Healthcare Operations Management: A Snapshot of Emerging Research

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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.

Key words: Healthcare operations management; healthcare ecosystem; behavior, incentive and policy issues in healthcare.
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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$^{\text{st}}$ 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 *mul-*

tiple 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 queueing 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; *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 inter-connected "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 US 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 macro-, meso-, and micro-level 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). (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 US 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. 2018), 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 UK (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 of 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 (HEM) 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.[1] 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; Dai et al. 2018), with a particular focus on the US 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 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 (OPTN policy 3.2.3), they ordinarily

[1] 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.

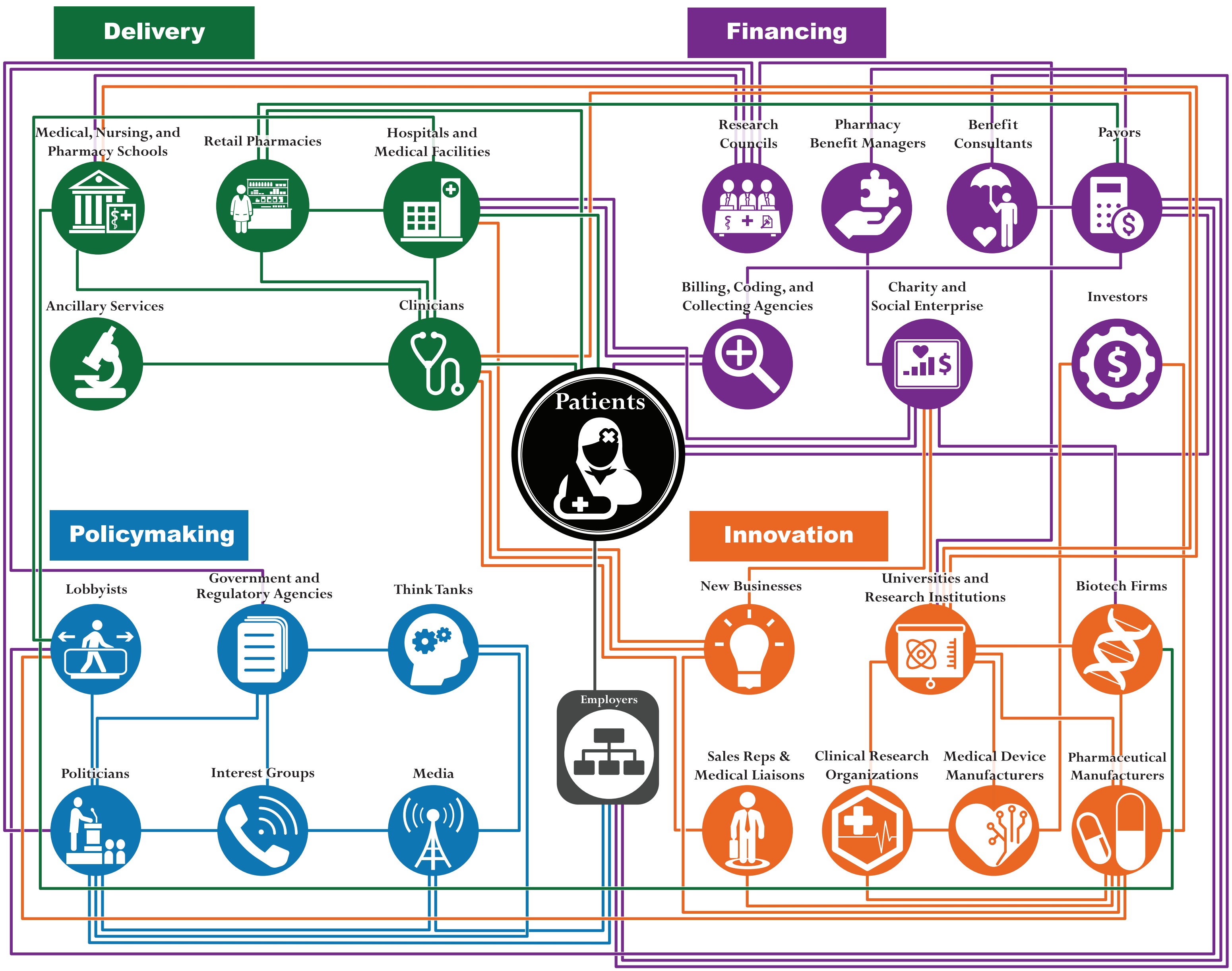

Figure 1 The Healthcare Ecosystem Map (HEM)

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.[2] The uptake of multiple listing 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 listing 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.[3] Losing those patients would mean lower margins on reimbursements and worse post-transplant outcomes.

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 US 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 three 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 new business models and operational approaches. The primary operational challenge this circle faces is to ensure 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,

[2] According to 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.

[3] Merion et al. (2014, p. 97) 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%).

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 US Congress established the Organ Procurement and Transplantation Network (OPTN) to (1) make organ-allocation policies and (2) collect transplant data, which it operates through the United Network of Organ Sharing (UNOS) and the Scientific Registry of Transplant Recipients (SRTR), respectively. Additionally, the Center for Medicare and Medicaid Services (CMS) stipulates policies regarding post-transplant 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 inter-entity 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*,[4] 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 §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 §4, we classify the recent literature in terms of both its methodological tools and research thrusts.

[4] Throughout the paper, we define the HOM literature as the healthcare research conducted by OR/MS 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.

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 (§3.1) connects healthcare providers, payors, and patients, and is relevant to the literature on the cost and access of care. The second subloop (§3.2) connects pharmaceutical manufacturers, charity organizations, and payors, and is relevant to the literature on healthcare supply chains. The third subloop (§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 Medicare), 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. (2018), 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 US 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 entitled "It's the Prices, Stupid: Why the United States is So Different from Other Countries," Anderson et al. (2003) show, contrary to popular belief, the US *trails* most OECD countries in terms of the *utilization* of health services; they attribute the high cost of US healthcare to its *pricing* practice. A more recent study by Papanicolas et al. (2018) draws nearly the same conclusion. Pricing practices in the US healthcare system are remarkably opaque and ad hoc. Consider a true story from Elisabeth Rosenthal's 2017 book, *An American Sickness*, 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 five-fold, 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 super-sized 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 (ACA), 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, US 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 US 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 queueing 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. (2018), Savva et al. (2018), and Song and Veeraraghavan (2018), have recognized the power of queueing 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; Cho and Zhao 2018) in various contexts, consists of pharmaceutical manufacturers, wholesalers, pharmacies, health insurance firms, and pharmaceutical benefit managers (PBMs). 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 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), outcome (e.g., mortality, adverse events, readmissions, patient experience, and access). Their survey suggests 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.[5] 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":

[5] 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.

> 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,

> 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, policymakers 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 WHO quality-of-care guidelines (WHO, World Bank, and OECD 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. 2017; Staats et al. 2016, 2017; Tucker 2015). 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 use 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): *Macro-level thrusts* deal with the supply of and demand for healthcare services, and how supply and demand are matched through healthcare entities and on marketplaces; *micro-level thrusts* deal with the operations of specific healthcare operations, such as ambulatory care, emergency care, and inpatient care; *meso-level thrusts* connect macro- and micro-level 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 macro-, meso-, and micro-level thrust, 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.

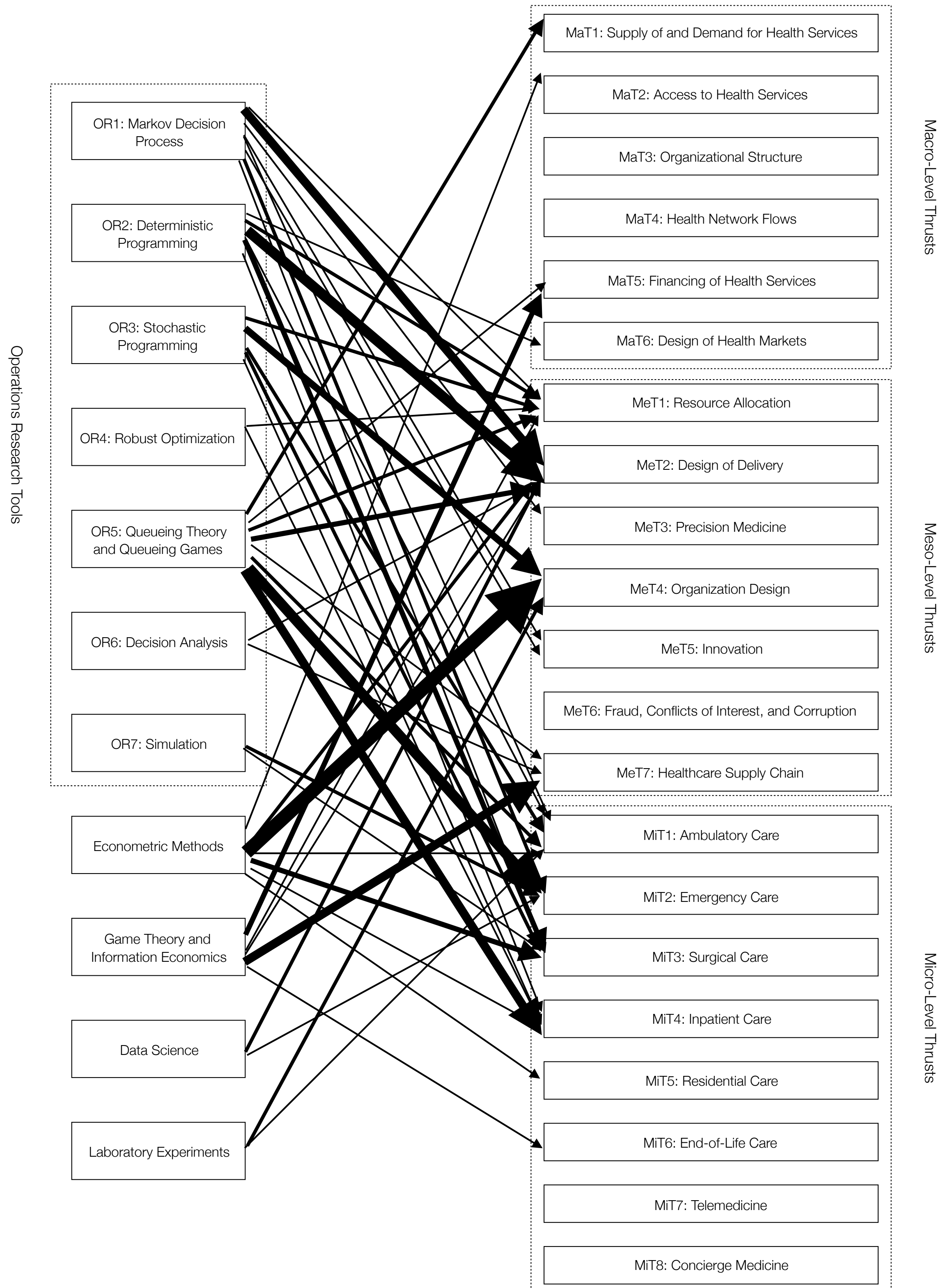

Figure 2 Tool-Thrust Graph: A Bipartite Graph Showing the Connections of Tools and Thrusts

4.1.1 Tools Among the methodological tools, queueing theory and queueing games (OR5) turns 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 (EM), 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 macro-level 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, accounting for 11% of the publications. Notably, game theory and information economics have found applications in both macro-level thrusts such as financing of health services (MaT5) and meso-level thrusts such as healthcare supply chain (MeT7).

Behavioral intervention tools such as “nudging,” popularized by behavioral economists (e.g., Thaler and Sunstein 2009), are under-represented. 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 control 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 macro-level thrust. Indeed, apart from the financing of health services (MaT5), with a share of 4%, most of the macro-level thrusts remain little explored, if at all. Collectively, macro-level 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 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 meso-level 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 meso-level thrusts, arise organically from the interface connecting micro- and macro-level 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.”

Micro-level 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 micro-level thrusts, including residential care (MiT5), end-of-life care (MiT6), telemedicine (MiT7), and concierge medicine (MiT8), 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

Table 1 Macro-level thrusts

Macro-Level 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 et al. (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 (2014); Sack (2012)	Roth (2003); Segev et al. (2005)	Glorie et al. (2014)

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, incentive, and policy issues in healthcare. Relevant to this approach, a sizable literature in several related fields (esp. 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, 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

Table 2 Meso-level thrusts

Meso-Level 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 et al. (2014); Chan et al. (2016); 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. (2017); Yamin and Gavious (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); Economist (2017b)	Gaba and Howard (2002)	Berry Jaeker and Tucker (2017); Ibanez et al. (2017); Kuntz et al. (2014); Ramdas et al. (2017); Senot et al. (2016); Song et al. (2015); Staats et al. (2016, 2017); Tucker (2016)
MeT5: Innovation	Topol (2013); Gawande (2013)	Curfman and Redberg (2011); Grimes (1993); Ramdas and Darzi (2017)	Kouvelis et al. (2017)
MeT6: Fraud, Conflict of Interests, 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 et al. (2013); Taneri and de Meyer (2017)

health-related activities) and custom services (diagnostic and treatment services) to the population. Inspired by the concept of "delayed differentiation," Thompson et al. (2018) 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.

Table 3 Micro-level thrusts

Micro-Level 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. (2017); 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); Saghafian et al. (2014); Xu and Chan (2016)
MiT3: Surgical Care	Pinkerton (2013); Rosenthal (2014)	Angelos (2010); Tsai et al. (2013)	Denton et al. (2013); Freeman et al. (2016); Ozen et al. (2016); Ramdas et al. (2017); Rath et al. (2017)
MiT4: Inpatient Care	Weaver (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. (200); 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); Wieczner (2013)	Hartzband and Groopman (2009)	

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 a 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) envisions in *The Nature of Technology*, 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.

Table 4 Technological innovations in healthcare

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

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 (HEM). 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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Appendix: Taxonomy of Healthcare Operations Management Literature

The **macro-level thrusts** (MaTs) include the following:

MaT1: Supply of and demand for health services (market mechanism vs. social optimum, excessive spending and counteracting strategies, 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], equity and efficiency in access to health services)

MaT3: Organizational structure (power equilibrium and dynamics in health organizations, healthcare vs. capitalism, 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, CMS reforms such as bundled payments)

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

The **meso-level thrusts** (MeTs), which bridge macro- and micro-level thrusts, include the following:

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

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

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

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

MeT5: Innovation (drug development, medical device development, regulators vs. innovators, data analytics, robotics, and 3d printing applied to medicine)

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

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

The **micro-level thrusts** (MiTs) include the following:

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

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

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

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

MiT5: Residential care (rising costs, lack of access)

MiT6: End-of-life care (ethics, costs)

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

MiT8: Concierge medicine (affordability, equity of access, 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),

Queuing theory and queueing games (OR5),

Decision analysis (OR6), and

Simulation (OR7)

(ii) Econometric methods

(iii) Game theory and information economics

(iv) Data science

(v) Laboratory experiments

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