

Perspectives on Healthcare Delivery Systems Research



NSF Workshop at SMU on Future Directions in Service, Manufacturing, and Operations Research

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Healthcare Delivery Systems – Facets of Workshop

- Societal impact
 - Critical areas (problem types/methods & application areas)
- OR/MS/Analytics interface with human and organizational behavior/change
 - High-touch systems (a shift for Operations Engr.)
 - customer has a direct relationship with the provider
 - human and organizational behavior aspects
 - improved interface with patients
 - Data analytics – descriptive, predictive, prescriptive
 - Exploding data from EHR (Elec. Health Record), genomics, personal technologies, ...
 - Computing, mobile & cloud computing, wearables, ...



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Caveats

- The topic is huge, complex, overwhelming
- “Personalized” Perspective (i.e., my opinions)

*“Opinion is the medium between
knowledge and
ignorance.” -Plato*



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Opinion: Key patient desires/needs include

- Access to healing:
 1. Receiving care eventually. 28 million people in US lacked health insurance⁽¹⁾ and many millions have inadequate health insurance
 2. **Timely or rapid access depending on medical urgency**
 - (people will wait if waiting means better care, but waiting can hurt outcomes)
- Wisdom (derived from holistic, integrated care)
 - But often receive siloed information of limited value instead
- Good outcomes
- While sometimes price-inelastic, most want good value
 - often made imperceptible due to insurance, but at least want value in insurance cost (and many people go bankrupt)
- “People crave connection and caring...a long-standing relationship with an accessible, trustworthy provider.” ⁽²⁾ -High touch
- ... others

⁽¹⁾ <https://www.kff.org/uninsured/fact-sheet/key-facts-about-the-uninsured-population/>

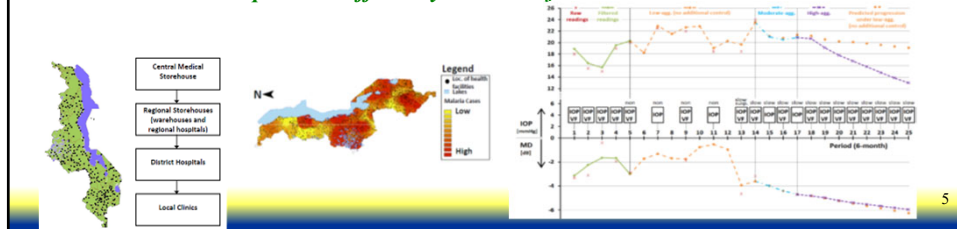
⁽²⁾ <https://www.psychologytoday.com/us/blog/the-doctor-is-listening/201401/what-do-people-want-their-healthcare>



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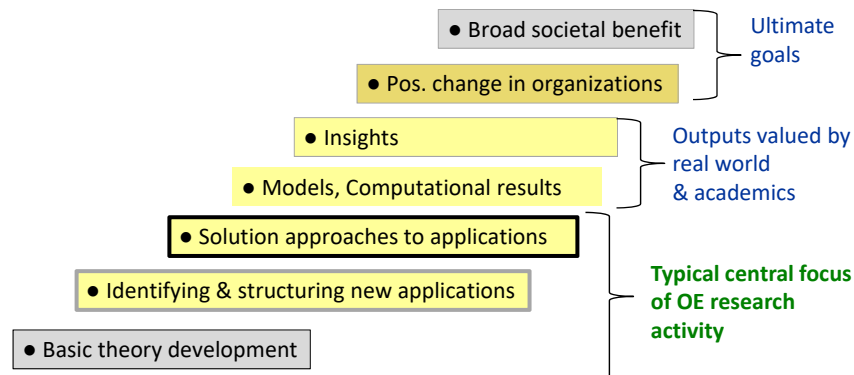
Sample of my experience with Operations Engr. for healthcare delivery

- **Mayo Clinic:** *Coordinated clinic & surgery appointment scheduling to achieve guaranteed wait times to surgical date.* (Machine learning, simulation, optimization). Translated to practice by Mayo.
- **St. Joseph Mercy:** *Online machine learning for personalized risk-based level of care admissions (ICU, PCU, General) for reduced readmissions and mortality.*
- **Michigan Medicine & Mayo:** *Coordinated outpatient appointment scheduling for access delay & patient itinerary performance (stratified approach)*
- **Michigan Medicine:** *Emergency Dept. Redesign (Triage modification, priority rules, & process/flow redesign)*
- **Malawi:** *Humanitarian medication supply chain and distribution with dynamic information*
- **Operational connection to Med Decision Making:** Kellogg Eye Inst: *Glaucoma disease modeling, monitoring, prediction, and control: Which tests, when to test impacts the efficiency and cost of care.*



Contributions from a research perspective:

- Researchers face many opportunities to generate “value”



- *NSF Operations Engineering: "... fundamental research on advanced analytical methods for improving operations in complex decision – driven environments."*

Healthcare is different from many other IE/OR areas

- Frequently super high-touch
 - Personalization
 - Privacy (HIPPA)
 - Researcher spends huge energy on data
- Accuracy & “Quality” matter, but complex to measure & achieve due to the nature of the service & the delivery processes.
- Governmental laws, policies, programs have significant impact
 - (CMS, FDA, VA, *NIH*, *Insurance*, HIPPA, ...)



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Healthcare is different, cont’d.

- Arguably a Quasi-Public Good (in US)
 1. (Not really) **Non-excludable**: Many, but not all people in US have a right to access to utilize (some) healthcare services. Only some services freely available to all.
 2. (Not really) **Non-rivalrous**: Consuming a healthcare service may prevent someone else due to *capacity limits* driven by budget or profit motives
- Government’s role is important
- Insurers and non-governmental healthcare play major role, including significant **incentives to reduce costs**.



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Healthcare is different cont'd.

- The “products ” (patients) are unique, sometimes exhibit price-inelasticity, and have a lot of legal protections surrounding them.
- The production “servers” are unique and important (i.e., physician autonomy, power, legal authority)
- Claim/opinion: Has a relatively small fraction of system/process professionals

Context matters more than in manufacturing

- One size does not fit all (every clinician & hospital is different, differences by sub-population),

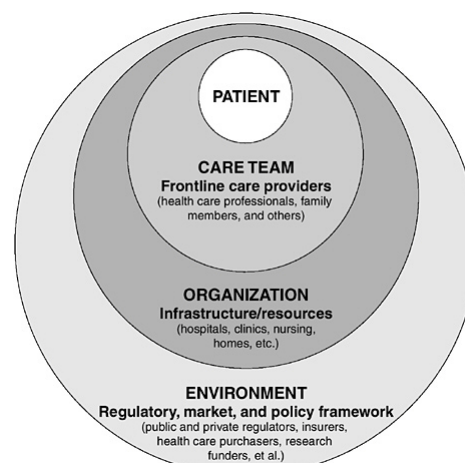
However, general principles & methods can be adapted



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4 Level Model of NAE/IOM “Building a Better Delivery System”

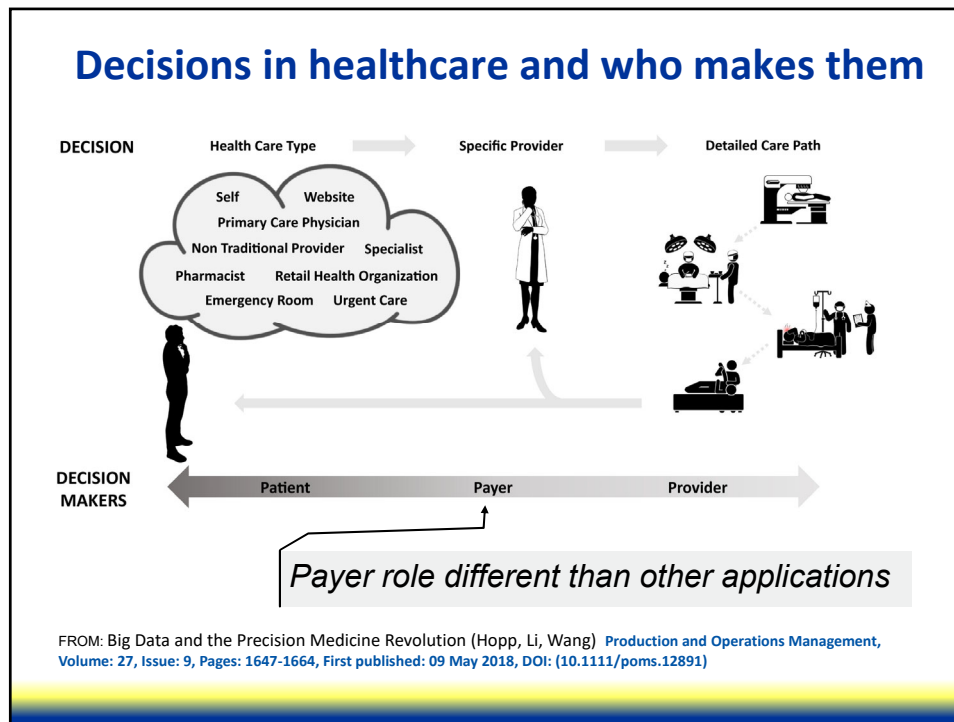
- Engineering Research tends to emphasize
 - **Organization (systems & processes)**
 - Care Team
 - Patient
- Personalized Medicine likely to span these 3 “inner circles” of space.
- In addition to Patient-care team interface, other levels can play a role in high-touch service



FROM: *Building a Better Delivery System: A New Engineering/Health Care Partnership* (2005) of the National Academy of Engineers (NAE) and the Institute of Medicine (IOM)



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Personalized or Precision “Medicine”

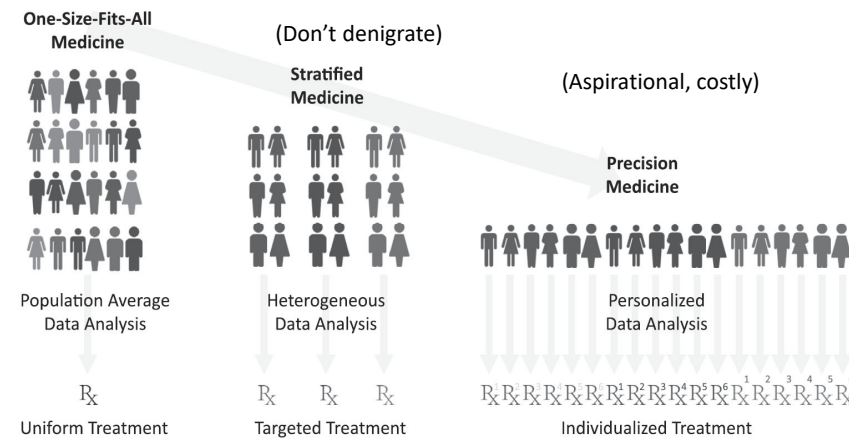


1. “**Personalized health care** is an [...] approach that is driven by personalized **health planning** empowered by personalized medicine tools, which are facilitated by advances in science and technology.”
 - Care tailored to the individual
 - Genomic profiling, genetic sequencing
 - Biologic information predictive of patient disease risk or treatment response
2. **Precision Medicine**: "an emerging approach for disease treatment and prevention that takes into account individual variability in genes, environment, and lifestyle for each person."

¹ **Personalized health care: from theory to practice.** Snyderman R. *Biotechnol J.* 2012 Aug;7(8):973-9. doi: 10.1002/biot.201100297. Epub 2011 Dec 16.

² NIH <https://ghr.nlm.nih.gov/primer/precisionmedicine/definition>

Simple concept of movement towards personalized/precision medicine



FROM: Big Data and the Precision Medicine Revolution (Hopp, Li, Wang) *Production and Operations Management*, Volume: 27, Issue: 9, Pages: 1647-1664, First published: 09 May 2018, DOI: (10.1111/poms.12891)

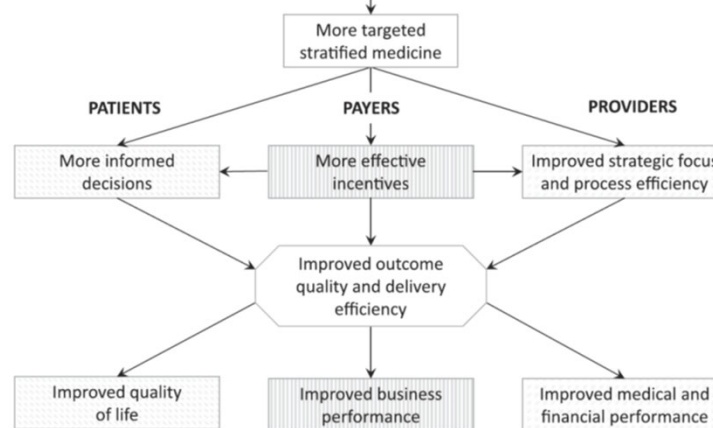
Personalized/Precision Healthcare *DELIVERY*

1. The aspirational goal of Personalized/Precision Care needs to extend to the delivery of care and the optimization of monitoring and treatment decision support. Examples:
 - Personal mortality risk used in admission to ICU, PCU
 - Using Quantile Regression Forest to support traditional or robust optim. of personalized surgical case start times
 - Glaucoma: personalized optimization of **time-to-next visit & which tests to take** (implicitly, **when to take them**)
2. Medicine traditionally discounts the delivery of care, but the direction of change is to take the operational aspects more seriously, often with widespread **lean** and/or **6 sigma/quality** training.
3. EHR and software systems have grown dramatically.
 - *Important path for innovation to impact practice.*
 - US Gov. spent \$36 Bn last 10 years on EHR - (HITECH) Act⁽¹⁾

⁽¹⁾ <https://www.healthaffairs.org/doi/10.1377/hblog20150304.045199/full/>

Elements and hoped-for benefits of personalized/precision medicine; Cost-effective?

Improved data collection, storage, processing, and huge increase in analytics linked to decision making



Edited FROM: Big Data and the Precision Medicine Revolution (Hopp, Li, Wang) [Production and Operations Management](#), Volume: 27, Issue: 9, Pages: 1647-1664, First published: 09 May 2018, DOI: (10.1111/poms.12891)

Machine Learning (ML) and AI are catalysts

ML/AI is seen the natural critical technology, given the uncertain nature of human health and disease plus the desire to provide descriptive, predictive and prescriptive information to patients,

- **Stochastic models, optimization, and the operational context are very attractive opportunities for OE researchers to uniquely incorporate ML/AI to add value.**
- My experience with MDM for glaucoma has shown tremendous thirst from ophthalmologists to use ML to help them get beyond current limits.
- Paradox: The more technology becomes the source of clinical information and even wisdom, the smaller the fraction of information value provided by the clinician.
 - → patient care becomes less high-touch (if one believes that the reduced incremental value provided by the human clinician makes it even harder for them to justify spending time on mutually satisfying encounters with the patient)



Patient Satisfaction, formally defined (Relative to individual's expectation)

Patient Satisfaction Questionnaire (PSQ) can measure a patient's satisfaction:

- 1) How their needs were addressed
- 2) The interaction in general
 - Did I wait a long time in the clinic?
- 3) Their active involvement in the interaction
- 4) **Information received**
 - *Opportunity for ML/AI + OE if we can link to improved coordination of care, scheduling, selection of best clinicians, etc.*
- 5) Emotional support

Answered on Visual Analogue Scales (VAS) from 0 to 100

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1494792/>



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Patient Experience includes emphasis on

- Aspects of healthcare that patients value highly
 - Provide access to a visit at the appropriate time
 - Emphasis on **access delay** from request date to visit date
 - Sometimes tightly linked to geographical distance
 - May be more important for urgent cases and new patients needing a diagnostic visit
 - Provider(s) communicate appropriate effectively & Patient **easily obtains** the information needed
 - Useful information, referrals made & **coordination of care**, medications updated, etc.
 - Problem: Lack of EHR interoperability

Experience = did provider do what it should have?

<https://www.ahrq.gov/cahps/about-cahps/patient-experience/index.html>



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NCQA* Patient-centered Medical Home - *Pillars*

1. **“Team-Based Care and Practice Organization:** ... structure a practice’s leadership, care team responsibilities and how the practice partners with patients, ...”
2. **“Knowing and Managing Your Patients:** ... data collection, medication reconciliation, evidence-based clinical decision support ...” (machine learning potential)
3. **Enhanced patient access to care - “Patient-Centered Access and Continuity:** Guide practices to provide patients with convenient access to clinical advice and helps ensure continuity of care.”

* NCQA - National Committee for Quality Assurance

<https://www.ncqa.org/programs/health-care-providers-practices/patient-centered-medical-home-pcmh/pcmh-concepts/>



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NCQA Patient-centered Medical Home, cont’d.

4. **“Care Management and Support:** ... identify patients who need more closely-managed care.” (machine learning potential)
5. **“Coordinated care** and care transitions: Ensures that primary and specialty care clinicians are effectively sharing information and managing patient referrals to minimize cost, confusion and inappropriate care.”
6. **“Performance Measurement and Quality Improvement”** (Core Operations, IE, & Sys. Engr work)

<https://www.ncqa.org/programs/health-care-providers-practices/patient-centered-medical-home-pcmh/pcmh-concepts/>



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Examples of operations/delivery topics

- Appointment Scheduling
- Hospital census/flow & admission control
- Emergency Dept. op's
- Operating Room sched.
- ICU flow & admission ctrl.
- Staffing & workforce cross-training
- Clinician, nurse shift design & shift scheduling
- Operational issues in disease management
 - Chronic diseases
- Clinical research & CRU's
- Clinical trials design
- Pre-discharge readmissions reduction
- Post-discharge readmission reduction
- Organ transplants
 - Allocation problems
- Treatment/screening policies
- Treatment optimization
 - Radiation therapy
- ...



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Examples of operations/delivery topics, cont'd.

- Blood Banks
 - Other bio-banks
- Vaccine and pharmaceutical supply chain
- Medical supply chain, inventory
- Layout
- Drug discovery
- Resident training, requirements, scheduling,...
- CT, MRI scheduling
- Improving laboratory operations
- Nurse patient allocation and workload balancing
- Primary care operations
- Pt.-centered med. home
- Telemedicine
- E-visits
- Tele-triage
- Emergency Med Services; ambulance routing
- ...



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Caution – Is healthcare so very different that we need to review it differently? An Opinion – Yes and No

- **Opinion: Yes, knowledge of healthcare research and real world delivery is important**
- Opinion: Most research in healthcare, in my experience, is driven by people eager to improve the health of people, but this mentality leads to a **double standard, which is not good**
- Opinion: Healthcare delivery systems are hard to make large changes to
 - In the details, lean, 6 sigma, and common sense changes are being made relatively frequently; however, this is not RESEARCH
 - Major innovations and overhauls are relatively rare
 - Concern for risk, a culture of reaction, and the lack of administrative power relative to clinicians lead to a political environment in which major changes are harder to make than in manufacturing
 - Claim: Innovations today will have maximum impact when implemented EHR type systems.

No, the double standard: Claim - Healthcare research is asked to be methodologically strong and also have major short term results – more than most areas in operations engineering

To maintain a high intellectual merit standard, healthcare reviews must not demand greater short term real world benefits than other areas (rather, possibly lower the bar due to increased barriers) .

- **Even if change is slow, the critical importance of improving outcomes and controlling costs makes healthcare systems research extremely important.**



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Healthcare planning & scheduling models

Issue of **access** to care.

1. Ability to gain the care needed (or to pay for it)
2. “Access delay” targets by tier/class while considering capacity – improve patient safety and health outcomes
 - I learned first hand this was a big problem in VA before it was news

Some of the settings I have studied

- **Outpatient visits in an integrated care system**
- **Surgical scheduling (+ coordination with clinic visits)**
- **Clinical research units – planning and resource allocation for in-advance scheduling**



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Outpatient Planning Context (Patient Pathways)

A Capacity Allocation Planning Model for Integrated Care and Access Management, Deglise-Hawkinson J., J.E. Helm, T. Huschka, D.L. Kaufman, M.P. Van Oyen 2018, *Production and Operations Management*. 27(12), 2270-2290

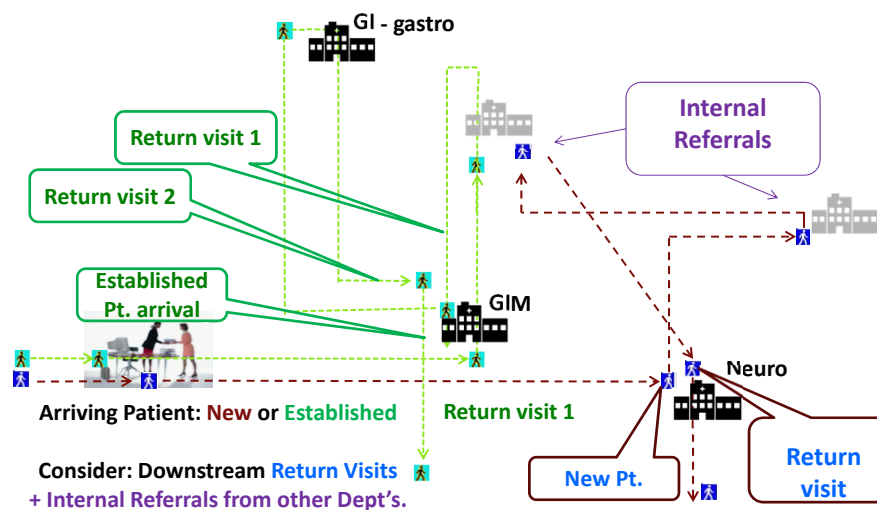
- Coordinated group of specialty services (GI, GIM, Neuro) serves patients **nationally**, **regionally**, and **locally**.
- Encourage timely visits for **Urgent** and/or **new patient access**
 - Medically speaking, diagnostics from specialists are the best care
 - Financially, new patients are critical to sustaining the org.
 - Long access delay drives patients elsewhere
- Optimize **capacity reservation in work templates** for department
- **Episode of care** begins with a **Root/initial visit**, with subsequent visits of the **itinerary of care** over time.
- **Delay of initial visit, especially for urgent/new pts.** must be short
- Access to downstream visits in episode of care must also occur rapidly to compress the itinerary

Partial funding - NSF Grant CMMI-1548201. NSF had no role in the design or conduct of this research



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Multiple services, pt. classes, downstream visits, Poisson appt. requests, episode of care



Performance metrics by patient class, dept.

- **Access delay (wait)** for the first visit of an itinerary:
% of patients exceeding a given T wks. wait target
 - **All “root” appointment dates are promised up front**
- **New (urgent) patient throughput** by department
 - Currently not managed (doc’s prefer returning pt.)
- **Overtime & capacity utilization** by department or subspecialty
- **Downstream visit delay probability**
% internal/return visits delayed (e.g. > 1 day)

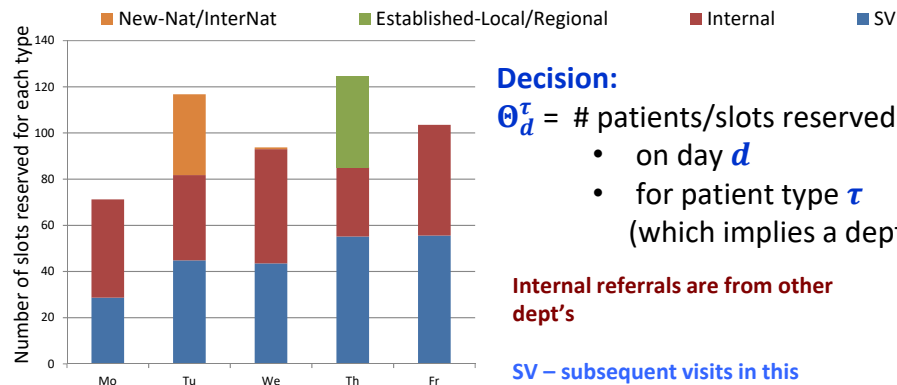
* **Time of day is not considered in planning model**



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Designing daily scheduling templates

Opt. Number of slots/pts of each type by day of the week?



Decision:

- Θ_d^τ = # patients/slots reserved
- on day d
 - for patient type τ
(which implies a dept.)

Internal referrals are from other dept's

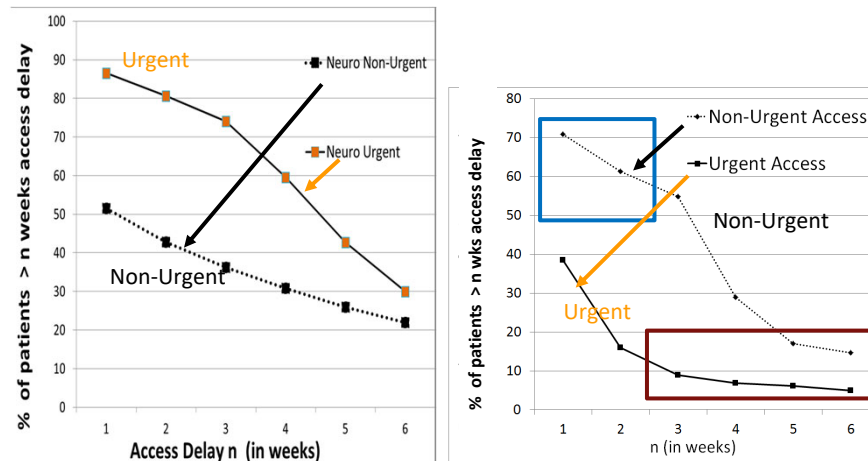
SV – subsequent visits in this service. Stochastic location process parameterized to capture itinerary

Illustration of solution



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Computing Before and After (Access delay Complementary CDF's)



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Similar goals: A heuristic scheduling approach to coordinated Clinic & Surgery scheduling

Pooyan Kazemian¹, Mustafa Y. Sir², Mark P. Van Oyen³, Jenna K. Lovely⁴,
David W. Larson³, Kalyan S. Pasupathy²

*J. of Biomedical
Informatics, v. 66*

- Colorectal surgery (CRS) at Mayo includes 8 surgeons that work in two teams: **orange** & **blue** that alternate between clinic & surgery days
 - Model daily-level **Clinical** & **Surgical** calendars for each surgeon
- Requests/orders arrive throughout the day.
- All orders need a clinic appt. (consult).
 - Will confirm need for surgery
- Fraction of clinic visits are followed by a surgery (predicted via machine learning) - must occur within access delay target

Partial funding - NSF Grant CMMI-1548201. NSF had no role in the design or conduct of this research.



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5 patient priority levels/types for surgery access

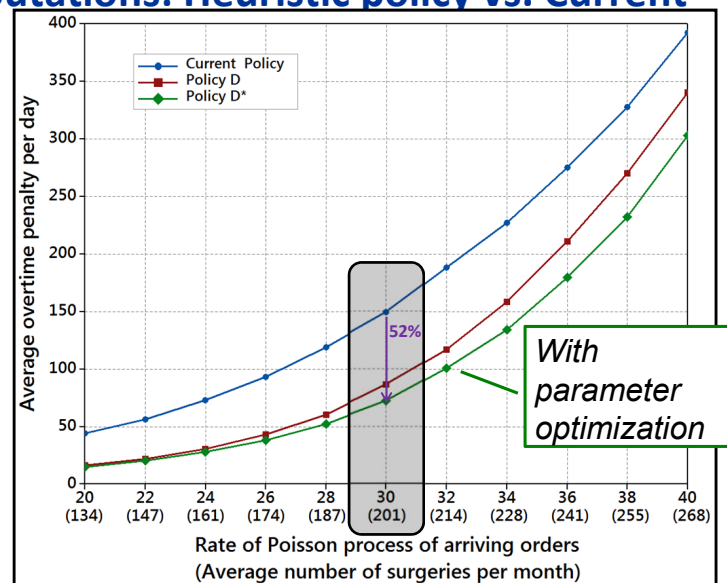
- **Priority Type** is determined based on patient's
 1. indication of disease
 2. geographical zone
 3. referral type
- Maximum wait time target (MWTT) to surgery:

Priority Type	Maximum Wait Time Target (MWTT) to Surgery [business days]
1	3
2	10
3	20
4	40
5	NA (only need a clinic visit)



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Computations: Heuristic policy vs. Current



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Taking the next step – deeper methodology

“Managing Coordinated and Priority-based Care in Clinical and Surgical Suites Under Integrated Uncertainty,” Keyvanshokoo, E., P. Kazemian, M. Fattahy, & M.P. Van Oyen, 2018.

Challenge I: Develop a Generalizable Optimization Approach.

- ❖ Will take a multi-stage stochastic programming approach to capture the dynamic information on arrival realizations over time
- ❖ A *rolling horizon* approach is used to make it practical for application

Challenge II: Handling **different types of uncertainty** in patient request arrivals (Poisson) & need for surgery (gained later) & service durations (Distributionally robust) simultaneously.

For many surgery types, insufficient reliable historical data to fit surgery duration tailored to surgery type due to surgeon-dependence.

Svc. Time Ambiguity Assumption: Only know Mean, St.Dev., and Support;
Worst Case - Adversarial realizations

See subm. paper: E. Keyvanshokoo, P. Kazemian, M Fattahy, Mark Van Oyen

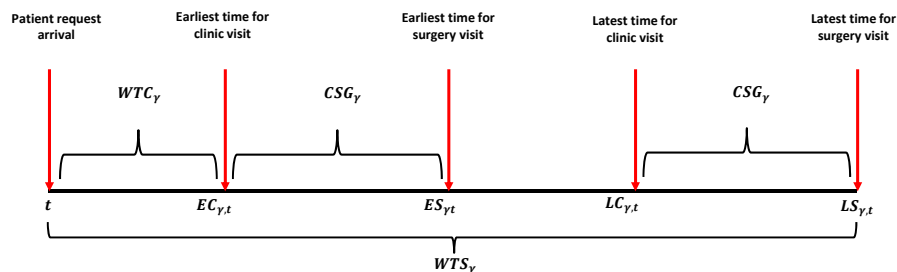
Partial funding - NSF Grant CMMI-1548201. NSF had no role in the design or conduct of this research.



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Problem has visit timing constraints

Clinic & surg. allowable times depend on the **type γ** of patient

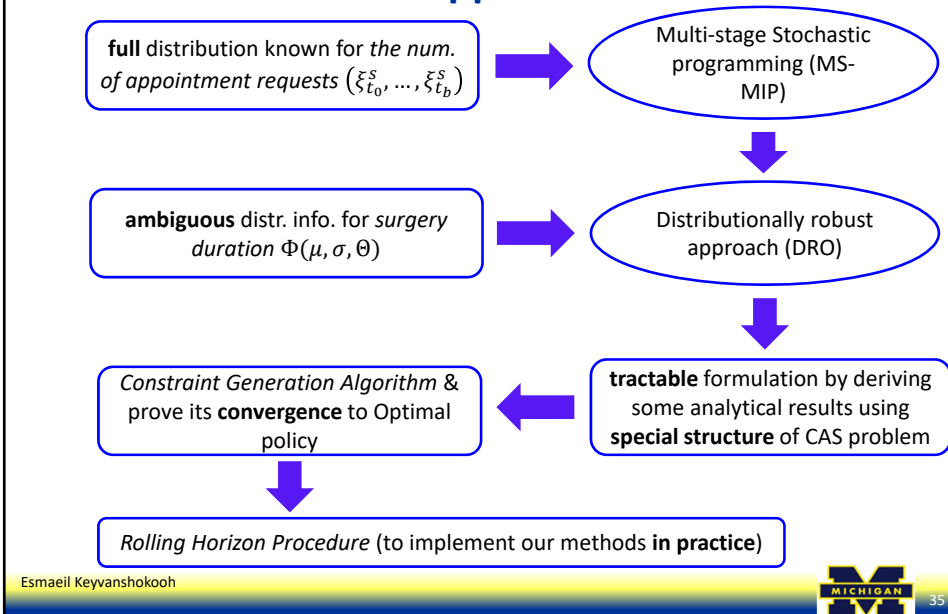


- **Approach:** develop an **Integrated Multi-stage Stochastic programming & Distributionally Robust Optimization** approach.
- **2nd Step:** Make *implementable* decisions via a **Rolling Horizon Procedure**.



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Overview of IMSDRO Approach



Analysis (ii): Surgical Access Times (days)

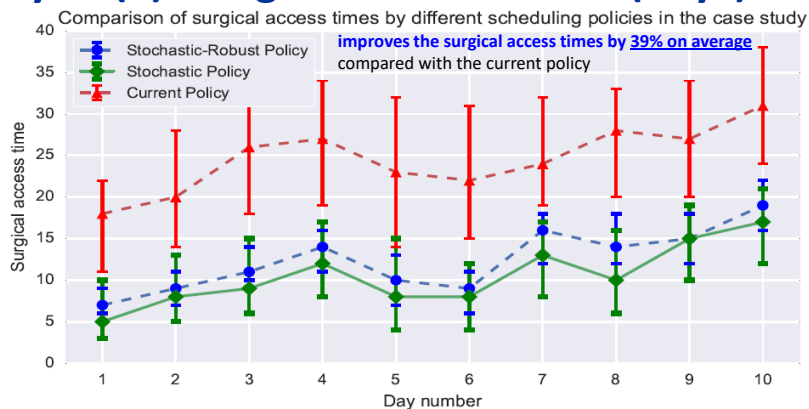


Figure 8 The comparison of surgical access times for patients arrived on different days obtained by the stochastic-robust, stochastic and current policies over an arrival horizon of 10 working week days implemented by the rolling horizon Algorithm 2 for the case study.

Note: Stoch or Stoch-robust policy is the best in terms of surgical access, but the current policy is the worst! This highlights importance of establishing care coordination between clinical & surgical calendars of surgeons.

Esmail Keyvanshokoh



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Analysis (iii): Importance of Care Coordination

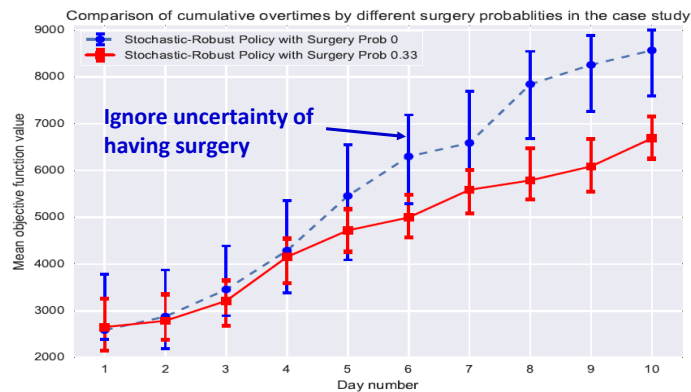


Figure 9 Importance of care coordination: the comparison of cumulative mean objective values obtained by the proposed stochastic-robust policy for the case study with surgery probabilities of 0 and 0.33 implemented by the RHP Algorithm 2 over an arrival horizon of 10 working week days.

Conclusion: the superiority of the case with surgery prob 0.33 increases over time in both mean overtime & its variability.

Note: The prob 0 case doesn't consider uncertainty on future surgeries.



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Online Personalized Hosp. Admission System

Working paper, M. Zhalechian, E. Keyvanshokoo, & M.P. Van Oyen, 2018.

- Challenge: admission decision support to provide a patient-specific care unit/ward assignment while accounting for capacity
- Many experts believe that a **high unplanned readmission** rate for a hospital indicates that the patient's health issues are **not adequately** addressed while in hospital.
- Recent studies have confirmed that there is a **relationship** between the **risk of readmission** and the **care unit placement**.
- Care unit placement decisions are inherently patient-specific, and human judgement is important, but can be improved .

Challenging Aspects

Concurrently Learning Readmission Risk and Length of Stay

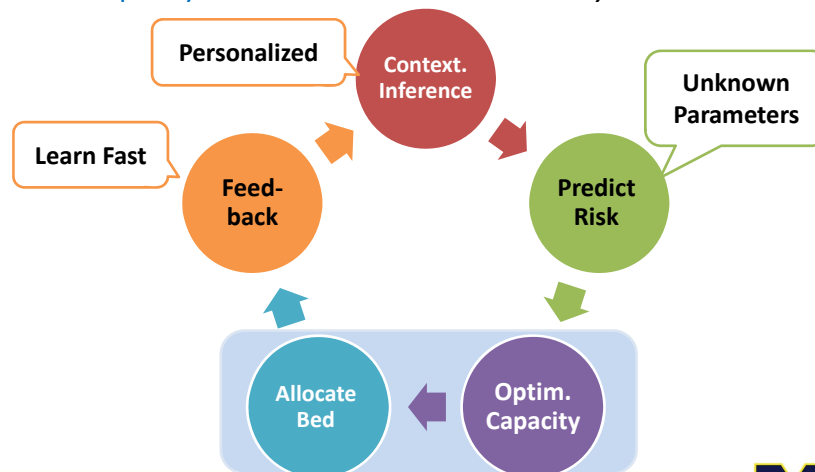
Given that

1. One cannot repeat “experiments” with a specific patient; only know what happened for the historical choice
2. Every hospital is unique in terms of:
 - Capacity
 - Patient demographics
 - Operational processes
3. Also, the hospital processes and patient population change over time in unpredictable ways.



Contextual Multi-Armed Bandits - Online Learning

Contextual Multi-Armed Bandits *integrated with Optimization of bed capacity* for a *Personalized Admission System*.



Interest & Value

1. Lightweight/fast algorithms suitable for large numbers of input/context variables
 - Suitable for real-time applications
2. Highly adaptable, able to incorporate system changes without any leading indicators fed into model
 - Offline methods can approximate this ability, but will likely require much more computation and separate design of how to perform updating and when.
3. Online learning is experiencing a lot of theoretical interest and advancing quickly



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Admission Control to higher level of care units (without Readmissions)

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Meisami A., Deglise-Hawkinson J., Cowen M.E., Van Oyen M.P. 2018, Data-driven optimization methodology for admission control in critical care units, Health Care Management Science, 1-18

- **Input:** *Personalized patient risk metric*
 - 30-day mortality risk unique to hospital to be used as a surrogate for the patient's "fragility" and need for either an ICU or PCU/Step down type of bed
- **Goal:** Personalized, selective "up-servicing" high risk patients with a higher level of care bed. (partner St. Joseph Mercy Hospital)
 - **Operational Complexity:** Account for network flows of care pathway, capacity, length of stay by patient characteristics.
 - This large queueing network control problem is solved using a mixed integer program for a model of 9 wards

Personal experience of trends (10 years Sr. Design)

- Health systems are growing more paranoid and risk-averse with regards to
 - Release/sharing of data; Compliance training
- Increasing partnership of the medical world with engineering
- Healthcare org's are slow, but they change quite a lot in 10 years. Bad, old habits with decades of history are changing.
- Consolidation & growth of successful systems (→ greater benefit from our efforts)
- Great interest in technology & devices (in part due to strong incentives not enjoyed by systems work)
- Meaningful use of certified EHR technology – data coverage and quality is improving (CMS Medicare and Medicaid EHR Incentives)
- The Affordable Care Act has pushed hospitals to care more about improving delivery & outcomes
 - Increased reporting and visibility of metrics
- CMS trying to advance beyond fee-for-service model (consider quality, bundled payments, readmissions reduction/penalties, *expand telehealth reimbursement*, ...)



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Thank You!

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& Thanks To

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 - Mohamad Zhalechian
 - Isaac Jones
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 - Jonathan Helm (Kelly, Indiana U.)
 - Pooyan Kazemian (Harvard Int. Med.)
 - Soroush Saghaian (Harvard Kennedy School of Pub. Pol.)
 - Hoda Parvin (Amazon)
 - Amir Meisami (Adobe Research)
 - Maya Bam (GM Research)

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