



## OM Forum

# Healthcare Operations Management: A Snapshot of Emerging Research

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**Abstract.** A new generation of healthcare operations management (HOM) scholars is studying timely healthcare topics (e.g., organization design, design of delivery, and organ transplantation) using contemporary methodological tools (e.g., econometrics, information economics, and queuing games). A distinguishing feature of this stream of work is that it explicitly incorporates behavior, incentive, and policy considerations arising from the entanglements across *multiple* entities that make up the complex healthcare *ecosystem*. This focus is a departure from an earlier generation of research that primarily centered on optimizing given operations of a single entity. This paper provides an introduction to this burgeoning field and maps out research opportunities. We start with identifying key entities of healthcare delivery, financing, innovation, and policymaking, illustrating them on a healthcare ecosystem map (HEM). Next, we explore the HOM literature examining the interactions among various entities in the HEM. We then develop a taxonomy for the recent HOM literature (published in *Manufacturing & Service Operations Management*, *Management Science*, and *Operations Research* between 2013 and 2017), provide a tool-thrust graph mapping methodological tools with research thrusts, and situate the HOM literature in context by connecting it with perspectives from medical journals and mass media. We close with a reference to technological innovations that have the potential to transform the healthcare ecosystem in future decades.

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**Keywords:** healthcare operations management • healthcare ecosystem • behavior, incentive, and policy issues in healthcare • healthcare analytics

## 1. Introduction

The field of healthcare operations management (HOM) addresses one of the most compelling issues in our society—providing affordable and inclusive access to quality healthcare, in a timely manner. An earlier generation of scholars focused on what is referred to as HOM 1.0, analyzing the operations of a *single* healthcare delivery organization (e.g., hospital and physician practice) and developing decision-support tools and consulting blueprints for improving given operations. Since the beginning of the 21<sup>st</sup> century, the current generation, hereafter referred to as HOM 2.0, has started to look beyond point-level operational improvements and examine the interactions of *multiple* entities, shifting our gaze onto the healthcare *ecosystem* in which these delivery organizations and other types of entities are embedded inextricably.

HOM 2.0 has touched upon timely topics (e.g., organization design, design of delivery, and organ transplantation), adopting and advancing contemporary methodological tools (e.g., econometrics, information

economics, and queuing games). What distinguishes this generation of research is that it centrally incorporates the *behavior* of *multiple* players in their *incentive* and *policy* environments: *Behavior* issues refer to the way individuals or entities make decisions in response to certain stimuli; *incentive* issues refer to the operating environments producing those stimuli; and *policy* issues refer to how the national, local, and organizational agenda is molded by the interactions among various entities and, in turn, shapes the incentives underlying healthcare delivery. Taken together, behavior, incentive, and policy (BIP) capture the broad theme of this emerging line of research, for which this paper aims to provide an introduction and map out research opportunities.

We begin with identifying key entities in a sufficiently complex healthcare system using a healthcare ecosystem map (HEM) that decomposes the system into four interconnected “circles,” each of which consists of entities in charge of healthcare delivery, financing, innovation, and policymaking. We illustrate the HEM with various aspects of the U.S. kidney-transplantation

system, in which the behavior of patients and providers is shaped by the policies in place that determine reimbursements and organ-allocation rules. Improving the system requires a different set of models as well as a different set of research questions, a fundamental departure from the preoccupations of HOM 1.0.

Next, to bring the reader up to speed on HOM 2.0, we connect the HEM to the emerging literature in two ways. On one hand, we use three subloops of the HEM to illustrate the need to examine the interactions among multiple entities and how such interactions relate to the emerging research. On the other hand, we have collected and categorized all the papers relevant to healthcare operations published in *Manufacturing & Service Operations Management*, *Management Science*, and *Operations Research* between 2013 and 2017. To structure these papers in a logical manner, we have done the following: (1) We developed a taxonomy of the literature consisting of various macrolevel, meso-level, and microlevel research thrusts; (2) we situated the literature in the context of actual issues in healthcare, by placing the literature alongside perspectives from the medical community (written by clinicians) and mass media (written by journalists, some of whom are also physicians, to bring important issues to light for a broader segment of our society); and (3) we identified which methodological tools have been employed for what types of analyses in the literature, thus connecting tools with thrusts in a tool-thrust graph.

In elucidating the institutional context underlying HOM 2.0, we use the U.S. healthcare system as the main backdrop to this paper, while noting that the literature has touched on many different parts of the world, including Germany (Kuntz et al. 2014), Hong Kong (Guo et al. 2019), India (Deo and Sohoni 2015), Singapore (Dai and Shi 2017), South Korea (Cho et al. 2014), sub-Saharan Africa (Jónasson et al. 2017), and the United Kingdom (Freeman et al. 2017), to provide a few examples.

## 2. Healthcare Ecosystem Map

A distinguishing feature of the emerging HOM 2.0 literature is its emphasis on the interactions among multiple healthcare entities. Thus, it is important to be familiar with key entities in the healthcare ecosystem. For this purpose, we have developed the healthcare ecosystem map to highlight four types of entities, in charge of healthcare delivery, financing, innovation, and policymaking, respectively. Existing frameworks often cover one or two types of the healthcare entities.<sup>1</sup> Creating a more comprehensive framework will help consultants, entrepreneurs, health economists, and policymakers, as well as HOM researchers, to gain a full picture of the healthcare

ecosystem as they look for ways to influence the behavior of various decision makers.

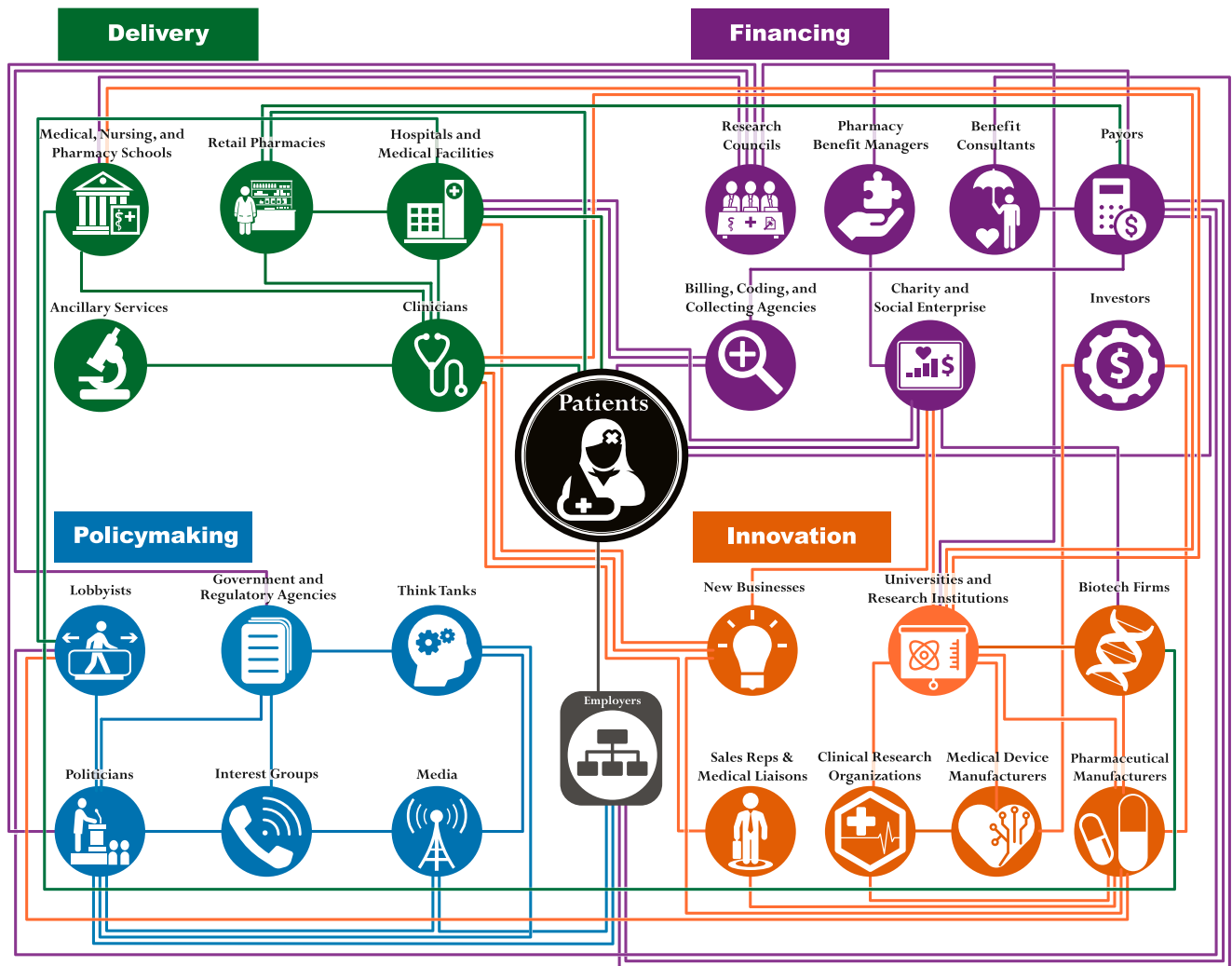
The HEM, shown in Figure 1, covers key entities that serve patients' health needs directly or indirectly. To receive care, patients interact with providers, who are financed by payors and funders and empowered by medical, technological, and business innovations. Because virtually all these aspects (delivery, financing, and innovation) of healthcare are heavily regulated, policymaking plays a prominent role in the healthcare ecosystem (Tuohy and Glied 2011). The HEM decomposes the complex web of interconnections between various entities into four circles. In illustrating each circle, we use a concrete example related to an active area in the HOM literature—organ transplantation (see, e.g., Su and Zenios 2004, Bertsimas et al. 2013, Sandikçi et al. 2013, Ata et al. 2017, and Dai et al. 2019), with a particular focus on the U.S. kidney transplantation system.

1. The circle of *delivery* consists of the entities in charge of delivering care to patients. The primary operational challenge facing this circle is to ensure that the right patients receive the right diagnostic and treatment services from the right providers at the right time.

For a patient suffering from end-stage renal disease (ESRD), dialysis is a life-prolonging option, but is inconvenient and painful; kidney transplantation is the preferred option. Accordingly, the circle of delivery includes nephrologists, dialysis centers, and transplant centers. Unfortunately, some dialysis patients are not informed of the transplantation option. Garg et al. (1999) show that for-profit ownership of dialysis centers is associated with significantly lower likelihoods of recommending transplantation to patients and higher mortality rates. This finding is an example of “competing interests” in healthcare delivery (Goh 2018).

Furthermore, although, by mandate, transplant nurses must inform their patients of the option of multiple listing at other centers with shorter waiting times [Organ Procurement and Transplantation Network (OPTN) Policy 3.2.3], they ordinarily bury this detail in a mountain of paperwork and a deluge of information sessions, thus satisfying the letter of the law but not the spirit.<sup>2</sup> The uptake of multiple listings is low—5.8% for kidney and 3.3% for liver (Merion et al. 2004). Many patients lack transportation options, but a key reason for the low uptake of multiple listings is adverse selection: The transplantation center is concerned that the patients most inclined to take advantage of the multiple-listing option are those with relatively good health and excellent private insurance.<sup>3</sup> Losing those patients would mean lower margins on reimbursements and worse posttransplant outcomes.

Figure 1. The Healthcare Ecosystem Map



2. The circle of *financing* consists of the entities providing and allocating funds needed for various activities in the healthcare ecosystem. This circle plays major administrative roles in healthcare. Its primary operational challenge is to fund service providers appropriately and incentivize them to organize their operations in the most productive way.

In the case of kidney transplantation, Medicare covers ESRD patients requiring dialysis or transplantation, spending more than \$30 billion per year, which is approximately 7% of its annual budget. This significant expenditure is an unintended consequence of a 1972 U.S. Congressional act extending Medicare coverage to ESRD patients; the lawmakers did not anticipate the explosion of kidney failures in the ensuing decades. Now, to make matters worse from a fairness-of-access viewpoint, for those patients below the age of 65, Medicare reimburses immunosuppressant drugs up to only 3 years, a policy criticized as “buying someone a new car and giving them only enough gas to drive around the block a few times” (Sack 2009),

forcing patients unable to afford such drugs to lose the efficacy of their transplanted kidneys, ending up returning to dialysis or seeking retransplantation. This reimbursement constraint, then, creates an incentive for transplant centers to not even list certain patients, effectively creating a shadow waiting list.

3. The circle of *innovation* consists of entities developing new drugs, therapies, medical devices, and business models and operational approaches. The primary operational challenge this circle faces is to ensure that the firms and research institutions continue to develop new technologies and that organizations continue to innovate their operations and business models.

In the case of kidney transplantation, medical and research institutions have made substantial progress in facilitating organ matches (e.g., by engineering a market for living kidney exchange) and utilizing marginal organs (e.g., by making it possible to transplant organs from HIV-positive donors) and are working toward developing artificial organs (e.g.,

using 3D printing). Innovations are not limited to medicine and technology. They can also be in terms of delivery of care and, more broadly, business models. OrganJet, studied by Ata et al. (2017), represents an innovative business model that transports transplant candidates in private jets (when necessary), financed by self-insured employers (e.g., Walmart) or private insurance firms, so that they can multiple-list and receive organ transplants across regions.

4. The circle of *policymaking* consists of the entities that shape, through their interactions, health policies (within an organization or at a local, state/provincial, and national level). Different from the other circles, this circle can be constraining, in the sense that healthcare organizations work within a highly regulated setting that will likely limit the set of feasible solutions to operational problems and impede their implementation.

In the domain of organ transplantation, the U.S. Congress established the OPTN to (1) make organ-allocation policies and (2) collect transplant data, which it operates through the United Network for Organ Sharing and the Scientific Registry of Transplant Recipients, respectively. Additionally, the Centers for Medicare and Medicaid Services (CMS) stipulates policies regarding posttransplant outcome thresholds that drive reimbursement. The various transplant centers work within these policies.

In reality, an entity may play multiple roles. For example, a hospital can both deliver care and function as a clinical trial site; see Levine (2018) for an overview of organization structures of healthcare providers. We map the healthcare ecosystem based on the primary role of each entity as is commonly understood (as its “first” purpose). This simplification also allows us to graph interentity interactions driven by their primary functions.

Seen through this lens, HOM 1.0 has concentrated largely on a single entity in the circle of *delivery*,<sup>4</sup> consisting of hospitals, physicians, patients, medical schools, and ancillary service providers, often without explicitly accounting for the other circles. This focus is what HOM 2.0 aims to shift—this emerging stream of research builds on an understanding of how the constraints (of reimbursements and allocation policy), metrics (of outcomes imposed by health policy), and other drivers of medical decision making are shaped by activities from the circles of financing, innovation, and policymaking.

In the rest of the paper, we examine the emerging HOM research in two ways: In Section 3, we survey the emerging HOM research in terms of how it captures the interactions among multiple entities in different “subloops” of the HEM. Then, in Section 4, we classify the recent literature in terms of both its methodological tools and research thrusts.

### 3. Interactions Among Healthcare Entities

Having identified key entities in the healthcare ecosystem, we now turn to their interactions—using three example subloops of the HEM—and outline relevant streams of emerging HOM research. The first subloop (Section 3.1) connects healthcare providers, payors, and patients and is relevant to the literature on the cost and access of care. The second subloop (Section 3.2) connects pharmaceutical manufacturers, charity organizations, and payors and is relevant to the literature on healthcare supply chains. The third subloop (Section 3.3) connects clinicians, patients, and hospitals and is relevant to the literature on the quality of care.

#### 3.1. Interactions Among Healthcare Providers, Payors, and Patients

We start with a subloop connecting healthcare providers (e.g., hospitals, physicians, and retail pharmacies), payors (e.g., private insurance firms, Medicare, and Medicaid), and patients. This subloop is related to a research area aimed to understand the supply of and demand for healthcare services and the economic interplay of both sides. Although a growing number of HOM scholars, including Dada and White (1999), Fuloria and Zenios (2001), Gupta and Mehrotra (2015), Adida et al. (2016), Dai et al. (2017), and Bastani et al. (2019), have examined insurance payments in formulating healthcare providers’ medical decisions, the area remains little explored and promising for future research.

To understand the importance of the subloop, consider the following questions: Why has cost reduction been so hard to accomplish? Is the high cost of U.S. healthcare a result of excessive utilization, high prices, or both? Are insurance companies simply victims of providers or physician power, or are they complicit in this failure, due to perverse incentives that are unintended consequences of well-intentioned health policy?

In an influential paper titled “It’s the Prices, Stupid: Why the United States Is So Different from Other Countries,” Anderson et al. (2003) show, contrary to popular belief, that the United States *trails* most Organisation for Economic Co-operation and Development countries in terms of the *utilization* of health services; they attribute the high cost of U.S. healthcare to its *pricing* practice. A more recent study by Papanicolas et al. (2018) draws nearly the same conclusion. Pricing practices in the U.S. healthcare system are remarkably opaque and ad hoc. Consider a true story from Elisabeth Rosenthal’s 2017 book, *An American Sickness: How Healthcare Became Big Business and How You Can Take It Back*, about Jeffrey Kivi, a chemistry teacher in New York City suffering from psoriatic arthritis (an autoimmune disease). Kivi initially received an infusion procedure every six weeks

in an outpatient clinic, costing \$19,000 per visit. In 2013, amid a wave of hospital consolidation, the clinic was acquired by an academic medical center. After the acquisition, with the same procedure from the same clinicians, the charge per visit increased more than fivefold, to nearly \$100,000 and, at a certain point, to more than \$130,000. Kivi's insurance firms swiftly paid these bills.

One might wonder why the insurance firm (payor) would be willing to accept these astronomical fees. Industry consolidation has led to supersized hospital groups and afforded them unprecedented bargaining powers, but that consolidation only partially explains the situation. A possibly more important, but often ignored, factor is that due to medical-loss ratio provision of the Affordable Care Act, insurance firms are now required to spend no less than 80% of premium dollars on reimbursing healthcare and no more than 20% on administrative expenses; otherwise, they are mandated to refund a proportion of unused premiums to consumers and subsequently lower future premiums. Because insurance firms' executive compensation is tied to the size of the pie (total premiums collected from consumers minus possible refunds), they have no incentive to reduce their payouts as long as they do not lose money for the current year. On the contrary, they likely have an incentive to *increase* their payouts to justify future premium increases. This pricing behavior is driven by an incentive environment that is, in turn, shaped by health policy.

Another example of the interactions among hospitals, payors, and patients involves the *deductible*, which is the cumulative amount a patient must pay out of pocket before the insurance kicks in. Historically, U.S. consumers have enjoyed low deductibles. In the last few years, however, they have been exposed to very high deductibles—in 2016, more than 50% of all U.S. employees had insurance plans with an annual deductible of at least \$1,000. Our conversations with senior healthcare executives revealed that high deductibles have major implications for patients' visit patterns and, hence, health providers' day-to-day operations. Such a calendar effect is particularly salient at the end of each year. According to a transplant surgeon,

The deductible issue is difficult to ignore in real world data. It clearly impacts demand, especially in the fourth quarter of a given year. It is almost as if coinsurance is a graded scale that differs by the month of the year. It changes from essentially 100% in January to close to 0% as the deductible is eliminated and the insurance kicks in. Patient and physician behavior are clearly influenced. (Axelrod et al. 2015)

The calendar effect also applies to the first few months of each year: "In the past five years, health insurers

went from paying 90% of patient care costs to only about 70%, and that's causing massive headaches for providers. . . . The stark reality of high-deductible healthcare . . . really hit home during the first four months of this year" (Barkholz 2017).

Although not all patients are strategic, these anecdotes are supported by empirical evidence of patients' strategic behavior under high-deductible environments (Brot-Goldberg et al. 2017), likely driven by the fact that many patients are cash-strapped and cannot absorb shocks. HOM scholars wishing to understand patients' visit decisions would thus need to incorporate their responses to high deductibles and the potential long-term health impact.

In this subloop, patients' visit patterns—arrival rates (or probability of joining) in queuing models, for example—is governed by a high-deductible incentive environment shaped by health policy. Queuing games (aka rational queuing theory) arise naturally as a suitable methodology. Indeed, a growing number of HOM scholars, including, for example, Su and Zenios (2004), Ata et al. (2017), Dai et al. (2019), Savva et al. (2019), and Song and Veeraraghavan (2018), have recognized the power of queuing games in capturing the endogenous nature of access to healthcare services. Yet, to date, the effect of deductibles on healthcare operations has not been formally analyzed in the HOM literature.

### 3.2. Interactions Among Pharmaceutical Manufacturers, Charity Organizations, and Payors

One entity has become the poster child for runaway costs in healthcare: pharmaceutical manufacturers. The pharmaceutical supply chain, studied by HOM 2.0 scholars (e.g., So and Tang 2000, Kouvelis et al. 2015, Dai et al. 2016, Chick et al. 2017, and Cho and Zhao 2018) in various contexts, consists of pharmaceutical manufacturers, wholesalers, pharmacies, health insurance firms, and pharmaceutical benefit managers. In a recent study, Sood (2017) finds that pharmaceutical manufacturers, on average, enjoy a gross margin of 71% and a net margin of 26%. The circle of policymaking (e.g., politicians, media, patient-advocacy organizations, and think tanks) has proposed various initiatives aimed at curbing such excessive profits, but most discussions have not generated tangible changes, partially due to the fear of discouraging activities in the circle of innovation (e.g., biotech firms, clinical research organizations, and pharmaceutical manufacturers).

Pharmaceutical manufacturers are aware of controversies surrounding their pricing and operating practices as characterized by the popular media, which are part of the circle of policymaking and have exerted outsized influence over health policy and utilization (Grilli et al. 2002). One logical approach to

improving public perception is for pharmaceutical companies to donate funds to charity organizations to assist patients, particularly those suffering from chronic conditions and experiencing difficulty affording high copays. Or is this approach actually a profit-maximizing strategy that further insulates companies from having to reduce prices?

How would one formulate a pharmaceutical manufacturer's alleged "corporate social responsibility" actions? Structurally, it resembles a price-discrimination problem in marketing, in which a manufacturer charges two prices, targeting consumers with different price elasticities. Upon closer examination, however, a pharmaceutical manufacturer can gain a hefty return from donations (Scott Morton and Boller 2017). To see why, note that the donated fund is used to cover patients' copays. Therefore, even if the manufacturer has a market share of as low as 25%, it can still generate a 60% return because of the leverage effect: Patients are subsidized to purchase the drug, and the insurance firm pays the rest of the bill. Thus, the donations vastly increase revenue and sales. Methods of formulating the firm's problem, studying social welfare, and analyzing stakeholders would change completely as we incorporate these "charitable acts" in our models.

The above discussion reflects a single firm's perspective without accounting for industry dynamics. Competition is present in the pharmaceutical marketplace. What would other firms' strategies be for charitable contributions? The answer is far from intuitive and requires rigorous analytical efforts from researchers who are not only well trained in this type of supply-chain competition problem, but are also keenly aware of the institutional realities unique to the pharmaceutical supply chain. Firms' donating behavior is driven by "looking-charitable" incentives shaped by the intentions of the circle of policymaking.

Note that charity donation is just one of the myriad tools pharmaceutical manufacturers use to achieve essentially the same end; other tools include offering copay coupons to consumers, donating to physician groups, donating to patient-advocacy groups, direct-to-consumer advertising, and lobbying. Each of these alternative means can be viewed as a subloop inside the HEM and is worth further scrutiny.

### 3.3. Interactions Among Clinicians, Patients, and Hospitals

We now turn to the *circle of delivery*, examining the interactions among clinicians, patients, and hospitals. Given that healthcare pricing is opaque and ad hoc, some knowledge of quality of care would be essential for the notion of "patient-centered healthcare" to be feasible. Unfortunately, quality-of-care data for individual clinicians (including physicians, physician assistants, and nurse practitioners) have largely been

kept secret, despite some aggregate-level data becoming available in recent years. Song and Veeraraghavan (2018) survey HOM research on quality of care, building on which they propose a classification of this literature that consists of structure (e.g., organizational design, resource-allocation scheme, and human-resource management), process (e.g., length of stay, waiting time, turnaround time, resource utilization, process compliance, and deviations), and outcome (e.g., mortality, adverse events, readmissions, patient experience, and access). Their survey suggests that patients have little access to quality-of-care information, let alone informed decisions, in choosing service providers.

One may point to online hospital and physician reviews as a proxy for quality of care. Yet, the consensus among the medical community is that online reviews are better at revealing a provider's logistics and organizational attributes than its actual quality of care.<sup>5</sup> Frequently, positive reviews are assigned to low-quality care, as illustrated in a vivid account by Dr. Martin Makary (2013), a surgeon at the Johns Hopkins Hospital. He describes a doctor who was phenomenally popular among his patients (many of whom were celebrities), but who was known among his medical colleagues as "Hodad"—"Hands of Death and Destruction":

Behind his charm and soothing bedside manner, Hodad's patients didn't really know what was going on. They had no way of connecting their extended hospitalizations, excessive surgery time, or preventable complications with the bungling, amateurish, borderline malpractice moves we on the staff all witnessed. . . . Some would thank Hodad for saving them from a worse fate. What his patients loved was his commanding authority, his fancy title, his Ivy League stripes, and his loving touch. His patients liked his care, despite its infernally low quality in the operating room. (Makary 2013, p. 12)

Makary (2013) points out that the tolerance for practitioners whose care is known among their peers as of "infernally low quality" is fairly common and exists in academic medical centers and community hospitals alike. Even celebrity patients, with seemingly unlimited access to information and connections, may still willingly choose to seek low-quality care. With this type of practice environment, implementing meaningful quality-improvement initiatives would be difficult. For our research on quality of care to generate real-world impacts, we need to incorporate organizational factors obvious in this setting but missing in the HOM 1.0 literature.

In a separate account, Gawande (2010a, p. 205) writes the following:

It used to be assumed that differences among hospitals or doctors in a particular specialty were generally insignificant. If you plotted a graph showing the results of all the centers treating [any disease], people

expected that the curve would look something like a shark fin, with most places clustered around the very best outcomes. But the evidence has begun to indicate otherwise. What you tend to find is a bell curve: a handful of teams with disturbingly poor outcomes for their patients, a handful with remarkably good results, and a great undistinguished middle.

Several (traditional operational) initiatives are aimed at improving the quality of care based on Total Quality Management, Lean, Six Sigma, Theory of Constraints, or some combination of these. More recently, policy-makers and insurance firms have advocated for a series of initiatives entailing a shift in provider payment from “volume to value,” but these initiatives have experienced low uptake and generated a negligible impact on quality of care (Burns and Pauly 2018). What they fail to address is the elephant in the room: How do we account for the remarkable heterogeneity in quality of care across health providers? How do we empower people when the most salient and fundamental quality issues are routinely and consciously neglected?

These questions are aligned with the World Health Organization (WHO) quality-of-care guidelines (WHO et al. 2018, p. 17), which stipulate that improving quality of care requires “transparency, people-centeredness, measurement and generation of information, and investing in the workplace, all underpinned by leadership and a supportive culture.” In other words, behavior, incentive, and policy considerations are instrumental in improving quality of care. Mirroring this need, a vibrant HOM 2.0 literature has incorporated these considerations into its study of quality of care (e.g., Ramdas et al. 2018; Staats et al. 2016, 2018; and Tucker 2016). Meanwhile, several papers addressing quality of care have expanded the prowess of methodological tools such as queueing theory by characterizing the effects of utilization (Kuntz et al. 2014) and service delays (Chan et al. 2017) on patient outcomes.

## 4. A Taxonomy of Healthcare Operations-Management Literature

In the preceding section, we used three subloops of HEM to demonstrate how the emerging HOM research captures the interactions among multiple entities. To gain a more systematic understanding of the existing research, we now develop a new taxonomy of the state of the art in the HOM literature, based on a survey of all the papers published in a printed issue or online ahead of print in three top INFORMS journals—namely, *Manufacturing & Service Operations Management*, *Management Science*, and *Operations Research*—during a five-year period between January 1, 2013, and December 31, 2017, and their clinical, economic, and policy contexts.

Motivated by Green (2012), we group various HOM research thrusts into three levels—macro, meso, and micro (see the appendix for details): *Macrolevel thrusts* deal with the supply of and demand for healthcare services and how supply and demand are matched through healthcare entities and on marketplaces; *microlevel thrusts* deal with the operations of specific healthcare operations, such as ambulatory care, emergency care, and inpatient care; and *mesolevel thrusts* connect macrolevel and microlevel thrusts, with a scope beyond a single healthcare institution, but do not explicitly address the design of an overall healthcare marketplace. Our bottom-up literature-classification scheme is drawn from a combination of (1) sampling of the HOM literature, (2) the Health Research Classification System of the U.K. Clinical Research Collaboration Partners, and (3) Part C of the *Journal of Economic Literature* classification codes. To be forward-looking and reflective of the scope of HOM 2.0, we have included several research thrusts despite their lack of coverage in this survey.

In addition, we summarize key methodological tools employed in the HOM literature, including operations-research tools (Markov decision process, deterministic programming, stochastic programming, robust optimization, queueing theory and queueing games, decision analysis, and simulation), econometric methods, game theory and information economics, data science, and laboratory experiments.

### 4.1. Tool-Thrust Graph

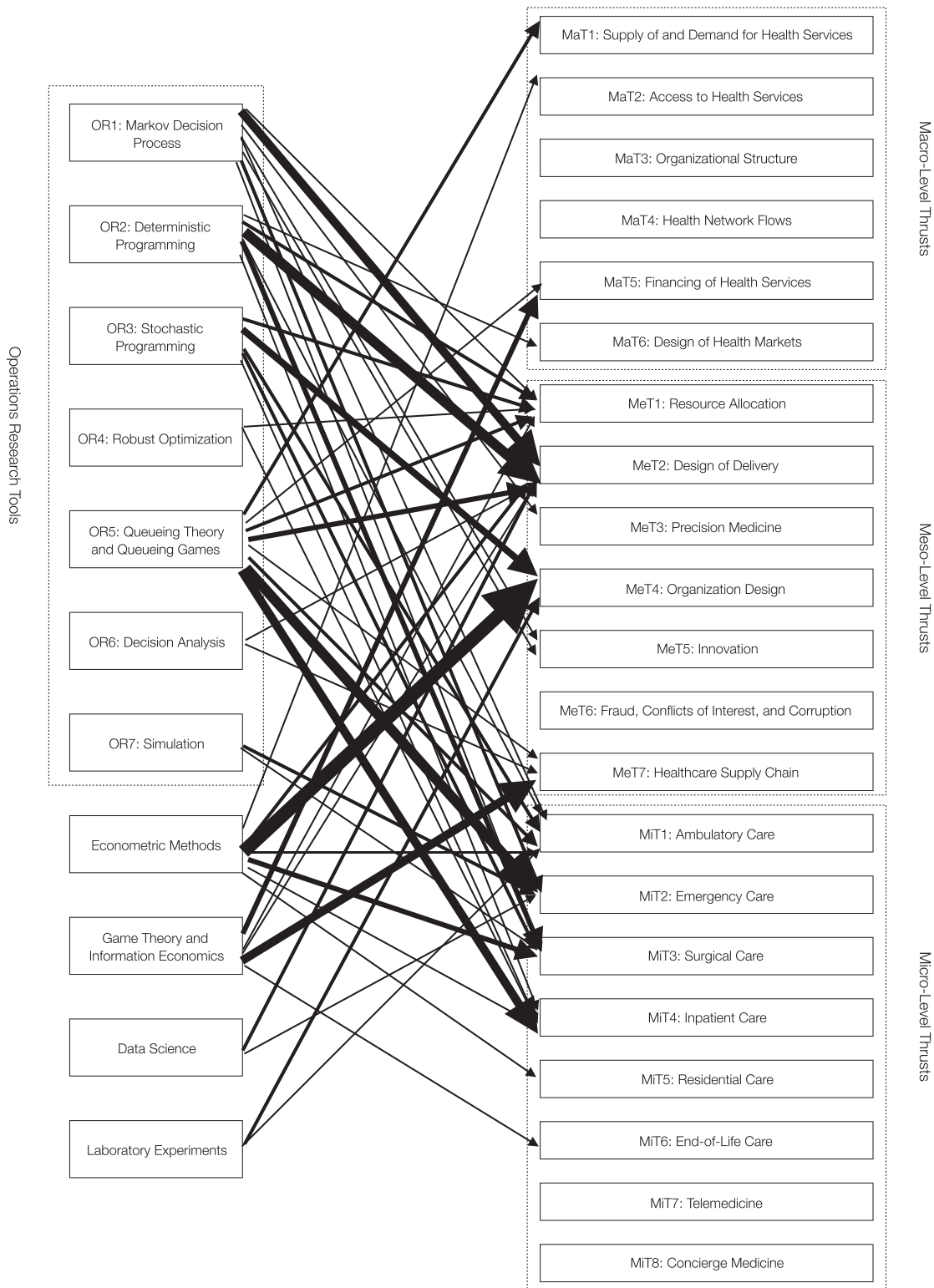
We jointly display in Figure 2 the thrusts and tools on a bipartite graph, referred to as the tool-thrust graph, which shows edges of different thickness, indicating incidence of use. For ease of reference, we use “MaT,” “MeT,” and “MiT” as labels corresponding to a macrolevel, mesolevel, and microlevel thrust, respectively, and use “OR” to label each operations-research tool.

We make a few observations from the tool-thrust graph, first from the side of tools, then from the side of thrusts, and, finally, in terms of tool-thrust combinations.

**4.1.1. Tools.** Among the methodological tools, queueing theory and queueing games (OR5) turn out to be the most popular research tools, representing 22% of all the healthcare papers published in the three leading journals between 2013 and 2017. Queueing has found its applications most extensively in the study of emergency care (MiT2), inpatient care (MiT4), and design of delivery (MeT2), with shares of 6%, 4%, and 2%, respectively.

The second most popular methodological tool is econometric methods (EMs), representing 17% of publications, particularly in studying organization design (MeT4), which alone accounts for 8%. We expect this trend to continue and possibly extend to

**Figure 2.** Tool-Thrust Graph: A Bipartite Graph Showing the Connections of Tools and Thrusts



macrolevel thrusts, including organization structure (MaT4), financing of health services (MaT5), and design of health markets (MaT6). KC (2018) presents an illuminating summary of the empirical HOM literature.

Both deterministic programming (OR2) and Markov decision processes (OR1) have been widely employed, responsible for 14% and 12% of publications, respectively. Both have been used to study the design of delivery (MeT2). We note that Markov decision



processes have been the only tool used in studying precision medicine (MeT3).

Mirroring the evolution of the broader field of operations management, HOM scholars have extensively applied game theory and information economics [see Dai (2018) for an introduction], accounting for 11% of the publications. Notably, game theory and information economics have found applications in both macrolevel thrusts, such as financing of health services (MaT5), and mesolevel thrusts, such as the healthcare supply chain (MeT7).

Behavioral intervention tools such as “nudging,” popularized by behavioral economists (e.g., Thaler and Sunstein 2009), are underrepresented. We expect growing usage of these tools as researchers deepen their understanding of the behavioral side of the decision making underlying healthcare operations and perform randomized controlled trials that are standard in clinical medicine and development economics.

**4.1.2. Thrusts.** Among the 21 thrusts, the top five most frequently published are: design of delivery (MeT2), emergency care (MiT2), organization design (MeT4), inpatient care (MiT4), and ambulatory care (MiT1), with shares of 24%, 17%, 10%, 9%, and 8%, respectively. These five thrusts make up the vast majority (68%) of the collection.

Conspicuously absent in the top-five list is any macrolevel thrust. Indeed, apart from the financing of health services (MaT5), with a share of 4%, most of the macrolevel thrusts remain little explored, if at all. Collectively, macrolevel thrusts account for a mere 8% of top-journal publications. Given that operations-management scholars have much to say about supply-demand problems of nearly any scale, we believe that opportunities abound, particularly in terms of supply of and demand for health services (MaT1), access to health services (MaT2), and design of health markets (MaT6).

The mesolevel thrusts have become the most active arena of HOM research, as evidenced by the 52% of publications residing in this group. Indeed, behavior, incentive, and policy considerations, although not unique to mesolevel thrusts, arise organically from the interface connecting microlevel and macrolevel thrusts. For example, in a survey of the global health-operations literature, Natarajan and Swaminathan (2018) note that ongoing HOM 2.0 research is bridging a major gap: the failure to account for the interactions among *multiple, simultaneous interventions* in program evaluations. As another example, Ata et al. (2018, p. 206) point out that one crucial research challenge in comparing policy proposals for the organ-transplantation system is “the endogenous nature of the transplant candidates’ behavior. That is, as the policy changes, the candidates’ behavior may change,

too.” Extant studies have not accounted for such endogeneity, but instead rely on historical data and assume static decisions (e.g., about accepting or rejecting an organ offer), which “fail to capture the change in patient behavior given the incentives provided by the new policy.”

Microlevel thrusts continue to flourish, accounting for 40% of the publications. Well-studied areas—such as ambulatory care, emergency care, and inpatient care—can be reinvigorated by incorporating behavioral, incentive, and policy issues. For example, many of the high-impact research opportunities pertaining to ambulatory care lie in incorporating patient behavior such as forgetting, cancellation, and balking, and such behavior crucially depends on policy and incentive interventions (Liu 2018). Furthermore, several important microlevel thrusts, including residential care (MiT5), end-of-life care (MiT6), telemedicine (MiT7), and concierge medicine (MiT8),<sup>6</sup> present rich opportunities for future research.

**4.1.3. Matching Tools with Thrusts.** We now turn to the combinations of tools and thrusts. The most frequently published combinations are the following:

No. 1. Econometric methods–organization design (MeT2): 8%

No. 2. Queueing theory and queueing games (OR5)–emergency care (MiT2): 6%

No. 2. Deterministic programming (OR2)–design of delivery (MeT2): 6%

No. 3. Queueing theory and queueing games (OR5)–design of delivery (MeT2): 5%

No. 3. Game theory and information economics–healthcare supply chain (MeT7): 5%

No. 3. Markov decision process (OR1)–design of delivery (MeT2): 5%

Emerging tools, such as data science, laboratory experiments, and field experiments using “nudge” (Thaler and Sunstein 2009), will likely gain representation as the HOM community explores understudied thrusts.

## 4.2. Connecting HOM Literature to Medical and Media Perspectives

We present illustrative triples of media coverage, physician perspectives, and the HOM literature for each thrust in Tables 1–3. The broad aim of providing these tables is to help connect HOM research to papers from the medical community and “public interest” articles that journalists (and, increasingly, physicians) have written for our broader society.

## 5. Looking Ahead

The emerging HOM 2.0 literature focuses on the interactions among multiple entities in the healthcare ecosystem, deepening our understanding of behavioral,

**Table 1.** Macrolevel Thrusts

Macrolevel thrusts	Media focus	Physician perspective	HOM literature (2013–2017)
MaT1: Supply of and demand for health services	Brooks (2017), Gawande (2009a, 2015), Reinhardt (2010), Rosenbaum (2017)	Fries et al. (1993), Gooch and Kahn (2014), Relman (1980)	Allon et al. (2013), Dai et al. (2017)
MaT2: Access to health services	Chapin (2017), Kristof (2010), Villarosa (2018)	Ubel (2014), Murray and Berwick (2003), Schneider and Squires (2017)	Goh et al. (2016)
MaT3: Organizational structure	Abelson (2016), Mathews (2012), Rosenthal (2017), Starr (2017), Young and Saltman (1985)	Fisher and Shortell (2010), McWilliams et al. (2016)	
MaT4: Health network flows	Fuchs and Lee (2015), Rosenthal (2013)	Dafny and Lee (2015), Ramirez (2014), Xu et al. (2015)	
MaT5: Financing of health services	Antos et al. (2012), Gawande (2009b), Reinhardt (2013), Rosenthal (2017), Burns and Pauly (2018)	Mechanic (2016), Rajkumar et al. (2014)	Adida et al. (2016), Ata et al. (2013), Gupta and Mehrotra (2015), Zhang et al. (2016)
MaT6: Design of health market	Lamas (2013), Sack (2012)	Roth (2003), Segev et al. (2005)	Glorie et al. (2014)

incentive, and policy issues in healthcare. Relevant to this approach, a sizable literature in several related fields (especially health economics, health services research, and information systems) examines some of the same topics from different lenses. Here, we outline three approaches for the emerging HOM research to complement and differentiate from those related fields, building on several key strengths of the broader field of operations management.

First, HOM scholars can play a central role in shaping *innovations in business models* of healthcare, leveraging time-tested operations-management tools and ideas. For example, the concept of “delayed differentiation” in the operations-management literature (e.g., Lee and Tang 1997 and Swaminathan and Tayur 1998) entails creatively revamping the business model of a manufacturer or service provider such that it focuses on the generic parts and does not commit to custom options until the last stages. If we view healthcare delivery as a supply-chain design problem, society has a choice in terms of the timing of offering common services (preventive care, screening, and health-related activities) and custom services (diagnostic and treatment services) to the population. Inspired by the concept of “delayed differentiation,” Thompson et al. (2019) empirically demonstrate the improvement in the value of care through implementing “temporal displacement of care” with a panel of 45,000 patients in Vermont, with an objective of shifting costly diagnostic and treatment services offered to sick patients to more intensive preventive services offered to healthy individuals.

Second, HOM scholars have a unique set of strengths in *microfounding supply of and demand for health services*, by leveraging classical operations-research techniques and modeling approaches. For instance, health economists often contend that lowering out-of-pocket expenses leads to higher demand

for healthcare services. What does “demand” mean exactly? Using a queueing theoretic approach, Dai et al. (2017) show the demand for outpatient services can be decomposed into two layers: the frequency of visits and the intensity of care per visit. The former can be captured by the arrival rate, whereas the latter can be captured by the service rate. As another example, the health-economics literature often models a medical decision as a vague “effort” that is determined by a clinician; a chosen effort corresponds to a predictable patient outcome. So and Tang (2000) use a Markov decision process to dynamically capture how the clinical pathway interacts with the evolution of a patient’s health status. Their model builds a micro-foundation that maps treatment decisions to patient outcomes.

Third, a central role of operations management is to “orchestrate technology,” fueling “changes in the way that physical, financial, information, and human resources are organized and managed” (Dai and Tayur 2017, p. 649). Medical and technological innovations have changed the way healthcare is delivered and financed in many specialties. Take, for example, diabetes. Thanks to breakthroughs in the diagnosis and treatment of diabetes, especially the radioimmunoassay for insulin, today’s diabetes patients can measure their own glucose levels using affordable electronic devices available in pharmacies or online without prescriptions. Furthermore, patients can determine their own dosage of insulin, either using a heuristic rule or aided by a fully automated algorithm, without consulting with a physician. They can also self-administer the insulin using a pump. With wearables and smart mobile devices connected to the cloud, progress continues to be made (Patel et al. 2015), with the potential of shaping how patients, physicians, providers, and payors interact and will lead to new BIP research areas. New technologies, as Arthur (2009, p. 209)

**Table 2.** Mesolevel Thrusts

Mesolevel thrusts	Media focus	Physician perspective	HOM literature (2013–2017)
MeT1: Resource allocation	Span (2015), Ubel (2001)	Evans (1983), Morden et al. (2014)	Alizamir et al. (2013), Angalakudati et al. (2014), Ata et al. (2017), Bertsimas et al. (2013), Chan et al. (2017), Deo and Sohoni (2015), Deo et al. (2013), Deo et al. (2015), Huh et al. (2013), Mamani et al. (2013), Natarajan and Swaminathan (2014), Sandikçi et al. (2013)
MeT2: Design of delivery	Gawande (2010a, 2011a, 2012), Makary (2013), Weick and Sutcliffe (2015)	Berwick et al. (2006), Blumenthal (1996), Brook et al. (1996), Donabedian (1988), Grol and Grimshaw (2003), Newman-Toker and Pronovost (2009), Wachter and Pronovost (2009)	Ayer et al. (2015), Bertsimas et al. (2016), Best et al. (2015), Campello et al. (2017), Chan et al. (2013), Chan (2014), Chan (2016), Chan (2018), Deo et al. (2015), Ekici et al. (2013), Erenay et al. (2014), Freeman et al. (2017), Goh et al. (2015), Helm and Van Oyen (2014), Helm et al. (2015), Khademi et al. (2015), Kim et al. (2015), Ormeci et al. (2015), Sabouri et al. (2017), Sabouri et al. (2017), Sun et al. (2018), Yamin and Gavius (2013), Yang et al. (2013), Yom-Tov and Mandelbaum (2014)
MeT3: Precision medicine	Aspinall and Hamermesh (2007), Graber (2015), Mukherjee (2017)	Collins and Varmus (2015), Coote and Joyner (2015), Garber and Tunis (2009), Joyner and Paneth (2015)	Skandari et al. (2015)
MeT4: Organization design	Bliss (2011), <i>The Economist</i> (2017b)	Gaba and Howard (2002), Rosenbaum (2019)	Berry Jaeker and Tucker (2017), Ibanez et al. (2018), Kuntz et al. (2014), Ramdas et al. (2017), Senot et al. (2016), Song et al. (2015), Staats et al. (2016, 2018), Tucker (2016)
MeT5: Innovation	Topol (2013), Gawande (2013)	Curfman and Redberg (2011), Grimes (1993), Ramdas and Darzi (2017)	Kouvelis et al. (2017)
MeT6: Fraud, conflicts of interest, and corruption	Groopman and Hartzband (2017), Harris (2010), Landro (2017), Rosenthal (2017)	Bosch (2008), McCoy et al. (2017), Rosenbaum (2015), Thompson (1993)	
MeT7: Healthcare supply chain	Scott Morton and Boller (2017), Sood (2017)	Chung and Meltzer (2009), Treanor (2004), Williamson and Devine (2013)	Chick et al. (2017), Cho and Tang (2013), Dai et al. (2016), Jónasson et al. (2017), Kouvelis et al. (2015), Stonebraker (2013), Taneri and de Meyer (2017)

envisions in *The Nature of Technology: What It Is and How It Evolves*, will usher in a “generative” economy that “is shifting from optimizing fixed operations into creating new combinations, new configurable offerings.” Technological innovations will create new business models and disrupt healthcare entities. For example, rapid growth in behavioral-health telemedicine has spurred major legislative changes in licensing requirements and healthcare reimbursements. Table 4 lists a number of such innovations.

In summary, this paper introduces HOM 2.0, which features the entangled interactions among multiple healthcare entities that can be made visible by the Healthcare Ecosystem Map. It uses the HEM to shed some light on HOM 2.0 and classifies the recent HOM

literature using the tool-thrust graph. Looking forward, we believe exciting opportunities abound for HOM researchers as the healthcare ecosystem experiences continued transformations.

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**Table 3.** Microlevel Thrusts

Microlevel thrusts	Media focus	Physician perspective	HOM literature (2013–2017)
MiT1: Ambulatory care	Gawande (2011b), Landro (2009)	Asplin et al. (2005), Braddock et al. (1999), Kellermann et al. (1994)	Feldman et al. (2014), Izady (2015), Liu et al. (2018), Mak et al. (2014), Qi (2017), Zacharias and Armony (2017)
MiT2: Emergency care	Beck (2016b), Reddy (2017)	Kellermann (2006)	Ang et al. (2016), Batt and Terwiesch (2015, 2017), Cho et al. (2014), Chong et al. (2016), Huang et al. (2015), KC (2014), Kim and Whitt (2014), Maxwell et al. (2014), McLay and Mayorga (2013), Mills et al. (2013), Saghaffian et al. (2014), Xu and Chan (2016)
MiT3: Surgical care	Pinkerton (2013), Rosenthal (2014)	Angelos (2010), Tsai et al. (2013)	Freeman et al. (2016), Ozen et al. (2016), Ramdas et al. (2017), Rath et al. (2017)
MiT4: Inpatient care	Weaver et al. (2015)	Bindman et al. (1995), Joynt and Jha (2012)	Chan et al. (2017), Dai and Shi (2017), Green et al. (2013), Kim and Mehrotra (2015), Meng et al. (2015), Pinker and Tezcan (2013), Samiedaluie et al. (2017), Shi et al. (2016), Wang and Gupta (2014)
MiT5: Residential care	NORC (2017), Wasik (2016)	Carman et al. (2000), Schulz et al. (2004), Spillman and Lubitz (2000)	Lu and Lu (2017)
MiT6: End-of-life care	Armour (2014), Gawande (2010b, 2014)	Curtis and Vincent (2010), Quill et al. (1997), Steinhauser et al. (2000)	Ata et al. (2013)
MiT7: Telemedicine	Beck (2016a), Chen (2010), Xu (2014)	Wachter (2008), Field and Grigsby (2002)	
MiT8: Concierge medicine	Schwartz (2017), Wiczner (2013)	Hartzband and Groopman (2009)	

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### Appendix. Taxonomy of Healthcare Operations Management Literature

The **macrolevel thrusts** (MaTs) include the following:

MaT1: Supply of and demand for health services (market mechanism versus social optimum, excessive spending and counteracting strategies, and supply and utilization of healthcare resources);

MaT2: Access to health services [access to healthcare providers, access to healthcare procedures and necessary

resources (e.g., organ transplants), and equity and efficiency in access to health services];

MaT3: Organizational structure (power equilibrium and dynamics in health organizations, healthcare versus capitalism, and care coordination in accountable care organizations);

MaT4: Health network flows (hospital consolidation, payor consolidation, network cost, and resource allocation);

MaT5: Financing of health services (insurance coverage, insurance structure, reimbursement for hospitals and physicians, price transparency, healthcare from investors' perspectives, and CMS reforms such as bundled payments);

MaT6: Design of health markets (entrepreneurial approach to healthcare issues, engineering new markets for health resources, and matching in two-sided health markets).

**Table 4.** Technological Innovations in Healthcare

New technologies	Application domains	Selected references
Artificial intelligence	Diagnosis, personalized medicine, drug and therapy development, hospital administration, and chronic-disease management	Cohn (2013), <i>The Economist</i> (2017a), Jha and Topol (2016), Mukherjee (2017), Topol (2019)
Additive manufacturing (3D/4D printing)	Personalized medicine, artificial organs, and efficient medical device production	Groopman (2014)
Blockchain	Electronic medical records, medical reimbursement and billing, and data sharing	Geron (2018)
Genetic technologies	Diagnostic (including prenatal) testing, medical research, drug development, and gene therapy	Kolata (2017), Naldini (2015)
Internet of things	Health supply chain management, medical device integration, design of delivery, and patient engagement	Topol et al. (2015)
Wearable technologies	Home healthcare, personal health data collection and sharing, and improving hand hygiene among healthcare workers	Patel et al. (2015)

The **mesolevel thrusts** (MeTs), which bridge macrolevel and microlevel thrusts, include the following:

MeT1: Resource allocation (organ allocation, rationing, public health, global health, humanitarian logistics, and quality-speed tradeoff);

MeT2: Design of delivery (standardization, checklist approach, diagnostic errors, referrals, screening, and gatekeepers);

MeT3: Precision medicine (personalized medicine, new diagnostic tools, and artificial intelligence);

MeT4: Organization design (hospital design, service-flow design, and utilization and patient safety);

MeT5: Innovation (drug development, medical device development, regulators versus innovators, data analytics, robotics, and 3D printing applied to medicine);

MeT6: Fraud, conflicts of interest, and corruption (hospital-physician alignment, physician altruism and incentives, and conflicts of interest of various stakeholders); and

MeT7: Healthcare supply chain (pharmaceutical supply chain, contract design, and environmental impact of healthcare sector).

The **microlevel thrusts** (MiTs) include the following:

MiT1: Ambulatory care (appointment scheduling, insurance and access to ambulatory care, and interfaces with other functions);

MiT2: Emergency care (billing practices, staffing, quality of care, and patient streaming);

MiT3: Surgical care (new technologies, billing practices, quality of care, and scheduling);

MiT4: Inpatient care (readmissions, billing practices, scheduling, and capacity planning);

MiT5: Residential care (rising costs and lack of access);

MiT6: End-of-life care (ethics and costs);

MiT7: Telemedicine (reimbursement, regulation, quality of care, and licensing); and

MiT8: Concierge medicine (affordability, equity of access, and physician altruism).

In addition to these 21 thrusts, we have identified essential methodological tools used in the HOM literature:

(i) Classical operations-research methods, including;

Markov decision process (OR1),

Deterministic programming (OR2),

Stochastic programming (OR3),

Robust optimization (OR4),

Queueing theory and queueing games (OR5),

Decision analysis (OR6), and

Simulation (OR7);

(ii) Econometric methods;

(iii) Game theory and information economics;

(iv) Data science; and

(v) Laboratory experiments.

## Endnotes

<sup>1</sup>For example, Tuohy and Glied (2011) emphasize the role of “oligarchy and policy networks” in policymaking, whereas the “market map for healthcare services and technology firms” developed by Onitskansky et al. (2018) focuses on innovations in the healthcare sector.

<sup>2</sup>According to United Network for Organ Sharing (UNOS) (2013), Policy 3.2.3, which states that transplant programs must inform patients of multiple-listing options, is among the top five most frequently cited transplant program policy violations.

<sup>3</sup>Merion et al. (2004) find the uptake of multiple listing among kidney-transplant patients whose primary source of payment is private insurance (7.2%) is significantly higher than among patients whose primary source of payment is Medicare (5.1%) or Medicaid (3.0%).

<sup>4</sup>Throughout the paper, we define the HOM literature as the healthcare research conducted by operations research/management science scholars with a focus on operations management, as exemplified by those published in the three leading journals (i.e., *Manufacturing & Service Operations Management*, *Management Science*, and *Operations Research*). Accordingly, we exclude the field of health economics from our discussions of the HOM literature.

<sup>5</sup>For example, Massachusetts General Hospital and Johns Hopkins Hospital, two leading academic medical centers, receive ratings of 3.5 and 3.0 out of 5, respectively, on Yelp.

<sup>6</sup>Gavirneni and Kulkarni (2018) analyze concierge medicine using a queueing-game approach.

## References

- Abelson R (2016) Cornerstone: The rise and fall of a health care experiment. *New York Times* (December 23), <https://www.nytimes.com/2016/12/23/business/cornerstone-the-rise-and-fall-of-a-health-care-experiment.html>.
- Adida E, Mamani H, Nassiri S (2016) Bundled payment vs. fee-for-service: Impact of payment scheme on performance. *Management Sci.* 63(5):1606–1624.
- Alizamir S, de Vericourt F, Sun P (2013) Diagnostic accuracy under congestion. *Management Sci.* 59(1):157–171.
- Allon G, Deo S, Lin W (2013) The impact of size and occupancy of hospital on the extent of ambulance diversion: Theory and evidence. *Oper. Res.* 61(3):544–562.
- Anderson GF, Reinhardt UE, Hussey PS, Petrosyan V (2003) It's the prices, stupid: Why the United States is so different from other countries. *Health Affairs* 22(3):89–105.
- Ang E, Kwasnick S, Bayati M, Plambeck EL, Aratow M (2016) Accurate emergency department wait time prediction. *Manufacturing Service Oper. Management* 18(1):141–156.
- Angalakudati M, Balwani S, Calzada J, Chatterjee B, Perakis G, Raad N, Uichanco J (2014) Business analytics for flexible resource allocation under random emergencies. *Management Sci.* 60(6):1552–1573.
- Angelos P (2010) The ethical challenges of surgical innovation for patient care. *Lancet* 376(9746):1046–1047.
- Antos JR, Pauly MV, Wilensky GR (2012) Bending the cost curve through market-based incentives. *New England J. Medicine* 367(10):954–958.
- Armour S (2014) End-of-life care in U.S. is lacking, report says conversations about dying should be held throughout life to save costs, improve care. *Wall Street Journal* (September 17), <https://www.wsj.com/articles/end-of-life-care-in-u-s-is-lacking-report-says-1410998804>.
- Arthur WB (2009) *The Nature of Technology: What It Is and How it Evolves* (Simon and Schuster, New York).
- Aspinall M, Hamermesh RG (2007) Realizing the promise of personalized medicine. *Harvard Bus. Rev.* 85(10):108–117.
- Asplin BR, Rhodes KV, Levy H, Lurie N, Crain AL, Carlin BP, Kellermann AL (2005) Insurance status and access to urgent ambulatory care follow-up appointments. *J. Amer. Medical Assoc.* 294(10):1248–1254.
- Ata B, Skaro A, Tayur SR (2017) OrganJet: Overcoming geographical disparities in access to deceased donor kidneys in the United States. *Management Sci.* 63(9):2776–2794.
- Ata B, Killaly BL, Olsen TL, Parker RP (2013) On hospice operations under Medicare reimbursement policies. *Management Sci.* 59(5): 1027–1044.
- Ata B, Freidewald JJ, Randa AC (2018) Organ transplantation. Dai T, Tayur SR, eds. *Handbook of Healthcare Analytics: Theoretical*

- Minimum for Conducting 21st Century Research on Healthcare Operations* (John Wiley & Sons, Hoboken, NJ), 187–215.
- Axelrod D, Dai T, Tayur SR (2015) Physician test-ordering behavior in response to patients' insurance structure via personal communication with the authors, November 8, 2015.
- Ayer T, Alagoz O, Stout NK, Burnside ES (2015) Heterogeneity in women's adherence and its role in optimal breast cancer screening policies. *Management Sci.* 62(5):1339–1362.
- Barkholz D (2017) Hospitals struggle with the high-deductible dilemma. *Modern Healthcare* (June 28), [https://www.modernhealthcare.com/article/20170628/NEWS/170629877?utm\\_source=modernhealthcare&utm\\_campaign=financedaily&utm\\_medium=email&utm\\_content=20170628-NEWS-170629877](https://www.modernhealthcare.com/article/20170628/NEWS/170629877?utm_source=modernhealthcare&utm_campaign=financedaily&utm_medium=email&utm_content=20170628-NEWS-170629877).
- Bastani H, Goh J, Bayati M (2019) Evidence of upcoding in pay-for-performance programs. *Management Sci.* 65(3):1042–1060.
- Batt RJ, Terwiesch C (2015) Waiting patiently: An empirical study of queue abandonment in an emergency department. *Management Sci.* 61(1):39–59.
- Batt RJ, Terwiesch C (2017) Early task initiation and other load-adaptive mechanisms in the emergency department. *Management Sci.* 63(11):3531–3551.
- Beck M (2016a) How telemedicine is transforming health care: The revolution is finally here—raising a host of questions for regulators, providers, insurers and patients. *Wall Street Journal* (June 26), <https://www.wsj.com/articles/how-telemedicine-is-transforming-health-care-1466993402>.
- Beck M (2016b) Patients may still get a “surprise” bill after an in-network ER visit, study finds. *Wall Street Journal* (November 16), <https://www.wsj.com/articles/patients-may-still-get-a-surprise-bill-after-an-in-network-er-visit-study-finds-1479333600>.
- Berry Jaeker J, Tucker A (2017) Past the point of speeding up: The negative effects of workload saturation on efficiency and patient severity. *Management Sci.* 63(4):1042–1062.
- Bertsimas D, Farias VF, Trichakis N (2013) Fairness, efficiency, and flexibility in organ allocation for kidney transplantation. *Oper. Res.* 61(1):73–87.
- Bertsimas D, O'Hair A, Relyea S, Silberholz J (2016) An analytics approach to designing combination chemotherapy regimens for cancer. *Management Sci.* 62(5):1511–1531.
- Berwick DM, Calkins DR, McCannon CJ, Hackbarth AD (2006) The 100,000 lives campaign: Setting a goal and a deadline for improving health care quality. *J. Amer. Medical Assoc.* 295(3):324–327.
- Best TJ, Sandikçi B, Eisenstein DD, Meltzer DO (2015) Managing hospital inpatient bed capacity through partitioning care into focused wings. *Manufacturing Service Oper. Management* 17(2):157–176.
- Bindman AB, Grumbach K, Osmond D, Komaromy M, Vranizan K, Lurie N, Billings J, Stewart A (1995) Preventable hospitalizations and access to health care. *J. Amer. Medical Assoc.* 274(4):305–311.
- Bliss M (2011) *The Making of Modern Medicine: Turning Points in the Treatment of Disease* (University of Chicago Press, Chicago).
- Blumenthal D (1996) The origins of the quality-of-care debate. *New England J. Medicine* 335(15):1146–1149.
- Bosch X (2008) Science for sale: The perils, rewards, and delusions of campus capitalism. *J. Amer. Medical Assoc.* 299(23):2800–2800.
- Braddock CH, Edwards KA, Hasenberg NM, Laidley TL, Levinson W (1999) Informed decision making in outpatient practice: Time to get back to basics. *J. Amer. Medical Assoc.* 282(24):2313–2320.
- Brook RH, McGlynn EA, Cleary PD (1996) Measuring quality of care. *New England J. Medicine* 335(13):966–970.
- Brooks D (2017) Do markets work in health care? *New York Times* (January 13), <https://www.nytimes.com/2017/01/13/opinion/do-markets-work-in-health-care.html>.
- Brot-Goldberg ZC, Chandra A, Handel BR, Kolstad JT (2017) What does a deductible do? The impact of cost-sharing on health care prices, quantities, and spending dynamics. *Quart. J. Econom.* 132(3):1261–1318.
- Burns LR, Pauly MV (2018) Transformation of the health care industry: Curb your enthusiasm? *Milbank Quart.* 96(1):57–109.
- Campello F, Ingolfsson A, Shumsky RA (2017) Queueing models of case managers. *Management Sci.* 63(3):882–900.
- Carman WF, Elder AG, Wallace LA, McAulay K, Walker A, Murray GD, Stott DJ (2000) Effects of influenza vaccination of health-care workers on mortality of elderly people in long-term care: A randomised controlled trial. *Lancet* 355(9198):93–97.
- Chan CW, Dong J, Green LV (2017) Queues with time-varying arrivals and inspections with applications to hospital discharge policies. *Oper. Res.* 65(2):469–495.
- Chan CW, Farias VF, Escobar GJ (2016) The impact of delays on service times in the intensive care unit. *Management Sci.* 63(7):2049–2072.
- Chan CW, Green LV, Lu Y, Leahy N, Yurt R (2013) Prioritizing burn-injured patients during a disaster. *Manufacturing Service Oper. Management* 15(2):170–190.
- Chan TCY, Shen Z-JM, Siddiq A (2018) Robust defibrillator deployment under cardiac arrest location uncertainty via row-and-column generation. *Oper. Res.* 66(2):358–379.
- Chan TCY, Craig T, Lee T, Sharpe MB (2014) Generalized inverse multiobjective optimization with application to cancer therapy. *Oper. Res.* 62(3):680–695.
- Chapin CF (2017) How did health care get to be such a mess? *New York Times* (June 19), <https://www.nytimes.com/2017/06/19/opinion/health-insurance-american-medical-association.html>.
- Chen PW (2010) Are doctors ready for virtual visits? *New York Times* (January 7), <https://www.nytimes.com/2010/01/07/health/07chen.html>.
- Chick SE, Hasija S, Nasiry J (2017) Information elicitation and influenza vaccine production. *Oper. Res.* 65(1):75–96.
- Cho S-H, Tang CS (2013) Advance selling in a supply chain under uncertain supply and demand. *Manufacturing Service Oper. Management* 15(2):305–319.
- Cho S-H, Zhao H (2018) Healthcare supply chain. Dai T, Tayur SR, eds. *Handbook of Healthcare Analytics: Theoretical Minimum for Conducting 21st Century Research on Healthcare Operations* (John Wiley & Sons, Hoboken, NJ), 159–185.
- Cho S-H, Jang H, Lee T, Turner J (2014) Simultaneous location of trauma centers and helicopters for emergency medical service planning. *Oper. Res.* 62(4):751–771.
- Chong KC, Henderson SG, Lewis ME (2016) The vehicle mix decision in emergency medical service systems. *Manufacturing Service Oper. Management* 18(3):347–360.
- Chung JW, Meltzer DO (2009) Estimate of the carbon footprint of the US health care sector. *J. Amer. Medical Assoc.* 302(18):1967–1972.
- Cohn J (2013) The robot will see you now. *Atlantic* (March), <https://www.theatlantic.com/magazine/archive/2013/03/the-robot-will-see-you-now/309216/>.
- Collins FS, Varmus H (2015) A new initiative on precision medicine. *New England J. Medicine* 372(9):793–795.
- Coote JH, Joyner MJ (2015) Is precision medicine the route to a healthy world? *Lancet* 385(9978):P1617.
- Curfman GD, Redberg RF (2011) Medical devices—balancing regulation and innovation. *New England J. Medicine* 365(11):975–977.
- Curtis JR, Vincent JL (2010) Ethics and end-of-life care for adults in the intensive care unit. *Lancet* 376(9749):1347–1353.
- Dada M, White WD (1999) Evaluating financial risk in the Medicare prospective payment system. *Management Sci.* 45(3):316–329.
- Dafny LS, Lee TH (2015) The good merger. *New England J. Medicine* 372(22):2077–2079.
- Dai T (2018) Game theory and information economics. Dai T, Tayur SR, eds. *Handbook of Healthcare Analytics: Theoretical Minimum for*

- Conducting 21st Century Research on Healthcare Operations (John Wiley & Sons, Hoboken, NJ), 337–354.
- Dai JG, Shi P (2017) A two-time-scale approach to time-varying queues in hospital inpatient flow management. *Oper. Res.* 65(2):514–536.
- Dai T, Tayur SR (2017) The evolutionary trends of POM research in manufacturing. Starr M, Gupta S, eds. *Routledge Companion to Production and Operations Management* (Routledge, London), 647–662.
- Dai T, Tayur SR, eds. (2018) *Handbook of Healthcare Analytics: Theoretical Minimum for Conducting 21st Century Research on Healthcare Operations* (John Wiley & Sons, Hoboken, NJ).
- Dai T, Akan M, Tayur SR (2017) Imaging room and beyond: The underlying economics behind physicians' test-ordering behavior in outpatient services. *Manufacturing Service Oper. Management* 19(1):99–113.
- Dai T, Cho SH, Zhang F (2016) Contracting for on-time delivery in the US influenza vaccine supply chain. *Manufacturing Service Oper. Management* 18(3):332–346.
- Dai T, Zheng R, Sycara K (2019) Jumping the line, charitably: Analysis and remedy of donor-priority rule. *Management Sci.* Forthcoming.
- Deo S, Sohoni M (2015) Optimal decentralization of early infant diagnosis of HIV in resource-limited settings. *Manufacturing Service Oper. Management* 17(2):191–207.
- Deo S, Irvani S, Jiang T, Smilowitz K, Samuelson S (2013) Improving health outcomes through better capacity allocation in a community-based chronic care model. *Oper. Res.* 61(6):1277–1294.
- Deo S, Rajaram K, Rath S, Karmarkar US, Goetz MB (2015) Planning for HIV screening, testing, and care at the veterans health administration. *Oper. Res.* 63(2):287–304.
- Donabedian A (1988) The quality of care: How can it be assessed? *J. Amer. Medical Assoc.* 260(12):1743–1748.
- Economist, The* (2017a) A digital revolution in health care is speeding up. *The Economist* (March 2), <https://www.economist.com/business/2017/03/02/a-digital-revolution-in-health-care-is-speeding-up>.
- Economist, The* (2017b) How hospitals could be rebuilt, better than before. *The Economist* (April 8), <https://www.economist.com/international/2017/04/08/how-hospitals-could-be-rebuilt-better-than-before>.
- Ekici A, Keskinocak P, Swann JL (2013) Modeling influenza pandemic and planning food distribution. *Manufacturing Service Oper. Management* 16(1):11–27.
- Erenay FS, Alagoz O, Said A (2014) Optimizing colonoscopy screening for colorectal cancer prevention and surveillance. *Manufacturing Service Oper. Management* 16(3):381–400.
- Evans RW (1983) Health care technology and the inevitability of resource allocation and rationing decisions: Part I. *J. Amer. Medical Assoc.* 249(15):2047–2053.
- Feldman J, Liu N, Topaloglu H, Ziya S (2014) Appointment scheduling under patient preference and no-show behavior. *Oper. Res.* 62(4):794–811.
- Field MJ, Grigsby J (2002) Telemedicine and remote patient monitoring. *J. Amer. Medical Assoc.* 288(4):423–425.
- Fisher ES, Shortell SM (2010) Accountable care organizations: Accountable for what, to whom, and how. *J. Amer. Medical Assoc.* 304(15):1715–1716.
- Freeman NK, Melouk SH, Mittenthal J (2016) A scenario-based approach for operating theater scheduling under uncertainty. *Manufacturing Service Oper. Management* 18(2):245–261.
- Freeman M, Savva N, Scholtes S (2017) Gatekeepers at work: An empirical analysis of a maternity unit. *Management Sci.* 63(10):3147–3167.
- Fries JF, Koop CE, Beadle CE, Cooper PP, England MJ, Greaves RF, Sokolow JJ, Wright D (1993) Reducing health care costs by reducing the need and demand for medical services. *New England J. Medicine* 329(5):321–325.
- Fuchs VR, Lee PV (2015) A healthy side of insurer mega-mergers. *Wall Street Journal* (August 26), <https://www.wsj.com/articles/a-healthy-side-of-insurer-mega-mergers-1440628597>.
- Fuloria PC, Zenios SA (2001) Outcomes-adjusted reimbursement in a health-care delivery system. *Management Sci.* 47(6):735–751.
- Gaba DM, Howard SK (2002) Fatigue among clinicians and the safety of patients. *New England J. Medicine* 347(16):1249–1255.
- Garber AM, Tunis SR (2009) Does comparative-effectiveness research threaten personalized medicine? *New England J. Medicine* 360(19):1925–1927.
- Garg PP, Frick KD, Diener-West M, Powe NR (1999) Effect of the ownership of dialysis facilities on patients' survival and referral for transplantation. *New England J. Medicine* 341(22):1653–1660.
- Gavirneni S, Kulkarni VG (2018) Concierge medicine. Dai T, Tayur SR, eds. *Handbook of Healthcare Analytics: Theoretical Minimum for Conducting 21st Century Research on Healthcare Operations* (John Wiley & Sons, Hoboken, NJ), 287–318.
- Gawande A (2009a) The cost conundrum. *New Yorker* (June 1), 36–44.
- Gawande A (2009b) Testing, testing. *New Yorker* (December 14), 34–41.
- Gawande A (2010a) *Better: A Surgeon's Notes on Performance* (Profile Books, London).
- Gawande A (2010b) Letting go: What should medicine do when it can't save your life? *New Yorker* (August 2), 36–49.
- Gawande A (2011a) *The Checklist Manifesto: How to Get Things Right* (Picador, New York).
- Gawande A (2011b) The hot spotters: Can we lower medical costs by giving the neediest patients better care? *New Yorker* (January 24), 40–51.
- Gawande A (2012) What big medicine can learn from the Cheesecake Factory. *New Yorker* (August 13), 53–63.
- Gawande A (2013) Slow ideas: Why innovations don't always catch on. *New Yorker* (July 29), 36–45.
- Gawande A (2014) *Being Mortal: Medicine and What Matters in the End* (Henry Holt and Company, New York).
- Gawande A (2015) Overkill. *New Yorker* (May 11), 44–55.
- Geron T (2018) How Blockchain could help lower health costs. *Wall Street Journal* (May 29), <https://www.wsj.com/articles/how-blockchain-could-help-lower-health-costs-1527559440>.
- Glorie KM, van de Klundert JJ, Wagelmans A (2014) Kidney exchange with long chains: An efficient pricing algorithm for clearing barter exchanges with branch-and-price. *Manufacturing Service Oper. Management* 16(4):498–512.
- Goh J (2018) Competing interests. Dai T, Tayur SR, eds. *Handbook of Healthcare Analytics: Theoretical Minimum for Conducting 21st Century Research on Healthcare Operations* (John Wiley & Sons, Hoboken, NJ), 51–77.
- Goh J, Pfeffer J, Zenios SA (2016) The relationship between workplace stressors and mortality and health costs in the United States. *Management Sci.* 62(2):608–628.
- Goh J, Bjarnadottir MV, Bayati M, Zenios SA (2015) Active post-marketing drug surveillance for multiple adverse events. *Oper. Res.* 63(6):1528–1546.
- Gooch RA, Kahn JM (2014) ICU bed supply, utilization, and health care spending: An example of demand elasticity. *J. Amer. Medical Assoc.* 311(6):567–568.
- Graber C (2015) The problem with precision medicine. *New Yorker* (February 5), <https://www.newyorker.com/tech/elements/problem-precision-medicine>.
- Green LV (2012) OM forum—The vital role of operations analysis in improving healthcare delivery. *Manufacturing Service Oper. Management* 14(4):488–494.
- Green LV, Savin S, Savva N (2013) “Nursevendor problem”: Personnel staffing in the presence of endogenous absenteeism. *Management Sci.* 59(10):2237–2256.

- Grilli R, Ramsay C, Minozzi S (2002) Mass media interventions: Effects on health services utilisation. *Cochrane Database Systematic Rev.* 1(1):CD000389.
- Grimes DA (1993) Technology follies: The uncritical acceptance of medical innovation. *J. Amer. Medical Assoc.* 269(23):3030–3033.
- Grol R, Grimshaw J (2003) From best evidence to best practice: Effective implementation of change in patients' care. *Lancet* 362(9391):1225–1230.
- Groopman J (2014) Print thyself. How 3-D printing is revolutionizing medicine. *New Yorker* (November 24), 78–85.
- Groopman J, Hartzband P (2017) Putting profits ahead of patients. *New York Review Books* (July 13), <https://www.nybooks.com/articles/2017/07/13/putting-profits-ahead-of-patients/>.
- Guo P, Tang CS, Wang Y, Zhao M (2019) The impact of reimbursement policy on social welfare, revisit rate and waiting time in a public healthcare system: Fee-for-service vs. bundled payment. *Manufacturing Service Oper. Management* 21(1):154–170.
- Gupta D, Mehrotra M (2015) Bundled payments for healthcare services: Proposer selection and information sharing. *Oper. Res.* 63(4):772–788.
- Harris G (2010) Doctor faces suits over cardiac stents. *New York Times* (December 6), A15.
- Hartzband P, Groopman J (2009) Money and the changing culture of medicine. *New England J. Medicine* 360(2):101–103.
- Helm JE, Van Oyen MP (2014) Design and optimization methods for elective hospital admissions. *Oper. Res.* 62(6):1265–1282.
- Helm JE, Lavieri MS, Van Oyen MP, Stein JD, Musch DC (2015) Dynamic forecasting and control algorithms of glaucoma progression for clinician decision support. *Oper. Res.* 63(5):979–999.
- Huang J, Carmeli B, Mandelbaum A (2015) Control of patient flow in emergency departments, or multiclass queues with deadlines and feedback. *Oper. Res.* 63(4):892–908.
- Huh WT, Liu N, Truong V-A (2013) Multiresource allocation scheduling in dynamic environments. *Manufacturing Service Oper. Management* 15(2):280–291.
- Ibanez MR, Clark JR, Huckman RS, Staats BR (2018) Discretionary task ordering: Queue management in radiological services. *Management Sci.* 64(9):4389–4407.
- Izady N (2015) Appointment capacity planning in specialty clinics: A queueing approach. *Oper. Res.* 63(4):916–930.
- Jha S, Topol EJ (2016) Adapting to artificial intelligence: Radiologists and pathologists as information specialists. *J. Amer. Medical Assoc.* 316(22):2353–2354.
- Jónasson JO, Deo S, Gallien J (2017) Improving HIV early infant diagnosis supply chains in sub-Saharan Africa: Models and application to Mozambique. *Oper. Res.* 65(6):1479–1493.
- Joyner MJ, Paneth N (2015) Seven questions for personalized medicine. *J. Amer. Medical Assoc.* 314(10):999–1000.
- Joynt KE, Jha AK (2012) Thirty-day readmissions—truth and consequences. *New England J. Medicine* 366(15):1366–1369.
- KC DS (2014) Does multitasking improve performance? Evidence from the emergency department. *Manufacturing Service Oper. Management* 16(2):168–183.
- KC DS (2018) Econometric methods in healthcare operations. Dai T, Tayur SR, eds. *Handbook of Healthcare Analytics: Theoretical Minimum for Conducting 21st Century Research on Healthcare Operations* (John Wiley & Sons, Hoboken, NJ), 381–402.
- Kellermann AL (2006) Crisis in the emergency department. *New England J. Medicine* 355(13):1300–1303.
- Kellermann AL, Conway C, Wolcott R, Hackman BB, Bogan S, Bernstein E, Fish S, Kerl T, Mitchell T, Ramsey C, Kelen GD (1994) Access of Medicaid recipients to outpatient care. *New England J. Medicine* 330(20):1426–1430.
- Khademi A, Saure DR, Schaefer AJ, Braithwaite RS, Roberts MS (2015) The price of nonabandonment: HIV in resource-limited settings. *Manufacturing Service Oper. Management* 17(4):554–570.
- Kim K, Mehrotra S (2015) A two-stage stochastic integer programming approach to integrated staffing and scheduling with application to nurse management. *Oper. Res.* 63(6):1431–1451.
- Kim S-H, Whitt W (2014) Are call center and hospital arrivals well modeled by nonhomogeneous Poisson processes? *Manufacturing Service Oper. Management* 16(3):329–480.
- Kim S-H, Chan CW, Olivares M, Escobar G (2015) ICU admission control: An empirical study of capacity allocation and its implication for patient outcomes. *Management Sci.* 61(1):19–38.
- Kolata G (2017) New gene tests pose a threat to insurers. *New York Times* (May 12), <https://www.nytimes.com/2017/05/12/health/new-gene-tests-pose-a-threat-to-insurers.html>.
- Kouvelis P, Milner J, Tian Z (2017) Clinical trials for new drug development: Optimal investment and application. *Manufacturing Service Oper. Management* 19(3):437–452.
- Kouvelis P, Xiao Y, Yang N (2015) PBM competition in pharmaceutical supply chain: Formulary design and drug pricing. *Manufacturing Service Oper. Management* 17(4):511–526.
- Kristof N (2010) Access, access, access. *New York Times* (March 17), <https://www.nytimes.com/2010/03/18/opinion/18kristof.html>.
- Kuntz L, Mennicken R, Scholtes S (2014) Stress on the ward: Evidence of safety tipping points in hospitals. *Management Sci.* 61(4):754–771.
- Lamas D (2013) To donate your kidney, click here. *New Yorker* (September 25), <https://www.newyorker.com/tech/annals-of-technology/to-donate-your-kidney-click-here>.
- Landro L (2009) Seeking a safer surgery some states crack down on doctors who perform unregulated outpatient procedures. *Wall Street Journal* (July 20), <https://www.wsj.com/articles/SB10001424052970203946904574300971306299860>.
- Landro L (2017) The medical-industrial complex: The American health-care system is in need of reform. But does it deserve to be condemned? *Wall Street Journal* (April 28), <https://www.wsj.com/articles/the-medical-industrial-complex-1493411760>.
- Lee HL, Tang CS (1997) Modelling the costs and benefits of delayed product differentiation. *Management Sci.* 43(1):40–53.
- Levine J (2018) Organizational structure Dai T, Tayur SR, eds. *Handbook of Healthcare Analytics: Theoretical Minimum for Conducting 21st Century Research on Healthcare Operations* (John Wiley & Sons, Hoboken, NJ), 1–20.
- Liu N (2018) Ambulatory care. Dai T, Tayur SR, eds. *Handbook of Healthcare Analytics: Theoretical Minimum for Conducting 21st Century Research on Healthcare Operations* (John Wiley & Sons, Hoboken, NJ), 217–242.
- Liu N, Finkelstein SR, Kruk ME, Rosenthal D (2018) When waiting to see a doctor is less irritating: Understanding patient preferences and choice behavior in appointment scheduling. *Management Sci.* 64(5):1975–1996.
- Lu SF, Lu LX (2017) Do mandatory overtime laws improve quality? Staffing decisions and operational flexibility of nursing homes. *Management Sci.* 63(11):3566–3585.
- Mak H-Y, Rong Y, Zhang J (2014) Sequencing appointments for service systems using inventory approximations. *Manufacturing Service Oper. Management* 16(2):251–262.
- Makary M (2013) *Unaccountable: What Hospitals Won't Tell You and How Transparency Can Revolutionize Health Care* (Bloomsbury Publishing, New York).
- Mamani H, Chick SE, Simchi-Levi D (2013) A game-theoretic model of international influenza vaccination coordination. *Management Sci.* 59(7):1650–1670.
- Mathews AW (2012) Can accountable-care organizations improve health care while reducing costs? *Wall Street Journal* (January 23), <https://www.wsj.com/articles/SB1000142405297020472-0204577128901714576054>.
- Maxwell MS, Ni EC, Tong C, Henderson SG, Topaloglu H, Hunter SR (2014) A bound on the performance of an optimal ambulance redeployment policy. *Oper. Res.* 62(5):1014–1027.



- McCoy MS, Carniol M, Chockley K, Urwin JW, Emanuel EJ, Schmidt H (2017) Conflicts of interest for patient-advocacy organizations. *New England J. Medicine* 376(9):880–885.
- McLay LA, Mayorga ME (2013) A dispatching model for server-to-customer systems that balances efficiency and equity. *Manufacturing Service Oper. Management* 15(2):205–220.
- McWilliams JM, Hatfield LA, Chernew ME, Landon BE, Schwartz AL (2016) Early performance of accountable care organizations in Medicare. *New England J. Medicine* 374(24):2357–2366.
- Mechanic RE (2016) When new Medicare payment systems collide. *New England J. Medicine* 374(18):1706–1709.
- Meng F, Qi J, Zhang M, Ang J, Chu S, Sim M (2015) A robust optimization model for managing elective admission in a public hospital. *Oper. Res.* 63(6):1452–1467.
- Merion RM, Guidinger MK, Newmann JM, Ellison MD, Port FK, Wolfe RA (2004) Prevalence and outcomes of multiple-listing for cadaveric kidney and liver transplantation. *Amer. J. Transplantation* 4(1):94–100.
- Mills AF, Argon NT, Ziya S (2013) Resource-based patient prioritization in mass-casualty incidents. *Manufacturing Service Oper. Management* 15(3):361–377.
- Morden NE, Colla CH, Sequist TD, Rosenthal MB (2014) Choosing wisely—the politics and economics of labeling low-value services. *New England J. Medicine* 370(7):589–592.
- Mukherjee S (2017) The algorithm will see you now. *New Yorker* (April 3), 46–53.
- Murray M, Berwick DM (2003) Advanced access: Reducing waiting and delays in primary care. *J. Amer. Medical Assoc.* 289(8):1035–1040.
- Naldini L (2015) Gene therapy returns to centre stage. *Nature* 526(7573):351–360.
- Natarajan KV, Swaminathan JM (2014) Inventory management in humanitarian operations: Impact of amount, schedule, and uncertainty in funding. *Manufacturing Service Oper. Management* 16(4):595–603.
- Natarajan KV, Swaminathan JM (2018) Global health. Dai T, Tayur SR, eds. *Handbook of Healthcare Analytics: Theoretical Minimum for Conducting 21st Century Research on Healthcare Operations* (John Wiley & Sons, Hoboken, NJ), 137–158.
- Newman-Toker DE, Pronovost PJ (2009) Diagnostic errors—the next frontier for patient safety. *J. Amer. Medical Assoc.* 301(10):1060–1062.
- NORC (2017) Long-term care in America: Views on who should bear the responsibilities and costs of care. Accessed September 13, 2017, <https://www.longtermcarepoll.org/project/long-term-care-in-america-views-on-who-should-bear-the-responsibilities-and-costs-of-care/>.
- Onitskany E, Reddy P, Singhal S, Velamoor S (2018) Why the evolving healthcare services and technology market matters. McKinsey & Company. Accessed December 20, 2018, <https://www.mckinsey.com/industries/healthcare-systems-and-services/our-insights/why-the-evolving-healthcare-services-and-technology-market-matters>.
- Ormeci EL, Gunes ED, Kunduzcu D (2015) A modeling framework for control of preventive services. *Manufacturing Service Oper. Management* 18(2):227–244.
- Ozen A, Marmor Y, Rohleder T, Balasubramanian H, Huddleston J, Huddleston P (2016) Optimization and simulation of orthopedic spine surgery cases at Mayo Clinic. *Manufacturing Service Oper. Management* 18(1):157–175.
- Papanicolaos I, Woskie LR, Jha AK (2018) Health care spending in the United States and other high-income countries. *J. Amer. Medical Assoc.* 319(10):1024–1039.
- Patel MS, Asch DA, Volpp KG (2015) Wearable devices as facilitators, not drivers, of health behavior change. *J. Amer. Medical Assoc.* 313(5):459–460.
- Pinker E, Tezcan T (2013) Determining the optimal configuration of hospital inpatient rooms in the presence of isolation patients. *Oper. Res.* 61(6):1259–1276.
- Pinkerton S (2013) The pros and cons of robotic surgery. *Wall Street Journal* (November 17), <https://www.wsj.com/articles/the-pros-and-cons-of-robotic-surgery-1384550504>.
- Qi J (2017) Mitigating delays and unfairness in appointment systems. *Management Sci.* 63(2):566–583.
- Quill TE, Dresser R, Brock DW (1997) The rule of double effect—A critique of its role in end-of-life decision making. *New England J. Medicine* 337(24):1768–1771.
- Rajkumar R, Conway PH, Tavenner M (2014) CMS—Engaging multiple payers in payment reform. *J. Amer. Medical Assoc.* 311(19):1967–1968.
- Ramdas K, Darzi A (2017) Adopting innovations in care delivery—The case of shared medical appointments. *New England J. Medicine* 376(12):1105–1107.
- Ramdas K, Saleh K, Stern S, Liu H (2018) Variety and experience: Learning and forgetting in the use of surgical devices. *Management Sci.* 64(6):2590–2608.
- Ramirez E (2014) Antitrust enforcement in health care—Controlling costs, improving quality. *New England J. Medicine* 371(24):2245–2247.
- Rath S, Rajaram K, Mahajan A (2017) Integrated anesthesiologist and room scheduling for surgeries: Methodology and application. *Oper. Res.* 65(6):1460–1478.
- Reddy S (2017) Can tech speed up emergency room care? *Wall Street Journal* (March 27), <https://www.wsj.com/articles/can-tech-speed-up-emergency-room-care-1490629118>.
- Reinhardt UE (2010) Competition’s shortcomings in curtailing health care costs. *New York Times* (November 5), <https://economix.blogs.nytimes.com/2010/11/05/competitions-shortcomings-in-curtailing-health-care-costs/>.
- Reinhardt UE (2013) The disruptive innovation of price transparency in health care. *J. Amer. Medical Assoc.* 310(18):1927–1928.
- Relman AS (1980) The new medical-industrial complex. *New England J. Medicine* 303(17):963–970.
- Rosenbaum L (2015) Beyond moral outrage—weighing the trade-offs of COI regulation. *New England J. Medicine* 372(21):2064–2068.
- Rosenbaum L (2017) The less-is-more crusade—are we overmedicalizing or oversimplifying? *New England J. Medicine* 377(24):2392–2397.
- Rosenbaum L (2019) Cursed by knowledge—building a culture of psychological safety. *New England J. Medicine* 380(8):786–790.
- Rosenthal E (2013) As hospital prices soar, a stitch tops \$500. *New York Times* (December 2), <https://www.nytimes.com/2013/12/03/health/as-hospital-costs-soar-single-stitch-tops-500.html>.
- Rosenthal E (2014) After surgery, surprise \$117,000 medical bill from doctor he didn’t know. *New York Times* (September 20), <https://www.nytimes.com/2014/09/21/us/drive-by-doctoring-surprise-medical-bills.html>.
- Rosenthal E (2017) *An American Sickness: How Healthcare Became Big Business and How You Can Take It Back* (Penguin Press, New York).
- Roth AE (2003) The origins, history, and design of the resident match. *J. Amer. Medical Assoc.* 289(7):909–912.
- Sabouri A, Huh WT, Shechter SM (2017) Screening strategies for patients on the kidney transplant waiting list. *Oper. Res.* 65(5):1131–1146.
- Sack K (2009) Plan for kidney drugs spurs division. *New York Times* (December 14), <https://www.nytimes.com/2009/12/15/health/policy/15kidney.html>.
- Sack K (2012) 60 lives, 30 kidneys, all linked. *New York Times* (February 18), <https://www.nytimes.com/2012/02/19/health/lives-forever-linked-through-kidney-transplant-chain-124.html>.
- Saghafian S, Hopp WJ, Van Oyen MP, Desmond JS, Kronick SL (2014) Complexity-augmented triage: A tool for improving patient safety and operational efficiency. *Manufacturing Service Oper. Management* 16(3):329–345.

- Sandikçi B, Maillart LM, Schaefer AJ, Roberts MS (2013) Alleviating the patient's price of privacy through a partially observable waiting list. *Management Sci.* 59(8):1836–1854.
- Samiedaluie S, Kucukyazici B, Verter V, Zhang D (2017) Managing patient admissions in a neurology ward. *Oper. Res.* 65(3): 635–656.
- Savva N, Tezcan T, Yildiz O (2019) Can yardstick competition reduce waiting times? *Management Sci.* 65(7):3196–3215.
- Schneider EC, Squires D (2017) From last to first—could the us health care system become the best in the world? *New England J. Medicine* 377(10):901–904.
- Schulz R, Belle SH, Czaja SJ, McGinnis KA, Stevens A, Zhang S (2004) Long-term care placement of dementia patients and caregiver health and well-being. *J. Amer. Medical Assoc.* 292(8):961–967.
- Schwartz ND (2017) The doctor is in. Co-pay? \$40,000. *New York Times* (June 3), <https://www.nytimes.com/2017/06/03/business/economy/high-end-medical-care.html>.
- Scott Morton F, Boller LT (2017) Enabling competition in pharmaceutical markets. Hutchins Center Working Paper 30, Brookings Institution, Washington, DC.
- Segev DL, Gentry SE, Warren DS, Reeb B, Montgomery RA (2005) Kidney paired donation and optimizing the use of live donor organs. *J. Amer. Medical Assoc.* 293(15):1883–1890.
- Senot C, Chandrasekaran A, Ward P, Tucker A, Moffat-Bruce S (2016) The impact of combining conformance and experiential quality on hospitals' readmissions and cost performance. *Management Sci.* 62(3):829–848.
- Shi P, Chou MC, Dai JG, Ding D, Sim J (2016) Models and insights for hospital inpatient operations: Time-dependent ED boarding time. *Management Sci.* 62(1):1–28.
- Skandari MR, Shechter SM, Zalunardo N (2015) Optimal vascular access choice for patients on hemodialysis. *Manufacturing Service Oper. Management* 17(4):608–619.
- So KC, Tang CS (2000) Modeling the impact of an outcome-oriented reimbursement policy on clinic, patients, and pharmaceutical firms. *Management Sci.* 46(7):875–892.
- Song H, Veeraraghavan S (2018) Quality of care. Dai T, Tayur SR, eds. *Handbook of Healthcare Analytics: Theoretical Minimum for Conducting 21st Century Research on Healthcare Operations* (John Wiley & Sons, New York), 79–108.
- Song H, Tucker A, Murrell K (2015) The diseconomies of queue pooling: An empirical investigation of emergency department length of stay. *Management Sci.* 61(12):3032–3053.
- Sood N (2017) Follow the money: The flow of funds in the pharmaceutical distribution system. Report, Schaeffer Center for Health Policy and Economics, University of Southern California, Los Angeles.
- Span P (2015) A quiet end to the “death panels” debate. *New York Times* (November 20), <https://www.nytimes.com/2015/11/24/health/end-of-death-panels-myth-brings-new-end-of-life-challenges.html>.
- Spillman BC, Lubitz J (2000) The effect of longevity on spending for acute and long-term care. *New England J. Medicine* 342(19): 1409–1415.
- Staats BR, Dai H, Hofmann D, Milkman KL (2016) Motivating process compliance through individual electronic monitoring: An empirical examination of hand hygiene in healthcare. *Management Sci.* 63(5):1563–1585.
- Staats BR, KC DS, Gino F (2018) Maintaining beliefs in the face of negative news: The moderating role of experience. *Management Sci.* 64(2):804–824.
- Starr P (2017) *The Social Transformation of American Medicine: The Rise of a Sovereign Profession and the Making of a Vast Industry* (Basic Books, New York).
- Steinhauser KE, Christakis NA, Clipp EC, McNeilly M, McIntyre L, Tulsky JA (2000) Factors considered important at the end of life by patients, family, physicians, and other care providers. *J. Amer. Medical Assoc.* 284(19):2476–2482.
- Stonebraker JS (2013) Product-generation transition decision making for Bayer's hemophilia drugs: Global capacity expansion under uncertainty with supply-demand imbalances. *Oper. Res.* 61(5): 1119–1133.
- Su X, Zenios SA (2004) Patient choice in kidney allocation: The role of the queueing discipline. *Manufacturing Service Oper. Management* 6(4):280–301.
- Sun Z, Argon NT, Ziya S (2018) Patient triage and prioritization under austere conditions. *Management Sci.* 64(10):4471–4489.
- Swaminathan JM, Tayur SR (1998) Managing broader product lines through delayed differentiation using vanilla boxes. *Management Sci.* 44(12-part-2):S161–S172.
- Taneri N, de Meyer A (2017) Contract theory: Impact on biopharmaceutical alliance structure and performance. *Manufacturing Service Oper. Management* 19(3):453–471.
- Thaler RH, Sunstein CR (2009) *Nudge: Improving Decisions About Health, Wealth, and Happiness* (Penguin Books, New York).
- Thompson DF (1993) Understanding financial conflicts of interest. *New England J. Medicine* 329(8):573–573.
- Thompson S, Whitaker J, Kohli R, Jones C (2019) How information technology and analytics create healthcare value: A theory of temporal displacement of care. *MIS Quarterly*. Forthcoming.
- Topol E (2013) *The Creative Destruction of Medicine: How the Digital Revolution Will Create Better Health Care* (Basic Books, New York).
- Topol EJ, Steinhubl SR, Torkamani A (2015) Digital medical tools and sensors. *J. Amer. Medical Assoc.* 313(4):353–354.
- Topol E (2019) *Deep Medicine: How Artificial Intelligence Can Make Healthcare Human Again* (Basic Books, New York).
- Treanor J (2004) Weathering the influenza vaccine crisis. *New England J. Medicine* 351(20):2037–2040.
- Tsai TC, Joynt KE, Orav EJ, Gawande AA, Jha AK (2013) Variation in surgical-readmission rates and quality of hospital care. *New England J. Medicine* 369(12):1134–1142.
- Tucker AL (2016) The impact of workaround difficulty on frontline employees' response to operational failures: A laboratory experiment on medication administration. *Management Sci.* 62(4): 1124–1144.
- Tuohy CH, Glied S (2011) The political economy of health care. Gliede S, Smith PC, eds. *The Oxford Handbook of Health Economics* (Oxford University Press, Oxford, UK).
- Ubel PA (2001) *Pricing Life: Why It's Time for Health Care Rationing* (MIT Press, Cambridge, MA).
- Ubel PA (2014) Transplantation Traffic—geography as destiny for transplant candidates. *New England J. Medicine* 371(26): 2450–2452.
- United Network for Organ Sharing (UNOS) (2013) Five most frequently cited transplant program policy violations. Accessed November 19, 2018, [https://www.transplantpro.org/wp-content/uploads/sites/3/Top\\_5\\_Tx\\_OPO.pdf](https://www.transplantpro.org/wp-content/uploads/sites/3/Top_5_Tx_OPO.pdf).
- Villarosa L (2018) Why America's black mothers and babies are in a life-or-death crisis. *New York Times Magazine* (April 11), <https://www.nytimes.com/2018/04/11/magazine/black-mothers-babies-death-maternal-mortality.html>.
- Wachter RM (2008) Perspectives on medical outsourcing and telemedicine—rough edges in a flat world? *New England J. Medicine* 358(15):1622–1627.
- Wachter RM, Pronovost PJ (2009) Balancing “no blame” with accountability in patient safety. *New England J. Medicine* 361(14): 1401–1406.

- Wang W-Y, Gupta D (2014) Nurse absenteeism and staffing strategies for hospital inpatient units. *Manufacturing Service Oper. Management* 16(3):439–454.
- Wasik JF (2016) The everything-in-one promise of a continuing care community. *New York Times* (February 26), <https://www.nytimes.com/2016/02/27/your-money/the-everything-in-one-promise-of-a-continuing-care-community.html>.
- Weaver C, Mathews AW, McGinty T (2015) Medicare rules reshape hospital admissions: Return-visit rate drops, but change in billing tactics skews numbers. *Wall Street Journal* (December 1), <https://www.wsj.com/articles/medicare-rules-reshape-hospital-admissions-1449024342>.
- Weick KE, Sutcliffe KM (2015) *Managing the Unexpected: Sustained Performance in a Complex World* (John Wiley & Sons, New York).
- Wieczner J (2013) Pros and cons of concierge medicine. *Wall Street Journal* (November 10), <https://www.wsj.com/articles/pros-and-cons-of-concierge-medicine-1383766139>.
- Williamson LM, Devine DV (2013) Challenges in the management of the blood supply. *Lancet* 381(9880):1866–1875.
- World Health Organization (WHO), World Bank, Organisation for Economic Co-operation and Development (OECD) (2018) Delivering quality health services: A global imperative for universal health coverage. Report, World Bank Group, Washington, DC.
- Xu K, Chan CW (2016) Using future information to reduce waiting times in the emergency department via diversion. *Manufacturing Service Oper. Management* 18(3):314–331.
- Xu R (2014) The doctor will see you onscreen. *New Yorker* (March 10), <https://www.newyorker.com/business/currency/the-doctor-will-see-you-onscreen>.
- Xu T, Wu AW, Makary MA (2015) The potential hazards of hospital consolidation: Implications for quality, access, and price. *J. Amer. Medical Assoc.* 314(13):1337–1338.
- Yamin D, Gavius A (2013) Incentives' effect in influenza vaccination policy. *Management Sci.* 59(12):2667–2686.
- Yang Y, Goldhaber-Fiebert JD, Wein LM (2013) Analyzing screening policies for childhood obesity. *Management Sci.* 59(4):782–795.
- Yom-Tov GB, Mandelbaum A (2014) Erlang-r: A time-varying queue with reentrant customers, in support of healthcare staffing. *Manufacturing Service Oper. Management* 16(2):283–299.
- Young DW, Saltman RB (1985) *The Hospital Power Equilibrium: Physician Behavior and Cost Control* (Johns Hopkins University Press, Baltimore).
- Zacharias C, Armony M (2017) Joint panel sizing and appointment scheduling in outpatient care. *Management Sci.* 63(11):3978–3997.
- Zhang DJ, Gurvich I, Van Mieghem JA, Park E, Young RS, Williams MV (2016) Hospital readmissions reduction program: An economic and operational analysis. *Management Sci.* 62(11):3351–3371.