since smoking cessation. Many other risk factors are associated with lung cancer incidence, yet screening eligibility is solely based on age and smoking history, leading to sub-optimal screening strategies. We develop a partially observable Markov decision process (POMDP) that provides individualized optimal screening policies for current and former smokers. Decisions are made based on the lung cancer risk of the individuals informed by past screening findings and changes in individuals' smoking behavior.

### 3 - Batch Bayesian Optimization for Healthcare Policy Optimization John Silberholz, University of Michigan, Ann Arbor, MI,

United States, Xueze Song

When establishing health policies, policymakers in a number of domains rely on input from comparative modeling exercises, in which multiple independent groups each model a complex health system with the goal of informing the same policy decision. For a variety of reasons, these groups rarely share their model source code or executables, making it challenging to identify the most effective policy decisions when selecting among a large number of possible decisions. In this work, we overcome this challenge using batch Bayesian optimization, and we demonstrate the promise of our approach with an example from prostate cancer screening policy.

#### 4 - Predicting Treatment Related Toxicity and Efficacy in Multiple Myeloma from Clinical Entities Extracted from Amazon Comprehend Medical

Emisa Nategh, University of Washington, Seattle, WA, 98105, United States, David Coffey, Michael R. Wagner, Yong-Pin Zhou

Multiple myeloma is an incurable cancer and the second most common hematologic malignancy in the USA. While 19 drugs have been approved to treat the disease, these treatments are not effective for everyone. Hence, the goal of the treating oncologist is to choose a therapy that maximizes efficacy while reducing toxicity. The aim of our research is to develop a machine learning model to match patients to the most effective therapy while minimizing related toxicities. We are using Amazon Comprehend Medical to extract clinical entities from patient's medical records in order to train a model that identifies which clinical features are most informative for predicting toxicity and efficacy.

# SuA05

E52 Samberg - Dining Room 2

### Healthcare Delivery Design and Innovation

Contributed Session

Chair: Valentina Marques da Rosa, Universidade do Vale do Rio dos Sinos, Porto Alegre, Brazil

### 1 - Designing Healthcare Services to Improve the Wellbeing of Children in Treatment for Cancer

Valentina Marques da Rosa, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, Leandro Miletto Tonetto, Claudia Libanio, Priscila Brust-Renck, Anderson Siqueira Pereira, Andressa Garcia, Francielle Daudt, Raíssa Fontoura, Roberta Rech Mandelli, Victoria Kern

This research was aimed at mapping guidelines for the design of hospital services in order to enhance the subjective wellbeing of patients being treated for cancer. Dealing with invasive treatments commonly generates negative emotions, which can interfere in their wellbeing. An exploratory study based on observations of children being treated at their rooms and in recreational activities, codesigning hospital services, allowed researchers to map design guidelines. Tangible interfaces for service prototypes were developed and tested, evidencing their impact on children's wellbeing.

# SuA06

E52 Samberg - Salon West

# Intersection of Healthcare Policy and Healthcare Operations

Emerging Topic: Public Health and Health Policy

Chair: Soroush Saghafian, Harvard Univeristy, Cambridge, MA, 02138, United States

1 - Yardstick Competition, Credence Goods, and the Design of Diagnosis Related Groups

Robert Shumsky, Dartmouth College, Tuck School of Business, Hanover, NH, 03755, United States, Laurens Debo, Nicos Savva

Hospitals throughout the developed world are reimbursed on the basis of diagnosis related groups (DRGs), a patient classification system first developed at the Operations Research department of Yale University. Under this scheme, the hospital receives a fixed fee per patient episode that is set based on yardstick competition (the fee is set to the average cost of providing care to similar patients in other hospitals). In this paper, we show that this payment system may give rise to incentives to "cherry pick" and/or "upcode" patients and examine potential solutions to this problem involving yardstick competition based on output statistics.

### 2 - Do Hospital Closures Improve the Efficiency and Quality of Other Hospitals?

Lina Song, Harvard University, Cambridge, MA, 02138, United States, Soroush Saghafian

We investigate the impact of the U.S. hospital closures on the surrounding hospitals' efficiency and quality and shed light on mechanisms through which they can be affected. Using and combining various data sources, we find that when a hospital closes, its nearby hospitals improve their operational efficiency without expanding their resources. However, they do so via a speed-up behavior (i.e., by reducing their service durations) instead of an effort to lower their average bed idle time. This speed-up response to the increased demand by nearby hospitals negatively affects some aspect of the care, including the 30-day patient mortality. Furthermore, hospital closures induce changes in directions that widen social disparity, as their adverse consequences fall disproportionately among hospitals administrators and policymakers who strive to improve the efficiency and quality of the healthcare system.

#### 3 - Resident Supervision and Patient Care: A Comparative Time Study in a Community-academic Versus a Community Emergency Department

Yue Yin, Northwestern University, Itai Gurvich, Jan A. Van Mieghem

The objective was to compare attending emergency physician (EP) time spent on direct and indirect patient care activities in emergency departments (EDs) with and without emergency medicine (EM) residents. We performed an observational, time-motion study on 25 EPs who worked in a community-academic ED and a nonacademic community ED. Two observations of each EP were performed at each site. Average time spent per 240-minute observation on main-category activities are illustrated in percentages. We report descriptive statistics (median and interquartile ranges) for the number of minutes EPs spent per subcategory activity, in total and per patient. We performed a Wilcoxon two-sample test to assess differences between time spent across two EDs. Conclusions: EPs in our study spent 14.2% of their time (8.5 minutes/hour) supervising residents. The time spent supervising residents was largely offset by time savings related to indirect patient care activities rather than compromising direct patient care.

4 - Can Public Reporting Cure Healthcare? The Role of Quality Transparency in Improving Patient-Provider Alignment Soroush Saghafian, Harvard Univeristy, Kennedy School of Government, Cambridge, MA, 02138, United States, Wallace J. Hopp

Public reporting of medical treatment outcomes is being widely adopted by policymakers in an effort to increase quality transparency and improve alignment between patient choices and provider capabilities. We examine the soundness of this approach by studying the effects of quality transparency on patient choices, hospital investments, societal outcomes (e.g., patients' social welfare and inequality), and the healthcare market structure (e.g., medical or geographical specialization). Our results offer insights into why previous public reporting efforts have been less than fully successful and suggest ways in which future efforts can be more effective.

# SuA07

E52 Samberg - Ballroom T

### **Data-driven Healthcare Operations**

Sponsored: MSOM/Healthcare

Chair: Susan F. Lu, Purdue University, West Lafayette, IN, 47907, United States

### 1 - Model Homes: Evaluating Approaches to Patient-Centered Medical Home Implementation

Philip Saynisch, Harvard, Guy David, Benjamin Ukert, Abiy Agiro, Sarah Husdon Scholle, Tyler Oberlander

This study evaluates impact of different approaches to patient-centered medical home (PCMH) adoption on healthcare utilization. It combines detailed data on PCMH capabilities from over 6,000 primary care practices with 5.3 million patient-years of claims data from the HealthCore Integrated Research Database. We first use hierarchical agglomerative clustering to group practices based on their PCMH capabilities, and then use generalized difference-in-differences models to estimate the PCMH effect. We find significant reductions in total expenditures and utilization of emergency department (ED) visits, outpatient care and lab and imaging services. The reduction in ED utilization is driven entirely by one cluster of practices that adopted enhanced electronic communications, suggesting these may act as substitutes for some patients. The PCMH model has significant impact on patterns of healthcare utilization, especially when heterogeneity in implementation is included in program evaluation.

### 2 - Assessing Primary Care Performance Using Emergency Department Data

Sandra Sülz, Erasmus School of Health Policy & Management Health, Regent's Park, Rotterdam, NW1 4SA, Netherlands, Nicos Savva

In the UK, the performance of primary care practitioners (GPs) is difficult to assess either due to data unavailability, low frequency of data collection, or inconsistent data collection. Emergency Department (ED) data, however, exists and is comparable across hospitals. Our study analyses how routinely collected ED data can be used to derive an objective measure of GP performance based upon avoidable ED presentations for ambulatory care sensitive conditions. The model results imply that some proportion of the variation in GP performance is systematic and GP-specific rather than random. We further validate our performance measure using patient satisfaction surveys.

### 3 - Personalized Health Care Outcome Analysis of Cardiovascular Surgical Procedures

Guihua Wang, Ross School of Business, University of Michigan, Ann Arbor, MI, 48105, United States, Jun Li, Wallace J. Hopp

Using patient-level data from thirty-five hospitals for six cardiovascular surgeries in New York state, we identify patient groups that exhibit significant differences in outcomes with a recently developed instrumental variable tree approach. We find that outcome differences between hospitals are heterogeneous across patients. By quantifying these differences, we demonstrate that a large majority of patients can achieve better expected outcomes by selecting providers based on personalized outcome information. We also show how personalized outcome information can help providers to improve their processes and payers to design effective pay-for-performance programs.

### 4 - Big Data In Non-profits: Insights From Staffing In Blood Donation

Wilson Lin, University of Southern California, Los Angeles, CA, United States, Susan F. Lu, Tianshu Sun, Ginger Jin

How can organizations leverage staffing to achieve better outcomes, beyond fulfilling operational needs? In collaboration with a Chinese blood bank, we observe whether and how different nurses may influence donors' donation decisions through interaction on the bloodmobile. Using a unique dataset at the interaction level, we estimate the effect of nurse donor matching on a donor's donation volume and return likelihood. We identify a trade-off between short and long term outcomes and find that improved matching can provide economically significant benefits for the blood bank.

# SuA09

E52 Samberg - Ballroom M Practice Oriented Session

# A Personalized Machine Learning Approach on Cerebrovascular Disease

Practice Oriented Session

Chair: Dimitris Bertsimas, Massachusetts Institute of Technology, Cambridge, MA, 02139, United States

Co-Chair: Agni Orfanoudaki, Massachusetts Institute of Technology, Cambridge, MA, 02142, United States

Our session will combine highlights from personalized analytical approaches to cerebrovascular diseases with insights from clinicians. The session will begin with presentations of the research projects and will conclude with an open discussion with Charlene J Ong, MD, MPHS and Dr. Amre Nouh, MD.

### 1 - Machine Learning Proves Stroke Risk is Not Linear

Agni Orfanoudaki, Massachusetts Institute of Technology, Cambridge, MA, 02139, United States, Emma Chesley, Christian Cadisch, Barry Stein, Amre Nouh, Mark Alberts, Dimitris Bertsimas

Most stroke risk assessment tools presume the impact of various risk factors is linear and cumulative leading to predictive models with limited accuracy. We created a novel interpretable and accurate non-linear stroke risk score that increases the accuracy of event prediction that can lead to effective personalized prevention of stroke. We utilized data from the clinical examinations of the Framingham Offspring cohort to develop the predictive model. We trained a treebased machine learning method to predict the 10-year risk of stroke that accounts for non-linear interactions among risk factors. The final model was validated with Electronic Health Records from the Boston Medical Center. Our results in both the training and validation populations suggested that the non-linear approach improves by 12.37% upon the existing stroke risk calculator in the c-statistic even in multi-ethnicity populations. The clinical implications include improved prioritization of risk factors at a patient level and targeting of interventions.

### 2 - Natural Language Processing of Radiology Reports for the Identification and Assessment of Ischemic Stroke Rebecca Zhang, Massachusetts Institute of Technology, Cambridge, MA, 02139, United States, Agni Orfanoudaki, Charlene Ong, Dimitris Bertsimas

Neurologists read radiology reports to evaluate and treat patients hospitalized with ischemic stroke events, which can be time-consuming and inefficient. A large proportion of ICD codes incorrectly identify patients with ischemic stroke and do not accurately distinguish acuity or location. We train a custom, neurology-specific set of GloVe word embeddings and present a comprehensive comparison of machine learning and NLP techniques to classify the presence, location and acuity of ischemic stroke. We find that interpretable classifiers perform nearly as well as deep recurrent methods, meaning the cost of interpretability is not high in this setting. Such an interpretable algorithm, with its strong performance, is valuable both for retrospective studies and for triaging critical reports in the clinical setting.

### 3 - Personalized Risk Profiles and Treatment of Hypertensive Patients: A Machine Learning Approach

Antonin Dauvin, Massachusetts Institute of Technology, Cambridge, MA, 02139, United States, Agni Orfanoudaki, Dimitris Bertsimas

Hypertension is a major public health issue worldwide, affecting more than a third of the adult population. Current clinical practice guidelines do not present a framework that considers personalized, individual patient-specific factors. We gained access to the Electronic Health Records of the Boston Medical Center and created a dataset that includes more than 8 million hospital visits corresponding to 150,776 patients, and 70 features. We developed personalized interpretable machine learning models that estimate the effectiveness of prescribed treatments and identify patients at high risk with accuracy up to 93%. Our models will serve as an actionable and readily implementable tool for physicians in practice.

### Panelists:

Charlene Ong, Boston University School of Medicine, Boston, MA, United States

Amre Nouh, Hartford Hospital, Hartford, CT, United States

# SuA10

E52 Samberg - Salon East

### **Emergency Department Analytics**

Contributed Session

Chair: Yong-Hong Kuo, The University of Hong Kong, Dept. of Industrial and Manu. Sys. Eng., Hong Kong

1 - Predictors of CTA Utilization for Patients with Stroke-Like Symptoms at Emergency Departments Marco Bijvank, University of Calgary, Calgary, AB, Canada, Eddy Lang

Stroke is one of the prominent diseases for which the CT scan of the head and neck may provide useful information for diagnosis. The ED evaluation for stroke is particularly challenging due to the wide range of clinical presentations, the presence of various stroke mimics, and evolving diagnostic and therapeutic guidelines. There are large differences in the number of CT angiography (CTA) scans performed in the province of Alberta and between physicians, suggesting overutilization. With the use of machine learning techniques, we propose alternative guidelines that can support physicians in their decision to order a CTA of the head and neck to diagnose minor stroke.

### 2 - Forecasting Patient Waiting Times in the Emergency Department using Machine Learning

Siddharth Arora, Research Fellow, University of Oxford, Oxford, United Kingdom, James W. Taylor

Accurate predictions of individual patient waiting times in the Emergency Department (ED) can help improve overall patient satisfaction and assist healthcare organizations to streamline patient-flow based on informed staff and resource allocation. Waiting time is inherently uncertain, and so a point forecast is unhelpful and potentially misleading and can thus result in greater dissatisfaction among patients. Using anonymized patient-level ED data, we adopt a machine learning approach to: (1) predict patient waiting times for both major and minor triage categories, and (2) identify the key variables that have the highest impact on modeling accuracy.

### 3 - Data Analytics and Simulation Modeling of Emergency Department Operations in Hong Kong

Yong-Hong Kuo, The University of Hong Kong, Pokfulam Road, Hong Kong, Janny M.Y. Leung, Colin Graham

In this talk, we will present our work of utilizing data analytics and simulation modeling for analyzing operations at a hospital emergency department in Hong Kong. We developed a calibration procedure to improve the performance of our simulation model. This simulation model can be used to assess the outcomes of different scenarios and strategies for enhancing system efficiency. Simulation-optimization approaches were also developed to determine resource allocation decisions.

# SuA11

E52 Samberg - Room 164

### Performance Targets and Incentives in Healthcare Delivery

Emerging Topic: Healthcare Economics

### Chair: Christopher J. Chen, London, NW14SA, United Kingdom

### 1 - Consumer Online Reviews, Government Ratings and Nursing Home Operations: Evidence from Yelp

Yuanchen Li, Purdue University, West Lafayette, IN, 47906, United States, Susan F. Lu, Lauren Xiaoyuan Lu

We study the effect of user-generated reviews on nursing homes' performance in the presence of government ratings. Employing the Yelp nursing home rating matched with OSCAR dataset from 2010 to 2017, we conduct a difference-indifferences analysis on nursing homes' financial performance and patient volume. We observe that a one-star increase in Yelp rating leads to a 1.9% increase in revenue. Our empirical analysis suggests that facilities increase their revenue by chasing more Medicare-covered patients while filtering Medicaid-covered patients.

### 2 - Hospital Readmissions Reduction Program Does Not Provide the Right Incentives: Issues and Remedies

Hang Ren, School of Business, George Mason University, Fairfax, VA, 22030, United States, Kenan Arifoglu, Tolga Tezcan

The Hospital Readmissions Reduction Program (HRRP) reduces Medicare payments to hospitals with higher-than-expected readmission rates where the expected readmission rate for each hospital is determined based on national average readmission levels. Using a principle-agent model, we study the effect of HRRP and show that: (i) HRRP over-penalizes hospitals with excess readmissions because of a multiplier and its effect can be substantial; (ii) the penalty cap in HRRP can curtail the effect of financial incentives and result in a no-equilibrium outcome when the cap is too low; and (iii) not allowing bonus payments leads to many alternative symmetric equilibria, including one where hospitals exert no effort to reduce readmissions. These results show that HRRP does not provide the right incentives for hospitals to reduce readmissions. Next we show that a bundled payment type reimbursement method, which reimburses hospitals once for each episode of care (including readmissions), leads to socially optimal cost and readmissions reduction efforts.

#### 3 - Managing with Targets in Healthcare: The Case of the 4-Hour Target

Basak Bebitoglu, London Business School, Paddington, W2 1TT, United Kingdom, Nicos Savva, Tolga Tezcan

In this paper, we look at the operational implications of a top-down waiting time target that has been instigated in the UK emergency departments in 2004. We first present an advanced dynamic model that can endogenously generate service times by capturing the impact of the target as well as other factors such as patient and unit characteristics. Then, using patient level visits from a large UK hospital, we show that the target creates a speed-up effect as patient gets closer to it during his/her treatment. Thus, it decreases the time that patient and doctor interact. Finally, we recreate reality by using our model to simulate the ED and conclude by exploring counterfactuals of this policy.

### 4 - Cherry-picking and its Negative Effect on System Service Level: Evidence from a Radiology Workflow Platform

Gonzalo Romero, Rotman, University of Toronto, Toronto, ON, M4K 3H6, Canada, Timothy Chan, Saman Lagzi

We use a large dataset from a radiology workflow platform connecting off-site radiologists with hospitals to empirically investigate 1) whether radiologists cherry-pick tasks with high pay-to-workload, and 2) if cherry-picking has a negative impact on the service level. Radiologists have discretion to select tasks from a common pool and the service level is characterized by meeting prioritydependent target turnaround times. We show that turnaround time is decreasing in pay-to-workload, suggesting cherry-picking, and tasks with low pay-toworkload are more likely to be delayed. Moreover, cherry-picking in low priority tasks can reduce the service level provided to higher priority tasks.

# SuA12

E62 Sloan - Room 221

### Data Analysis Methods for Therapy Response Prediction

Sponsored: Healthcare Applications

Chair: Marleen Balvert, Centrum Wiskunde en Informatica/Utrecht

University, Amsterdam/Utrecht, Netherlands.

#### 1 - MHC Class 1 Peptide Binding Prediction Using Structurally Informed Machine Learning

David Craft, PhD, Massachusetts General Hospital/Harvard Medical School/Broad Institute

The major histocompatibility complex (MHC) is a set of proteins that display peptides on the outer cell surface for recognition by T-cells. MHC class 1 displays small protein fragments degraded from inside the cell to cytotoxic T-cells; an immune response is invoked if the peptides displayed are of foreign origin or mutated. Predicting if a given peptide will bind to a given MHC protein is needed for the design of class 1 based personalized cancer vaccines. We developed a systematic framework for training and evaluating the performance of algorithms in predicting MHC-binding peptides and will present a comparison of several modeling approaches trained and tested with a ground truth dataset of 95 MHC alleles with their binding peptides.

# 2 - Molecular Networks as Determinants of Therapy Response

Lodewyk Wessels, PhD, Netherlands Cancer Institute

We present Comparative Network Reconstruction, a method to reconstruct signaling networks based on incomplete perturbation data, and to identify which edges differ between two or more signalling networks. Prior knowledge about network topology is not required but can straightforwardly be incorporated. We extensively tested our approach using simulated data and applied it to perturbation data from a BRAF mutant, PTPN11 KO cell line that developed resistance to BRAF inhibition. Comparing the reconstructed networks of sensitive and resistant cells suggests that the resistance mechanism involves re-establishing wildtype MAPK signaling, possibly through an alternative RAF-isoform.

#### 3 - A Machine Learning Approach for Mid-Treatment Prediction of Radiotherapy Outcome for Liver Metastasis Patients

Ali Ajdari, Massachusetts General Hospital and Harvard Medical School, Boston, MA, 02115, United States

We investigated the performance of Random Forest (RF) and Bayesian Network (BN) for mid-treatment prediction of radiotherapy outcome. Dataset consisted of 89 liver metastasis patients undergoing SBRT in our institution. Pre- and mid-treatment patient-specific biomarkers (e.g., gene mutation status, blood-biomarker, and contrast-enhanced MRI signal), as well as other clinicopathological and dosimetric features were included in the model. The metrics of interest were probability of liver toxicity and RT failure. The predictive benefit of adding mid-treatment information was evaluated. Furthermore, the possibility of combining RF and BN to arrive at a more interpretable and generalizable prediction model was also investigated.

#### 4 - Interpretable Learning Models for Predicting Cancer Drug Response from Genomic Characteristics Marleen Balvert, Centrum Wiskunde en Informatica/Utrecht

University, Amsterdam/Utrecht, 5037 AB, Netherlands

Cancer is caused by genetic characteristics, and the underlying causative genetic variants of two tumors that seem the same at first glance may actually be different. This leads to differences in treatment response between patients, though the exact relation between genetics and drug response is generally unknown. Current research focuses on the prediction of treatment response from genetic characteristics of tumor cell lines using well-known machine learning techniques. Often these models are difficult to interpret. Here we present an alternative approach with the focus on interpretation of model outcomes and hence practical usability.

# SuA13

E62 Sloan - Room 223

### Healthcare Payment and Risk Adjustment Models

Sponsored: MSOM/Healthcare

Chair: Turgay Ayer, Georgia Institute of Technology, Atlanta, GA, 30332, United States

Co-Chair: Zhaowei She, Georgia Institute of Technology, Atlanta, GA, 30067, United States

### 1 - Fair Regression for Health Care Spending

Anna Zink, Harvard University, Cambridge, MA, United States

Risk adjustment formulas predict spending in health insurance markets in order to provide fair health care coverage for all enrollees, regardless of their health status. Unfortunately, current risk adjustment formulas are known to underpredict spending for specific groups of enrollees leading to undercompensated payments to health insurers. This incentivizes insurers to design their plans such that individuals in undercompensated groups will be less likely to enroll, impacting access to health care for these groups. To improve risk adjustment formulas for undercompensated groups, we expand on concepts from the fairness and health economics literature to develop fair regression methods for continuous outcomes. Our data application using the IBM MarketScan Research Databases and simulation studies demonstrate that these fair regression methods may lead to improvements in group fairness with only small reductions in overall fit.

### 2 - Measuring Physician Work using Electronic Health Records

Michael Hu, MIT, Cambridge, MA, 02130, United States, Stephanie Eisenstat, Retsef Levi, Walter O'Donnell

As electronic health records (EHRs) have become more prevalent, physicians are spending substantial time completing EHR-related work. Observational studies indicate that half of physicians' office time is spent on EHR work. Furthermore, many physicians report they are forced to complete EHR work after hours, which has significantly contributed to physician burnout. In this work we achieve the following: (1) establish a rigorous methodology for accurately measuring physician time spent on EHR tasks using click-level EHR data; and (2) explore how EHR work is distributed temporally and across different types of patients.

# 3 - Can Big Data Cure Risk Selection in Healthcare Capitation Programs?

Zhaowei She, Georgia Institute of Technology, Atlanta, GA, 30067, United States, Turgay Ayer, Daniel Montanera

We analyze the risk selection problem in Medicare Advantage (MA), the largest capitation payment program in the U.S. healthcare market. In practice and current literature, the observed risk selection in MA market is primarily attributed to data limitations and low explanatory power (e.g. low R^2) of the current risk adjustment design. However, our study shows that MA cannot eliminate risk selection even if its risk adjustment design becomes informationally perfect (e.g. R^2 = 1) in the age of big data. To address risk selection in capitation programs, practitioners and policy makers should not solely rely on big data and advanced ML algorithms, and and need to consider mechanisms other than pure statistical risk adjustment designs.

# SuA14

E62 Sloan - Room 250

### Health IT, Analytics, and Patient Care Coordination

Emerging Topic: Healthcare Information Technology and Management

Chair: Indranil R. Bardhan, PhD, The University of Texas at Austin, Austin, TX, 78705, United States

1 - Friend or Foe? The Influence of Artificial Intelligence on Human Performance in Skilled Work

Weiguang Wang, University of Maryland, College Park, MD, 20742, United States, Guodong (Gordon) Gao, Ritu Agarwal

Machine learning powered artificial intelligence (AI) offers an opportunity to profoundly influence knowledge work. Yet, like other technological revolutions through history, concern is being voiced about the potential inequalities it may cause. To date, few studies have unpacked the impact of AI on real-world practice. We examine the impact of an AI on worker productivity in medical chart reviewing. Using a difference in differences method, we identify the significant boost that AI exhibits on performance. Interestingly, we find that productivity gains are heterogeneously distributed: the performance of experts improves less than that of novices. The interactions between AI and human factors (e.g., work time and job title) are further analyzed and the mechanism underlying AI's effect is discussed.

### 2 - Performance Implications of Accountable Care Organizations: Learning or Selection Effects?

Sezgin Ayabakan, Temple University, Philadelphia, PA, 19122, United States, Indranil R. Bardhan, Rajiv Banker

Little is known about the implications of performance-based incentive programs at the organizational level. In this study, we investigate Accountable Care Organizations (ACOs) between 2013 and 2017 and empirically examine whether selection and effort effects play a role on the performance levels of these ACOs after joining Medicare Shared Savings Program (MSSP). We show the existence of selection effect among ACOs who take part in MSSP but we cannot provide a significant trace of effort effect. We contribute to the incentives literature and inform policy makers amidst the current debate on proposed changes to MSSP whether to impose more incentives to increase participation in the program.

### 3 - Patient-Sharing Network, EHR Adoption, and Healthcare Outcome: An Empirical Investigation

Sezgin Ayabakan, Temple University, Philadelphia, PA, United States, Zhe Deng, Subodha Kumar, Paul Pavlou

Patient-sharing networks informally develop as patients see multiple physicians over the course of their treatments. The implications of patient-sharing network structures in the presence of health information technologies on patient outcomes have not been studied in the prior literature. In this study, we investigate the interplay of physician's network centrality, electronic health record adoption, and patient outcomes. In our empirical analyses, we use the State of Maryland's 2.5M inpatient discharge summary data between 2013 and 2017. Our study can inform healthcare participants on how best to design care-coordination mechanisms and collaboration efforts among physicians.

# SuA15

E62 Sloan - Room 262

### Optimization Methods: Personalized Medicine to Healthcare Systems

Sponsored: Healthcare Applications

Chair: Kimia Ghobadi, Johns Hopkins University, Baltimore, MD

### 1 - Robust Direct Aperture Optimization for Radiation Therapy Treatment Planning

Danielle Ripsman, University of Waterloo, Waterloo, ON, N2L 3G1, Canada, Houra Mahmoudzadeh

Optimizing intensity modulated radiation therapy treatment plans is a mathematically complex problem, wherein global optimality is often sacrificed in favour of solving simpler sub-problems. Global approaches, like direct aperture optimization (DAO), have traditionally been difficult to solve and lack the integration of the advanced patient requirements addressed in sub-problem approaches. In this work, a DAO model that addresses motion uncertainty using robust optimization, is proposed. Modelling efficiency is discussed, and the model is applied to a clinical 4D breast cancer patient dataset.

### 2 - Readmission Risk Trajectories for Heart Failure Patients Using a Dynamic Prediction Approach

Sauleh Ahmad Siddiqui, Johns Hopkins University, Baltimore, MD, 21218, United States

We develop a dynamic readmission risk prediction model that yields daily predictions for hospitalized heart failure patients toward identifying risk trajectories over time and identify clinical predictors associated with different patterns in readmission risk trajectories. A two-stage predictive modeling approach combining logistic and beta regression was applied to electronic health record (EHR) data accumulated daily to predict 30-day readmission for a cohort of 534 heart failure patient encounters over 2,750 patient-days. Unsupervised clustering was performed on predictions to uncover time-dependent trends in readmission risk over the patient's hospital stay. Dynamic clinical predictors capturing lab results and vital signs had the highest predictive value compared to demographic, administrative, medication and procedural data included. Using unsupervised clustering, we show that dynamically predicting readmission and quantifying trends over patients' hospital stay illuminated fundamental risk trajectory groups.

#### 3 - The Public Healthcare, the Private Healthcare, and the Waiting Game: Evidence from Strategic Gaming Models of Two-tier Health Systems

Jorge Acuna, PhD Student, University of South Florida, Tampa, FL, United States, Jose L. Zayas-Castro, Diego Martinez

In this talk, we formulate and solve a sequential optimization game to mimic market dynamics in two-tier Health Systems with explicit guarantees of access and waiting time. We discuss how better coordination among public hospitals and governing institutions at the local and regional level can reduce waiting times. We also show through a bi-objective model the potential role that private hospitals can play as a backup system when the public hospital struggle to meet demand. We conclude with insights as to how public and private hospitals can cooperate to achieve better results than each hospital acting by itself.

#### 4 - Outpatient Management of Heart Failure to Reduce Hospitalizations

Michael Hu, MIT, Cambridge, MA, 02130, United States, Bethany Daily, Peter Dunn, Blair Fosburgh, Retsef Levi, Ana Cecilia Zenteno

Heart failure (HF) is a chronic medical condition that affects the heart's ability to either fill with or pump blood. The HF population in the United States is expected to increase from ~6.5 million to ~10 million patients by 2037, with total treatment costs inflating to over \$70 billion/year. In this work, we first propose a predictive model to assign risk scores to patients according to their likelihood of index hospital admission. We then discuss how these analyses are currently being deployed to redesign outpatient heart failure management with the goal of reducing HF-related hospital admissions.

# SuA16

E62 Sloan - Room 276

### **Empirical Healthcare Operations**

Emerging Topic: Healthcare Economics

Chair: Michael Freeman, INSEAD, Singapore

### 1 - How to Manage Doctor Appointments with a Shared Medical Appointment Option

Nazli Sonmez, London Business School, Regent's Park, London, NW1SN, United Kingdom, Kamalini Ramdas, Sarang Deo

Shared medical appointments (SMAs) are an alternative to traditional one-onone appointments for routine care of chronic diseases that offer an innovative, interactive approach to healthcare delivery. In an SMA, a group of patients with similar chronic conditions meet with a doctor simultaneously and receive one-onone care. SMAs are not widely used despite their potential to reduce costs and improve outcomes. To adopt this new healthcare delivery method, a service provider must make an upfront decision on how to allocate service capacity. We develop a model that will incorporate what we learn about how patients make trade-offs while choosing an appointment, when offered two different appointment types, using the data from a healthcare provider. This model will provide insight into how many appointments of each type need to be scheduled.

#### 2 - Is Seniority of Emergency Physician Associated with the Weekend Mortality Effect? An Exploratory Analysis of Electronic Health Records in the UK

Larry Han, Harvard University, Cambridge, MA, United States, Jason Fine, Susan Robinson, Adrian Boyle, Michael Freeman, Stefan Scholtes

Admission to hospital over a weekend is associated with increased mortality, but the underlying causes are poorly understood. We analyzed ED attendances to Addenbrooke's Hospital over a seven-year period with 30-day mortality as the primary outcome and discharge as a competing risk. 229,401 patients made 424,845 ED attendances, of which 158,396 (37%) were admitted. 3,947 (3.3%) admitted on a weekday and 1,454 (3.7%) admitted at a weekend died within 30 days. The weekend effect for patients treated by junior doctors (aHR 1.15; 1.06 to 1.24) was larger than for patients treated by senior doctors (aHR 1.08; 0.98 to 1.19). Changes to NHS policy should emphasize consultant-led ED services at weekends.

### 3 - Evidence and Consequences of Black-Swan Distributions in Hospital Costs

Harshita Kajaria, Cambridge Judge Business School, St. Edmunds College, Mount Pleasant, Cambridge, CB3 0BN, United Kingdom, Paul Kattuman, Michael Freeman, Stefan Scholtes

The NHS UK reimbursement scheme for hospitals sets tariffs based on past year's average cost per-patient for each DRG. The assumption — that the sampling variance of the mean is low — does not hold if the cost distribution is heavy tailed. Robust inference methods applied to tail indices estimated for high volumes DRGs using patient-visit-level costing data from 2009-2015 for 41 NHS trusts rejects the hypothesis of finite variance for many DRGs. The precariousness of NHS finances points to urgent need to devise and adopt a better tariff system. We present one such and examine its validity.

### 4 - Did England's Policies on Sepsis and Antibiotic Resistance have Their Intended Effects?

Christos Oikonomou, INSEAD, Fontainebleau, France, Stephen E. Chick, Stephen Harris, Edward Palmer, Mervyn Singer, Spyros Zoumpoulis

Sepsis is a life-threatening condition. The treatment guidelines of sepsis mandate the immediate use of antibiotics in suspected cases. However, the increase of antibiotic resistance has raised concerns regarding the appropriate usage of antibiotics. These concerns led to the design of policies in 2016 that target the potential excess usage of antibiotics in all levels of care. Using patient level data from intensive care units of several hospitals in England, we study the impact of such policies on the usage of antibiotics and health outcomes.

# Sunday, 10:00am- 10:50am

## Plenary

E52 Samberg - Ballroom, 7th Floor

# Upstream: Leveraging Technology and the Social Determinants of Health to Chart

Emerging Topic: Plenary Emerging Topic Session

 Upstream: Leveraging Technology and the Social Determinants of Health to Chart a New Course for Mental Health Care Don Mordecai, Kaiser Permanente, San Francisco, CA

The incidence of mental health and addiction conditions is increasing in our country, and demand for services has also been going up rapidly. Yet, roughly half of people struggling with a mental health condition in our country received no care in the past year for that condition (and even fewer struggling with addiction). We know treatment works for the great majority of people; how do we ensure that treatment is available to those who need it? Can new technologies help us solve for this problem? Potentially even greater opportunities exist in the realms of early detection and prevention. How can predictive analytics help us move "upstream" and allow our health care system to be proactive rather than reactive? Finally, we will look far upstream to see what potential may exist to address social determinants of health, specifically Adverse Childhood Experiences (ACE's), to get at some of the origins of ill health in our society. Could we prevent a substantial amount of mental health and addiction conditions (and multiple physical conditions) by preventing and ameliorating the impacts of ACE's?

# Sunday, 11:10AM - 12:40PM

# SuB01

E52 Samberg - Dining Room 6

## Medical Decision Making and Disease Progression Modeling

Contributed Session

Chair: Poria Dorali, University of Houston

1 - Multistate Survival Analysis for Optimal Lymphoma Treatments Caglar Caglayan, Georgia Institute of Technology, Atlanta, GA, United States, Turgay Ayer, Qiushi Chen, Christopher Flowers

We study the clinical course of follicular lymphoma (FL) and diffuse large B cell lymphoma (DLBCL) following initial treatment. Our objectives are to (1) assess the effectiveness of various FL treatment sequences, (2) identify a cutoff point to stop monitoring DLBCL patients receiving the standard R- CHOP therapy, and (3) examine the role of clinical and socio-demographic factors on the clinical course of these diseases. We develop two different multistate survival analysis models to capture the courses of FL & DLBCL, utilize Cox proportional hazards models to specify the impact of prognostic factors on clinical events, and use the Aalen-Johansen estimator to project the course of these diseases.

### 2 - Determining the Optimal Screening Intervals for Patients with Diabetic Retinopathy

Poria Dorali, University of Houston, Houston, TX, United States, Zahed Shahmoradi, Christina Weng, Taewoo Lee

Diabetic retinopathy (DR) is the leading cause of blindness among American adults. While timely treatment can prevent up to 98% of DR-related vision loss, only 30-60% of the patients are screened on a yearly basis due to high cost and inconvenience. Teleretinal screening is emerging as an affordable and moderately accurate alternative, yet there is a gap in how it should be implemented to maximize clinical benefit and patient adherence. In this study, we develop a POMDP model and simulation to determine the optimal timing of DR teleretinal screening and in-clinic screening exams using data from a teleretinal screening system in Harris County.

## SuB02

E52 Samberg - Dining Room 5

### **Emerging Topics in Healthcare Operations**

Emerging Topic: Healthcare Supply Chains

Chair: Yuqian Xu, University of Illinois at Urbana-Champaign, Champaign, IL, 61820, United States

### 1 - Perishable Inventory Sharing in a Two-location System

Can Zhang, Duke University, Durham, NC, 27708, United States, Turgay Ayer, Chelsea C. White

Motivated by a platelet inventory management problem, we present one of the first analysis of perishable inventory sharing in a two-location system. We formulate the problem as a stochastic dynamic program and derive structural properties of an optimal transshipment policy. We then develop a simple closed-form transshipment policy that we show provides a lower bound on the optimal transshipment quantity. We further derive approximations of the expected cost functions and present heuristic ordering policies. Using extensive numerical analyses, we show that our proposed policies perform near optimal. Comparing our results with those from the existing inventory literature, we further establish several counter-intuitive findings with managerial insights.

### 2 - Data Driven Decision Making in Chronic Care

Ujjal Mukherjee, University of Illinois at Urbana Champaign, Champaign, IL, United States, Han Ye, Dilip Chhajed

In this paper, we propose a method of data driven dynamic resource allocation for managing chronic disease. Using a large longitudinal data on diabetes patients from a clinic in United States, we demonstrate the application of the proposed method and use simulation study to show that the proposed method has the potential to significantly improve healthcare outcomes for diabetes patients. The method is general enough to accommodate the application to other chronic disease conditions which require continued engagement of patients with providers over a long period of time which includes multiple regular encounters.

### 3 - Triaging with Overcrowding: Does ED Congestion Matter?

Shuai Hao, University of Illinois Urbana-Champaign, Champaign, IL, 61820, United States, Zhankun Sun, Yuqian Xu

In this paper, we study the impact of ED congestion on triaging decision, in particular, the fast-track routing decision. Utilizing a unique data set from three hospitals in Canada, we are able to identify the ED congestion effects on fast-track routing decisions. We further examine the patients outcomes if being selected to the fast-track.

# SuB03

E52 Samberg - Dining Room 4

# Mathematical Modeling to Inform Infectious Disease Policy

Emerging Topic: Public Health and Health Policy

Chair: Eva A. Enns, University of Minnesota, Minneapolis, MN, 55455, United States

#### 1 - Playing Sex Games - An Application of Evolutionary Game Theory in Sexually Transmitted Infections

Szu-Yu Kao, MA, University of Minnesota School of Public Health, Minneapolis, MN, 55455, United States, Ankur Mani, Karen M. Kuntz, Eva A. Enns

Sexual behaviors (e.g., condom use and partner selection) influence the spread of sexually transmitted infections. In men who have sex with men (MSM), due to the concern of high risk of HIV transmission/acquisition, HIV prevalence and the knowledge of the HIV status of sex partners may affect the decision whether to have sex or the choice of condom use with sexual encounters. We employed an evolutionary game theoretic framework to understand the decision-making process behind the observed sexual behaviors in MSM.

#### 2 - Attributing Treatment and Prevention Benefits in HIV Interventions Portfolios

Eva A Enns, University of Minnesota, Minneapolis, MN, 55455, United States, Horacio A. Duarte

In HIV resource allocation, there is an ongoing question of how to allocate funding between prevention and treatment. The advent of treatment-asprevention complicated this question, as treatment was found to confer benefits to both HIV-positive and HIV-negative individuals. While the net benefits of different intervention portfolios are measured in terms of quality-adjusted lifeyears, it may be desirable to understand to whom benefits accrue and to what extent they are due to averted infections versus improved quality or quantity of life among people living with HIV. In this talk, we present methods for disentangling benefits accrual in population simulation models of HIV interventions.

### 3 - Modeling Within-host Virologic and Immunologic Dynamics of HIV Infection and Implications for ART Adherence

Yookyung Christy Choi, University of Minnesota, Minneapolis, MN, 55455, United States, Eva A. Enns

Routine clinical monitoring of blood HIV VL and CD4 count serves as surrogate markers for treatment outcomes and may reflect the extent of existing damage to the immune system, levels of ongoing infection, and treatment response. That is, these biomarkers seem to indirectly reflect a patient's physiologic capacity for immune recovery (patient heterogeneity) and treatment effect (ART adherence). To better understand longitudinal virologic and immunologic dynamics during ART and their association with individual covariates to account for patient heterogeneity, we developed a within-host mathematical model to describe a patient's clinical trajectory from biologic and pharmacokinetic estimates in patients newly initiating ART. We plan to calibrate model parameters with longitudinal data from a clinical trial with immediate- and deferred initiation groups with comparable baseline demographics and clinical characteristics. This will allow us to describe influences of timing of ART initiation and ART adherence on long-term outcomes.

# 4 - Optimizing HIV Treatment Initiation in the Context of Resistance in Mexico

Fernando Alarid-Escudero, Assistant Professor, Center for Research and Teaching in Economics (CIDE), Aguascalientes, Mexico, Carlos Chivardi, Yanink Caro-Vega, Sandra G. Sosa-Rubi, Juan Sierra-Madero, Eva A. Enns

In Mexico, resistance to first-line antiretroviral therapy (ART) is estimated to be 11%. The WHO recommends that countries initiate HIV patients on alternate ART regiments when resistance to standard first-line ART exceeds 10%. However, in Mexico, these alternate regimens are much more expensive. Routine resistance testing prior to initiating ART is an alternate approach. We evaluated the costs and benefits of different ART initiation strategies in light of drug resistance using a simulation model of HIV care and treatment in Mexico. We identify the optimal policy under current epidemiological conditions, as well as how the optimal policy changes as first-line ART resistance increases.

# ■ SuB04

E52 Samberg - Dining Room 3

### **Data Analytics in Prevalent Healthcare Issues**

Sponsored: Public Sector OR

Chair: Shengfan Zhang, University of Arkansas, Fayetteville, AR, 72701, United States

Co-Chair: Ryan Sanders, University of Arkansas, Fayetteville, AR, 72521, United States

### 1 - Understanding Efficiency of Emergency Care Providers

Yuan Zhou, University of Texas at Arlington, Arlington, TX, 76019, United States

Efficiency is an important performance measure that has been widely used in healthcare to link quality and cost. Although there is extensive literature on measuring the efficiency, the knowledge of what factors are influential on efficiency and at what level is still insufficient. This presentation will discuss two efficiency studies that attempt to fulfill some gap in this area. This first study examined the differences in efficiency of emergency department (ED) attending physicians when they worked alone versus worked jointly with residents. The second study used a linear, temporal-structured regression model to examine the impacts of contextual factors on task efficiency of ED nurses.

### 2 - Learning Preferences from Noisy Data Using Inverse Linear Programming with Application to Diet Guidelines

Taewoo Lee, University of Houston, Houston, TX, 77204-4008, United States, Zahed Shahmoradi

Given inconsistent or noisy observations as input data, we develop a new inverse optimization model that determines a set of objective functions of an LP that represents the decision maker's preferences by making the most relevant subset of the observations near-optimal. We show that the proposed inverse model identifies objective functions that are less sensitive to inconsistency or noise in the data than those obtained by the previous models. We demonstrate the proposed model in the diet recommendation context where collected diet history data can be inconsistent.

### 3 - Stacked Ensemble Learning to Predict Risk of Microvascular Events in Patients with Diabetes

Breanna Swan, North Carolina State University, Raleigh, NC, 27703, United States

Patients with diabetes are at higher risk of adult-onset blindness, renal failure, and lower limb amputations due to microvascular complications; each treatable

with early diagnosis. Here, we identify patients with diabetes at high risk of adverse microvascular events based on the ACCORD clinical trial. Stacked ensemble models with varying threshold optimization techniques are built to maximize predictive value and accuracy. Consideration is given to sampling methods aimed at balancing data of such rare microvascular events. This integrated approach was found to more accurately identify patients at high risk of adverse events than other classification methods.

### 4 - Dynamic Prediction of Tuberculosis Treatment Outcomes using a Landmark Modeling Framework

Shengfan Zhang, University of Arkansas, Department of Industrial Engineering, Fayetteville, AR, 72701, United States, Maryam Kheirandish

In this paper, we present a dynamic model to predict treatment outcomes of tuberculosis (TB) patients, which can be used to facilitate treatment decision making. We used follow-up records of pulmonary TB patients of Republic of Moldova to train the dynamic model which is designed based on a landmark modeling framework and machine learning methods. We found that collecting laboratory test results helps to predict TB patient outcomes more precisely especially between 2nd and 9th month of treatment. Sputum culture and smear test results are always among the most important variables; however, not always the most recent sputum test result is the most informative one. Anding more layers of information through follow-up test results helps improve the predictive accuracy and power of the prediction models.

# SuB05

E52 Samberg - Dining Room 2

### **Care Provider Team Behavior**

Contributed Session

Chair: Nicholas Soulakis, Northwestern University

### 1 - Healthcare Behavioural OR

Paul Harper, Cardiff University, Cardiff, United Kingdom

Behavioural OR (BOR) is defined as the study of behavioural aspects related to the use of OR methods in modelling, problem solving and decision support. In this talk I will present some motivating healthcare BOR examples including recent research exploring the nature of the relationship between service times and workload in order to assess and quantify any workforce (server) behaviours within an Emergency Department. I will also briefly report on the key findings from a comprehensive literature review on the implementation of behavioural aspects in the application of OR in healthcare (co-authored with Martin Kunc and Konstantinos Katsikopoulos).

# 2 - A Network Model for Identifying High-performing Teams in the ICU

Nicholas Soulakis, Northwestern University, Chicago, IL, United States

We present a quantitative measure of provider relationships that independently predicts stroke patient outcomes. After prospectively ascertaining severity, complications, and outcomes, we retrospectively retrieved team member activities as documented in the electronic health record, then created a bipartite provider-patient network to identify healthcare providers who jointly participated in patient encounters. An objective, risk-adjusted composite performance measure was then calculated. Our findings reveal significant differences in patient complications and outcomes between provider groups.

# ■ SuB06

E52 Samberg - Salon West

### Improving Health Systems Performance

Emerging Topic: Public Health and Health Policy

Chair: Paul Griffin, Purdue University, West Lafayette, IN, 47907-1971, United States

1 - Quantifying the Impact of Acute Stroke System of Care Transfer Protocols on Patient Outcomes

Min Kyung Lee, MS, Purdue University, West Lafayette, IN, 47907, United States

Roughly 800,000 people each year experience a new or recurrent stroke. Based on recommendations from the Joint Commission in 2015, several states have implemented a 'stroke system of care' protocol that gives EMS agencies the responsibility of diagnosing stroke patients and bypassing hospitals that are not accredited as stroke centers. We quantify the impact of implementing a stroke system of care, including potential technology changes, in both rural and urban settings using discrete-event simulation to model the stroke process that reflects policies and guidelines. We show the results for the state of Indiana, one of the eleven states in the "stroke belt".

#### 2 - Group Model Building Techniques for Improving Healthcare Systems

Niyousha Hosseinichimeh, PhD, Virginia Tech, Blacksburg, VA, 24061, United States

Group model building (GMB) is a set of techniques for developing system dynamics (SD) models with diverse stakeholders. Prior studies showed that GMB creates consensus, refines mental models, and increases the chance of applying the results. Using a case study—improving infant mortality in Ohio—this study articulates how GMB techniques are applied to develop an SD model of infant mortality with stakeholders and investigate the impact of two interventions on birth outcomes. This study contributes to modeling healthcare systems by showing how to systematically identify key stakeholders, formulate their behavior in a simulation model, and investigate their impact on health outcomes.

### 3 - Where Do I Belong? Redefining Patient Groups in a Hospital

Esmaeil Bahalkeh, MS, Purdue University, West Lafayette, IN, 47907, United States, Tze C Chiam, Yuehwern Yih

Capacity management efforts in hospitals require an effective approach to cluster patients based on their clinical needs. Grouping patients based on their service lines seems to be a natural way of doing so. However, some patients could belong to multiple service lines. Moreover, patients who are grouped in the same service line may require vastly different resources. This study aims to define patient groups based on their needs and clinical pathways. We use unsupervised learning algorithms to cluster patients based on a set of outcome measures, then we attach the cluster labels to electronic health record data and run supervised learning algorithms to derive a set of patient groups in order to optimize availability of hospital resources for each group. Since our proposed method is able to capture individual, clinical, and operational characteristics, it can complement data-driven models (e.g. simulation, Markov decision process) for effective clinical decision supports.

#### 4 - An Efficient Frontier Approach to Scoring and Ranking Hospital Performance

Daniel Adelman, PhD, University of Chicago, Chicago, IL, United States

The Centers for Medicare and Medicaid Services (CMS) Star Ratings methodology for publicly evaluating hospitals uses a latent variable model that is based on the presumption of a single, but unobservable, hospital-specific quality factor. We show how under this approach, even if hospitals improve along every dimension, they may nonetheless score lower. We develop a new approach that does not exhibit this behavior, yet also has the capability to autonomously adjust weights as measures are added or subtracted over time. Using data we score and rank nearly every hospital in the United States, and demonstrate the extent to which it agrees or disagrees with the existing approach to the CMS Star Ratings.

# SuB07

E52 Samberg - Ballroom T Practice Oriented Session

### Applications of Real Time Locating Systems in Ambulatory Oncology (Panel)

Practice Oriented Session

**Moderator**: Nikolaos Trichakis, MIT, MIT, Cambridge, MA, 02143, United States

### Panelists:

Sarah Kadish, Dana-Farber Cancer Instititue, Boston, MA, United States

Ryan Leib, Dana-Farber Cancer Instititue, Boston, MA, United States

Avishai Mandelbaum, Technion, Haifa, Israel

Arik Senderovich, University of Toronto, Toronto, ON, Canada Nikolaos Trichakis, MIT, Cambridge, MA, 02143, United States

Jessica Cleveland, Dana-Farber Cancer Institute, Boston, MA

Real Time Locating Systems (RTLS) implementations have increased in the healthcare industry despite few studies supporting efficacy. Dana-Farber Cancer Institute (DFCI) has been one of the early adopters of the technology, having deployed RTLS at its Yawkey Center, a state-of-art facility with more than 100 exam rooms and 150 infusion spaces, which are spread over eight floors, where 300-400 care providers cater to approximately 1,000 cancer outpatients, on a daily basis. In this session, researchers from DFCI, the Technion Israel Institute of Technology, MIT and University of Toronto will present a mix of successful, ongoing and future applications of RTLS as a tool for reshaping hospital operations management.

### SuB08

E52 Samberg - Ballroom I

### Stochastic Models in Healthcare Operations

Emerging Topic: Healthcare Delivery

### Chair: Vahid Sarhangian, University of Toronto, Toronto, ON, Canada

1 - Staffing and Scheduling to Differentiate Service in Time-Varying Multiclass Service Systems

Xu Sun, University of Florida, Gainesville, FL, 10027, United States, Yunan Liu, Kyle Hovey

Motivated by the Canadian triage and acuity scale (CTAS) that classifies patients in the emergency department into five acuity levels, we consider a joint staffing and scheduling problem for a multiclass queue with the objective of achieving differentiated service for each customer class. We propose new control principles (via staffing and scheduling) to guarantee that each class can achieve its prescribed performance target. Effectiveness of proposed policy is substantiated by limit theorems. We also conduct computer simulations to provide engineering confirmation and to gain insights.

#### 2 - Impact of Length of Stay on the Risk of Emergency Department Admission Decisions and Patient Outcomes

Gabriel Zayas-Caban, Mechanical Engineering Building, Madison, WI, 53706-1691, United States, Sebastian Alvarez-Avendano, Amy Cochran, Keith Kocher

We address the question of how to optimize patient outcomes in a decisionmaking scenario using causal inference in a latent variable setting. We approach this question by controlling the length of stay, which affects the decision to admit or discharge a patient over time. We examine which adjustments optimize a patient's outcome. We then analyze the impact of optimized adjustments on patient flow in the Emergency Department.

### 3 - Data-Driven Advance Scheduling of Patients with Different Priority Levels and Service Requirements

Hossein Abouee Mehrizi, University of Waterloo, Department of Management Sciences, Waterloo, ON, N2L 3G1, Canada, Mohammad Hossein Eshraghi, Vahid Sarhangian

We consider advance scheduling of multi-class multi-priority patients where different priority levels have different wait targets, and different classes have different service durations. We assume that, on any given day, the scheduling calendar is open only for the next fixed number of days, and patients who are not scheduled on the day of their arrivals will be waiting to be scheduled in the future. Using MRI data of over 3 million patient records from around 50 hospitals, we provide a discrete-time data-driven model of the problem in a finite horizon setting. We analyze the proposed model and provide an analytical gap between the expected wait time of different priority levels under the optimal offline policy and a class of online scheduling polices under some conditions. Using the MRI data, we show that although these conditions may not hold for some classes of patients, the derived gap is quite accurate for all priority levels

# SuB09

E52 Samberg - Ballroom M Practice Oriented Session

# Developing Operational Frameworks for Complex Systems (Panel)

Practice Oriented: MSOM/Healthcare

Practice Oriented Session

**Moderator**: Mitchell H. Tsai, University of Vermont Medical Center, South Burlington, VT, 05403, United States

In complex health care systems, clinical providers often use heuristics to make clinical and operational decisions. However, the underlying operational frameworks are lacking and not validated. In this session, four anesthesiologists will provide brief descriptions of the clinical processes that they have adopted from the systems engineering and economics literature. Using concepts such as parallel processing, factory cells, airplane utilization, and performance frontiers, the panelists will describe a variety of clinical systems ranging from preoperative services, pediatric sedation, and trauma responses to mass casualty events. Following the presentation, the moderator will open up the discussion to the participants in a generative manner to test the adopted frameworks.

### Panelists:

Duane Dunston, Northeastern University, Boston, MA, United States

Richard Urman, Brigham and Women's Hospital, Boston, MA, United States

Shawn Beaman, MD, University of Pittsburgh School of Medicine, Pittsburgh, PA, United States

# ■ SuB10

E52 Samberg - Salon East

### **Hospital Operations: Quality and Efficiency**

Contributed Session

Chair: Lina Song, Harvard University, Cambridge, MA, 02138, United States

### 1 - The Quality Spillover of Managed Care: An Empirical Investigation of Cancer and Racial Disparities

Lina Song, Harvard University, Cambridge, MA, United States, Joseph P Newhouse, Mary Beth Landrum, John Hsu

Managed care health plans aim to improve quality while reducing spending and are increasingly becoming popular. Evidence shows that managed care plans encourage the use of high-value care such as cancer screening, but there is a limited understanding of their quality spillover. We empirically study the spillover effect of managed care activity on care quality and racial disparities, focusing on colorectal cancer screening and incidence. We find that greater managed care penetration improves cancer screening rates in the area by encouraging the use of less invasive, cheaper screening options. However, racial disparities are aggravated as the spillover effect fell mostly among white patients.

### 2 - Vertical Integration and Quality: Evidence from the Specialist-hospital Integration

Lina Song, Harvard University, Cambridge, MA, United States, Joseph P. Newhouse, Mary Beth Landrum, John Hsu

Hospitals and physicians increasingly are consolidating ("vertical integration") in the U.S. healthcare system. In theory, consolidation could achieve better clinical integration, but also increase unnecessary use or reduce quality. We empirically examine how vertical integration affects care quality through gastroenterologists' provision of colorectal cancer screening and diagnosis. We find the evidence of a reduction in quality (i.e., increase in complications and bleeding postcolonoscopy) after physicians vertically integrate, which is mainly driven by lower use of appropriate anesthesia. Our results suggest that financial integration does not ensure quality improvement.

# 3 - Online Routing for Bed Cleaning at Wards: A Decomposed MDP Approach

Maarten Otten, University of Twente, Enschede, Netherlands, Aleida Braaksma, Richard J. Boucherie

Before admission of patients, beds at nursing wards need to be cleaned. A central bed-cleaning team visits the wards. High patient turnover and lack of buffer capacity to store clean beds result in small time windows to clean beds. We propose routing the bed-cleaning team in an online fashion and model this as a Markov Decision Process (MDP). We optimize the policy of a single ward given the policies of the other wards by solving a small-scale MDP. The small-scale MDPs are connected to each other by transforming the initial MDP into a multiplayer stochastic game. The performance of our approach is demonstrated for a case study at a Dutch hospital.

#### 4 - Predicting Bone Marrow Transplant Clinic Staffing Requirements from Historical Patient Forecasts

Richard J. Dixon, Senior Operations Research Analyst, CANA Advisors, Richmond, VA, United States

Virginia Commonwealth University's Massey Cancer Center Bone Marrow Transplant Center requested an analysis of their historical patient data to help forecast future staffing requirements. This analysis uses a myriad of machine learning and analysis tools (SAS Enterprise Miner, Tableau, and R/RStudio) with System Dynamics to formulate a staffing forecast model.

# SuB11

E52 Samberg - Room 164

### Improving Healthcare Efficiency

Emerging Topic: Healthcare Economics

Chair: Robert Batt, Wisconsin School of Business, UW-Madison, Madison, WI, 53706, United States

### 1 - Off-service Placement in Inpatient Flow Management

Jing Dong, Columbia University, New York, NY, 60208, United States, Pengyi Shi, Fanyin Zheng, Xin Jin

To facilitate coordination of care, inpatient ward beds are usually grouped into specialized units. However, inpatient wards are often associated with high server utilization and demand variability. When the waiting time for primary beds is long, patients may be placed off-service in non-primary wards. In this work, we take a data-driven approach to study off-service placement by accounting for three key aspects of the problem: the network structure of wards, the complex bed assignment policies and the effect of off-service placement on patient outcome. Our analysis quantifies the tradeoff between off-service placement and admission delay and provides solutions for performance improvement.

### 2 - Who is an Efficient and Effective Physician? Evidence from Emergence Medicine

Raha Imanirad, Harvard Business School, Cambridge, MA, 02472, United States, Soroush Saghafian, Stephen Traub

Improving the performance of the healthcare sector requires a deep understanding of the efficiency and effectiveness of care delivered by physicians. Despite recent advances, scientific methods of measuring efficiency and effectiveness of physicians have proven elusive. In this study, we utilize a large data set along with Data Envelopment Analysis to shed light on scientific metrics that can gauge physician performance in terms of efficiency and effectiveness. We also carry out a Tobit analysis to identify factors that are associated with higher levels of physician performance. In addition, our findings establish evidence for the effect of peer characteristics on physician performance.

### 3 - Coordinated Care for Mental and Physical Health

Sandeep Rath, University of North Carolina at Chapel Hill -Kenan Flagler, Chapel Hill, NC, 27599, United States, Jayashankar M. Swaminathan

Multiple clinical trials have demonstrated the benefits of coordinating treatment of mental health conditions like depression and chronic physical conditions like diabetes. However, sustainability of coordinated care outside trial settings has not been fully demonstrated. A sustainable coordinated care will be revenue neutral for the providers and improve patient outcomes. Towards this, we propose a mathematical optimization model which would optimize care management plans to improve patient outcome while balancing revenue and resource usage costs.

### 4 - The Physician Learning Curve for Quality And Cost Outcomes for Congestive Heart Failure Patients

Benjamin Grant, Kellogg School of Management, Evanston, IL, 60201, United States, Jillian Berry Jaeker, Hannah A. Jackson, R. Kannan Mutharasan, Nicholas Soulakis, Clyde Yancy, Jan A. Van Mieghem

Congestive Heart failure (CHF) has some of the highest readmission rates, mortality rates and cost of treatment. While the relationship between physician experience and improvement in health outcomes is documented for procedures, such as surgeries, it is not clear if this relationship is present for chronic illness care. We find evidence that recent accumulated physician experience, or learning, is associated with a reduction in readmissions, mortality, and costs for CHF patients.

# SuB12

E62 Sloan - Room 221

## **Designing and Learning from Clinical Trials**

Sponsored: Healthcare Applications

Chair: Hamsa Sridhar Bastani, Wharton School, Philadelphia, PA, 19104, United States

Co-Chair: John M. Silberholz, Ross School of Business, MIT, Boston, MA, 02134, United States

### 1 - Adaptive Clinical Trial Designs with Surrogates: When Should We Bother?

Arielle Anderer, University of Pennsylvania-Wharton, Wynnewood, PA, 19096, United States

Surrogate outcomes have long been used in clinical trials when the true outcome of interest is expensive, time consuming, or otherwise difficult to measure. In this work we propose optimal adaptive clinical trial designs that integrate surrogate and true outcomes, and we analytically and empirically characterize regimes where our designs are especially beneficial.

### 2 - Failing to Terminate: The Effect of Large Public Failures on Investments in Clinical Trials

Kira Stearns, University of California-Los Angeles, Los Angeles, CA, United States

There is a growing literature on the positive role that failure may play in shaping firm innovation. In this paper, I hypothesize that failure may be advantageous for recalibrating firm-level investment and development decisions. Using pipeline data from the pharmaceutical industry, I demonstrate that when firms receive negative feedback from the FDA, they are more conservative in investing in future products. Furthermore, I show this leads to higher probabilities of approval on unrelated future products. Finally, I demonstrate that this result only holds when the feedback is from decision makers external to the firm. These results have novel implications for how feedback may impact routines.

### 3 - Safely Learning to Personalize from Observational Data Angela Zhou, Cornell University/Cornell Tech, New York, NY,

14853, United States, Nathan Kallus We study the problem of learning personalized decision policies from

observational data while accounting for possible unobserved confounding. Previous approaches, which assume unconfoundedness, i.e., that no unobserved confounders affect both the treatment assignment as well as outcome, can lead to policies that actually introduce significant harm rather then benefit. Our framework optimizes the minimax regret of a candidate policy against a baseline policy over an uncertainty set for propensity weights. We prove that if the uncertainty set is well-specified, our robust policy will do no worse than the baseline and improve upon it if possible. We characterize the optimization subproblem and use efficient algorithmic solutions to optimize over parametrized spaces of decision policies such as logistic treatment assignment and decision trees. We assess our methods on synthetic data and on a clinical trial of stroke treatment, demonstrating our robust approach guarantees safety and focuses on well-evidenced improvement.

### 4 - Personalized Fluid Management in Sepsis Using Transcriptomic Endotypes

Stephen E. Chick, INSEAD, Boulevard de Constance, Fontainebleau Cedex, F-77305, France, Andres Alban, Brendon P. Scicluna, Fabrice Uhel, Alexander P. Vlaar, Spyros Zoumpoulis

Transcriptomic data has previously been used to cluster the sepsis patient population into endotypes (Scicluna et al. 2017). We explore whether the fluid strategy can be tailored to each endotype using observational data from the Molecular Diagnosis and Risk Stratification of Sepsis (MARS) project (NCT01905033). Moreover, we propose a Bayesian model of a clinical trial to determine which subpopulations can benefit from the treatments under consideration

# ■ SuB13

E62 Sloan - Room 223

### **Topics in Healthcare Operations**

Sponsored: MSOM/Healthcare

Chair: Michael Freeman, INSEAD, Singapore

### 1 - Optimal Stopping for Medical Treatment with Forecast Information

Zhichao Zheng, Singapore Management University, Lee Kong Chian School of Business, Singapore, Guang Cheng, Jingui Xie

Recent development of machine learning techniques enables accurate forecast of patient condition in the future. How to efficiently utilize the forecast information in a multi-stage medical decision-making environment, however, remains understudied. In this paper, we develop discrete-time finite horizon (partially observable) Markov decision process models incorporating (imperfect) forecast information to support medical treatment continuation decisions. We characterize the structure of the optimal policies and show that knowing even moderately accurate forecast information can lead to more personalized policies and significantly improved medical outcomes. We calibrate and test our model for the extubation problem in the intensive care unit (ICU). Using a patient-level dataset of more than 3,000 cases, we compare the performance of different extubation policies and show that incorporating forecast information can significantly decrease extubation failure rate and ICU length of stay.

### 2 - Optimizing Bed Allocation and Utilization in Nursing Homes Yangzi Jiang, PhD Student, Kellogg School of Management, Northwestern University, Evanston, IL, 60201, United States, Lauren Xiaoyuan Lu, Jan A. Van Mieghem

Nursing homes serve two types of residents: (1) Medicare-covered residents with high daily reimbursement but short length of stay (LOS); (2) Medicaid-covered residents with low daily reimbursement but long LOS. Our paper proposes a queueing model that determines the optimal bed allocation policy to maximize revenue and minimize waiting time.

### 3 - Reducing the Dimensionality of the Patient Journey: A Methodology to Analyze Medical Claims Data

Katherine Bobroske, University of Cambridge, CB2 1AG, United Kingdom, Lawrence Huan, Christine Larish

Medical and pharmaceutical claims provide a rich basis for research in healthcare operations; however, the structure and level of detail in medical claims makes it difficult to draw generalizable insights from the data. We propose a data-driven methodology to extract an overview of the patient journey. The algorithm identifies main sequential journey patterns through a combination of preprocessing, sequence analysis, and unsupervised learning. Researchers can adapt this methodology to study the effectiveness of treatment options for specific conditions or diseases within the context of real-world patient and health system complexities.

## SuB14

E62 Sloan - Room 250

### **HAS Student Paper Competition**

Sponsored: Healthcare Applications

Chair: Timothy Chan, University of Toronto, Toronto, ON, M5S 3G8, Canada

Co-Chair: Nicos Savva, London Business School, London, NW1 4SA, United Kingdom

### 1 - Optimal Genetic Screening for Cystic Fibrosis

Hussein El Hajj, Virginia Tech, VA, 24060, United States, Ebru Korular Bish, Douglas R. Bish

Newborn screening for cystic fibrosis (CF), a life-threatening genetic disorder, often involves a genetic test that searches for a subset of the 312 known CF causing mutation variants. As it is cost prohibitive to search for all variants, an important decision is which variants to select. Newborns that are classified screen positive are referred to diagnostic testing, which corrects any false positives, but a false screen negative represents a missed CF diagnosis, with potentially dire consequences for the newborn. We develop novel stochastic optimization models for selecting variants, identify structural properties of optimal selections, and develop efficient algorithms.

#### 2 - Improving the Efficiency of the Operating Room Environment with an Optimization and Machine Learning Model Michael Fairley, Stanford University, Palo Alto, CA, 94304,

United States, David Scheinker, Margaret L. Brandeau

In many hospitals, the post-anesthesia care unit (PACU), where patients recover after their surgical procedures, is a bottleneck. If the PACU reaches capacity, patients must wait in the operating room until the PACU has available space, leading to delays and possible cancellations for subsequent operating room procedures. We develop an optimization and machine learning approach to sequence operating room procedures to minimize delays caused by PACU unavailability. Using data from Lucile Packard Children's Hospital Stanford, simulation of the second half of 2016 shows that our model could have reduced total PACU holds by 76% without decreasing operating room utilization.

#### A Robust Approach to Study Multiple Treatments: 3 **Hierarchical Contrast-Specific Propensity Score** Shasha Han, National University of Singapore, NUS Business

School, Singapore, Joel Goh, Fanwen Meng, Donald Rubin

To prevent or delay the onset of the complications for diabetic patients is challenging, in part because healthcare providers lack treatment guidelines at clinic operational level. In this study, we are motivated by this setting, specifically, a provider has to decide among three treatment options: no-medication and two classes of medications (statins and fibrates) to control cholesterol for a newlydiagnosed diabetic patient. We develop a new approach that obtains causal effects of multiple treatments from observational data. We discuss how our approach overcomes several limitations of existing methods; in particular, the approach enjoys robustness to some model misspecifications.

### 4 - Does Telemedicine Reduce Emergency Department **Congestion? Evidence from New York State** Shujing Sun, University of Rochester, Rochester, NY, 14623, United States, Susan Feng Lu, Huaxia Rui

Overcrowding in emergency departments (EDs) is a common yet nagging problem. It not only is costly for hospitals but also compromises care quality and patient experience. Using a large dataset covering all ED patients of New York State, we investigate the role of telemedicine in enhancing ED e ciency. We show that on average, ED telemedicine adoption significantly reduces patients' length of stay, and the effect is larger when an ED becomes more congested. More importantly, we show that such an e ect is not a byproduct of several widely adopted health IT applications, and the e ciency improvement does not come at the expense of care quality or patient cost.

### 5 - On Withholding Capacity from Strategic Patients

Yunchao Xu, New York University, New York, NY, 10012, United States, Mor Armony, Nan Liu

Common wisdom suggests that everything else being equal, seeing patients sooner rather than later is preferable: health outcomes improve with reduced delay and so does patient satisfaction. Meanwhile, if the delay to care is reduced, rescheduling becomes easier and patients may be more inclined not to show up for their current appointments and to reschedule. We study how an outpatient care provider should manage capacity facing such patient strategic behavior. We find that under some circumstances, it is optimal for the provider to withhold capacity from patients to elicit them to show up.

# ■ SuB15

E62 Sloan - Room 262

### **Health IT and Operations**

Emerging Topic: Healthcare Information Technology and Management

Chair: Susan F. Lu, Purdue University, West Lafayette, IN, 47907, United States

### 1 - The ZocDoc Effect: How Does Online Information Impact Appointment Availability in Outpatient Care?

Yuqian Xu, University of Illinois at Urbana-Champaign, Champaign, IL, 61820, United States, Mor Armony

With the rapid development of online technology, patients are exposed to a lot of information about doctors before making appointments. This increasing availability of information raises questions regarding the impact of online channels on patients' valuation and doctors' service incentives. In this paper, we propose a queueing model to study the impact of online information on patients and doctor's decisions. We characterize the optimal strategy of the doctor and show that when the potential market size is large, the optimal strategy falls into the partial market coverage regime; while when the market size is small, the optimal strategy falls into the full market coverage regime.

### 2 - Speed-Quality Tradeoffs in Home Health: The Effects of Visit Length on Hospital Readmission

Hummy Song, The Wharton School, University of Pennsylvania, Philadelphia, PA, 19104, United States, Elena Andreyeva, Guy David

This study uses a novel dataset from a home health agency to examine the presence of a speed-quality tradeoff in the context of home health care delivery. Specifically, we use an instrumental variable approach to quantify the effects of the length of a post-acute home health visit on the likelihood of readmission to the hospital. We find that longer than average home health visits are associated with a significant reduction in the likelihood of hospital readmission.

#### 3 - The Value of Health IT Interoperability: Evidence from Inter-hospital Transfer of Heart Attack Patients Yao Li, Purdue University

We empirically investigate the effects of health IT interoperability and health information exchange on the interhospital transfer of heart attack patients. Using the New York State ED and Inpatient Databases and HIMSS Database from 2007 to 2014, we characterize the effects in terms of the speed of the transfer process and the health outcome and expenditure of transferred patients.

### 4 - Examining the Impact of Hospital Internal and External Factors on Bias in Medical Treatment

Sharma Luv, USC, Deepa Wani

This study looks at hospital, patient, legislative and market specific factors that can lead to biases in medical treatment as well as conditions under which these biases negatively influence clinical outcomes.

# ■ SuB16

E62 Sloan - Room 276

### Shocks and Innovation in Health Care Product Markets

Emerging Topic: Healthcare Economics

Chair: Ariel Stern, Harvard Business School, Boston, MA, 02163, United States

### 1 - Find and Replace: R&D Investment Following the Erosion of Existing Products

Joshua L. Krieger, PhD, Harvard Business School, Boston, MA, 02163, United States

How do R&D-intensive firms react to negative shocks to their existing products? We explore this question using FDA Public Health Advisories as exogenous shocks to approved drugs. We use detailed project-level data to examine how firms react in terms of their R&D investment and financing decisions. We document that these negative shocks lead affected firms to increase R&D expenditures, which they finance with debt. Affected firms increase theiracquisitions of drug projects from other firms, rather than developing new projects internally. Investigating the channels behind these in-licensing effects, we explore heterogeneity in treatment and competitor spillovers.

### 2 - Rushed Innovation: Reactive Licensing in the Pharmaceutical Industry

Manuel Ignacio Hermosilla, Johns Hopkins University, Carey Business School, Baltimore, MD, 21202, United States

We study an organizational source of development attrition in the pharmaceutical industry, rushed decisions. Compared to the standard notion of accelerated new product development, rush entails a lack of premeditation and a focus on nearfuture actions. The phenomenon is studied in the context of drug licensing decisions (acquisition of external drug development projects) by large pharmaceutical firms. Organizational rush is introduced quasi-experimentally, as a reaction to the pipeline gaps created by Phase 3 failures (P3Fs). Consistent with the idea that firms experience rush, we find that P3Fs significantly increase probability of licensing but only in the immediate near-future, that roughly symmetrical shocks (Phase 3 successes) do not produce the opposite effect, and that licensing is not rewarded by financial markets. Impacts on attrition are inferred by comparing development outcomes of drugs licensed in two different contexts: licensed shortly after a P3F event and otherwise. Whereas a main effect associates pre-licensing P3Fs to 0.1 higher attrition rates in post-licensing development, heterogeneous treatment effect estimates suggest that impacts vary widely and are not always significant. Suggestive evidence points to an execution mechanism whereby attrition impacts would follow from a combination of weaker due diligence and design of collaboration agreements.

### 3 - Recalls, Innovation, and Competitor Response: Evidence from Medical Device Firms

Jeffrey Macher, Georgetown University, Washington, DC, United States, Ariel Stern, George Ball

Innovation and new product development are the lifeblood of medical technology firms, yet malfunctioning products can cause immense damage. Product failures thus create managerial challenges and opportunities for focal firms and their competitors. Focal firm failures often result in sales decreases and cost increases associated with remedial public relations and manufacturing activities. Competitor firm failures, however, can create market opportunities and elicit strategic responses by focal firms. We develop theory and provide empirical evidence of how innovative activity changes in response to product recalls in the U.S. medical device industry.

# Sunday, 2:00PM - 3:30PM

# SuC01

E52 Samberg - Dining Room 6

## **Data and Models in Healthcare Operations**

Emerging Topic: Healthcare Delivery

Chair: Taewoo Lee, University of Houston, Houston, TX, 77204-4008, United States

Co-Chair: Temitayo Ajayi, Rice University, Houston, TX, 77004, United States

Co-Chair: David Mildebrath, Rice University, Houston, TX, 77005, United States

### 1 - Optimizing Lung Transplantation Waitlist Composition from the Transplant Program's Perspective

David Mildebrath, Rice University, Houston, TX, 77005, United States

Under recent regulations by the Centers for Medicare and Medicaid (CMS) and Organ Procurement Transplantation Network (OPTN), the United States has seen a rise in risk-adverse behavior among transplant programs, resulting in an increase in organ discard rate. In this work, we optimize the mix of patients on the transplant waitlist, in order to simultaneously maximize transplantation volume and manage the risk of penalization under CMS and OPTN regulation. We present a chance-constrained mixed-integer programming model for the waitlist composition problem, and derive several analytical results to provide clinical insight on the decision-making process. In addition, we derive a computationally tractable approximation model, which we use to provide the first direct qualitative comparison between CMS and OPTN regulations. We conclude that both CMS and OPTN regulation have an adverse affect on lung transplantation volume, with the latter regulations being particularly severe.

#### 2 - Data-driven Objective Selection in Multi-objective Optimization Temitayo Ajayi, Rice University, Houston, TX, 77004, United States, Taewoo Lee, Andrew J. Schaefer

A challenge in radiation therapy treatment planning is selecting which clinical objectives to use in the optimization. We propose an inverse optimization method with a cardinality constraint to infer the most important objectives from historical treatment plans. We use two methods to efficiently select a subset of objectives. The first method is a greedy algorithm, and we provide theory, in the form of a generalization of results by Nemhauser (1978), to support our results. The second method is a heuristic that selects objectives based on user-prescribed similarity metrics. We compare the proposed methods to the cardinality-constrained inverse problem and show that our method efficiently finds a small number of objectives that generates clinically acceptable treatment plans.

### 3 - Quantile Inverse Optimization: Improving Stability in Inverse Optimization

Taewoo Lee, University of Houston, Houston, TX, 77204-4008, United States, Zahed Shahmoradi

Inverse linear programming can be very sensitive to inconsistency, noise, and measurement errors in input data. We develop a new inverse linear programming approach that determines a set of objective functions of a linear program by addressing quantile statistics of optimality error. We show that the proposed inverse model improves on the previous models in terms of stability against noise and inconsistency in data. We propose an efficient algorithm to approximate the model by exploiting its connection to maximum clique problems.

#### 4 - Aperture Shape Control in Volumetric Modulated Arc Therapy Marina A. Epelman, University of Michigan, IOE, Ann Arbor, MI, 48109-2117, United States, Wilmer Henao, Edwin Romeijn, Kelly Paradis, Daniel Polan, Carlos Anderson, Martha Matuszak

Complex aperture shapes with a large perimeter relative to their area may lead to dosimetric errors within VMAT radiotherapy methodologies. Most existing planning techniques do not explicitly take this complexity into account, which may lead to treatment plans with undesirable aperture shapes. We propose to mitigate this problem by including aperture shape control into the treatment planning process. Using a column-generation heuristic, we incorporate proxies of conventional aperture shape measures into treatment optimization. Our algorithm was tested in real cases, reducing the complexity of apertures and increasing dosimetric accuracy at the expense of minimal changes in plan quality.

### 5 - Multi-point Inverse Optimization of Constraint Parameters

Houra Mahmoudzadeh, University of Waterloo, Department of Management Sciences, Waterloo, ON, N2L 3G1, Canada, Kimia Ghobadi

Consider a problem for which we know a set of feasible points (observations), say, provided by an expert, but do not know the exact constraints that shape the feasible region of the problem. Given a new observation, we would like to find out whether the new point is feasible based on past observations. Additionally, we would like to identify the optimal solution if the objective function changes. To this end, we propose a multi-point data-driven inverse optimization framework for recovering the full constraint set in partially-observable forward problems. We focus on forward linear programming models in which the objective function is known but a subset of the constraint matrix is unknown. Our inverse framework recovers the entire constraint matrix such that all the past observations are feasible, and the best-observed solution becomes optimal.

# SuC02

E52 Samberg - Dining Room 5

### Improving Quality and Motivation in Patient Care

Emerging Topic: Healthcare Supply Chains

Chair: Jon M. Stauffer, Texas A&M University, College Station, TX, 77843, United States

1 - Cross Dependence in Focus: Imperatives for Quality

Sriram Venkataraman, University of South Carolina, Department of Management Science, Moore School of Business, Columbia, SC, 29208, United States, Luv Sharma, Jayanth Jayaram

In this study, using patient-level data from California hospitals, we examine the moderating impacts of cross-dependence and similarity index on the relationship of care volume with clinical quality of care.

#### 2 - Sustaining Process Improvement in Healthcare: A Mixed-Methods Study of Learning Among Heterogeneous Users

Edward Anderson, University of Texas, McCombs School of Business, Austin, TX, United States, Aravind Chandrasekaran

Implementing and sustaining process improvement (PI) initiatives continues to be a challenge for organizations from various industries, particularly if the workers are heterogeneous (e.g. nurses and physicians). We use a multi-method approach based on a number of case studies combined with a system dynamics model to explore what factors affect the implementation and sustainment of PI initiatives under these conditions. A key insight is that the PI program's success is temporally nuanced based on employee goals, turnover, and burnout as well as management support.

### 3 - Healthcare Payment Model Impact on Hospital Readmissions

Jonathan Helm, Indiana University, Kelley School of Business, Bloomington, IN, 47401, United States, Jon M. Stauffer, Kurt M. Bretthauer

We examine how pay-for-performance (P4P) reimbursement plans, such as bundled payments and the Hospital Readmission Reduction Program (HRRP) impact the motivation for providers to reduce readmissions. Results show that P4P plans do motivate extra readmission reduction effort, but that misalignments can occur between the provider's efforts and the minimum total system cost effort. We also find there is only a small window when the bundled payment price is large enough to motivate all providers to reduce readmissions, but not so large as to over-motivate a smaller provider to perform effort exceeding the minimum total system cost effort.

# SuC03

E52 Samberg - Dining Room 4

# Applications of Decision-Making Models in Healthcare

Emerging Topic: Public Health and Health Policy

Chair: Hadi El-Amine, George Mason University, Fairfax, VA, 22030, United States

1 - Natural History Model of Depression

Melike Yildirim, Georgia Institute of Technology, Atlanta, GA, United States, Pinar Keskinocak, Julie L. Swann

We propose a natural history model of depression and examine our model with parameters from literature. We show that even negligible bias of parameters may collectively cause a significant mismatch in a model. Therefore, we systematically adjust our parameters in the line with literature to address the issues caused from biased data. A validated model might be utilized for further analysis to project the burden of disease, cost effectiveness of interventions or treatment programs.

### 2 - Analysis of Kidney Trade Networks via Webscraping

Naoru Koizumi, George Mason University, School of Public Policy, Arlington, VA, 22201, United States, Abu-Bakkar Siddique, Amit Patel, Wilson Brian

The transnational transplant tourism has been on the rise. Several regional hubs are emerging including South/East Asia, Central America, and Middle East. The kidney trade networks tend to be complex involving transnational actors of buyers, sellers, brokers and surgeons. However, this field lacks scientific tools and empirical data that can help understand the extent of the problem. We developed an algorithm to gather data from newspaper articles from the regional hubs of kidney trade. Using Python libraries: Selenium, NLTK, GeoText, Requests, and BeautifulSoup, we identified transnational networks of buyers, sellers and medical/service providers.

### 3 - Optimal Test Selection for the Screening of Heterogeneous Populations

Hrayer Aprahamian, Texas A&M, College Station, TX, 77840, United States, Hadi El-Amine

We study the design of large-scale group testing schemes under a heterogeneous population (i.e., subjects with potentially different risk), and with the availability of multiple tests. The objective is to classify the population, as positive or negative for a given binary characteristic (e.g., the presence of an infectious disease), as efficiently and accurately as possible. Our approach examines components often neglected in the literature, which are especially relevant in a heterogeneous setting. By developing key structural properties of the resulting NP-complete problems, we are able to solve them in polynomial time. Our case study, on the screening of HIV in the United States, demonstrates the substantial benefits of the proposed approach over conventional screening methods.

### 4 - Optimization of Public Access Defibrillators Compared to Guidelines-based Deployment

Christopher Sun, University of Toronto, Toronto, ON, M5G 2R2, Canada, Timothy Chan

Public access defibrillators can be used by bystanders with no prior training to resuscitate cardiac arrest victims. Optimization has been shown to improve defibrillator location decisions, maximizing cardiac arrest coverage, a measure of spatial proximity and temporal accessibility of defibrillators to cardiac arrests, as well as increasing positive patient outcomes. Despite this, optimization has yet to be compared to established defibrillator placement guidelines. We present a comparison of optimal defibrillator placement guidelines. We present a placements over a nine year study period using real patient data. Decisions in each approach were made only using historical cardiac arrest data and were evaluated on future (out-of-sample) cardiac arrests, emulating a real life deployment scenario. Depending on the number of deployed defibrillators in each approach, optimized locations increased cardiac arrest coverage by 50.7%-117.2% over the guideline-based locations and significantly improved estimated patient outcomes.

# SuC04

E52 Samberg - Dining Room 3

# Predictive and Prescriptive Analytics for Hospital Operations

Emerging Topic: Personalized Medicine and Disease Modeling

Chair: Dimitris Bertsimas, Massachusetts Institute of Technology, Cambridge, MA, 02139, United States

1 - Novel Regression Methods for Predicting Emergency Department Volume

Ivan Paskov, Massachusetts Institute of Technology, Cambridge, MA, 02139, United States,

We investigate the problem of predicting how many patients will show up to the Emergency Department of the Beth Israel Deaconess Medical Center on any given day (and of those, how many will need to be admitted, and to where). We began by exploring the modern suit of time series models, regularized regression models, and regression trees to establish a baseline. Based on these results, we were motivated to develop a new prediction tool, what we call "Stable Regression," that not only yields the highest prediction accuracy of all techniques, but also is highly interpretable - and thus is particularly appropriate for deployment in such high stakes environments as a hospital.

# 2 - Length of Stay and Mortality Prediction for a Major Hospital through Interpretable Machine Learning

Jean Pauphilet, Massachusetts Institute of Technology, Cambridge, MA, 02139, United States, Dimitris Bertsimas

We investigate how machine learning can provide precise information about various aspects of patient discharges, from predicting a patient's length of stay (LOS) to anticipating discharge destination, including mortality. Using data from the electronic health records, we predict same-day and next-day discharges with AUC in the 0.9+ range, long-stay patients with an AUC in the 0.8+ range. Similarly, we predict hospital mortality with above 90% accuracy. Among all methods, simpler and interpretable models, such as linear regression or decision trees, demonstrate very good predictive power, provide insights on discharge barriers and have been instrumental in interacting with care providers. In addition, those models are, compared to deep learning approaches, frugal in data and computational power and provide production-level analytics for EHRs.

# SuC05

E52 Samberg - Dining Room 2

### **Hospital High Level**

Contributed Session

Nalan Gulpinar, Warwick Business School, Coventry, United Kingdom.

1 - Performance Measurement Outcomes: An Analysis of Hospital Associated Infections in New York State

Herbert F. Lewis, Associate Professor, Stony Brook University, Stony Brook, NY, United States, Christine Pitocco, Jonathan Liu

An estimated 2 million patients will acquire a hospital associated infections (HAIs) while receiving care in a medical facility. The Center for Disease Control formulates yearly reports on national and state progress in preventing HAIs. In this paper, we utilize New York State (NYS) health data to measure the performance of hospitals in four HAI categories. We show the current method used by NYS to measure performance is flawed and propose an alternative based on tail probabilities. The analysis uncovers some differences in performance of years to find if there are hospitals consistently performing well or poorly.

### 2 - Prediction of Hospital Demand: A Recurrent Neural Network Approach

Susie Yin, Geisinger Health Systems, Danville, PA, United States, Andres Garcia-Arce, Eric Reich, Jason S. Puckey, Qianyu Hu

Overcrowding is an issue that is linked to many adverse events. We propose a long short-term neural network model to predict the hospital's demand for the next 5 days. Hospital demand is defined as the occupancy plus holds. This information enable leadership to take preventive actions. A Random Forest model was used as feature selection. The performance of the model is measured by the mean absolute error (MAE). The model's performances are 10.5±1.2, 13.5±2.1, 15.0±2.2, 15.3±2.9, 15.3±3.4, for the days 1 to 5 respectively. After validation, this model will be deployed across hospital campuses.

### 3 - Restructuring Inpatient Wards at a Public Hospital

Nalan Gulpinar, University of Warwick, Coventry, United Kingdom, Sebastian Rachuba, Elvan Gokalp

Structures and sizes of inpatient wards at public hospitals have grown historically and only few changes are made to the allocation of beds to wards and departments. Restructuring of existing allocations is thought to be promising with regards to a more efficient bed utilisation, especially with seasonal demand. However, resulting changes cause disruption and would affect daily working practice. We present a mixed-integer optimisation model to support ward restructuring at a public hospital. We demonstrate effects of restructuring using real world data and analyze trade-offs between restructuring effort, the resulting costs and the quality of new structures.

# SuC06

E52 Samberg - Salon West

# Disease Modeling and Data Analytics for Medical Decision Making and Health Policy Analysis

Emerging Topic: Public Health and Health Policy

Chair: Diana Maria Negoescu, University of Minnesota, Minneapolis, MN, 55455, United States

### 1 - Incentive Mechanism for the Prevention of Seasonal Influenza Outbreak

Shan Liu, University of Washington, Seattle, WA, 98195-2650, United States, TingYu Ho, Zelda B. Zabinsky, Paul A. Fishman

Vaccination and antiviral medications e ectively prevent serious flu-related complications and outbreaks. We propose an integrated health insurance mechanism, including vaccination incentives and treatment cost-sharing policies, and formulate the dynamic interaction between a single insurer and multiple insureds as a Stackelberg game. We then embed the game into an agent-based simulation to model the spread of flu in a large population. We present optimized healthcare policies in a Seattle setting using machine learning and simulation optimization approaches.

### 2 - Decision Analysis Model for Informing Breast Cancer Screening Guidelines in Peru

Shifali Bansal, University of Massachusetts, Amherst, MA, United States, Jeremy Lauer, Andre Ilbawi, Filip Meheus, Chaitra Gopalappa

Peru is currently in preparation of a national 'investment case' for the prevention of premature mortality from non-communicable diseases including breast cancer. This is informed by quantitative economic analysis of current and potentially implementable health interventions. Due to lack of suitable mathematical models specific to the Peruvian population, current mammography screening guidelines in Peru are based on extrapolations of global analysis. They also do not match with current infrastructure availability. We applied a newly developed Markov process method, developed specific to data settings that lack longitudinal data, for parameterization of a natural cancer progression model. We also applied a Markov decision process model for identifying optimal screening schedules under different choices for the lifetime number of screens. Results from this work can help inform screening guidelines specific to Peru and development of an investment case.

#### 3 - The Impact of Vaccination Delays on the Measles Epidemic in Uganda: Implications for Incentive Programs Aimed at Removing Transportation and Monetary Barriers to Vaccination Diana Maria Negoescu, University of Minnesota, 111 Church Street SE, Minneapolis, MN, 55455, United States, Vaclav Cvicek, Saif Benjaafar, Nicole Basta

Measles is a highly contagious, vaccine-preventable, viral infection. Despite recent progress, measles continues to affect children especially in resource-limited settings such as Uganda, where up to 10% of infected children die as a result of the infection. We build an age-stratified dynamic compartmental model of measles transmission and use it to assess the impact of various vaccination delay scenarios on the total number of infections expected to occur in Uganda. We then use the model to estimate the cost-effectiveness of various incentive interventions aimed at removing transportation or monetary barriers to vaccination.  4 - Is What We Observed What Really Happened? Impact of Surveillance Systems in the Biasedness of Real-time Influenza Reported Data During an Emergent Outbreak Diana Prieto Santa, Assistant Professor, Johns Hopkins University, Baltimore, MD, United States, Yuwen Gu, Richard VanEnk,

Rajib Paul, Elise Dedoncker It is unclear how data collection operations for surveillance alter the disease portrayal that influenza reported trends attempt to provide in real time during an emergency. We developed a model that simulates the surveillance operations for collection and testing of influenza specimens after an emerging outbreak is declared in the State of Michigan. We conducted screening and response surface experimental design to understand which operational factors have a significant impact in the predictive accuracy of influenza incidence trends, and to quantify the predictive power of influenza incidence trends. Our results show that all the factors significantly affect the predictive accuracy, and that the trend that better predicts the original ILI is the trend of specimens submitted for viral characterization in the Public Health Laboratories. State Health departments can benefit from the explanatory power of the submitted trend in its efforts to improve the epidemiological characterization of emergent influenza viral strains.

# SuC07

E52 Samberg - Ballroom T Practice Oriented Session

### Deceased-Donor Organ Transplantation in the US: Critical Challenges for Procurement, Utilization and the OPTN (Panel)

Practice Oriented Session

**Moderator**: Diwakar Gupta, University of Texas, Austin, TX, 78712, United States

The combination of acute shortage of transplantable human organs and the lifesaving potential of organ transplantation has brought intense scrutiny of the US deceased-donor organ procurement and utilization system. Broadly speaking, this system consists of three key players – procurement and donor management (OPO), utilization and recipient management (TxC), and management of supply and demand matching (OPTN). Researchers play a role by informing OPTN committees about the consequences of policy changes being contemplated. The session brings together experts from the three areas and a researcher. After brief remarks by the four participants, the session will provide an opportunity for open discussion on current and looming challenges facing the US Organ Transplantation System.

### Panelists:

Kevin Myer, LifeGift, Houston, TX, United States Ryan Ehrensberger, United Network for Organ Sharing,

Richmond, VA, United States

Timothy Pruett, University of Minnesota, Minneapolis, MN, United States

# SuC08

E52 Samberg - Ballroom I

# Empirical and Analytical Models in Pain Management

Emerging Topic: Healthcare Delivery

Chair: Metin Cakanyildirim, The University of Texas at Dallas, Richardson, TX, 75080, United States

Co-Chair: Abdullah Gokcinar, The University of Texas at Dallas, Richardson, TX, 75080, United States

1 - Pain Management via Opioids: Incorporating Opioid Induced Hyperalgesia

Abdullah Gokcinar, The University of Texas at Dallas, Dallas, TX, 75206, United States

Use of opioids in pain management constitutes a significant challenge in healthcare. Underprescription of opioids yields inadequate pain-relief, while overprescription leads to ongoing opioid epidemic. Both under-overprescription yield social, medical, and financial burdens for the society. Although opioids are widely accepted strong pain relief agents, they come with serious side effects, such as constipation, respiratory depression, dependence, and addiction. Furthermore, opioids can paradoxically induce even higher pain, rather than reducing it. We study the optimum opioid-use decisions in an analytical (probabilistic) model under various prescription / treatment policies. To the best of our knowledge, this work is the first application of optimization theory to the pain management context and provides us and medical professionals with a novel pain model. 2 - Dynamic Policies to Control Opioid Epidemic in United States Sina Ansari, Tuck School of Business Dartmouth College, Hanover, NH, 03755, United States, Shakiba Enayati

We are currently in a public health crisis of opioid addiction and mortality. Many interventions are proposed in practice to address the opioid epidemic. Some are directed at preventing new cases of addition with long-term benefits (e.g., prescriptions drug monitoring programs) and some aim to mitigate the impact of current cases with short-term benefits (e.g., increasing Naloxone availability). We use dynamic compartmental modeling of U.S. adults opioid use and addiction to compare the impact of preventive and mitigating interventions on population health outcomes. We discuss implications for practice.

### 3 - Aiding the Prescriber: A Machine Learning Approach to Personalized Risk Modeling for Chronic Opioid Use

Margret Bjarnadottir, PhD, University of Maryland, College Park, MD, 20742, United States

The opioid epidemic is of considerable public policy concern. The literature and policy briefs have implicated the prescribing behavior of clinicians as an important factor fueling the sharp rise in opioid use and addiction. We develop and validate high performing prediction models that can serve as the foundation for real-time decision support for prescribers making treatment choices related to opioid therapy. In contrast to prior work that has focused on patients in hospital and pain clinic settings, our context is the understudied outpatient encounter where 70% of opioid prescriptions are written. We apply a variety of machine learning algorithms to these data and examine their comparative performance. Further we derive a parsimonious set of factors and corresponding scoring mechanism that provide good predictive accuracy in data-poor health services delivery settings. Our models help isolate the most important characteristics of patients who are at risk of opioid dependence and can serve as the foundation for clinical decision support.

### 4 - Adjusting for Time Varying Confounding in Adaptive Interdisciplinary Pain Management Program Amith Viswanatha, University of Texas-Arlington, Arlington, TX,

76013, United States, Nilabh Ohol

Interdisciplinary pain management programs involve diverse medical professionals to administer a mix of analgesic and cognitive treatments to improve quality of life in patients suffering from chronic pain . The Eugene McDermott Center of Pain at University of Texas at Southwestern Medical Center in Dallas employs a two-stage adaptive interdisciplinary pain management program with the aim to improve current and future pain outcomes. The goal is to develop a decision support tool using statistics-based optimization approaches which can be used by physicians. The observational nature of the data along with treatments administered over time lead to time varying confounding between treatments and patient's state variables and pain outcomes. This induces bias in the state transition and outcome model employed in this framework. This presentation discusses the inverse probability of treatment weighting framework to address time varying confounding in estimating causal effects of treatments.

# SuC09

E52 Samberg - Ballroom M Practice Oriented Session

# Personalized Cancer Therapies using Genomic Information

Practice Oriented Session

Chair: Dimitris Bertsimas, Massachusetts Institute of Technology, Cambridge, MA, 02139, United States

Co-Chair: Holly Mika Wiberg, MIT, Cambridge, MA, 02144, United States

This session will address analytical and clinical perspectives on leveraging genomic information for cancer treatment. The rapid growth of genomic data availability offers the potential for unprecedented precision in oncology care delivery. However, this data also presents unique challenges due to its high dimensionality and biological complexity. This session will consist of three research presentations as well as a panel discussion with oncologists from Massachusetts General Hospital, Eddy Chen, MD, and Shrikanta Chattopadhyay, MBBS.

### 1 - Novel Target Discovery of Existing Therapies: Path to Personalized Cancer Therapy

Daisy Zhuo, Interpretable AI, Cambridge, MA, 02139, United States, Dimitris Bertsimas

We present a novel, machine learning and optimization-based method to identify potential targets of existing cancer drugs. Using clinical and genomic data from large national cancer hospitals, we modeled cancer signaling and treatment pathways with mixed integer optimization, and found highly promising new targets. The results are validated in external datasets and known mechanisms of action with high discovery rates. The findings suggest that a data-driven optimization approach to precision cancer medicine may lead to breakthroughs in the drug discovery process.

### 2 - Understanding Drug-Target Interactions through Gene Regulatory Networks

Holly Wiberg, Massachusetts Institute of Technology, Cambridge, MA, 02139, United States, Dimitris Bertsimas, Agni Orfanoudaki

We propose a novel graph-based optimization approach to modeling gene regulatory networks for the purpose of understanding gene interactions and pathway function in the presence of mutations. This formulation allows for the assessment of pathway disruption and provides biological insight into the optimal drug targets for a given mutation profile. Empirical results suggest that this approach recovers biologically valid relationships between genes. We extend the work by Bertsimas and Zhuo to incorporate this structured pathway model and demonstrate recovery of new drug-target interactions.

### 3 - Tensor Completion with Noisy Side Information for the Prediction of Anti-Cancer Drug Response

Colin Pawlowski, Massachusetts Institute of Technology, Cambridge, MA, 02139, United States, Dimitris Bertsimas

We consider the problem of predicting drug response of cell lines to anti-cancer treatments at particular dosages. Given (cell line, drug, dosage) data, we propose a novel method for tensor completion that learns a low-rank representation of the data and leverages noisy side information available on the rows (cell lines) and/or columns (drugs). We test our method for tensor completion with genomic side information on the Genomics of Drug Sensitivity in Cancer and the Cancer Cell Line Encyclopedia data sets. On prediction tasks with 20%-80% missing data, we show that our proposed method outperforms all state-of-the-art methods including the original tensor model and a multilevel mixed effects model.

### Panelists:

Eddy Chen, MGH, Boston, MA, United States Shrikanta Chattopadhyay, MBBS (MGH), Boston, MA, United States

# SuC10

E52 Samberg - Salon East

### **Global Health Delivery**

Emerging Topic: Healthcare Delivery

Chair: Hummy Song, Philadelphia, PA, 19104, United States

1 - Deployment Guidelines for Community Health Workers in sub-Saharan Africa

Jonas Oddur Jonasson, MIT Sloan School of Management, Cambridge, MA, 02142, United States, Carri Chan, Sarang Deo, Jeremie Gallien

Community health workers (CHWs) are increasingly important to healthcare delivery in many African countries. Leveraging an extensive dataset featuring time, clinical findings, and GPS information for CHW visits in sub-Saharan Africa, we develop a stochastic model describing the health dynamics of a population served by a time-constrained CHW. We report closed-form solutions quantifying the impact of CHW deployment on public health for a special case and build a heuristic to solve a policy maker s CHW deployment problem.

### 2 - Sustainable Development in Global Surgery

Mark Shrime, Center for Global Surgery Evaluation, Massachusetts Eye and Ear Infirmary, Boston, MA, United States

The UN's SDGs call for the end of poverty and the equitable provision of healthcare. An extended cost-effectiveness analysis using an agent-based simulation examined the numbers of lives saved, catastrophic expenditure averted, impoverishment averted, costs, and the distribution of benefits across the wealth spectrum for surgical interventions in Uganda. Only two policies provide simultaneous health and financial benefits efficiently and equitably: mobile surgical units and governmental policies that simultaneously address surgical scaleup, the cost of surgery, and the cost of transportation. Policies that only remove user fees are dominated, as is the common "surgical mission trip".

### 3 - Value of Combining Patient and Provider Incentives in Humanitarian Healthcare Service Programs

Karthik Natarajan, University of Minnesota, Minneapolis, MN, 55443, United States, Mili Mehrotra

We analyze the incentive design problem faced by a budget-constrained humanitarian organization managing a healthcare delivery program. Incentives offered to the healthcare provider are aimed at improving the quality and quantity of services offered, and demand-side incentives are used to encourage patients to seek care. In practice, incentives are often targeted at improving the availability of healthcare services. However, our results suggest that by offering the right combination of incentives to the provider and patients, program performance can be improved significantly. Furthermore, using the right incentives is critical to fully realizing the benefits of fundraising efforts.

# SuC11

E52 Samberg - Room 164

### **Economics in Healthcare**

Emerging Topic: Healthcare Economics

Chair: Susan F. Lu, Purdue University, West Lafayette, IN, 47907, United States

### 1 - The Impact of Bundled Payment Policy on Health Care Operations: Evidence from China

Jingui Xie, University of Science and Technology of China, School of Management, Hefei, 230026, China, Fan Yiming, Jingqi Wang, Yugang Yu

This paper studies the impact of bundled payment system on health care expenditures, utilization, and quality. We use insurance claim data in China to evaluate the impact of bundled payment on hospital operational performance. Our evidence suggests that transitioning from fee-for-service to bundled payment reimbursement resulted in declines in expenditures and length of stay but increases in readmissions to inpatient wards and revisits to outpatient clinics. We also investigate the effects of bundled payment price decreases compared to the historical expenditures, the impact on expenditures becomes weak. Thus, policymakers should design bundled payment prices very carefully. Our findings, in fact, indicate that a generous initial bundled payment price (e.g., a few percents less than the historical expenditures) would encourage bundled payment implementation, reducing medical expenditures while maintaining treatment quality.

#### 2 - Work after Work: The Impact of New Service Delivery Models on Work Hours

Hessam Bavafa, Wisconsin School of Business, Madison, WI, 53706, United States, Christian Terwiesch

In many professional services, an expert server such as a physician or lawyer delivers services to customers across multiple channels: in-person meetings, phone calls, and emails. In these settings, there exists a risk that work obligations encroach on the personal lives of the experts and that the content of their work might suffer. We empirically examine these concerns in the setting of physicians providing care to patients via two channels: in-person office visits and online e-visits. Our data include 3.4 million patient encounters (more than one million of which are e-visits) covering a 8.5-year timespan.

### 3 - Process Innovation in the Pharmaceutical Industry

Dimitrios Andritsos, HEC Paris, Jouy-en-Josas, France, Ivan Lugovoi, Claire Senot

Even if process innovation is commonly claimed to be a major source of competitive advantage for firms, it has received substantially less attention than product innovation. We conduct a multi-dimensional evaluation of a firm's portfolio of process innovations at the product level and carry out econometric analyses for a large-scale sample of drugs open to competitive advantage. We find a positive association between overall process innovation and firm performance. When differentiating between dimensions of process innovation, results further suggest that high novelty is beneficial, and complemented by a broad scope, but only for patents applying to the later phase of the pharmaceutical manufacturing process.

### 4 - The Impact of Delay Announcements on Hospital Network Coordination and Waiting Times

Jing Dong, Columbia University, New York, NY, 60208, United States

We investigate the impact of delay announcements on the coordination within hospital networks. We offer empirical evidence suggesting that patients take delay information into account when choosing emergency service providers, and such information can help increase coordination among hospitals, leading to improvements in Emergency Department delays. Our numerical results indicate that the level of coordination that can be achieved is limited by several factors. The most important one is the method hospitals use to estimate delays. We show that delay estimators that are based on historical averages may cause extra oscillation in the system.

# SuC12

E62 Sloan - Room 221

### From individualized Healthcare to Global Health: **Optimizing Interconnected Systems**

Sponsored: Healthcare Applications

Chair: Sauleh Ahmad Siddiqui, Johns Hopkins University, Baltimore, MD, 21218, United States

### 1 - Designing Resilient Supply Chain Against Bio-attacks

Yun Zhang, Massachusetts Institute of Technology, Cambridge, MA, 02139, United States, Nikolaos Trichakis, David Simchi-Levi

We study the problem of prepositioning medical countermeasure inventory against bio-attacks. Modeling it as a two-stage robust optimization problem, we solve large instances via so-called affine policies, prove its optimality under mild assumptions, and perform a thorough case study on prepositioning inventory in the US to guard against anthrax attacks.

### 2 - Nurse Scheduling Under Predictive Workload

Kimia Ghobadi, MIT, Cambridge, MA, 02142, United States

In this talk, we consider the problem of staff scheduling in hospitals. We employ a prediction tool to estimate the patient census and workload for the support staff in the unit. A set of optimization problems are then developed and solved to schedule the support staff in the long- and also short-term under patient arrival uncertainty.

### 3 - A Decision-support Framework to Optimize Border Control for **Global Outbreak Mitigation**

Lauren Gardner, Johns Hopkins University, Baltimore, MD, 2052, United States

Network optimization and mathematical modeling tools can be used to improve our understanding of infectious disease spreading patterns and minimize risk. This talk will introduce a decision support framework that can provide robust outbreak control policies, and minimize the risk posed by an infectious disease. The tool relies on an integrated simulation-optimization framework to solve a resource allocation problem for epidemic planning and decision making.

4 - Complex Clinical Trial Protocols are Associated with Failure to **Progress Through Regulatory Approval** Sauleh Ahmad Siddiqui, Johns Hopkins University, Baltimore, MD, 21218, United States, Felipe A. Feijoo

A significant majority of of new treatments fail during the clinical testing stage, with the majority of attrition happening at the later, most costly stages. To develop recommendations for improving productivity and reducing human and financial costs, we developed a generalizable set of models using machine learning techniques and natural language processing algorithms to analyze over 10,000 unique clinical trials and research the factors that are linked with failure in phases II and III for a diverse set of therapeutic areas. Our results indicate that common protocol characteristics across therapeutic areas — including the number of endpoints and the complexity of the eligibility criteria — are linked to failure. Our model predicts clinical trials phase transitions with an average accuracy of 80% and the methodologies developed here offer the opportunity for all stakeholders to manage risk and cut attrition, which would, in turn, begin to address the significant human and financial costs associated with bringing a drug to market.

# SuC13

E62 Sloan - Room 223

### **Empirical Research in Healthcare Operations Using Behavioral Insights**

Sponsored: MSOM/Healthcare

Chair: Maria Ibanez, Kellogg School of Management at Northwestern University, Evanston, IL, United States

1 - Incident and Near-miss Reporting in Radiation Oncology Olivia S. Jung, Harvard Business School, Boston, MA, United States, Palak Kundu, Amy C. Edmondson

Near misses-harm averted due to chance or intervention-present a low-cost learning opportunity. To study whether near misses are reported and perceived as success or failure, we surveyed radiation oncology staff and linked responses to submissions. Respondents were more likely to indicate willingness to report (WTR) scenarios deemed as failure than success. Those expressing higher psychological safety were more likely to indicate WTR for scenarios clearly due to a human error that led to a poor outcome. Conversely, those expressing lower psychological safety were more likely to use the reporting system. We also observe differences in submission of incidents by role, suggesting impact of hierarchy on likelihood to use the reporting system.

### 2 - Focusing Provider Attention: An Empirical Examination of **Incentives and Feedback in Flu Vaccinations**

Robert Niewoehner, Kenan-Flagler Business School, Chapel Hill, NC, United States, Bradley R. Staats

The US Center for Disease Control classified the 2017-18 flu season as the worst in recent history. Health literature has estimated the average annual society costs for flu are \$10.4 billion. And yet, the recent adult flu vaccination rate has remained between 38% and 44%. An OM approach would consider the supplyside: driving compliance by focusing attention on provision. Through two interventions among health clinics, we find such an approach leads to increased flu shots. In a randomized experiment, we find clinics who are provided performance feedback outperform the control and incentivized clinics. Moreover, the clinics who receive performance feedback also exhibit rank response behaviors.

### 3 - Using Social Determinant to Predict Health Outcomes

Min Chen, Florida International University, Miami, FL, 33331, United States, Rema Padman

We integrate social determinant data into patient-level clinical information and examine how this data integration will affect predictive accuracy of health outcomes.

# SuC14

E62 Sloan - Room 250

### Improved Capacity Allocation and Patient Flow in **Health Care**

Sponsored: Healthcare Applications

Chair: Antoine Sauré, University of Ottawa, Ottawa, ON, K1N 6N5, Canada

### 1 - A Queuing Network Approach to Capacity Planning for **Community Care**

Jonathan Patrick, University of Ottawa, Ottawa, ON, K1N 6N5, Canada, Hadi Bidhandi, Pedram Noghani, Peyman Varshoei

Community care services are becoming increasingly important to health delivery as patients live longer but with chronic disease. In this research, we propose a queuing network approach to capacity planning for a network of services. We take advantage of existing heuristics that calculate the probability of blocking for a given capacity plan and utilize the output of these heuristics to run a simulated annealing approach to optimize capacity allocation across the network subject to a performance guarantee related to the sum of the blocking probabilities. We apply this model to a local health region with a network of six services -acute care, long term care, assisted living, home care, rehabilitation and chronic care. We test the results of the optimization model through a simulation that incorporates more realism than is possible in the queuing model and that also allows us to determine the transient behaviour of the system as it transitions from current capacity levels to the those proposed by the optimization model.

### 2 - A Framework for Dynamic ICU Bed Management in a Public-Private Multi-Hospital System

José Tomás Marquinez, Pontificia Universidad Católica de Chile, Santiago, Chile, Antoine Sauré, Alejandro Cataldo, Juan-Carlos Ferrer

We consider a dynamic ICU bed management problem and propose a methodology that seeks to identify policies for transferring patients (classified according to diagnosis-related groups) between public hospitals and to private clinics. The methodology is based on the formulation of a discounted infinitehorizon Markov Decision Process and the use of an affine approximation architecture to represent the value function in this model. We adopt the linear programming approach to Approximate Dynamic Programming and solve the corresponding equivalent linear program using column generation. The resulting approximate optimal policies are somewhat counterintuitive as they proactively transfer some patients to other public hospitals and derive others to private clinics, even when beds are still available at the arriving hospital. The performance of the proposed methodology is evaluated by simulating its performance for a practical case based on the problem faced by the hospital network in the city of Santiago, Chile.

# SuC15

### 3 - Dynamic Advance Patient Scheduling with Short-Term Follow-Up Appointments

Vusal Babashov, University of Ottawa, Ottawa, ON, K2B 8K3, Canada, Antoine Saure, Onur Ozturk, Jonathan Patrick

In many healthcare systems, patients require multiple visits to a healthcare provider. In general, the first visit is known as the consult visit and all the subsequent visits are known as the follow-up visits. The latter typically occurs according to predefined booking guidelines. We develop a Markov Decision Process model to efficiently allocate available capacity to consults and follow-up visits in a dynamic fashion. We solve this model using the linear programming approach to Approximate Dynamic Programming (ADP) and discuss the characteristics of the approximate optimal booking (AOP) policy for a multi-class patient setting. We compare the performance of the AOP policy to that of a myopic policy through simulation.

### 4 - Dynamic Multi-appointment Patient Scheduling with Resource Compatibility Restrictions

Antoine Sauré, University of Ottawa, Ottawa, ON, Canada, Ingeborg Bikker, Xiang Claire Ma, Nathaniel Horvath, Richard J. Boucherie, Scott Tyldesley

Motivated by the importance of timely access to cancer care, we formulate and approximately solve a discounted infinite-horizon Markov Decision Process (MDP) for scheduling cancer treatments in Radiation Therapy (RT) units. The problem considers the advance scheduling of RT appointments and involves multiple treatment units with different capabilities. The main purpose of the proposed model is to identify good policies for allocating available treatment capacity to incoming demand for care, while reducing patient wait times in a costeffective manner. We develop an Approximate Dynamic Programming approach for this problem by first rewriting the MDP as a set of weakly coupled MDPs, then applying Lagrangian relaxation to the linking constraints, and finally using affine value function approximations and column generation. The benefits from the proposed method are evaluated by simulating its performance for two practical applications based on data provided by the British Columbia Cancer Agency, Canada.

# ■ SuC15

E62 Sloan - Room 262

### **Healthcare Decision Analysis**

Emerging Topic: Healthcare Information Technology and Management

Chair: M. Zia Hydari, University of Pittsburgh, Pittsburgh, PA, United States

Co-Chair: Yeongin Kim, Virginia Commonwealth University, Glen Allen, VA, 23059, United States

1 - Comparing the Distribution and Predictive Power of Medication Adherence Indexes

Changmi Jung, Assistant Professor, Johns Hopkins University, Baltimore, MD, 21202, United States, Hadi Kharrazi, Xiaomeng Ma

Prescription (Rx) complexity, as reflected in EHRs, can impair patient Rx filling adherence, and may associate with adverse outcomes such as hospitalization and increased cost. To quantify the medication management complexity and patient adherence, we adopted validated Rx adherence of Medication Regimen Complexity Index, Medication Possession Ratio, and Rx Fill-rates. We calculated these Rx adherence indicators at the patient level and summarized their distributions within a given population.

### 2 - Drivers of the Physicians Referral Networks: An Empirical Analysis

Saeede Eftekhari, State University of New York-Buffalo, Buffalo, NY, 14228, United States, Niam Yaraghi, Ram Gopal, Ramaswamy Ramesh

The objective of this research is to study the determinant factors of the referrals among physicians. Referrals usually occur when a primary care physician determines that specialist care is needed during the patient care. We model referral as the outcome of a two-stage decision process: In the first stage, the physician identifies a set of potential specialists. Typically, the identified set consists of specialists known to the primary care physician. In the second stage, the physician determines the utility of referring the patient to each specialist in the set and chooses the one that maximizes the utility value. We consider the referrals among physicians as a directed network in which a node represents a physician and a link indicates a referral from a physician to another. The flow over the link represents number of patients. We employ the zero-inflated logit regression to model the link flows by a set of physicians-level attributes. Our findings further can predict how the referral businesses will evolve over time under the referral structure.

#### 3 - Empowering Patients can Increase Digital Divide: The Effects of Patient Portals on Kidney Allocation Vengin Kim, Virginia Commonwealth University, Pic

Yeongin Kim, Virginia Commonwealth University, Richmond, VA, 23059, United States, Mehmet U.S. Ayvaci, Srinivasan Raghunathan, Bekir Tanriover

The recent healthcare reform promotes the use of information technology, such as patient portals, to provide patients better access to information sources. Motivated by the kidney transplant decision, we empirically analyze the impact of the patient portals on outcomes including time to deceased-donor transplant. We show that, overall, the adoption of a patient portal is positively associated with the probability of receiving a deceased-donor kidney. However, the impact is less for minority groups who have limited access to transplant service, which may imply further service divide in kidney transplant.

# 4 - If You're Not First, You're Last: Activity Trackers, Gamification, and Healthful Activity

Muhammad Zia Hydari, University of Pittsburgh, Katz Graduate School of Business, Pittsburgh, PA, 15260, United States, Idris Adjerid, Aaron Striegel

Lack of physical activity represents a growing global health crisis, leading stakeholders to find interventions to improve individuals' health behaviors. Gamification of health behavior such as the use of leaderboards is one intervention that has the potential to increase healthful activity. However, the extant literature does not provide conclusive evidence on the benefits of such gamification. In this paper, we investigate the effect of Fitbit leaderboards on the number of steps taken by the user. Using a unique dataset of hundreds of Fitbit wearable users, some of whom participate in a leaderboard, we find that leaderboards lead to around 350 step increase (3.5 percent increase) in the users' daily physical activity. This increase is highly heterogeneous and depends on the individual's level of activity prior to adoption. Surprisingly, we find that those who were highly active prior to adoption are hurt by leaderboards and walk around 630 fewer steps daily post-adoption, whereas previously sedentary users get a large increase of 1300 steps.

# Sunday, 4:00PM - 5:30PM

# SuD01

E52 Samberg - Dining Room 6

### **Empirical Studies in Health Care Operations Management**

Emerging Topic: Healthcare Delivery

Chair: Diwakar Gupta, University of Texas, Austin, TX, 78712, United States

1 - A Data-driven Approach for Increasing the Supply of Deceaseddonor Kidneys for Transplant

Paola Martin, PhD Student, University of Texas at Austin, Austin, TX, 78706, United States, Diwakar Gupta, Timothy Pruett

In the US there is a severe shortage of kidneys available for transplant. Annually, only 15% of the patients on the national waiting list receive transplants. The greatest potential for increasing supply comes from deceased adults over 60, who constitute the majority of deaths. Spain has been particularly successful in utilizing older donor kidneys. However, in the US older donor kidneys are hard to place because of quality concerns. OPTN data shows that 55% of patients who received kidneys from older donors have either normal or nearly normal 1-yr post transplant kidney function. This talk will describe our efforts to use machine-learning techniques to identify such donor and recipient features.

# 2 - Determinants of Acquisition Performance: Evidence from U.S. Nursing Home Chains

Kejia Hu, Assistant Professor, Vanderbilt University, Nashville, TN, 37215, United States, Susan F Lu, Lauren Lu

We studied in acquisition how determinants of the acquirer and the acquiree impact the acquisition outcomes such as financial performance, service offerings, and service quality. Based on 10-year acquisition dataset and detailed performance of nursing homes, we use quasi-experiments to evaluate the determinants of successful acquisitions. The interesting result suggests the financial status of the acquirer dominates the pre-acquisition financial status of the acquiree. Moreover, a success acquisition highly depends on whether the strategic fit of the two sides and the context familiarity in terms of geographical location.

#### 3 - Unintended Consequences of Hospital Regulation: The Case of the Hospital Readmissions Reduction Program Christopher J. Chen, London Business School, Regent's Park, London, NW14SA, United Kingdom, Nicos Savva

We study the impact of the Hospital Readmissions Reduction Program on admissions decisions. Exploiting variation in hospitals' financial exposure to the program, we show that hospitals tried to reduce readmission rates by increasing the number of patients that were classified as admitted for "observation," which avoided potential penalties associated with a regular admissions.

### 4 - How to Elicit Physician Judgment to Improve Surgery Duration Prediction Algorithms

Song-Hee Kim, University of Southern California, Los Angeles, CA, 90089, United States, Rouba Ibrahim, Jordan D. Tong, Joan Brown

Increasingly, hospitals are trying to use algorithms to predict surgery duration times. These algorithms may use both observable data and physician judgmental forecasts. Using field data, we find that physician forecasts add significant predictive value when included in algorithms — so it is desirable to incorporate their judgment. We then study how to best elicit physician judgment when these judgments are not used directly, but rather indirectly as inputs for algorithms. Through behavioral models and controlled experiments, we conjecture and find evidence that there are better ways to elicit physician judgment than directly asking physicians for their surgery duration forecast.

### 5 - The Impact of Primary Care Provider Availability on Patient Care

Hessam Bavafa, Wisconsin School of Business, Madison, WI, United States, Christian Terwiesch

Emergency room (ER) overcrowding and overuse are significant problems in the United States, and prior studies have shown that a large portion of ER patients could have been treated by a primary care provider. If this is the case, why do patients spend hours waiting in the ER for a problem that their primary care physician could have addressed? One common answer is that primary care providers are too busy to provide timely appointments, making the ER a more attractive alternative for their patients. In this paper, we use a large dataset from the Veterans Health Administration to shed light on this claim.

# SuD02

E52 Samberg - Dining Room 5

## **Decision-Making & Scheduling in Healthcare**

Emerging Topic: Healthcare Supply Chains

Chair: Melike Yildirim, Georgia Institute of Technology, Atlanta, GA

Chair: Pinar Keskinocak, Georgia Institute of Technology, Atlanta, GA, 30332, United States

### 1 - A Distributionally Robust Patient Access Planning Model for Operating Rooms

Mohammad Zhalechian, PhD Student, University of Michigan, Ann Arbor, MI, 48109-2117, United States, Mark P. Van Oyen

Controlling the access delay of surgical patients based on urgency is important, but methods are lacking. We model an integrated network of surgical services with multiple surgical classes, multiple specialties, and a range of due dates. We reserve operating room time slots for different types of surgeries. Due to the uncertainty in surgical demand, we formulate this problem as a distributionally robust optimization model (DRO) which benefits from the hospital's historical data (moment information) and provides less conservative solutions than the RO approach.

### 2 - Optimal Testing Schedules and Improved Stopping Boundaries for Sequential Adaptive Clinical Trials

Alba Rojas-Cordova, Southern Methodist University, Dallas, TX, 75219, United States

Traditionally, Phase 3 clinical trials for new drugs and therapies recruit a fixed sample size of patients over several years, and the trial's results are not analyzed until the full sample has been collected. Sequential adaptive designs allow for early termination for benefit or futility reasons at different interim analysis points. Existing sequential testing methods prescribe stopping boundaries based on statistical significance and power, but do not prescribe a testing schedule, i.e., the number of patients to recruit and observe in between any two interim analyses. We solve a stochastic dynamic programming model with Bayesian updates to derive optimal testing schedules under different success criteria, so as to maximize expected profit. We also quantify the impact of those success criteria, and provide improved futility stopping boundaries, which can be paired with existing benefit stopping boundaries, preserving statistical significance and power while incorporating financial considerations and learning from interim data.

### 3 - Stochastic Appointment Scheduling in a Team Primary Care Practice with Two Flexible Nurses and Providers

Ana Muriel, University of Massachusetts, Dept of Mechanical &Industrial Eng, Amherst, MA, 01003, United States, Ekin Koker, Hari Balasubramanian

We consider a flexible team primary care practice in which patients are seen by one of two available nurses before seeing one of two available providers. Flexibility in the nurse step is common across practices; flexibility in the provider step is relevant under primary care settings where continuity of care is not as big a concern as the timely availability of care. Both steps have uncertain durations and cross-overs may occur; that is, patients with later appointments may complete the nurse step and get to see the provider earlier than a previous patient. We generalize our two-stage stochastic programming model from Alvarez-Oh et al. (2018) to accommodate flexibility in the provider step. Computational results explore the structure of optimal schedules and the value of adding flexibility to the provider step.

#### 4 - Efficient Methodology for Extracting Features from Time-dependent Variables in Transaction Data Ryan Sanders, University of Arkansas, Cave City, AR, 72521, United States

The goal of this project is to develop an efficient methodology for extracting features from time-dependent variables in transaction data. Transaction data is collected at varying time intervals making feature extraction more difficult. Supervised representational learning techniques are investigated, and the results compared with those from other feature engineering techniques. A successful methodology provides features that improve the accuracy of any machine learning technique, as well as features that are easy to interpret. This methodology is then applied to insurance claims data in order to find features to predict whether a patient is at risk of overdosing on opioids. This data covers prescription, inpatient, and outpatient transactions.

### 5 - Static Risk-based Group Testing Schemes under Imperfectly Observable Risk

Hrayer Aprahamian, Texas A&M, College Station, TX, 77840, United States, Ebru Korular Bish, Douglas R. Bish

Testing multiple subjects with a single test applied to a group is an essential tool for classifying a large population of subjects as positive or negative for a certain binary characteristic (e.g., a disease) in an efficient manner. We study the design of easily implementable, static group testing schemes that take into account operational constraints, heterogeneous populations, and uncertainty in subject risk. We derive key structural properties of optimal risk-based testing designs, and show that the problem can be formulated as network flow problems. Our reformulation requires the evaluation of computationally expensive higher-dimensional integrals. We develop a novel statistical expression that substantially reduces the dimensionality of the required integrals, allowing us to efficiently represent and solve the reformulations. We demonstrate the impact of this research through a case study on chlamydia screening, which reveals that risk-based testing designs lead to less expensive, more accurate, and more robust schemes.

# SuD03

E52 Samberg - Dining Room 4

### Improving Healthcare Operations Through Analytics

Emerging Topic: Healthcare Supply Chains

Chair: David L. Kaufman, University of Michigan, Dearborn, MI, 48126, United States

### 1 - Managing Coordinated and Priority-based Care in Clinical and Surgical Suites under Integrated Uncertainty

Esmaeil Keyvanshokooh, University of Michigan, Ann Arbor, Ann Arbor, MI, 48108-1020, United States, Pooyan Kazemian, Mark P. Van Oven

Providing timely access to care is crucial for patients with high acuity diseases in surgical suites. We develop an integrated multi-stage stochastic and distributionally robust optimization approach for coordinating both clinic and surgery appointments to meet access delay service levels. Our methodology is applied to historical hospital data to benchmark its better performance.

### 2 - Empirical Analysis of Patient Willingness to Wait Behavior

Mustafa Y. Sir, Mayo Clinic, Rochester, MN, 55905, United States, Derya Kilinc, Esma S. Gel, Kalyan Pasupathy

We analyze patient willingness-to-wait (WtW) behavior that significantly influences patients' decisions on booking and fulfilling appointments. WtW behavior is not directly observable from historical patient appointment data. To estimate patient WtW empirically, we develop two nonparametric statistical models. We show that the proposed models can effectively identify patients' sensitivity to offered appointment delays and accurately estimate the probability of a patient fulfilling an appointment with a given delay. These models can inform designing optimal scheduling policies.

### 3 - Introducing Swing Shifts to Dynamically Respond to Emergency Department Workload Uncertainty

David L Kaufman, University of Michigan, Dearborn, MI, 48126, United States, Jianing Man, Kalyan Pasupathy, Daniel Cabrera, Mustafa Y. Sir

A fundamental problem of emergency care is matching resources to uncertain patient demands. Staffing allocation decisions require good matching with workloads but also consider the needs of emergency providers at very high risk of burnout. Mayo Clinic Emergency Department recently introduced a "swing shift," which allows physicians to leave early depending on a workload threshold. While popular, swing shifts introduce several challenges: How to design a threshold mechanism? What is the optimal length of the furlough? When should these shifts start and what is their impact? We introduce an effective and tractable datadriven optimization model for a complex stochastic problem.

# ■ SuD04

E52 Samberg - Dining Room 3

### Modeling, Performance Analysis and Control of Healthcare Delivery Systems

Emerging Topic: Healthcare Delivery

Chair: Carri Chan, Columbia Business School, New York, NY, 10027, United States

Co-Chair: Jing Dong, Columbia University, New York, NY, 60208, United States

 Dynamic Individualized Alarm Setting in the Intensive Care Unit Steven Shechter, University of British Columbia, Vancouver, BC, V6T 1Z2, Canada, Hossein Piri, Woonghee Tim Huh, Darren Hudson

ICUs are rife with alarms, many of which are false. This leads to "alarm fatigue," in which ICU clinicians may inadvertently start ignoring alarms. We develop a model to dynamically set alarm thresholds for a patient's vital signs, so as to balance the risks of false positives and negatives. We consider patient heterogeneity in safety limits for vital signs, which are initially only known through a population-based prior distribution. The model performs Bayesian updates during a patient's ICU stay. We also incorporate the "cry wolf" effect by reducing alarm response probabilities with increasing prior false alarms. We present structural properties and comparative statics of the optimal solution.

#### 2 - Online Advance Scheduling with Overtime: A Primal-Dual Approach

Esmaeil Keyvanshokooh, University of Michigan, Ann Arbor, MI, 48108-1020, United States, Cong Shi, Mark P. Van Oyen

We study an online advance scheduling problem with reward and service time heterogeneity under budgeted overtime. This is an online adversarial setting in which nothing is known about the arrival process of customers. Upon each arriving customer, the scheduler chooses both a resource and a day over a scheduling horizon without any information on the subsequent customers. By solving an online linear program, we develop new online optimization algorithms and prove a theoretical performance guarantee. Our online policies are (i) robust to future information, (ii) easy-to-implement and extremely efficient to compute, and (iii) admitting a theoretical competitive ratio. A case study of outpatient clinic scheduling is conducted to evaluate the practical performance of our online policies.

### 3 - Managing Queues with Different Resource Requirements: Insights for Patient Management

Noa Zychlinski, Columbia Business School, Israel, New York, NY, 34354, United States, Carri Chan, Jing Dong

Clinical guidelines suggest that patients should be classified based on the level of medical attention/supervision required. To understand the role of the different resource requirements on patient management, we propose a queueing model where customers may require different amounts of resources to be served. We show that a modified c-mu policy, which accounts for a patient's resource requirement, is optimal in several settings. Additionally, we show that a non-idling variant of our proposed policy exhibits several properties that make it desirable for use in practice.

### 4 - Joint Patient Selection and Scheduling under No-Shows: Theory and Application in Proton Therapy

Nikolaos Trichakis, MIT, Cambridge, MA, 02143, United States, Soroush Saghafian, Ruihao Zhu

Motivated by the acute supply-demand mismatch facing healthcare providers that adopt emerging treatment technologies, we develop a patient selection and scheduling policy that strives to make the most efficient use of available capacity. The policy we derive is simple, interpretable, robust to no-shows, and is backed by theoretical performance guarantees. Numerical experiments with real data from the Proton Radiation Therapy Center of a leading US hospital showcase the potential benefits of using our approach.

# SuD05

E52 Samberg - Dining Room 2

### Scheduling

Contributed Session

Chair: Marco Bijvank, University of Calgary, Calgary, AB, T2N 1N4, Canada

1 - Online Appointment Scheduling with Different Urgencies and Appointment Lengths

Aleida Braaksma, University of Twente, Enschede, Netherlands, Jivan Romain Deglise-Hawkinson, Brian T. Denton, Mark P. Van Oyen, Richard J. Boucherie, Martijn R. Mes

The challenge in online appointment scheduling is to not only schedule the current appointment optimally, but also enable efficient scheduling of future appointment requests. We study a problem with different access time norms and appointment lengths for different patient types. The objective is to maximize the number of patients served within their access time norm, while utilizing resources efficiently. We develop an Approximate Dynamic Programming approach to determine both the day and starting time for each appointment request, and illustrate its performance by application to a short stay nursing ward in the Amsterdam University Medical Center, the Netherlands.

### 2 - Optimal Stationary Appointment Schedules

Alex Kuiper, University of Amsterdam, Amsterdam, Netherlands

A prevalent operations research problem concerns the generation of appointment schedules that deal with variation in service times. In this talk we focus on the situation in which there is a large number of statistically identical customers, leading to an essentially equidistant ('stationary') schedule. We develop a powerful approach that minimizes an objective function incorporating the service provider's idle times and the customers' waiting times. Our main results concern easily computable, or even closed-form, approximations to the optimal schedule with a near-perfect fit. In addition, explicit heavy-traffic approximations are provided, which, as we argue, can be considered as robust.

#### 3 - A Sequential Approach to Optimal Appointment Scheduling and Sequencing

Robert H Lee, University of Amsterdam, Amsterdam, Netherlands, Alex Kuiper

We consider the joint problem of both sequencing and scheduling heterogeneous patients. We consider the case of log-normally distributed service times. Based on the mean and standard deviation we develop a method that sequencingly comes to an optimal schedule. We prove that for a given mean sequencing in increasing order of variance is optimal, and when idle time is considered more important than waiting time sequencing in order of increasing mean is also optimal. For the cases in which the mean and variance move in opposite directions we provide contour plots to decide which client should be scheduled next. As such the paper provides guidelines for practitioners in the field.

### 4 - Scheduling of Physicians with Time-Varying Productivity Levels in Emergency Departments

Zhankun Sun, City University of Hong Kong, Kowloon, Hong Kong, Farzad Zaerpour, Marco Bijvank

Traditionally, physicians are assigned to shifts based on preferences or other conditions like fairness or ergonomics. As a result, physicians are considered interchangeable. However, each physician has a different productivity (measured as the number of new patient assessments in an hour, or PPH rate). Ignoring the heterogeneity between physicians can lead to congested EDs. We show with a regression analysis that the PPH rate is a physician characteristic independent of the congestion level at the ED. Next, we solve the physician scheduling problem with a stochastic programming formulation, where we incorporate the stochastic nature of both patient arrivals and physician productiveness.

## SuD06

E52 Samberg - Salon West

### **Treatment and Access Policies**

Emerging Topic: Public Health and Health Policy

Chair: Gregory Critchley, Ivey Business School - Western University, Delaware, ON, N0L1E0, Canada

### 1 - Medical Reversals: Understanding De-adoption of Ineffective or Unsafe Treatments

Pinar Karaca-Mandic, University of Minnesota, Minneapolis, MN, 55455, United States, Lucas Higuera, Nihar Desai, Bryan Dowd, Alex Everhart, Jeph Herrin, Molly Jeffery, Anupam Jena, Joseph Ross, Laura Smith, Aaron Spaulding, Nilay Shah

In most cases, new clinical evidence supporting approval by federal regulators demonstrates efficacy of new treatments; after approval, new evidence for existing treatments may show them to be ineffective or unsafe. Much of the focus on diffusion of evidence is focused on adoption of new treatments; less is known about de-adoption of treatments that are shown to be ineffective or unsafe. The de-adoption process is not necessarily the reverse image of adoption. Using administrative claims data for Medicare Fee-for-Service, Medicare Advantage and commercially insured populations in the United States, and focusing on several case studies in which clinical evidence or guidelines show treatments to be ineffective or unsafe, we examine several questions: Whether and how fast do physicians de-adopt? What is the extent of physician variation in de-adoption? Which physician characteristics are associated with the de-adoption? Are there racial/ethic, socioeconomic, and geographic disparities that emerge in the de-adoption process?

### 2 - Modeling the Effect of Presumed Consent on Organ Transplant Waiting List Candidates

Luke DeRoos, University of Michigan, Ann Arbor, MI, 48104, United States, Wesley Marrero, Mariel Sofia Lavieri, David W. Hutton, Neehar Parikh

We present an analysis of how a presumed consent, opt-in organ donation policy would have affected solid organ transplant waiting lists in the United States from 2004-2014. The model considers a range of deceased donor donation rate increases, as well as a range in organ allocation efficiency to estimate the impact of presumed consent. The key metrics studied are the number of patients who become too sick or die while waiting for transplant, the quantity of waiting list candidates, and estimated patient life years gained.

### 3 - Coordinating Multi-payer Health Care Systems

Gregory Critchley, Ivey Business School - Western University, Delaware, ON, N0L1E0, Canada

Multi-payer health care systems are common. In the United States and Canada many individuals are covered under private or employer-sponsored health plans prior to age 65 and, thereafter, covered by public insurance. The objectives of this study are to analytically characterize the optimal treatment policy for a multi-state progressive disease within a single-payer system, compare the results to the optimal treatment policies in a multi-payer system, and to develop contracts between the payers that coordinate the system. We formulate the problem as a multi-decision-maker Markov decision process and analytically characterize and compare the optimal treatment policies.

### 4 - Modeling the Cost-effectiveness of Liver Cancer Treatments

David W Hutton, University of Michigan, Ann Arbor, MI, 48105, United States, Amit Singal, Neehar Parikh, Kexun Zhou, Qiu Li

This talk will provide an overview of some recent liver cancer treatments and discuss modeling and evaluation of the cost-effectiveness of these different therapies and how cost-effectiveness may vary in different countries. Specifically, we will discuss the cost-effectiveness of sorafenib versus selective internal radiation therapy for patients with unresectable hepatocellular carcinoma (HCC), the cost-effectiveness of lenvatinib as first-line treatment for HCC, and the cost-effectiveness of regorafenib as a second-line therapy for patients with advanced HCC in China and the United States.

# SuD07

E52 Samberg - Ballroom T

# Healthcare Queuing Systems: Modeling and Prediction

Sponsored: MSOM/Healthcare

Chair: Fernanda Bravo, UCLA Anderson School of Management, Los Angeles, CA, 90024, United States

1 - Structural Estimation of Intertemporal Externalities on ICU Admission Decisions

Yiwen Shen, Columbia Business School, New York, NY, United States, Carri Chan, Fanyin Zheng

The ICU in a hospital often has the highest cost and congestion level. Patient care in capacity-constrained hospital units sometimes results in adverse scenarios. Our study focuses on the intertemporal externalities on the ICU admission decisions. We take the structural estimation approach which allows us to estimate the intertemporal externalities from data. We use two years of detailed patient-level data from 21 hospitals in the estimation. We find there is substantial heterogeneity in the estimated discount factors across hospitals. Those hospitals with higher proportion of ICU admission from surgical patients tend to be more forward-looking in making the admission decision.

### 2 - Hybrid Decision Making: When an Interpretable Model Collaborates with a Black-box Model

Tong Wang, University of Iowa, Pappajohn Business Building, Iowa City, IA, 52245, United States

This work addresses the situation where a black-box model outperforms all its interpretable competitors. The existing solution to understanding the black-box is to use an explainer model to generate explanations, which can be ambiguous and inconsistent. We propose an alternative solution by finding an interpretable substitute on a subset of data where the black-box model is overkill or nearly overkill and use this interpretable model to process this subset of data, leaving the rest to the black-box. This way, on this subset of data, the model gains complete interpretability and transparency to replace otherwise non-perfect approximations by an external explainer. This transparency is obtained at minimal or no cost of the predictive performance. Under this framework, we develop Partial Substitute Rules (PSR) model that uses rules to capture the subspace of data. PSR is agnostic to the black-box model. We apply PRR to several medical datasets and experiments show that PSR obtains an effective trade-off between transparency and interpretability.

### 3 - Simple Rules for Predicting Congestion Risk in Queueing Systems

Yuting Yuan, Simon Business School, University of Rochester, Rochester, NY, United States, Fernanda Bravo, Cynthia Rudin, Yaron Shaposhnik

We study the problem of predicting congestion in service systems in order to improve the overall system performance by initiating preventive measures, such as rescheduling activities or increasing short-term capacities. To this end, we define "high-risk states" as system states that are likely to lead to a congested state in the near future, and strive to formulate simple rules for determining whether a given system state is high-risk. We show that for some queueing systems such as the  $M/M/\infty$  queue with multiple customer classes, such rules could be approximated by a quadratic function on the state space. For more general queueing systems, we demonstrate through extensive computational study that machine learning algorithms can be effectively used to devise simple rules of various forms, and that in many cases linear classifiers provide very accurate proxies.

# SuD08

### E52 Samberg - Ballroom I

## Models and Methods for Addressing Patient Outcomes in Healthcare Delivery

Emerging Topic: Healthcare Delivery

Chair: Gabriel Zayas-Caban, University of Wisconsin-Madison, Madison, WI, United States

### 1 - Robust Statistical Learning Methods for Difference-in-Differences Designs

Toyya Pujol, Graduate Research Assistant, Georgia Institute of Technology, Atlanta, GA, United States, Sherri Rose

Typical methods for difference-in-differences (DID) analyses rely on parametric statistical models that make strong assumptions about the unknown underlying functional form of the data. Our project extends statistical machine learning methods to target a DID parameter while (1) considering a larger nonparametric model space that makes fewer assumptions and (2) accounting for nuances commonly found in health care research questions. We develop this framework for health care DID designs that also allows researchers to estimate causal or statistical effect quantities using double robust machine learning while providing statistical inference. The method is demonstrated in simulation settings and a health care policy application estimating the effect of an episode-based bundled payment program on perinatal spending.

#### 2 - A Newsvendor Model for Optimizing Surgical Preference Cards Berk Gorgulu, University of Toronto, Toronto, ON, Canada, Vahid Sarhangian

Surgical procedures require a large number of supplies that need to be picked and prepared before the surgery. A surgical preference card, associated with each surgery, specifies the required supplies and their fill quantity. As the usage in the surgery room is subject to uncertainty, in addition to fill number, for each supply the cards also indicate how many items should be opened at the beginning of the surgery, and how many should be kept on hold. Opened items that are unused are wasted, while unused supplies need to be returned and re-shelved for later use. In this work, we formulate the problem of determining the optimal fill and open quantities on a surgical preference card as a generalized newsvendor problem, which aims to balance the expected total operational and wastage costs incurred for the surgery. We explore the structure of the problem and identify simple solutions that are largely robust to the usage distribution and the cost parameters. We evaluate the performance of our solution using usage data from a hospital in Ontario, Canada.

### 3 - Impact of Split-flow Models in Emergency Departments on Patient Outcomes

Gabriel Zayas-Caban, Mechanical Engineering Building, Madison, WI, 53706-1691, United States, Juan C. David-Gomez, Amy Cochran, Brian Patterson

Many interventions have been proposed to alleviate crowding in Emergency Departments (EDs). One group of interventions that has gained popularity is the creation of "split flow" models, in which a provider is stationed at patient intake and briefly sees all walk-in patients. In this project, we use observational data from a tertiary teaching hospital to evaluate the impact of the split-flow model on length of stay and other patient outcomes (e.g., ED revisits, readmissions).

### 4 - A Community-based Approach to Address Opioid Use Disorder Paul Griffin, Purdue, Regenstrief Center for Healthcare

Engineering, West Lafayette, IN, 47907-1971, United States

Substance use disorder, including opioid use disorder (OUD), is a challenging mental health issue that no single intervention can effectively address. Rather, a systems approach that actively engages an OUD individual with their related community entities (i.e., small care neighborhood) is needed. We present our current efforts to reduce opioid-related overdoses and relapse and to improve referral coordination in two communities in Indiana.

# SuD09

E52 Samberg - Ballroom M

### **Public Health and Health Policy**

Contributed Session

Chair: Sayanti Mukherjee, The State University of New York-Buffalo, Buffalo, NY, 14260, United States

1 - Using Domain Knowledge from Gbd Studies to Guide Models of Observational Data for Evaluating Impact of Behavioral Interventions on Dalys

Ozden F. Gur Ali, Koc University, Istanbul, Turkey

We introduce a method to evaluate the potential impact of a public health intervention by guiding individual level disease prevalence models of local observational data with domain knowledge. The estimate reflects impact of multiple risk factors, their uncertainty and heterogeneity. Empirical evaluation on impact of behavioral interventions on Ischemic Heart Disease (IHD) and Diabetes prevalence in the Turkish adult population indicates that the method predicts disease prevalence better than Random Forest, while complying with domain knowledge. Causal Forest models show a similar average treatment effect, while getting the sign of the impact incorrect for a quarter of the population.

### 2 - Comparative Analysis of Climate-induced Suicidal Rates among Urban and Rural Populations in the U.S.

Sayanti Mukherjee, Assistant Professor, University at Buffalo, The State University of New York, Buffalo, NY, United States, McKenzie Worden, Andrew Kopanon

Millions of Americans suffer from mental illness. Climate change has significant influence on mental health, with marginalized population and disadvantaged groups - rural communities, elderly, children and women, being the most vulnerable. Here, we propose a data-centric framework to evaluate climate-induced mental health issues, measured by suicidal rates. We train a wide range of statistical learning models to quantify such impacts across rural / urban populations in the U.S. We select the best model based on goodness of fit and predictive accuracy. Proposed framework will aid in informed decision making to design efficient healthcare programs / response strategies to minimize such effects.

#### 3 - A Data-driven Framework to Identify and Assess the Risk Factors Leading to Suicide Ideation and Attempts Among Youths

Sayanti Mukherjee, Assistant Professor, University at Buffalo, The State University of New York, Buffalo, NY, United States, Hiteshkumar Bharat Gohil, Shivam Mayankbhai Dave, Aditya Maunakabhai Patel

Suicide occurs often among older than the younger generation, but it is still one of the primary causes of death in late childhood and adolescence globally. This not only results in direct loss of young lives but also has disruptive psychosocial and adverse socioeconomic effects. Here we present a data driven framework to investigate various risk factors leading to increased rate of suicide ideation/attempts, leveraging advanced statistical learning methods and using survey data from the Youth Risk Behavioral Surveillance System. Understanding the complex interplay of key risk factors will aid in informed decision making and development of effective prevention strategies for the youth suicides.

# SuD10

E52 Samberg - Salon East

### Admissions and Appointment Scheduling

Contributed Session

Chair: Yin Xi, UT Southwestern Medical Center, Dallas, TX, 75390-9061, United States

### Determinants of ICU Readmission Prediction Model Performance: A Systematic Review and Meta-analysis Shiping Liu, University of Maryland, College Park, MD, United States, Sean Barnes, Miranda Myers, Guodong Gao, Michael T. McCurdy

We performed a systematic review and meta-analysis of intensive care unit (ICU) readmission prediction. We extracted characteristics about data collection and model development from eligible studies, and identified several variables significantly associated with model performance via an iterative forward stepwise variable selection procedure. Our analysis should inform better ICU readmission prediction modeling and motivate similar studies involving other relevant outcomes.

### 2 - Decision Analysis on Targeted Intervention to Reduce Patient No Show

Yin Xi, Assistant Professor, UT Southwestern Medical Center, Dallas, TX, United States, Kelsea Marble, Karen Wang, Seth Toomay, Mujeeb Basit

Accurate identification of appointments with high no-show probability is a vital step in optimizing health care outcomes. Literature on retrospective patient no-show predictive modeling often ignore cancellations. The Medical record system in our institution provides daily probability of no show for all scheduled appointments. This enable the possibility of targeted reminder/overbook on appointments with high no-show risk. We investigated the optimal intervention time and targeted threshold for three strategies of manual phone call reminder. We maximize the number of refilled slots for every additional manual phone call.

# ■ SuD11

E52 Samberg - Room 164

# Optimization Model to Improve Population Health Outcomes

Emerging Topic: Public Health and Health Policy

Chair: Shan Liu, University of Washington, Seattle, WA, 98195-2650, United States

### 1 - Modeling of Population Impact of Efforts to Eliminate Hepatitis B

David W Hutton, University of Michigan, Ann Arbor, MI, 48105, United States, Sam So, Mehlika Toy

Hepatitis B (HBV) afflicts 250 million people and kills over 850 thousand people each year worldwide. We evaluate the cost-effectiveness and population impact of efforts to eliminate HBV. In many countries around the world, efforts to identify affected individuals and get them life-saving treatment are highly cost-effective. In the United States alone, dramatic increases in screening and treatment would prevent between 80,000-100,000 cases of cirrhosis, 50,000-60,000 cases of liver cancer, and 80,000-100,000 HBV-related deaths over the next 50 years. Policymakers around the world can use online tools to see a country-specific customized evaluation of cost-effectiveness of HBV treatment.

### 2 - Radiotherapy with Imperfect Information

Archis Ghate, University of Washington, Seattle, WA, 98155, United States

The goal in radiotherapy for cancer is to maximize tumor-kill while limiting toxic effects on nearby healthy anatomies. This is attempted via spatial localization and temporal dispersion of radiation dose. Existing research attempts to adaptively optimize spatial and temporal distributions of radiation dose based on the tumor's observed response to treatment. It assumes that the stochastic evolution of tumor's condition can be modeled without error. I will present an imperfect information variation that relaxes this assumption and then outline a few competing approximate solution methods. Preliminary numerical experiments may be described if time permits.

### 3 - Optimizing Diabetes Screening Schedules

Sze-chuan Suen, University of Southern California, Los Angeles, CA, 90089-0193, United States, Chou-Chun Wu

High body mass index (BMI) may raise the risk for acquiring type 2 diabetes, but current guidelines do not provide BMI-category-specific screening frequency recommendations by age and prior testing history. We aim to determine the optimal screening policy with the above factors using a Partially Observable Markov Decision Process. We assume the physician has an estimate of the likelihood the patient is healthy, pre-diabetic, or diabetic at each period and updates his beliefs about the patient's health given progression trends and observed test results. We find that the current recommended screening policy is sub-optimal, and high-risk individuals should be screened roughly every six months between ages 45 and 85.

### 4 - An Evolving Contact Network Algorithm for Simulating HIV Epidemic Predictions

Sonza Singh, University of Massachusetts, Amherst, MA, United States, Matthew Eden, Rebecca Castonguay, Buyannemekh Munkhbat, Hari Balasubramanian, Chaitra Gopalappa

Agent-based network modeling (ABNM) is suitable for simulating multiple interacting events related to contact network structures, behavior, and care access for predicting epidemic trajectories. However, ABNM is challenging to use for national-level epidemic prediction modeling of HIV due to disproportionate HIV prevalence across population groups in the US and low overall prevalence. We present a new modeling technique, the evolving contact network algorithm (ECNA), that simulates only infected persons and immediate contacts by utilizing properties of degree correlations in scale-free networks.

# SuD12

E62 Sloan - Room 221

# Mathematical Modeling for Capacity Management

Sponsored: Healthcare Applications

Chair: Shannon Harris, The Ohio State University, Columbus, OH, 43203, United States

Chair: Sean Barnes, Univ of Maryland-College Park, College Park, MD, 20742, United States

 Proactive Rescheduling to Mitigate the Effects of Advance Cancellations and to Improve Clinic Resource Utilization Shannon Harris, Virginia Commonwealth University, Richmond, VA, 43203, United States, Luis G. Vargas, Jerrold H. May, Bjorn Berg

It is a common assumption that outpatient clinics are passive participants in the appointment booking process. If a patient cancels an appointment during the appointment lead time and another patient does not book an appointment in the time slot, it will remain empty. However, if the clinic can proactively manage appointments, it may be able to increase the expected utilization of its appointment slots, by potentially rescheduling appointments. We model the evolution of an appointment during its lead time and prescribe general rules for when and how such appointment movements should occur in order to maximize expected utilization. We demonstrate our results on a dataset from local outpatient clinics.

### 2 - Advanced Practice Providers in Emergency Departments to Improve the Patient Experience

Krista Foster, University of Notre Dame, Notre Dame, IN, 15217, United States, Jennifer S. Shang

We study the current roles of advanced practice providers in emergency departments throughout a large multi-facility network and identify conditions under which the addition of advanced practice providers would benefit hospitals (reduce costs) and patients (reduce waiting times). We propose a model to optimally staff hospitals with emergency physicians and advanced practice providers to meet patient demand.

### 3 - The Role of Asset Sharing in Sustaining Shortage of Equipment in Hospital Units: Evidence From Networks and Egocentric Probabilistic Models

Diego A. Martinez, Assistant Professor, Johns Hopkins University, Baltimore, MD, 21287, United States

Timely availability of infusion pumps is central to the provision of high-quality care, particularly for patients with acute conditions in need of infusion therapy including surgery and sepsis. However, infusion pumps are a shared asset among hospital units with no central system managing their allocation. We performed a quantitative analysis of the nature and extent of the unit-to-unit infusion pump movement as a possible factor contributing to a perceived shortage of infusion pumps in the hospital floor and designed and implemented a smart asset management system to relocate equipment where needed. We demonstrate how we exploit network phenomena to spread positive behavior, in part because a hospital unit's perceptions of their own risk of losing equipment depend on the units around them. Hospital units are connected, and so their operational performance is connected.

# SuD13

E62 Sloan - Room 223

# Behavior, Incentive and Policy: Stochastic Modeling and Field Studies

Sponsored: MSOM/Healthcare

Chair: Tinglong Dai, Johns Hopkins University, Baltimore, MD, 21202, United States

Co-Chair: Can Zhang, Duke University, Durham, NC, 27708, United States

# 1 - Nudge(able?): Field and Experimental Studies on Organ and Tissue Donation

Sridhar R Tayur, Carnegie Mellon University, Tepper School of Business, Pittsburgh, PA, 15213, United States, Jonathan Kush, Brandy Aven

More than 60 percent of US citizens die without having given first-person consent for organ donation. We focus on increasing the next-of-kin donation rate by introducing a behavioral "nudge" via a video intervention to increase consent. We conducted three studies: a quasi-experiment with pre-post design for organ donation decisions with the New Jersey OPO (Study 1), a randomized field experiment on tissue donation decisions with the Nevada OPO (Study 2), and an online experiment for a hypothetical donation scenario (Study 3). We compared the efficacy of two types of videos on donation: informational videos (Video-I) and interviews with next-of-kin representative of the minority communities (Video-D). We found that Video-D worked slightly better on targeted minorities but both videos demonstrated some efficacy in increasing donation rates. Our findings suggest that incorporating informational videos into current processes is an effective, low-cost intervention to increase overall donation rates.

### 2 - Jumping the Line, Charitably: Analysis and Remedy of Donor-Priority Rule

Tinglong Dai, Johns Hopkins University, Baltimore, MD, 21202, United States, Ronghuo Zheng, Katia P. Sycara

The ongoing shortage of organs for transplantation has generated an expanding literature on organ allocation. By contrast, organ donation has been little explored. In this paper, we develop a parsimonious model of organ donation to analyze the welfare consequences of introducing the donor-priority rule, which grants registered organ donors priority in receiving organs, should they need transplants in the future. We model an individual's decision to join the donor registry, which entails a tradeoff between abundance of supply, exclusivity of priority, and cost of donating (e.g., psychological burden). We show that, in contrast to the literature, introducing the donor-priority rule can lower social welfare due to unbalanced incentives across different types of individuals. In view of the potentially undesirable social-welfare consequences, we consider a freeze-period remedy. We show this additional market friction helps rebalance the incentive structure and guarantee an increase in social welfare.

### 3 - Size Based Exception Points for Fair Liver Allocation

Mustafa Akan, Associate Professor of Operations Management, Pittsburgh, PA, 15213, United States, Musa Eren Celdir, Sridhar R. Tayur

Patients on the waiting list for liver transplants receive priority based on their Model for End-Stage Liver Disease (MELD) scores, which reflect the severity of liver disease. Recent studies have shown that for patientw with Hepatocellular Carcinoma (HCC), shorter candidates and women (which may relate to smaller stature) have longer wait times and lower probability of liver transplant. Using a queueing model and data from the Scientific Registry of Transplant Recipients (SRTR), we investigate whether additional MELD exception points would help equalize the sizebased disparity in organ access.

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### 4 - Prioritizing Hepatitis C Treatment in US Prisons

Can Zhang, Duke University, Durham, NC, 27708, United States, Turgay Ayer, Anthony Bonifonte, Anne Spaulding, Jagpreet Chhatwal

Hepatitis C virus (HCV) prevalence in prison systems is ten times higher than in the general population in the United States. Hence, prison systems offer a unique opportunity to control the HCV epidemic. New HCV treatment drugs are very effective, but providing treatment to all inmates is prohibitively expensive, which precludes universal HCV treatment in prison systems. Current practice recommends prioritizing treatment based on clinical and incarceration-related factors, including disease staging, remaining sentence length, and injection drug use (IDU) status. However, there is controversy about how these factors should be incorporated because of the complicated trade-offs. In this study, we propose a restless bandit modeling framework to support hepatitis C treatment prioritization decisions in prisons. We also validate our model using real-world data and test the performance of our proposed policy against several benchmark policies using a realistic agent-based simulation model.

# ■ SuD14

E62 Sloan - Room 250

# Data-driven and Personalized Medical Decision-Making

Sponsored: Healthcare Applications

Chair: Gian-Gabriel P. Garcia, University of Michigan, Ann Arbor, MI, 48105, United States

Co-Chair: Mariel Sofia Lavieri, University of Michigan, Ann Arbor, MI, 48109-2117, United States

## 1 - Optimal Defibrillator Deployment Versus Actual Deployment

Timothy Chan, University of Toronto, Mechanical and Industrial Engineering, Toronto, ON, M5S 3G8, Canada

Public defibrillators, which are located throughout cities worldwide, can be used to resuscitate cardiac arrest victims by bystanders with no training. However, actual location decisions to date are largely not data-driven. In this talk, we present a head-to-head comparison of optimal defibrillator locations (intervention) against actual defibrillator locations (control) using nine years of real data. At every decision epoch, the optimization model can only make decisions based on past data. On out-of-sample, future cardiac arrests, the optimization model improves spatiotemporal coverage, a measure of spatial proximity to cardiac arrests and temporal accessibility of the defibrillator, by 50-100% compared to actual location decisions. Estimated survival increase due to this coverage improvement is 50-80%.

### 2 - The Value of Missing Information in Severity of Illness Score Development

Osman Ozaltin, North Carolina State University, Industrial and Systems Engineering, Raleigh, NC, 27605, United States, Joseph Kapena Agor, Julie Simmons Ivy, Muge Capan, Ryan Arnold, Santiago Romero

The objective of this work is to quantify the impact of missing and imputed variables on the performance of prediction models used in the development of sepsis-related severity of illness scoring systems using EHR data. We find that there is a significant increase in performance when moving from models that do not indicate missing information to those that did. This increase is higher in models that use summary scores compared to those that use all variables as predictors. We conclude that there is important clinical information in the fact that certain fields are missing in EHR data and the development of scoring systems can perform better by considering which variables are missing.

### 3 - Optimizing Treatment Decisions Under Objective Clinical Measures and Strategically Reported Symptoms

Gian-Gabriel P. Garcia, University of Michigan, Ann Arbor, MI, 48105, United States, Mariel Sofia Lavieri, Thomas McAllister, Michael McCrea, Steven Broglio

Doctors must often synthesize subjective and objective measurements to make informed treatment decisions. We model this problem using a multi-perspective stochastic dynamic framework where the patient's exhibits strategic symptom reporting behavior and his health is partially observable. Analytically, we identify conditions which guarantee that the doctor's optimal policy presents a threshold structure. We then apply our model to concussion management and compare our optimal policy to heuristic policies based on common clinical practice.

### 4 - Redesigning SNAP Considering Meal-Preparation Time Matt Olfati

The Supplemental Nutrition Assistance Program (SNAP) is the largest federal assistance program and a key tool in poverty alleviation and fighting food insecurity. We seek to examine the association between two basic assumptions of the SNAP program, cooking time and benefit amount, on the nutritional profile of beneficiaries. To do this, we take a discrete optimization approach in order to design a novel model that anticipates the meal choices of SNAP recipients. We find that meal preparation time, rather than the funding amount, is the main limitation to SNAP families consuming nutritious meals, appearing to be a main driver of the percentage of meals that are cooked, and in fruit and vegetable consumption. Increased funding leads to increased intake of protein and sodium, and has a positive, yet diminishing, impact on fruit and vegetable consumption. These results show that increased funding alone is insufficient to improving nutritional profiles for SNAP beneficiaries.

# SuD15

E62 Sloan - Room 262

# The Impact of Information Technology in Medical Care

Emerging Topic: Healthcare Information Technology and Management

Chair: Ozden Engin Cakici, American University, Washington, DC, 20016, United States

### 1 - How Much Does HIT Usage Profile Contribute to Community Health?

Jeong-ha Oh, Georgia State University, Atlanta, GA, 30302-4015, United States

The impact of health IT implementation to healthcare performance has been studied extensively. However, the linkage between the usage and quality measure is yet to be tested. In this study, the impact of the usage profile of technology modules of the physicians to healthcare performance is investigated in terms of population health quality.

## 2 - Operational Impact of mHealth Adoption in Clinical Practice

Balaraman Rajan, California State University East Bay, Hayward, CA, 94588, United States, Saligrama Agnihothri, Arvind Sainathan

Chronic conditions account for a bulk of the healthcare expenditure in most developed countries. Besides, they also affect the quality of life for the associated individuals. Continuous monitoring of the health condition is the only long-term solution given the nature of these conditions. In addition, medical literature shows continuous monitoring helps improve patient health. But with conventional mode of care, continuous monitoring comes at a significant cost. Digital innovations such as mHealth technology can be used to provide efficient, effective, and patient-centered healthcare. However, when a clinic implements mHealth technology it may warrant some changes in the composition of clinical staff and patient flow. In this paper, we evaluate the trade-offs of implementing mHealth technology in a clinical practice.

### 3 - Who Drives Digital Innovation?: Evidence from the U.S. Medical Device Industry

Ariel Stern, Harvard Business School, Boston, MA, 02163, United States, Cirrus Foroughi

Does the large-scale technological change that is characteristic of an industrywide digital transformation entrench industry leaders or enable the rise of new entrants? We offer a novel approach to this question by focusing on the medical device industry, a unique setting in which we observe all new product commercialization over recent years and where the introduction of software has created fresh opportunities for new product development. Pioneering a new application of text analysis, we consider over 35,000 new medical devices that came to market in the United States from 2002-2016 in order to identify predictors of digital innovation. We examine the relative importance of within firm know-how, geography, and the role of financial resources. We find that prior digital product area commercialization experience and location in a region of concentrated expertise reinforce one another as predictors of digital innovation.

### 4 - Managing Medical Item Inventories under Order Loss

Ozden Engin Cakici, American University, NW, Washington, DC, 20016, United States

In hospitals, order information for medical items go through multiple departments before being submitted to a medical supplier. At times, order information is inadvertently lost on the way, leading to order-loss. Using our case study at MRI units, we propose a periodic review policy which provides a minimum cost benchmark that enables conducting an incremental cost-benefit analysis for process improvement. We provide managers with nuanced guidelines about how our proposed policy should be used and when to give "buy/don't buy" decisions for two technology features to mitigate and/or eliminate order-loss.

# SuD16

E62 Sloan - Room 276

### **Empirical Studies in Healthcare Operations**

Emerging Topic: Healthcare Economics

Chair: Maria Ibanez, Kellogg School of Management at Northwestern University, Evanston, IL, 60208, United States

#### 1 - The Impact of IT on Health Outcomes: Evidence from Telemedicine

Cirrus Foroughi, Harvard Business School, Boston, MA, United States

Using data from a large hospital network in New York, I estimate the outcomes effects of a sweeping telemedical intervention across intensive care units (ICUs) within the network, in which in-person physicians are either entirely substituted or complemented by remote care. I control for patient health utilizing detailed, patient-encounter level medical records and estimate a reduction in mortality of 13-18% across a variety of specifications. These effects are heterogenous across patient severity, with the healthiest patients experiencing an increase in mortality, while sicker patients see the greatest decrease. Telemedical care is more effective as a complement than as a substitute—mortality improvements are two-times larger for patients treated at facilities with dedicated on-site critical care physicians. Learning effects do not appear to drive results in this setting. Preliminary analyses of mechanisms indicate that this effect is driven in part by reduced monitoring burden, freeing up staff time to more actively pursue treatment.

### 2 - Charted Territory: Evidence from Mapping the Cancer Genome and the Pharmaceutical Industry

Jennifer Kao, Harvard, Fremont, CA, United States

This paper explores how publicly available scientific information shapes the quantity and profitability of private-sector research. I examine the impact of large-scale cancer genome mapping studies, which systematically map the genetic abnormalities in cancer, on research productivity in the pharmaceutical industry. I find that mapping information increases private-sector investment in clinical trials by 50 percent and disproportionately increases trials evaluating drugs previously tested for one disease in an additional disease. I also find that cancer mapping information increases the profitability of firms' research decisions: when genetic information is known, firms are more likely terminate drug investment projects that are unlikely to be successful in the long run and to continue investment projects that publicly available, detailed scientific maps can increase and improve private research efforts.

# 3 - Does Announcing the Visit Matter? An Empirical Examination in US Nursing Homes

Sehwon Kang, University of Minnesota, Minneapolis, MN, 55455, United States, Rachna Shah, Kevin W Linderman

Supply chain partners and regulatory agencies often rely on inspections to help manage quality and safety. Two dominant strategies are announcing the inspection visit in advance or making an unannounced visit with little advance notification. Although practitioners have long debated the value of announced versus unannounced strategies, researchers have not distinguished between announced and unannounced inspections clearly and examined their immediate and sustained effects precisely. In this study, we examine the effect of announced and unannounced inspections on the immediate and sustained quality performance in US nursing homes. Analysis of panel data from multiple data sets spanning a 4-year period shows that both inspection types increase quality performance but unannounced inspections lead to a more sustained quality performance when compared to announced visits. This research draws on the attention-based view of the firm to provide strong theoretical grounding for the differing results of the two inspections strategies.

### 4 - Decomposing Volume's Impact on Performance: Lessons from Kidney Transplantation

Philip Saynisch, Robert Huckman, Nikolaos Trichakis

In markets for credence goods (such as medical care), suppliers act as not only as providers but also as expert advisors: they diagnose a buyer's need for that service before providing the service in question. This dual role of the supplier introduces a crucial complication to learning-by-doing explanations of the widely-documented volume-outcome relationship: improvements in outcomes may result from better decision making or better execution. This paper explores kidney transplantation, where clinical decision-making and surgical performance are clearly delineated and separately observable. We find that greater volume is predictive of lower rates of organ offer acceptance. We also find that greater volume is associated with improved post-transplant outcomes, but worse decision-making. This tension between improved execution and reduced decision quality implies that practice may not make perfect in complex medical decision-making.

# Monday, 8:00AM - 9:30AM

# MA01

E52 Samberg - Dining Room 6

### Analytics, Decision Making, and Healthcare Policy

Emerging Topic: Healthcare Delivery

Chair: Manaf Zargoush, McMaster University, Hamilton, ON, Canada 1 - The Use of Distributionally Robust Optimization in Mental Care

# Fan E, McGill University, Angelos Georghiou, Vedat Verter

Healthcare research is uniquely challenging due to the prevalent lack of data. This limitation on data availability are caused by privacy concerns, data collection practice traditions, and sometimes the rarity of the illness studied. Mental care research is even more challenging where accurate measures of patient status is near non-existent. The small amount of data, the high level of uncertainty and heterogeneity all motivate the application of robust optimization techniques. While traditional robust optimization modeling suffers from the criticism of being overly conservative, distributionally robust optimization (DRO) calibrates its uncertainty based on real data to overcome this shortcoming.

#### 2 - Hypertension Management: A Value of Information Perspective Manaf Zargoush, McMaster University, Hamilton, ON, L8S 4M4, Canada, Mehmet Gumus, Vedat Verter, Stella Daskalopoulou

The traditional technique for blood pressure measurements involves noise. These measurements, however, constitute the basis for hypertension management. We present an analytical framework to characterize the optimal treatment policies in the presence of noise and the value of information obtained from less noisy technology or optimized learning behavior.

### 3 - Sensitivity of Preventive Health Intervention Decisions in Markov Decision Processes

Lauren N. Steimle, Brian T. Denton, University of Michigan, Ann Arbor, MI

Prevention of chronic diseases is typically governed by a sequence of decisions over the course of the patient's lifetime that weighs uncertain future benefits and harms of treatment. Markov decision processes (MDPs) have found success in modeling this process as a decision-maker controlling a deteriorating Markov chain with selected health interventions. However, the optimal timing of interventions is sensitive to the transition probabilities that describe the Markov process. We discuss an algorithmic framework for mitigating the impact of parameter uncertainty in MDPs and give an example in the context of prevention of cardiovascular disease.

# MA02

E52 Samberg - Dining Room 5

### **Health Services and Data Analytics**

Emerging Topic: Public Health and Health Policy

Chair: Chanaka Edirisinghe, Rensselaer Polytechnic Institute, Rensselaer Polytechnic Institute, Troy, NY, 12180-3590, United States

### 1 - Competing on Quality: Evidence from Award-winning Hospitals in California

Bogdan C. Bichescu, The University of Tennessee, Knoxville, TN, 37996-0525, United States, Randy V. Bradley, Wei Wu

Healthcare is a highly competitive environment in which hospitals compete against one another to both provide services to patients and attract indispensable resources (i.e., nurses and physicians) to deliver their services. We investigate the marketing, operational, and financial benefits associated with winning quality awards, by performing an empirical, longitudinal comparison of quality awardwinning hospitals from the state of California to comparable hospitals without quality awards during the period of our study. This study contributes to the literature and provides insights to practitioners on the benefits of applying for and winning a quality award.

### 2 - Money-back Guarantee and Service Quality: The Marketing of In-vitro Fertilization Services

Mrinal Ghosh, University of Arizona, Tucson, AZ, 85721, United States, Shan Yu, Madhu Viswanathan

Marketing practices like Money Back Guarantees (MBG) are prevalent in many expert service markets but are often decried for taking advantage of poorly informed consumers. In this research, conducted in the market for In-Vitro Fertilization services, we empirically analyze whether clinics that offer MBGs provide higher quality of care as compared to clinics that don't. We infer the quality of care by analyzing the impact of MBGs on treatment outcomes while controlling for observed and unobserved patient fertility mix and treatment aggressiveness. Our analysis is conducted on a large and unique longitudinal dataset that includes clinic-level treatment and outcome statistics for almost all IVF clinics in the U.S., fertility clinic characteristics, and information on state-level insurance mandates, demographic, and geographic characteristics. Our results suggest that MBG clinics are more likely to be high quality clinics and, on average, to be beneficial to the consumers than being harmful.

# 3 - Novel Computer-aided Detection of Breast Cancer: Stalking the Serial Killer

Hamparsum Bozdogan, University of Tenneesse-Knoxville, Dept of Business Analytics &, Statistics, Knoxville, TN, 37996-0532, United States

Breast cancer is the second leading cause of death among women worldwide. Preventing it is beyond current medical abilities. Much research attention has been focused on early detection and post diagnostic treatment. But early detection has flaws. Even mammography, the most effective tool for detecting the cancer, misses up to 30 percent of breast lesions. The missed evidence is attributed to poor-quality radiographic images and eye fatigue and oversight on the part of radiologists who read the images. In this presentation, we present several novel statistical modeling and machine learning techniques for computer-aided detection (CAD) of breast cancer on 1,269 Italian patients by introducing and developing flexible supervised and unsupervised classification methods using information complexity criterion. The efficiency of our approach is shown in computer-aided diagnostic tools that show promise in increasing the ability to spot cancerous lesions.

#### 4 - Non-convex Discrete Optimization Approach for High-dimensional Regression

Yuji Nakagawa, Smart Analytics, Inc., Department of Informatics, Tokyo, 569-1095, Japan, Yoshiko Hanada, Yoichi Takenaka, Chanaka Edirisinghe

We transform the all possible regression method equivalently into a non-convex discrete optimization problem with a cardinality constraint and present a successive optimization method. To show the efficacy of our approach, we analyze genomic data with 10,031 or 906,600 variables. In first experiment, the comparative results with Ridge or Lasso show that our algorithm offers much better and much more reliable performance. Using actual data of 214 breast cancer patients and 906,600 variables, we selected 53 variables containing 17 variables that are known to cause breast cancer.

### 5 - Privacy Preserving Synthetic Health Data

Andrew Yale, Rensselaer Polytechnic Institute, Troy, NY, United States, Saloni Dash, Ritik Dutta, Isabelle Guyon, Adriene Pavao, Kristin Bennett

We examine the feasibility of using synthetic data generated from real medical data for health informatics research and education. Because use of real data is greatly constrained by laws protecting patients' privacy, our focus lies on making a variety of medical datasets available to students and researchers. We compare 6 data generative methods, including our deep learning HealthGAN approach, and compare the results with novel resemblance, privacy, and utility metrics. Our results demonstrate that HealthGAN outperforms the other methods.

# ■ MA03

E52 Samberg - Dining Room 4

### Health 3.0: Data, Process and Outcome Opportunities

Emerging Topic: Healthcare Information Technology and Management

Chair: Gondy Leroy, University of Arizona, Tucson, AZ, 85721, United States

Co-Chair: Haijing Hao, PhD, Bentley University, Waltham, MA, 02452, United States

Co-Chair: Ping Yu, University of Wollongong, Wollongong, NSW, Australia

### 1 - Digital Transformation in Healthcare: A View from Senior Leaders

Monica J. Garfield, Bentley University, COBA Dept IS/CS, Waltham, MA, 33620, United States, Kaushik Ghosh, Michael Dohan, Hareesh Veldandi

Currently, healthcare organizations are under tremendous pressure due to new regulations, financial strains, and patient consumerism. While patient care has always been healthcare industry's focus, the burden to improve care processes and focus on patient outcomes have brought new challenges to the industry. Many experts consider focus on digital transformations to be significant to enable healthcare organizations to counter these challenges. In that regard, senior healthcare leaders are taking initiatives related to digital transformation in a widerange of ways. We interviewed 18 such leaders to understand how digital transformation is being embraced by their organizations.

### 2 - Big Biomedical Data Analysis Using Ontology and Semantic Technologies

Cui Tao, University of Texas Health Science Center at Houston, Houston, TX, United States

The explosively growing big biomedical data provides enormous opportunities to revolutionize the current clinical practices as well as the biomedical research if the accompanied challenges of heterogeneity in knowledge discovery on biomedical big data can be addressed with novel informatics technologies. Our team has been working on developing semantic technologies to normalize, integrate, query, and analyze the massive volumes of biomedical data as well as to infer new knowledge based on what is known. The core technologies we are developing are based on ontologies, the Semantic Web, and natural language processing, and machine learning. Here we share our vision on applying these novel informatics techniques to clinical knowledge and data representation, as well as to retrieve useful information and knowledge from EHR or online resources.

### 3 - Fault Trees and Diagnostic Error

Sriram Iyengar, Texas A&M Health Science Center Abstract is not available at this time.

# ■ MA04

E52 Samberg - Dining Room 3

### Machine Learning and Precision Medicine

Emerging Topic: Personalized Medicine and Disease Modeling

Chair: Yonatan Mintz, Georgia Institute of Technology

### 1 - Predictive and Personalized Treatment Planning for Managing Diabetes

Eva Lee, Georgia Tech, Atlanta, GA, United States

Diabetes affects 422 million people globally, costing over \$825 billion per year. We develop personalized treatment plan by 1) deriving a predictive dose-effect model that uses fluid dynamics, a compartmental model of partial differential equations, constrained least square optimization, and statistical smoothing. The model leverages a patient's routine self-monitoring of blood glucose and prescribed medication and establishes a direct relationship between drug dosage and drug effect. 2) formulating a multi-objective mixed integer programming model that incorporates the personalized dose-effect knowledge along with clinical constraints. The resulting system produces optimized plans that provide better glycemic control while using less drug. This work is joint with Grady Health Systems.

#### 2 - SDP Formulations for Fair PCA in Insurance Rate-Setting Mahbod Olfat, PhD Student, University of California, Berkeley, CA, 94702, United States

Though there is a growing literature on fairness for supervised learning, incorporating fairness into unsupervised learning has been less well-studied. This paper studies fairness in the context of principal component analysis (PCA). We first define fairness for dimensionality reduction, and our definition can be interpreted as saying a reduction is fair if information about a protected class (e.g., race or gender) cannot be inferred from the dimensionality-reduced data points. Next, we develop convex optimization formulations that can improve the fairness (with respect to our definition) of PCA and kernel PCA. These formulations are semidefinite programs, and we demonstrate their effectiveness using several datasets. We conclude by showing how our approach can be used to perform a fair (with respect to age) clustering of health data that may be used to set health insurance rates.

### 3 - Model Based Approach to Precision Heparin Dosing

Yonatan Mintz, Georgia Tech, Atlanta, GA, 30308, United States, Eva Lee

Miss-dosing patients with time sensitive drugs, such as heparin, can lead to adverse health effects. In particular, correctly dosing a patient with heparin is challenging as its concentration in the blood cannot be measured directly and the rates at which patients metabolize it vary greatly between individuals. In this talk we design a precision medicine framework for optimizing heparin doses in an ICU setting. Utilizing a pharmacokinetic predictive model, we infer the current concentration of heparin and predict future therapeutic effects. We validate the predictive capabilities of our model against existing machine learning techniques and show how it can be used to optimize patient dosing.

## ■ MA06

E52 Samberg - Salon West

# Planning and Scheduling for Emergency and Specialist Care

Emerging Topic: Public Health and Health Policy

Chair: Michael G. Klein, San Jose State University, CA, 95192-0069, United States

 Evaluating Capacity Planning Methods for Loss Systems: Application to Emergency Medical Services Mohammad Delasay, Assistant Professor of Operations Management, East Setakut, NY, 11733, United States, Armann Ingolfsson, Amir Rastpour

We evaluate capacity planning methods in loss service systems with continuous random cyclic demands. Emergency medical services is an example of such systems. We use numerical techniques to evaluate the accuracy of methods that rely on independent period-by-period steady state distributions. We investigate how the accuracy of such approximations depends multiple factors, including the average service rate and the shape of the service time distribution.

### 2 - Physician Staffing and Shift Scheduling at Emergency Departments with Time Varying Productivity

Alireza Sabouri, Haskayne School of Business, University of Calgary, Calgary, AB, T2N 1N4, Canada, Negar Ganjouhaghighi, Marco Bijvank

We consider the problem of physician staffing and shift scheduling for an emergency department (ED). In EDs, patients show up according to a non-homogenous random arrival process and the productivity of physicians (measured as the patient-per-hour rate) varies over time and between physicians. The variable productivity alongside the stochastic nature of number of arrivals (demand) to the healthcare system, create a mismatch between demand and the number of patients that can be served by the scheduled physicians during a particular period of time. We propose a stochastic programming formulation for the staffing and shift scheduling problem with the objective of minimizing this mismatch. We develop a novel two step solution procedure to find near-optimal shift schedules within reasonable computational time. Our numerical results based on data from an ED in Calgary suggest that our proposed schedules lead to shorter average waiting times and more balanced shifts in terms of workload.

### 3 - Centralized Waiting List for Outpatient Physiotherapy Kaitlin Miles, Dalhousie University, Halifax, NS, Canada,

Peter Vanberkel, Majid Taghavi, Alissa Decker

This thesis utilizes discrete event simulation to model four outpatient physiotherapy locations at the Nova Scotia Health Authority. Centralization of intake is being considered to increase efficiency and allow for pooling of resources in the network of four locations. The model allows the user to modify the scheduling policy, effectively changing the queuing discipline, to schedule patients in to New and Return appointments. Management is considering sending low priority patients to other locations in the network to alleviate their long and volatile wait times. The model also allows the user to modify the master schedule of available appointments.

### 4 - Designing a Dynamic Network of Dialysis Facilities

Michael G. Klein, San Jose State University, San Jose, CA, 95192-0069, United States

Kidney failure is treated with dialysis until transplant or death. Regardless of the travel burden, many patients always opt to go to a facility, while some always opt for home dialysis. For others, the choice varies depending on the location of available facilities. Existing patients also switch dialysis modes (e.g. from facility-based dialysis to home dialysis) bringing different requirements for providers over time. I propose a new model to determine the best network of dialysis facilities from an access to care perspective. Through a California case study, I propose to illustrate the model and help identify areas for improvement.

### 5 - Optimization of Telemedicine Clinic Locations for Bladder Cancer Screening

Ayca Erdogan, San Jose State University, Davidson College of Engineering, Industrial and Systems Engineering, San Jose, CA, 95192, United States, Van Khanh Phan, Tracey Krupski, Jennifer Mason Lobo

Telemedicine provides medical care to patients from rural, remote or sequestered areas the opportunity to access specialty care that is often not available locally. We present a location model for telemedicine clinics to be opened in Virginia to increase access to bladder cancer screening. The model considers the distribution of rural patients and aims to optimize the location decisions while maximizing patient adherence (participation) to screening. The model assumes that the patients can choose central hospital or a telemedicine clinic, and adherence is negatively affected by distance.

# ■ MA07

E52 Samberg - Ballroom T

### Strategic Patients in Healthcare Systems

Sponsored: MSOM/Healthcare

Chair: Lerzan E. Ormeci, Koc University, Istanbul, 34450, Turkey

### 1 - Regulation of Private Healthcare Subsidies

Pelin Canbolat, Assistant Professor, Koc University, Rumeli Feneri Yolu Sariyer, Istanbul, 34450, Turkey, Lerzan E. Ormeci, Seyedehsaloumeh Sadeghzadeh

We consider a healthcare system consisting of public and private centers, which differ in price and service rate. We model each center as an M/M/1 queue and assume that the public center charges a smaller fee as compared to the private one, but also provides service at a lower rate, leading to larger waiting costs. We find the Nash equilibrium when patients selfishly choose which queue to join, and the allocation of patients to queues that minimizes the total expected cost of all patients. We then determine whether subsidizing the private fee can drive the equilibrium closer to the optimum, and if it does, how much of the fee should be subsidized to assure that the equilibrium and the optimal strategies overlap.

### 2 - Physician Dual Practice

Dimitrios Andritsos, HEC Paris, Departement MOSI, Jouy-en-Josas, 78351, France, Lerzan E. Ormeci, Yiannis Dimitrakopoulos

We develop a game-theoretic queueing model to analyze the effects of a physician's decision to practice in both the public and private sectors. Our analysis explores the equilibrium decisions of three agents: i) The government, which regulates dual practice ii) The physician, who decides on availability at each sector and iii) The patients, who decide where to seek care.

### 3 - Analysis of Appointment Systems with Strategic Walk-Ins

Lerzan E. Ormeci, Koc University, Dept of Industrial Engineering, Istanbul, 34450, Turkey, Evrim D. Gunes, Feray Tuncalp

We consider an outpatient clinic which allocates some slots to walk-in patients. We analyze equilibrium behavior of patients who can choose between waiting for the given appointment or applying to the clinic as a walk-in, given different costs of each option. We compare the socially optimal and equilibrium behaviors.

## **MA08**

### **MA08**

E52 Samberg - Ballroom I

# Multi-armed Bandit and Online Learning in Healthcare

Emerging Topic: Healthcare Delivery

Chair: Esmaeil Keyvanshokooh, University of Michigan, Ann Arbor, MI, 48108-1020, United States

Co-Chair: Mark P. Van Oyen, University of Michigan, Ann Arbor, MI, 48109-2117, United States

### 1 - Non-Stationary Bandits for Personalized Healthcare

Yonatan Miniz, Georgia Tech, Atlanta, GA, 30308, United States, Anil Aswani, Philip Kaminsky, Elena Flowers, Yoshimi Fukuoka

Fitness tracking devices are often ineffective in motivating users to exercise because their recommendations are not tailored to specific individuals. In this talk, we propose a new multi-armed bandit framework, which we call ROGUE mutli-armed bandits, to use the data and infrastructure of fitness tracking devices to personalize exercise programs for users. To optimize this non-stationary model, we develop two different algorithms and validate their results. We present both computational and theoretical results for these algorithms that show the efficacy of this modeling approach when compared to existing precision fitness and multi-armed bandit approaches.

### 2 - Online Learning and Decision-Making under Generalized Linear Model with High-Dimensional Data

Xue Wang, Penn State University, PA, United States Mike Mingcheng, Tao Yao

We propose a minimax concave penalized multi-armed bandit algorithm under generalized linear model (G-MCP-Bandit) for a decision-maker facing highdimensional data in an online learning and decision-making process. We demonstrate that the G-MCP-Bandit algorithm asymptotically achieves the optimal cumulative regret in the sample size dimension , O(log T), and further attains a tight bound in the covariate dimension d, O(log d). In addition, we develop a linear approximation method, the 2-step weighted Lasso procedure, to identify the MCP estimator for the G-MCP-Bandit algorithm under non-iid samples. Under this procedure, the MCP estimator matches the oracle estimator with high probability and converges to the true parameters with the optimal convergence rate. Finally, through experiments based on synthetic data and two real datasets (warfarin dosing dataset and Tencent search advertising dataset), we show that the G-MCP-Bandit algorithm outperforms other benchmark algorithms, especially when there is a high level of data sparsity or the decision set is large.

### 3 - Online Personalized Care Framework to Reduce Readmission Risk

Mohammad Zhalechian, University of Michigan, Ann Arbor, MI, 48109-2117, United States, Esmaeil Keyvanshokooh, Mark P. Van Oven

In hospitals, physicians are uncertain about the impact of each admission action for each specific patient. However, testing each experiment is expensive due to the ethical issues and we need to learn as much as possible as information accrues. We develop a novel personalized admission system which can address the exploration-exploitation trade-off under a bed capacity constraint. Based on the real-time demand for critical care units and the available capacity of care units, the best care unit is chosen for each patient and readmission events are observed as a stochastic binary reward. We provide a finite-time regret analysis and test it with real data.

### 4 - Dynamic Learning of Personalized Patient Progression in Chronic Diseases

Esmaeil Keyvanshokooh, University of Michigan, Ann Arbor, MI, 48108-1020, United States, Mark P. Van Oyen,

Mariel Sofia Lavieri, Chris Andrews, Joshua Stein

We develop new online learning methods based on the multi-armed bandit theory to learn/predict personalized patient progression for chronic diseases as it receives patient data over various visits. We use clinical trials of glaucoma disease to evaluate our proposed methods.

# MA09

# E52 Samberg - Ballroom M

## Panel: Physician Burnout

Practice Oriented Session

Chair: Stephanie Eisenstat, Harvard Medical School, Boston, MA

Co-Chair: Walter O'Donnell, Harvard Medical School, Boston, MA

A major consequence of the Health Reform Act was the widespread implementation of electronic medical record (EHR) systems. The impact of EHR systems on physician work and in particular physician burden and burnout have been widely discussed but not well-studied nor significantly remedied. This session discusses new research approaches that adopt data-driven quantification of physician burnout, provide insights into the problem and ultimately aim to address it through work transformation. The session brings together researchers from MIT as well as physicians from multiple health systems that provide unique perspectives on these issues and highlight open research questions and important practical challenges. The first part of the session centers around a preliminary report from a collaboration between an IT-intense operations research team from MIT and clinical practitioners at Massachusetts General Hospital (MGH), with commentary from national leaders in physician work and burnout. This is then followed by a panel consisting of physician leaders who discuss related issues in a broader context.

### Panelists:

Christine Sinsky, American Medical Association, Dubuque, IA, United States

Michael Hu, MIT, Cambridge, MA, 02130, United States

Stephanie Eisenstat, Harvard Medical School, Boston, MA, United States

Retsef Levi, MIT, Sloan School of Management, Cambridge, MA, 02142, United States

Walter O'Donnell, Harvard Medical School, Boston, MA, United States

Stephen Strongwater, Atrius Health, Boston, MA, United States Simon Talbot, Harvard Medical School, Boston, MA, United States

# ■ MA10

E52 Samberg - Salon East

### **Applied Health Analytics**

Contributed Session

Chair: Trung Le, North Dakota State University, Fargo, ND, 58108-6050, United States

### Revolutionizing Precision Medicine with Big Data – The Individual Exposure Health Risk Profile (IEHRP) Mark Oxley PhD, Professor, Mathematics, Air Force Institute of Technology, WPAFB, OH, United States, Richard Hartman PhD

The presentation will introduce the Individual Exposure Health Risk Profile (IEHRP), a novel approach that integrates occupational, lifestyle, and environmental exposure data from traditional and new personal monitoring exposure assessment technologies with clinical and genomic data to provide a new and novel capability for personalized health. We will demonstrate how IEHRP will create unique opportunities to shift from a healthcare delivery system dependent heavily on infrastructure and staffing to one that allows individuals to take ownership of their health and drive their behaviors and health-related choices by leveraging a Big Data infrastructure and advanced analytics.

### 2 - A Python Method to Extract and Display Physiologic Waveform Data

John Zaleski, Chief Analytics Officer, Bernoulli Health, Inc., Elkton, MD, United States

A simple method is presented for extracting and processing base64 waveform data obtained from GE Carescape physiologic monitors for the purpose of enabling raw data analysis and display. The method presented translates the output into a comma-delimited format consumable by Microsoft Excel and other tools for the purpose of facilitating further data analysis. The innovation in this method is the automated handling of multiple monitors and time windows, and the translation from a base64 message into human-readable format that facilitates post-processing for electrocardiographic waveform assessment.

#### 3 - Improving Patient Experience with Text Analytics Rawan I Najar, PhD Candidate, Binghamton University, Binghamton, NY, United States

Improving patient experience is critical to the success of healthcare systems. Open-ended questions that allow patients to provide comments on their visit are used in surveys to provide additional insight on patients' experience. Analyzing complex patterns within patients' comments can reveal areas for improvement that might not be discovered from matrix or rating scale-based questions. This study utilized patients' comments collected after their visit to an outpatient practice at a large urban teaching hospital. The results were used to explore different areas of improvement and helped construct actionable recommendations for the practice.

### 4 - Detection and Localization of Infarct-related Artery in Acute Myocardial Infarction from Compressed Paper- Based Electrocardiogram (ECG)

Trung Le, North Dakota State University, Fargo, ND, United States

Recent advances in machine learning and vectorcardiography (VCG) provide an opportunity to fully harness information from paper-based ECG to localize IRAs at the first response. We developed a Poincare pattern ensemble-based reconstruction method to extract the diagnostic features from the paper ECG recordings that are capable of tracking the complex spatiotemporal evolution of the underlying cardiac dynamics. The proposed method improves the authors' earlier graph theoretic approach for identification of the IRAs, and not mere localization of the infarcted cardiac tissues, using only 2.5 seconds long paper ECG recordings.

# MA11

E52 Samberg - Room 164

## Cancer Screening

### Contributed Session

Chair: Mehrad Bastani, Stanford University, Mountain View, CA, 94040, United States

### 1 - Predicting Breast Cancer Accurately with Machine Learning Models

Bhumika Pant (Sharma), Cliffside Park, NJ, United States, Sukumar Pant

Breast cancer, the most common cancer and one of the major causes of death among women worldwide. Although cancer is preventable and curable in initial stages, most patients are diagnosed with cancer at a later stage. This research aims to impart relative evaluation of various Machine Learning approaches on the Wisconsin Breast Cancer Data with three objectives. 1) If accurate classification of breast cancer is possible through Machine Learning 2) Can an automated diagnostic model be designed for best classification 3) Finding features producing high classification accuracy of breast cancer as benign or malignant.

### 2 - Screening and Other Risk Management Strategies for Women at High Risk for Breast Cancer

Caglar Caglayan, Georgia Institute of Technology, Atlanta, GA, United States, Turgay Ayer, Kalyan Pasupathy, Donatus Ekwueme, Sandhya Pruthi

Women with BRCA 1/2 gene mutations are at higher risk for breast cancer. Preventive surgeries (e.g., prophylactic mastectomy) are effective at significantly reducing the breast cancer risk in high-risk population but are not very popular options. On the other hand, other risk management strategies such as chemoprevention (i.e., risk-reducing oral medications) and screening require high levels of adherence to achieve their desired benefits. We first study the multi-modality screening problem for high-risk population, and then, investigate the role of adherence in the effectiveness of screening and/or chemo-prevention strategies (compared to preventive surgeries).

#### 3 - Evaluation of Alternative Subsequent Screening for LungRADS Criteria on the Effectiveness of Lung Cancer Screening Mehrad Bastani, Postdoctoral Scholar, Stanford University, Stanford, CA, United States, Iakovos Toumazis, Ann Leung, Sylvia Plevritis

U.S. Preventive Services Task Force recently recommended a low-dose computed tomography lung screening for high-risk current and former smokers based on the National Lung Screening Trial (NLST). In response to the high rates of false-positive findings observed in NLST (27.3%), the American College of Radiology developed Lung-RADS, a standardized system for reporting and following-up LDCT findings. Past studies revealed that Lung-RADS substantially reduces the false-positive rate when applied to NLST. To complement these studies, we evaluate the effect of alternative subsequent screening for Lung-RADS on the mortality reduction and life-year gained associated with lung cancer screening.

# Monday, 9:45AM - 11:15AM

## MB01

E52 Samberg - Dining Room 6

### **Managing Uncertain Patient Demand**

Emerging Topic: Healthcare Delivery

Chair: Craig Froehle, University of Cincinnati, Cincinnati, OH, 45221-0130, United States

Chair: David James Rea, Cincinnati, OH, 45220, United States

# 1 - Simulating the Flow of Patients with Aortic Dissection through a Cardiac Intensive Care Unit

Amanda Moreno-Hernandez, University of Michigan, Ann Arbor, MI, United States, Amy Cohn, Hitinder Gurm

Patients experiencing aortic dissection in the state of Michigan often request transfer to Michigan Medicine (MM) at the University of Medicine to receive advanced surgical care for a critical medical condition. Whether MM can accept these patients is typically not a function of surgeon or operating room availability but rather the availability of adequate capacity in the cardiac intensive care unit (CICU) for the several days of intensive follow-up care required after the surgical procedure. We present our simulation approach and associated analysis of policies to address variability and improve accessibility of the CICU.

### 2 - Patient Behavior Profiles and Implications for Patient Care and Clinic Management

Quinton J. Nottingham, Virginia Polytechnic Institute, Blacksburg, VA, 24060, United States, C. Baker, R.S. Russell

Clinic no-shows and cancellations result in inefficient use of resources and create problems for clinic sustainability and the ability to serve patients. This research explores patient behavior at a large medical group with clinic locations in three southeastern states. Using demographic factors such as age, gender, race and ethnicity, medical specialty, type of care, and prior patient experiences such as cancellations, and no-shows, we develop patient behavior profiles that predict a patient's reliability to keep an appointment. We illustrate how determinations of patient reliability can help clinics schedule patients, manage resources, and provide better care to a larger number of patients.

### 3 - Staff Planning with Cost Estimation and Optimization

Sandeep Rath, University of North Carolina, Chapel Hill, NC, 27599, United States, Kumar Rajaram

We consider the staff planning problem of anesthesiologists which consists of determining how many anesthesiologists have to be on regular duty and on call each day. We model this problem as a two-stage integer stochastic dynamic program. We use data from the anesthesiologist staff planning at UCLA Ronald Reagan Medical Center to first estimate the inconvenience costs of on-call staffing. We use these estimated cost parameters in a two-stage integer stochastic dynamic programming model of staff planning. We develop a solution algorithm and test the model with real data from the UCLA medical center.

#### 4 - Managing Uncertainty Via Distributional Demand Forecasting David Rea, PhD Candidate, University of Cincinnati, Cincinnati, OH, 45220, United States, Craig Froehle

The cited motivation behind many demand forecasting models is their ability to support capacity decisions. However, the translation of model output into an actionable plan is often treated as tangential to the modeling process. In juxtaposition to the common practice of forecasting average staffing needs, this research proposes the use of a distributional forecast to create a tiered staffing-plan. Regular and backup staff are assigned hourly based on the quantiles of a demand-forecast and target staffing-ratios. The merits of this approach are considered in the context of the Emergency Department: a capacity-constrained and highly uncertain environment. Proposed strategies for using the forecasted distributional information in staff-planning decisions are illustrated using substantial primary data from practice.

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## ■ MB02

E52 Samberg - Dining Room 5

### **Operations in Hospitals and Service Systems**

Emerging Topic: Healthcare Supply Chains

Chair: Yunchao Xu, New York University, New York, NY, 10012, United States

Chair: Svenja Schoonover, New York University, New York University

### 1 - Surgeon Impact on Surgery Durations: The Case of Coronary Artery Bypass Graft

Svenja Lagershausen Schoonover, New York University, New York, NY, United States, Michael L. Pinedo, Vikram Tiwari

Estimation of operating room durations is crucial for an efficient use of operating rooms which are one of the main cost factors in hospitals. The scheduler of the surgeries typically has to balance the cost of operating room idle time with the cost of overtime. We analyze Coronary Artery Bypass Graft (CABG) surgeries to develop reliable estimators for the durations of such surgeries. Our analysis shows to what extent the surgery duration is influenced by the operating surgeon and by the number of bypasses. Surgery schedulers may want to take into account the operating surgeons to improve the utilization of the operating rooms through better scheduling.

### 2 - Control of Queueing Systems with Distorted Customer Types

Dongyuan Zhan, University College London, School of Management, Gower Street, London, WC1E 6BT, United Kingdom, Arturo Estrada, Rouba Ibrahim

We study queueing systems where customers may distort their true types to shorten their waiting. For example, such systems arise in healthcare settings where patients exaggerate their own symptoms in order to be seen faster, or with public housing applications where applicants may lie on their applications to jump the queue. We investigate optimal joint inspection and routing policies in such a setting. An inspection reveals some additional information about the true types of the customer, but is costly to the inspector, and a routing policy classifies customers according to different priority levels, thus resulting in different, priority-dependent, waiting times.

### 3 - What Moderates a Hospital's Response to Disruptions? David Dreyfus, Rutgers Business School, Anand Nair

Healthcare is affected by various types of disruptions. We examine the antecedent types of complexity on service disruption risk in acute episodes of care within the operating room. Specifically drawing on the current theoretical work of supply chain disruptions and teams, this study investigates the moderating roles of risk management infrastructure and information exchange among care providers.

# MB03

E52 Samberg - Dining Room 4

### **Healthcare Analytics**

Emerging Topic: Healthcare Information Technology and Management

Chair: Raj Sharman, State University of New York-Buffalo, Buffalo, NY, 14260-4000, United States

Co-Chair: Ashish Gupta, Auburn University, Auburn, AL, 36830, United States

1 - Sports Analytics using IoT: Research Opportunities and Framework for Improving Health and Safety

Ashish Gupta, Auburn University, Auburn, AL, 36830, United States

Sports is a high revenue operation with the projected revenue running in billions of dollars. Unfortunately, poor operations, game logistics and just the sheer nature of certain sports (such as contact sports) lead to inefficiencies and exposes players to injury risks. In this study, we will present a novel IoT based platform and the framework that guides the development of such platform for predicting player injuries in a cost and time effective manner. This IoT based novel platform is referred to as 'Sports Injury Prevention Screen.' This platform is coupled with a machine learning model for performing predictive analytics but also has various reporting tools for drill down analysis and a 360 view of an athlete's health.

### 2 - Analyzing Providers' Overcharge Behavior in Medicare Procedures

Amit Deokar, University of Massacusetts-Lowell, Lowell, MA, United States, Sagnika Sen

Medicare payment to care providers varies widely despite cost-of-living adjustments. In turn, providers bill more than the allowable limit, i.e., they overcharge. In this research, our focus is to identify the key predictors of such overcharge. Using the Medicare data, we explore three procedures with the highest degree of payment variation. We model this as binomial classification problem based on feature sets comprised of provider, procedure, practice, and demographic characteristics. Using machine learning algorithms, we analyze the classification performance to find the best predictive model. Our results illustrate that there is a strong correlation between practice and provider level overcharge, and provider propensity to overcharge increases with the volume of patients they serve.

### 3 - Classifying Information Needs of Sexually Transmitted Diseases (STD) Patients - A Design Science Approach

Pavan Kumar Mulgund, State University of New York-Buffalo, Bufallo, NY, United States, Raj Sharman, Sandeep Purao

World health organization defines 'Sexually Transmitted Diseases' (STDs) are defined as infections that are passed from one person to another through sexual activity. The main causes of STDs are bacteria, viruses, yeasts and parasites. There are more than 20 types of STDs. STDs affect both men and women. More than 1 million STDs are acquired every day worldwide. Each year, there are an estimated 357 million new infections with 1 of 4 STDs: chlamydia, syphilis, gonorrhea, and trichomonasis. In 2016, as per Center for disease prevention (CDC) reports, there has been 1.59 million cases of chlamydia, 468514 cases of gonorrhea, 27814 cases of syphilis and 628 cases of congenital syphilis. All these infections saw a significant rise in incident rates when compared to 2015. STDs have a profound influence on social and reproductive health. STDs can lead to serious consequences beyond the immediate impact of the infection. Some STDs can increase the risk of acquiring HIV. Mother-to-child transmission of STDs can result in stillbirth, congenital deformities and prematurity. Despite such high incidence rates and catastrophic consequences, affected individuals are not very comfortable or refrain from discussing this in person with their physicians [5] as they are very concerned about privacy and security of their identity due to the stigma associated with STD's. In some cases, the physicians themselves do not want to be identified when talking about STDs [7]. Further, one of the most prevailing reasons for increasing STD rates among individuals is found to be the insufficient or lack of information about the subject being imparted in schools and other educational institutions [4]. Given the sensitivity of the topics and the need for privacy, security and anonymity, patients use online portals to seek information and interact with doctors/providers about their apprehensions and concerns [8]. However, existing online portals available today do not cater to the personalized needs of the patients as they present the same static information regardless of the needs of the person seeking information. The overarching aim of our research is to develop an automated identification and selection of relevant information based on different factors such as age, gender, ethnicity, education etcetera. But as a precursor to that study, we want to identify and classify various patient information needs. This paper aims to present our classification and characterize various information products that cater to patients of STD's.

# ■ MB04

E52 Samberg - Dining Room 3

### Using Machine Learning to Improve Healthcare

Emerging Topic: Personalized Medicine and Disease Modeling

Chair: Hamsa Sridhar Bastani, Wharton School, Philadelphia, PA, 19104, United States

Co-Chair: Arielle Anderer, Wharton, Philadelphia, PA, 19104, United States

1 - Learning Decision Rules with Observational Data

Stefan Wager, Stanford Graduate School of Business, Stanford, CA, 94305, United States

In many areas, practitioners seek to use observational data to learn a treatment assignment policy that satisfies application-specific constraints, such as budget, fairness, simplicity, or other functional form constraints. For example, policies may be restricted to take the form of decision trees based on a limited set of easily observable individual characteristics. In this talk, I will present some recent advances on structured decision making stochastic systems based on observational data.

### 2 - Staffing for Better Outcomes: Insights from Blood Donation

Wilson Lin, University of Southern California, Los Angeles, CA, United States, Susan F. Lu, Tianshu Sun, Ginger Jin

How can organizations leverage staffing to achieve better outcomes, beyond fulfilling operational needs? In collaboration with a Chinese blood bank, we observe whether and how different nurses may influence donors' donation decisions through interaction on the bloodmobile. Using a unique dataset at the interaction level, we estimate the effect of nurse donor matching on a donor's donation volume and return likelihood. We identify a trade-off between short and long term outcomes and find that improved matching can provide economically significant benefits for the blood bank.

3 - Re-identifying Physical Activity Data with Machine Learning Liangyuan Na, Massachusetts Institute of Technolgy-Operations Research Ctr, Sidney Pacific Graduate Community, Cambridge, MA, 02139, United States, Cong Yang, Chi-Cheng Lo, Fangyuan Zhao, Yoshimi Fukuoka, Anil Aswani

Despite data aggregation and removal of protected health information, there is concern that deidentified accelerometer-measured physical activity (PA) data can be reidentified. We evaluate the feasibility of using machine learning methods to reidentify 14451 individuals' data from the National Health and Nutrition Examination Surveys. Linear support vector machine and random forests reidentify the 20-minute-level physical activity data of approximately 80% of children and 95% of adults. The findings suggest that current practices for deidentifying PA data are insufficient for privacy and that deidentification should aggregate the PA data of many people to ensure individuals' privacy.

# 4 - Using Search Queries to Understand Health Information Needs in Africa

Rediet Abebe, Cornell University, Gates Hall, Ithaca, NY, 14853, United States

A key challenge in combating the impact of diseases in developing nations is understanding individuals' health information needs. To help address this, we propose a bottom-up approach using search data to uncover health information needs of individuals in Africa. We analyze Bing searches related to HIV/AIDS, malaria, and tuberculosis and derive a set of common topics. We expose the different patterns that emerge by demographic groups and country. We also uncover discrepancies in the quality of content returned by search engines to users by topic. Combined, our results suggest that search data can help inform discussions on health policy and targeted education efforts.

# MB05

E52 Samberg - Dining Room 2

### **Cancer Treatment**

Contributed Session

Chair: Eyyub Yunus Kibis, The College of Saint Rose, Albany, NY, 12203, United States

1 - Decision Support Tool in Treatment After Surgery of Breast Cancer for Patients Older Than 70 Years

Rak Smey PHAN, Mines Saint-Etienne, Saint-Etienne, France, Danielle Hooijenga, Vincent Augusto, Xiaolan XIE, Pierre Etienne Heudel

Breast cancer concerns about 54 000 new cases in France and 11 500 deaths per year (Source INCa). For the majority of cancers, the risk of being affected increases with age. After breast cancer surgery, many factors influence adjuvant treatment decisions including patient characteristics, life expectancy and tumor biology. The goal of this study is to propose a tool, which permits to determine for early breast cancer patients older than 70 years, treated by surgery, the best possible treatment. The criteria of efficiency are the rate of survival and the recurrence of the cancer. This study is a cooperation between Mines Saint-Etienne and Centre Leon Berard, a Comprehensive Cancer Center in Lyon, France.

### 2 - Performance Evaluation of Machine Learning Methods for Breast Cancer Treatment

Melike Hazal Can, Northeastern University, Boston, MA, United States, Abe Zeid, Sagar Kamarthi, Stephen Agboola, Kamal Jethwani, Ramya S. Palacholla

Breast cancer is the most common cancer diagnosed among women both in the US and worldwide. Although there has been a dramatic increase in the number of breast cancer treatments available including the recent neoadjuvant treatments, treatment outcomes have not improved significantly. The goal of this research is to investigate several machine learning methods to formulate a model that accurately predicts tumor response to selected neoadjuvant therapy for breast cancer patients. For this purpose, we considered individual variability in baseline patient characteristics and tumor characteristics, and we evaluated model performances by several calibration measures.

### 3 - Strategies for Optimal Chemotherapy Dosing: Balancing Treatment Efficacy and Drug Toxicity

Kirti M. Yenkie, Assistant Professor, Rowan University, Glassboro, NJ, United States, Alex D'Aloia, Eric Purcell, Matthew Razze, Katherine Schmidt

Cancer survivors are likely to suffer from cardiovascular diseases. Reason being multiple side-effects of chemotherapy such as immune-suppression and cardiotoxicity. Effective treatment must simultaneously balance treatment efficacy and residual toxicity; herein lies an optimization problem. To this end, a systems engineering based mathematical model for cancer proliferation, tumor degradation, immunotoxic and cardiotoxic effects has been developed and validated to facilitate the identification of clinical biomarkers responsible for long-term toxicity. The resultant control problem was solved with maximum principle and non-linear programming to predict optimal dosing policies.

### 4 - Optimizing Multi-modal Cancer Treatment Under 3D Spatio-Temporal Tumor Growth

Eyyub Kibis, The College of Saint Rose, Troy, NY, United States, Esra Buyuktahtakin Toy

In this paper we introduce a new mixed-integer linear programming (MIP) model that explicitly integrates the spread of cancer cells into a spatio-temporal reaction-diffusion (RD) model of cancer growth, while taking into account treatment effects. This linear but non-convex model appears to be the first of its kind by determining the optimal sequence of the typically prescribed cancer treatment methods—surgery (S), chemotherapy (C), and radiotherapy (R)—while minimizing the newly generated tumor cells for early-stage breast cancer in a unique three-dimensional (3D) spatio-temporal system.

# ■ MB06

E52 Samberg - Salon West

### **Demand Management at Emergency Departments**

Emerging Topic: Public Health and Health Policy

Chair: Shrutivandana Sharma, Singapore University of Technology and Design, Singapore, 138682, Singapore

1 - Engineering the Delay Announcement to Improve Patient Satisfaction

Sina Ansari, Laurens G. Debo, Seyed Iravani

Excessive wait-time is the most common reason patients become dissatisfied and leave the Emergency Department (ED) before being treated, which have negative financial and medical consequences. In a field experiment in an urban ED, we study the impact of announcing wait-times on patient satisfaction. Our study demonstrates how a wait-time predictor that is relatively inexpensive to develop and implement, can improve significantly patient satisfaction and the hospital's financial performance as the Centers for Medicare and Medicaid in the US tie reimbursements to patients' assessment ratings.

### 2 - Calling for Care: The Risky Proposition of Teletriage in Healthcare Demand Management

Alex F. Mills, Baruch College, City University of New York, New York, NY, 10010, United States, Ozden Engin Cakici

In theory, teletriage should help patients with an acute illness choose an appropriate provider, reducing unnecessary and duplicate provider visits, yet teletriage is not widely used despite a growing push for telemedicine in healthcare operations. We show that teletriage is a risky proposition because there are several reasons why adding teletriage to the healthcare system could produce a negative outcome. Teletriage should not be free, which would encourage use by patients with low levels of uncertainty and actually increase the payer's total cost. Moreover, overtriage rate is a key driver of performance and must be managed carefully.

### 3 - Non-Urgent Visits at Emergency Departments: Patients' Choice and Hospital Interventions

Shrutivandana Sharma, Singapore University of Technology and Design, Singapore, 138682, Singapore, Ying Xu, Manu Kumar Gupta

We present a queueing games framework to investigate how non-urgent patient visits at emergency departments (ED) are influenced by patients' perception of their criticality and their self-interested choice. We explore the impact of economic incentives and reduction of perception error on diverting non-urgent demand from ED to general practitioners (GP). Our results show that reduction of perception errors may decrease non-urgent ED visits under some equilibria, but may increase non-urgent ED visits and social cost under other equilibria. It however always decreases optimum social cost. Motivated by incentive schemes introduced by some hospitals, we design and compare two types of monetary incentives that align equilibrium flows with optimum flows. Our results imply that measures that only focus on reducing perception errors may not always prove beneficial. Instead, a combination of these measures with economic incentives that conduct the system can be more promising.

### 4 - Emergency or Primary Care – Understanding Patient Preferences to Reduce Non-urgent Emergency Department Visits

Yuliu Su, Singapore University of Technology and Design, Singapore, Shrutivandana Sharma, Semra Ozdemir, Wai Leng Chow, Bikramjit Das, Costas Courcoubetis, Hong-Choon Oh

This paper uses discrete choice experiments to examine the underlying factors influencing non-urgent patient choices between emergency department (ED) and primary care provider (PCP). Our findings suggest that waiting time, test facilities, out-of-pocket payment, and patients' perception of their severity significantly influence patient preferences for ED and PCP. In addition, patients are heterogeneous in their preferences, particularly with respect to the availability of test facilities and cost of care. The relative importance of the different factors quantified by the choice model suggest various countermeasures that can be beneficial for reducing non-urgent visits to ED.

## **MB08**

### MB08

E52 Samberg - Ballroom I

# Modeling and Optimization in Integrated Healthcare Systems

Emerging Topic: Healthcare Delivery

Chair: Nan Kong, Purdue University, West Lafayette, IN, 47906-2032, United States

Co-Chair: Jie Song, Peking University, Peking University, Beijing, 100871, China

### 1 - Optimal Differential Pricing Policy Design for a Workload-Imbalanced Outpatient Care Network

Nan Kong, Purdue University, 206 South Marting Jischke Drive, Biomedical Engineering, West Lafayette, IN, 47906-2032, United States, Yewen Deng, Na LI, Zhibin Jiang, Xiaoqing Xie

Normal 0 false false EN-US ZH-CN X-NONE Substantial workload imbalance may occur in a multi-hospital network where patients have free choices to different hospitals. We studied the problem of optimal government-to-patient subsidy differential (G2P-SD) policy design to incentivize patients to visit hospitals with low workload. Combining choice model and approximate performance measures of a large-scale network, we formulated a nonlinear optimization model to minimize the aggregate wait time. Our study verifies the effectiveness of the modified G2P-SD policy and benefits of further tailoring the policy design.

### 2 - Optimal Intervention Policies for TJR Postoperative

### Care Process

Hyo Kyung Lee, University of Wisconsin-Madison, Madison, WI, United States, Jingshan Li, Christine Baker, Philip Bain

Total joint replacement procedures are performed for more than a million cases each year and are subject to increase substantially due to the aging population. To prevent readmissions and restore functional mobility, patients go through postoperative intervention process in which they receive physical therapy and/or some form of rehabilitative services. However, there is a worldwide variation in intervention practices with no agreement on which interventions given in which timeframes lead to optimal patient outcomes. To address these gaps, we investigate the decision problem faced by healthcare professionals: When should we provide interventions to which group of patients to minimize the total expense? We formulate the postdischarge intervention process as a finite-horizon discrete-time Markov decision process. The optimal policy of the model shows that the common practice of focusing intervention resources on immediate postoperative periods needs further justification.

### 3 - Learning to Rank Under Evolving Consumer Reviews

Jingtong Zhao, Columbia University, New York, NY, United States, Van-Anh Truong, Jie Song, Xin Pan, Zhen Xu

In many electronic healthcare platforms, patients are encouraged to leave reviews about their experiences. Subsequent patients and the platforms make use of the information to infer the quality of the physicians along various dimensions, such as medical expertise, bed side manner, openness, etc. The body of reviews grows over time, providing a valuable source of information. An important service provided by a platform is the recommendation of physicians that best meet patients' care criteria. We study how a platform can learn from patient reviews, as well as the way that they make subjective choices about the type of care they want when presented with such recommendations, in order to form increasingly accurate estimates about patient preferences, physician quality, and patientphysician compatibility. We provide an algorithm to learn from data and to make personalized recommendations to patients. The objective is to maximize patients' long-term satisfaction. We use the notion of regret to evaluate the algorithm's performance.

## MB09

E52 Samberg - Ballroom M Practice Oriented Session

# Stories from the Frontline: Research Opportunities from Physicians' Perspectives (Panel)

Practice Oriented Session

Chair: Anita L. Tucker, Boston University, Boston, MA, 02215, United States

In this panel session, physician leaders share insights from their efforts to reduce hospital readmissions, reduce length-of-stay, and improve efficiency and effectiveness in primary care. The physicians will speak about challenges facing health care delivery organizations, and how these challenges might present research opportunities. The session will also include time for audience questions.

### Panelists:

Brian Jack, MD, Boston University Center for Health System Design and Innovation, Boston, MA, United States Daniel Blumenthal, MD, MBA, Devoted Health, Boston, MA, United States

Christopher Manasseh, MD, Boston Medical Center, Boston, MA, 02118, United States

# ■ MB10

E52 Samberg - Salon East

### Inventory and Stockpiling

Contributed Session

Chair: Pradip Kumar Ray, Indian Institute of Technology Kharagpur

1 - Medicine Inventory Control in Hospitals Considering Physician Prescription Behavior

Esha Saha, Indian Institute of Technology Kharagpur, Kharagpur, India, Pradip Kumar Ray

Physicians are the prime generator of demand for medicines in a healthcare system. The dynamics in their prescribing behaviour influence significantly the medicine inventory systems. In the present study, an integrated hidden Markov model and partially observable Markov decision process for determining the optimal inventory control policy is developed and validated by a case study. Prescription behaviour is defined by patient conditions, type of care units and length-of-stay in hospitals.

#### 2 - Incorporating Dependence in Risk Assessments of Future Antibiotic Resistance: Eliciting and Modelling Probabilistic Dependence

Abigail Colson, University of Strathclyde, Glasgow, United Kingdom, Christoph Werner, Alec Morton, Tim Bedford

Healthcare systems rely on having a range of effective antibiotics available to treat patients with resistant infections. The threat of multidrug resistance means that assuming rates of resistance to different antibiotics are independent may severely underestimate risks to the current portfolio of drugs. We illustrate the problem and model dependence between certain bug-drug combinations. We present a method for eliciting dependence from experts in a formal and structured manner that promotes transparency and reproducibility of the results and mitigates against common cognitive fallacies.

### 3 - How Much Should We Invest in Antibiotics? Investigating Their Option Value

Itamar Megiddo, Chancellor's Fellow, Lecturer (Asst. Professor), University of Strathclyde, Glasgow, United Kingdom, Dusan Drabik, Tim Bedford, Alec Morton, Justus Wesseler, Ramanan Laxminarayan

The existing business models for antibiotics fail to promote antibiotics stewardship to preserve our existing portfolio of drugs, while at the same time funding for research and development has been insufficient in recent decades, as only two novel classes of antibiotics have been introduced since the 1970s. The UK is considering novel mechanisms for paying for antibiotics to overcome these issues. We will explore the option value for preserving novel antibiotics for extreme events. We will discuss the option value implications for investment in new antibiotics and possible extensions to the model.

### 4 - Inventory Management of Medicines in Healthcare Systems using Markov Decision Processes

Pradip Kumar Ray, Indian Institute of Technology Kharagpur, Department of Industrial and Systems Engg, Kharagpur, 721 302, India, Esha Saha

Continuous monitoring of patients admitted in hospital may result in multidimensional information on patient conditions and medicine consumption over time which can be utilized in making diverse managerial decisions in healthcare systems. In the present study, a Markov Decision Process model for determining the optimal inventory control system for medicines is developed and validated by a case study. The patient conditions are described by the treatment stages and care units at each treatment stage that significantly improves the optimal inventory control systems for medicines.

# MB11

E52 Samberg - Room 164

# Stochastic Modeling and Analytics for Decision Support in Healthcare Policy

Sponsored: Public Sector OR

Chair: Xiaolei Xie, Tsinghua University, Beijing, 100084, China

Co-Chair: Na Li, SJTU, Shanghai, 200240, China

- 1 Coordination through Thresholds Control Contract in Health Care System Reverse Referral Process
  - Na Li, SJTU, 800 Dongchuan Road, Minhang, Shanghai, 200240, China, Nan Kong, De Teng

Reverse referral strategy, i.e. referring patients from upper-level hospitals to lower-level hospitals in the Hospital Alliance, has been proposed to alleviate the problem of imbalanced utilization of medical resource in chinse hierarchical health care system. Despite these initiatives have brought some positive effects, it remains unclear that how to make optimal decisions for the partnering hospitals to implement the reverse referral strategy. In this study, we proposed an operational control level contract for the implementation in Reverse referral process. We designed a method as well as a tool to help the negotiation, which provides potential sets of cooperation implementation thresholds. The potential sets come from Pareto frontier. With the tool, the hospitals can make final decision according to the relative bargaining power of them. A case study of reverse referral partnership in China is proposed, we can find that the operational level contract is effective.

### 2 - Assessing the Impact of Dietary Interventions in an Urban Environment – An Agent-Based Modeling Approach

Yan Li, The New York Academy of Medicine, New York, NY, 11374, United States, Donglan Zhang

Despite national and local initiatives to promote healthy dietary behaviors, unhealthy diets remain a difficult, perplexing health challenge requiring initiatives and solutions at the community level. Prior to investing in implementation, health practitioners and policymakers need to compare the impact of different dietary interventions to then determine priorities. We developed an agent-based model of dietary behaviors to predict fruit and vegetable consumption at the neighborhood level in New York City. The results showed that the impact of an intervention could vary significantly based on the population characteristics and food environment in the neighborhood.

### 3 - Hospital Choice Prediction Model for Inpatients in China

Bowen Pang, Tsinghua University, Beijing, 100084, China, Xiaolei Xie, Haibo Wang

In 2016, the Hospital Quality Monitoring System (HQMS) includes 788 major hospitals and 27.44 million inpatients records in China. The percentage of inpatients from different province is up to 7.2%, which exerts large burden to health care delivery system. We analyze the risk factors including age, gender, marriage status, insurance type, home province, and diagnosed disease, etc., in order to predict which hospital, the patients will choose according to their personal characteristics. The question is divided into three sub-problems. After parameterizing three logistic regression models, we obtain the final model, which provides the possible choice of hospitals for the inpatients.

# Monday, 11:30AM- 1:00PM

## MC01

E52 Samberg - Dining Room 6

### **Data Analytics in Healthcare Operations**

Emerging Topic: Healthcare Delivery

Chair: Retsef Levi, MIT, Cambridge, MA, 02142, United States

 Empirical Analysis of the Impact of Operational Factors on Clinical Decision Making in a Chronic Care Clinic Zehra Önen, Koc University, Rumelifener yolu Sariyer, Istanbul, 34450, Turkey, Evrim D Gunes, Tolga Tezcan, Raj Sengupta

The rising prevalence of chronic conditions (for which there is currently no cure, and which are managed with drugs and other treatment) is one of the main challenges facing health-care systems globally. We investigate how non-clinical operational factors affect clinical decisions of health professionals using 75,702 patient visit data from a rheumatology outpatient clinic in Bath, UK. We focus particularly on the decision to follow-up or discharge a patient and re-attendance of discharged patients. We show that increasing workload and patient waitlist size decrease discharges and increase re-attendances. By contrast, continuity of care increases discharges and decreases re-attendances.

### 2 - Stochastic Scheduling of Operating Rooms and Reusable Medical Devices

Enis Kayis, Ozyegin University, Borazanlar Istanbul, 14100, Turkey, Elvin Coban, Kian Farajkhan

Health care expenditures are expected to grow every year, and more than 40% of a hospital's total expenses and revenues are generated by surgical operations. One of the major resources required during surgeries is reusable medical devices (RMDs). RMDs are surgical instruments used during surgeries which have to be reprocessed by thorough cleaning followed by sterilization after each use. RMDs have to be planned with operating rooms (ORs) concurrently since insufficient RMDs may cause delays in operation starting times. However, the management of RMD sterilization stage is nontrivial: RMDs are sent to sterilization at different times and thus how to load the sterilization machines (i.e., batching) is a complicated decision. In this paper, we study the integrated scheduling of ORs and sterilization of RMDs under stochastic surgery durations. We propose a simulation optimization approach to tackle this problem, and through numerical studies show that our approach could lead to significant cost savings for a hospital.

3 - Machine Learning to Address Hospital Capacity: Predicting Discharges and Identifying Opportunities to Increase Efficiency Taghi Khaniyev, MIT Sloan School of Management, Cambridge, MA, 02142, United States, Kyan Safavi, Jonathan Zanger, Retsef Levi, Peter Dunn

Hospital congestion is caused by, among other factors, an imbalance of the timing of patient admissions and discharges. We implemented a real-time clinical support tool to predict next-day's surgical patient discharges and identify the barriers to successfully transitioning them out of hospital. We trained a machine learning model using 20,745 previous patients' recovery care paths at a large academic medical center. Then, with an iterative process, we analyzed mismatches between predicted and actual discharges to identify areas for improvement in the discharge process and to enhance the accuracy of the tool. The model achieved an average out-of-sample AUC of 0.87 and identified an estimated 128 savable bed-days during the 90-day study period.

### 4 - Machine Learning: Multi-site Evidence-based Best Practice Discovery

Eva Lee, Georgia Tech, Industrial & Systems Engineering, Ctr for Operations Research in Medicine, Atlanta, GA, 30332-0205, United States

This study establishes interoperability among electronic medical records from 737 healthcare sites and performs machine learning for best practice discovery. A novel mapping algorithm is designed to disambiguate free text entries and provide a unique and unified way to link content to structured medical concepts despite the extreme variations that can occur during clinical diagnosis documentation. Redundancy is reduced through concept mapping. A SNOMED-CT graph database is created to allow for rapid data access and queries. These integrated data can be accessed through a secured web-based portal. A classification machine learning model (DAMIP) is then designed to uncover discriminatory characteristics that can predict the quality of treatment outcome. We demonstrate system usability by analyzing Type II diabetic patients. DAMIP establishes a classification rule on a training set which results in greater than 80% blind predictive accuracy on an independent set of patients. By including features obtained from structured concept mapping, the predictive accuracy is improved to over 88%. The results facilitate evidence-based treatment and optimization of site performance through best practice dissemination and knowledge transfer.

## ■ MC02

E52 Samberg - Dining Room 5

## Healthcare Analytics Applications

Emerging Topic: Healthcare Supply Chains

Chair: Yann Ferrand, Clemson University, Clemson, SC, 29634, United States

### 1 - Staffing in a Tele-ICU: Dedicated vs Flexible

Muer Yang, University of St. Thomas, Minneapolis, MN, 55403, United States, Xuanjing Li, Michael Fry, Xiaolei Xie

Tele-ICU might be a solution to bridge the gap between the increasing ICU service demand and the shortage of eligible ICU staff. This paper uses simulation models to analyze operational aspects of a tele-ICU system to improve efficiency and effectiveness by comparing dedicated and flexible staff-scheduling approaches. Our findings can help tele-ICU administrators to choose the optimal schedule approach based on the effects of interruptions on the processing time of admissions and interventions by the medical staff.

### 2 - Who, If Anyone, Should Be Screened for Diabetes in the **Emergency Department?**

M. Gabriela Sava, Assistant Professor, Clemson University, Clemson, SC, 29634, United States, Jerrold H. May, Ronald G. Pirrallo, Jingyuan Tian

Diabetic screening of ED patients can proactively improve health outcomes, but it is uneconomic to screen all such patients. We present a modeling approach for identifying patients who have a negligible risk of diabetes, so that available resources can be used to screen those with a non-negligible risk.

### 3 - Impact of Focus on Efficiency and Financial Performance in Hospitals: Moderating Effect of Information Technology

Sriram Venkataraman, PhD, University of South Carolina, Columbia, SC, United States, Rajendra Singh

We examine the impact of focus on efficiency and financial performance of hospitals. Further, we examine the moderating impact of various health information technology bundles on the relationships of focus with efficiency and financial performance.

#### 4 - Understanding the Human Aspects of the Healthcare System Dotan Shvorin, PhD, Clemson University, Greenville, SC, United States,

Humans are the most important part of the healthcare delivery system. With innovative technologies, we can explore exciting aspects of humans when considering their line of work within this complex environment. Bio-sensors allow us to understand how our human body changes in response to our experiences. Surveys help present the perception of the human within a certain situation and his internalization within the short term and the long run. Two case studies will be presented to expose how emergency medicine physicians respond to clinical experiences. Preliminary conclusions could be drawn when considering the direction of the investigation.

# MC03

E52 Samberg - Dining Room 4

### Machine Learning & Data Driven Prediction Models in Healthcare

Emerging Topic: Healthcare Information Technology and Management

Chair: Ravi Aron, Johns Hopkins University, Baltimore, MD, 21202, United States

### 1 - Making Machine Learning Useful by Reducing Dimensionality in Health Data

Praveen Pathak, Associate Professor, University of Florida, Gainesville, FL, 32607, United States, Ravi Aron, Phillip H. Phan

The problem of high dimensional data bedevils the use of Machine Learning (ML) to create predictive models in health care. We propose a method to reduce the problem of dimensionality in health care by combining ML techniques with latent domain knowledge in health care.

### 2 - Machine Learning in Chronic Care Management

Praveen Pathak, Warrington College of Business, University of Florida, Gainesville, FL, United States

In this paper we investigate and show how machine learning algorithms are used for chronic care. The algorithms are able to correctly identify patients that are getting better worse or getting better. We also discuss how this is related to other indicators

### 3 - Machine Learning to Predict Risk of Deterioration using Continuous Vital Signs Monitoring Wearables

Ravi Aron, Johns Hopkins University, Carey Business School, Baltimore, MD, 21202, United States, Phillip Phan, Amartya Mukhopadhyay, Khek-Yu Ho

Significant physiological deterioration usually precedes serious events like cardiac arrest. Warning scores based on physiological parameters (e.g., MEWS) have shown to improve detection of deranged physiology. However, physiology-based scoring systems that prompt bed side attention rely on vitals observed by nurses every 4 or more hours and in-between, subtle deterioration can go unnoticed. We hypothesize that continuous monitoring with wearables offer the opportunity to identify deranged physiology earlier than fixed time intervals. In the IRB approved study, we collected data from 177 consented medical patients from the NUHS Acute Medical Unit admitted from the emergency department with National Early Warning Score  $\geq$ 3. Variables included BP, pulse, SpO2, respiratory

rate, and skin temp collected at 5 minute intervals with a Sotera ViSi Mobile® wrist unit; age, gender, time/date of admission/discharge, comorbidities, and primary complaint. Targets were SpO2<90% and BP>160/90. 70% of dataset for training with 10-fold cross validation using average value; 30% for model testing with stratified sampling followed by normalization [0,1]. Grid search mechanism was used to optimize parameters. Results for SpO2 are Random Forest Classifier (Accuracy=0.955; AUC=0.91), Neural Network (Accuracy=0.946; AUC=0.917), K-Nearest (Accuracy=0.945; AUC=0.838), SVM (Accuracy=0.942; AUC=0.878) compared with Naive Bayes (Accuracy=0.199; AUC=0.672), and Logistic Regression (Accuracy=0.939; AUC=0.776). Results for BP are Random Forest Classifier (Accuracy=0.98; AUC=0.971), Neural Network (Accuracy=0.971; AUC=0.982), K-Nearest (Accuracy=0.969; AUC=0.935), SVM (Accuracy=0.956; AUC=0.948), compared to Naive Bayes (Accuracy=0.256; AUC=0.61), and Logistic Regression (Accuracy=0.938; AUC=0.83). In conclusion, machine learning was superior to statistical methods.

# ■ MC04

E52 Samberg - Dining Room 3

### Health Analytics and Operations Management

Emerging Topic: Personalized Medicine and Disease Modeling

Chair: Zhichao Zheng, Singapore Management University, Singapore, 178899, Singapore

Co-Chair: Frank Y. Chen, City University of Hong Kong, Hong Kong

### 1 - The Analytics of Bed Shortages: Coherent Metric, Prediction and Optimization

Jingui Xie, University of Science and Technology of China, Hefei, China, Gar Goei Loke, Melvyn Sim, Shao Wei Lam

Bed shortages in hospitals usually have a negative impact on patient satisfaction and medical outcomes. In practice, healthcare managers often use bed occupancy rates (BOR) as a metric to understand bed utilization, which is insufficient in capturing the risk of bed shortages. We propose the bed shortage index (BSI) to capture more facets of bed shortage risk than traditional metrics such as the occupancy rate, the probability of shortages and expected shortages. The BSI is based on the well-known Aumann and Serrano (2008) riskiness index and it is calibrated to coincide with BOR when the daily arrivals in the hospital unit are Poisson distributed. Our metric can be tractably computed and does not require additional assumptions or approximations. As such, it can be consistently used across the descriptive, predictive and prescriptive analytical approaches. We also propose optimization models to plan for bed capacity via this metric. These models can be efficiently solved on a large scale via a sequence of linear optimization problems.

### 2 - Predicting Depressive Disorders in the Elderly with Multitask **Recurrent Neural Network**

Qingpeng Zhang, City University of Hong Kong, Kowloon, 12180, Hong Kong, Zhongzhi Xu, Mingyang Li

This research aims to develop a state-of-the-art deep learning model for the individualized prediction of depressive disorders with a 22-year longitudinal survey data among elderly people in the United States. The experiments indicate that (a) machine learning models can provide an accurate prediction of the onset of depressive disorders for elderly individuals; (b) the temporal patterns of risk factors are associated with the onset of depressive disorders; and (c) the proposed multitask deep learning model exhibits superior performance as compared with baseline models. This finding demonstrates the capability of deep learning models in capturing temporal and high-order interactions among risk factors.

### 3 - Real-time Estimated SOFA Score: An Improvement of **Early Warning**

Zhichao Zheng, Singapore Management University, Lee Kong Chian School of Business, Singapore, 178899, Singapore, Yan He, Qian Luo, Hai Wang, Haidong Luo, Oon Cheong Ooi

We built a new framework to enhance existing risk monitoring systems in the intensive care units (ICUs), which typically use a single number to quantify a patient's condition, e.g., the Sequential Organ Failure Assessment (SOFA) score. These systems fail to capture the uncertainty in the risk assessment and consequently fail to trigger an early warning for timely intervention. In our framework, we mimic a physician's practice and use machine learning algorithms to predict the long lead-time variables using patient's historical data and vital signs that can be measured in real time. In a case study, the new system improves the accuracy of risk-level classifications for more than 8% of the patients.

**MC03** 

# MC05

E52 Samberg - Dining Room 2

### Behavioral

Contributed Session

Chair: Yin Xi, UT Southwestern Medical Center, Dallas, TX, 75390-9061, United States

1 - Physician Burnout - A Literature Review of the Influence of Electronic Health Records (EHRs)

Renee Pratt, Assistant Professor, University Massachusetts-Amherst, Amherst, MA, United States, Rudolph Bedeley, Julian Atiam

Although physician burnout is a popular topic in medical journals, the information systems discipline has not explored it extensively with respect to the influencers and outcomes of enterprise systems. We conduct a literature review. Three authors independently searched the top IS and HIS journals, using the agreed upon inclusion criteria, to analyze and review the full papers for physician burnout. We identify current areas researched, theories used, and gaps related to continuous usage of EHRs in the IS discipline that impact clinicians. This study contributes to IS literature through identifying the significance of the IT design artifact in improving physician productivity and satisfaction.

#### 2 - Squeeze in: Challenging the Newsvendor Model in Operating Room Management

Tinglong Dai, Associate Professor, Johns Hopkins University, Baltimore, MD, United States,, Soo-Hoon Lee, Phillip H. Phan, Nehama Moran, Jerry Stonemetz

The newsvendor paradigm is standard in research on operating room (OR) management. Our observations of actual practice challenge this approach. We collect a large dataset of ex-ante and ex-post factors affecting OR schedules. We show surgeons consistently under-book OR times when time to surgery is short. That the 'squeeze-in' drives patient outcomes. Ex-post factors confronting the surgeon on day of surgery upends the newsvendor model. We identify a 'safety tipping point' with implications for healthcare operations and patient safety.

### 3 - Investigate the Benefit of a Phone Call Reminder for Reducing Patient No Show

Yin Xi, Assistant Professor, UT Southwestern Medical Center, Dallas, TX, United States, Kelsea Marble, Karen Wang, Mujeeb Basit, Seth Toomay

Phone call reminders are considered low-cost and patient-friendly for reducing patient no show. In our institution, an automatic phone call reminder was sent to the patients three days before the appointment date. We compare the odds of no show to completion between patient received and did not received the phone call reminder within the same department. Further, patients can be categorized according to their response to the reminder. Odds of no show of these subgroups are estimated.

# ■ MC06

E52 Samberg - Salon West

### **Chronic Disease Management**

Emerging Topic: Public Health and Health Policy

Chair: Mariel Sofia Lavieri, University of Michigan, Ann Arbor, MI, 48109-2117, United States

Co-Chair: Wesley Javier Marrero Colon, University of Michigan, Ann Arbor, MI

### 1 - Informing Hepatitis C Elimination Using Hep C State Policy Simulator

Yueran Zhuo, PhD, Massachusetts General Hospital, Boston, MA, United States, Jagpreet Chhatwal, Peter Mueller, Tiannan Zhan

Hepatitis C Virus (HCV) infection is a serious health problem in the U.S. with 3 million people chronically infected. The availability of direct antiviral agents (DAA) therapy has brought hope to the elimination of HCV. In this study, we develop an online interactive tool to simulate the intervention policies of hepatitis C treatment in all the states in the U.S., while providing the cost burden and disease burden estimates in the coming years up to 2030. The analysis delivered by the tool shed insights on the possibility of eliminating HCV worldwide from the healthcare payer's perspective.

### 2 - A Conceptual Decision Support Tool for Personalized Treatment Selection in Chronic Depression

Shan Liu, University of Washington, Seattle, WA, 98195-2650, United States, Mutita Siriruchatanon

Early detection of ineffective treatment plays a key role in developing optimal treatment plans. Staying on ineffective treatments may incur unnecessary high cost and/or lead to drug-resistance or addiction. We propose a computerized

decision support tool that can assist mental health care providers to optimize monitoring and treatment selection. We formulate a Markov decision process and estimate the individual treatment effect on disease transitions leveraging on subgroups of the progression patterns in the population and their associated treatment effect distributions. We present new results on optimal treatment policies using simulated data of chronic depression.

### 3 - Optimal Cholesterol Treatment Plans and Genetic Testing Strategies for Cardiovascular Diseases

Wesley Javier Marrero Colon, University of Michigan, Ann Arbor, MI, 48105, United States, Mariel Sofia Lavieri, Jeremy Sussman

We present a simulation-based framework to estimate the risk for atherosclerotic cardiovascular disease due to clinical and genetic factors. Cholesterol treatment plans are modeled as a Markov decision process (MDP). Additionally, we determine which patients should receive genetic testing and the time of testing using the value of perfect information (VoPI). We model the health trajectory of patients stochastically and determine treatment and testing decisions simultaneously.

# **MC08**

E52 Samberg - Ballroom I

### **OR Methods to Improve Patient Comfort**

Emerging Topic: Healthcare Delivery

Chair: Prashant Meckoni, University of Massachusetts, Amherst, MA, United States

 Optimizing Patient Scheduling in Interventional Radiology Ekin Koker, University of Massachusetts, Mechanical and Industrial Engineering, Amherst, MA, 01003, United States, Michael Prokle, Ranjith Tellis, Olga Starobinets, Nandini Raghavan

We propose a new patient scheduling heuristic which increases workflow efficiency measured by typical workflow KPIs (i.e., patient wait time, last patient exit time) for the IR department at a major hospital. We develop mathematical models that optimizes the daily patient schedule and propose a tool that can be used by the scheduler. By comparing the new schedules to current best practice through our existing simulation model, we find that the new patient schedule generated by our model can decrease patient wait times up to 25% on average and create a capacity increase of 5%.

# 2 - Lower Bound Capacity for Medical Appointment Scheduling with Patient Flexibility

Prashant Meckoni, University of Massachusetts, Amherst, MA, United States, Hari Balasubramanian

Many Primary Care Practitioners (PCPs) offer medical appointments that can be booked several weeks in advance. They face the challenge of servicing certain patients at shorter notice. In order to get an appointment day of the patient's choice, the PCPs need to provide a daily appointment capacity large enough to cover the variance in demand. This can lead to underutilized capacity on other days when the demand for appointments is lower than average. Instead of having more capacity to handle variance in demand, many PCPs require patients to be flexible in their requests for appointments around available slots. We explore the lower bound of the capacity that PCPs should provide for their panel of patients that can be flexible in their appointment requests. The lower bound capacity is determined by using the perfect knowledge in allocation of all future appointment requests of all patients.

### 3 - Hospice Candidate Classification Modeling Among ACO Beneficiaries

Michael Rossi, University of Massachusetts, Amherst, MA, 01002, United States

The 2016 median length of stay was only 24 days in the interdisciplinary advanced illness care model known as hospice among Medicare beneficiaries, Despite strong evidence for improved symptom management, increased patient and family satisfaction, and reduction in health care costs. Many value-based care organizations are now invested in identifying patients that are candidates for palliative care or hospice while a patient is hospitalized. The present contribution aims to demonstrate the relationship between prior utilization, comorbidities, and patient characteristics in identifying patients who are reaching their end-of-life and benefit from hospice care.

## ■ MC09

E52 Samberg - Ballroom M

### Healthcare Information Technology and Management

Emerging Topic: Healthcare Information Technology and Management

Chair: Sanghee Lim, Johns Hopkins Carey Business School, Baltimore, MD, 21202, United States

#### Digitizing Disclosure: The Case of Restaurant Hygiene Grades Weijia (Daisy) Dai, Purdue University, West Lafayette, In, 18015, United States,, Michael Luca

Collaborating with Yelp and the City of San Francisco, we revisit a canonical example of quality disclosure by evaluating and helping to redesign the posting of restaurant hygiene scores on Yelp.com. We implement a two-stage intervention that separately identifies consumer response to information disclosure and a disclosure design with improved salience-a consumer alert. We find score posting is effective, but improving salience further increases consumer response. Moreover, the presence of an alert for a low-score restaurant reduces its probability of getting a low score again.

### 2 - Promoting Patient Engagement: Does "Trialability" Increase the Adoption of Online Care?

Changmi Jung, Johns Hopkins Baltimore, MD, 21202, United States, Rema Padman, Ateev Mehrotra

Free trials have been a widely used tactic in many industries to raise awareness and the adoption of a new product or service. In this study, we analyze the impact of 'trialability,' the term borrowed from Rogers' innovation diffusion theory, on patients' subsequent paid online care usage. We found that mere availability of free consultation service for a while increases the odds of the adoption, and patients who exercised the opportunity are more likely to use the actual paidservice later on. Also, we offer insights to which patients are more likely to respond to the trial opportunity provided by their practices and positively influenced to use the service later. The results give the practical implications for strategic deployments of digital innovations in consumer healthcare delivery.

#### 3 - Carrot or Stick? Check the Weather First. The Effect of Weather on Mobile-Based Interventions for Physical Activity Sanghee Lim, Johns Hopkins Carey Business School, Baltimore,

MD, 21202, United States, Nakyung Kyung, Byungtae Lee

Weather is an exogenous and uncontrollable condition that determines various aspects of our daily behaviors. As mobile-based technologies can identify an individual user's location, there is an increasing interest in whether and how we should leverage the weather information of each user in designing mobile-based personalized promotions and interventions. In this study, we provide the results of a field experiment that examines the effectiveness of different mobile-based interventions (i.e., gain, loss, and neutral framed) in different weather conditions. Using an activity tracking app, we leveraged the weather information of each user and sent an intervention message for promoting physical activity. Our results show that a loss-framed message is more effective on sunny days, while a gain-framed message is more effective on sunny days, while a gain-framed message is more effective on sunny days, while a gain-framed message is discussed as a strong moderator.

### 4 - Determinants of Mhealth Effectiveness: Evidence from a Large-scale Experiment

Weiguang Wang, University of Maryland, College Park, MD, 20742, United States, Yanfang Su, Guodong (Gordon) Gao, Ritu Agarwal

Mobile health technologies (mHealth) are increasingly being utilized in healthcare delivery. However, most mHealth treatments failed to achieve a significant impact on clinical outcomes, and there is surprisingly little knowledge of the factors that affect mHealth effectiveness. This study examines mHealth effectiveness from a social determinant perspective. We leverage one of the world's largest field experiments on reducing cesarean sections. We find that the husband's healthy behavior is pivotal to enable mHealth effectiveness. The cesarean section reduction is 12 times larger women whose husbands exercise often than those whose husbands do not exercise. Further analyses reveal that the husband exercise behavior has a stronger influence on mHealth effectiveness when the husband has a more dominant socioeconomic status.

# MC10

E52 Samberg - Salon East

### Telehealth

Contributed Session

Chair: Chengye Wenjia, Beijing Institute of Technology

#### 1 - Telehealth Decision Support to Optimize Safety and Quality Prison Inmate Healthcare

Benjamin Schooley Schooley, Associate Professor, University of South Carolina, College of Engineering and Computing, Columbia, SC, United States, Melissa Almont, Brad Moody, Amelia Bischoff, Daniel Mullins, Nick Patel

Prison systems are tasked with providing access to essential healthcare services for inmates in a safe environment for providers and patients alike using taxpayer dollars. This pilot study implemented a telehealth solution in the health clinic of one SC state prison; integrated the solution with prison and health system EHR systems; and aims to provide health services to 300 inmates over four months, and design and test decision support functionality using health visit and transport data. The system will assist with triaging and resource decision making for inclinic, emergency, and non-emergency care decisions. Preliminary results indicate lowered transport costs and improved access to care.

### 2 - A Voice Assisted Smart Mirror Interface to Heterogeneous

**Health Data to Motivate Physical Activity and Personal Wellness** Prashant Duhoon, Data Scientist and Research Associate, University of South Carolina, Columbia, SC, United States, Benjamin Schooley, Neset Hikmet

This study designed and tested an application inclusive of a voice assistant (Amazon Alexa) and smart mirror visual interface to provide personalized physical activity monitoring and motivation to individuals. Prior studies have tested either one or the other type of UI - not in combination. The system integrates personal preferences and data from the cloud and IOT fitness tracking devices (Fitbit), and summarizes daily activity reports both on screen and through voice feedback for an interactive and hands-on and/or hands-off user experience. Preliminary results indicate an enhanced unobtrusive means for users to gain personal health intelligence from IOT device data.

### 3 - Modeling and Analysis for Teleconsultation Appointments in China

Chen Wenjia, Beijing Institute of Technology, Beijing, China, Li Jinlin

Teleconsultation(TC) aim to alleviate scarcity of high-level doctors in China. Several patient groups divided by different diseases are appointed in a time slot for one consulting room. However, it remains unclear how to schedule patient groups and how many patients should be in a group to minimize patients' and doctors' waiting time, and total time of the system. In this study, we analysis oneyear TC data to evaluate uncertain service time, then propose a new stochastic optimization model, and effective algorithms are designed to find optimal scheduling strategy. The results of this research will provide valuable insights for TC appointments.





