Empirical Research in Healthcare Operations: Past Research, Present Understanding, and Future Opportunities

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Abstract

We examine the published empirical literature in healthcare operations management over the last 20 years. We note several unique characteristics of the research in healthcare operations, including a focus on operational and organizational variables, an interest in the underlying mechanisms that explain operational causal pathways, and an interest in economic and managerial implications. We organize the prior findings under five distinct themes: importance of operational variables, importance of volume, routing patients through healthcare systems, to err is human, and managing the improvement process. We also identify several key areas of future research, including personalized medicine, value-based healthcare, and connected health. We conclude with a call to action for greater engagement with the medical community in areas where tools and insights of operations management can bring about improvements in healthcare delivery.

Key words: healthcare operations management; empirical operations management; literature review; trends

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1. Introduction

Large healthcare systems are commonly analyzed along three dimensions, which are often referred to as the Iron Triangle of Healthcare (Kissick 1994): cost, access, and quality. If one examines these three dimensions to assess performance, it is clear that the healthcare systems of most countries are in a state of crisis. Healthcare costs have increased rapidly. In 1960, the United States spent 5% of its GDP on healthcare. This number grew to 18% by 2017[1]. Despite the rise in costs, access to care continues to be problematic for many patients. In the United States, 27 million patients are uninsured, severely restricting access to care due to reimbursement issues. In Canada and most of Europe, where every person has the right to be insured or is covered by government insurance, access to care is still hampered by long waiting times. Finally, quality of care has also been heavily critiqued. A recent study estimates that some 700 patients die every day due to medical errors and 8.9% of surgeons self-report having made a major surgical error in the last three months (Shanafelt et al. 2017).

The three dimensions of cost, access, and quality are at the heart of any introductory operations management course or text-book (Cachon and Terwiesch 2019). Moreover, the practice of operations management offers the promise that systems can be improved. Contrary to Kissick's (1994) Iron Triangle paradigm, which postulates that any improvement in one dimension will be detrimental to the performance of at least one of the other two dimensions, the field of operations management is founded on the notion that system inefficiencies are complex and not unilaterally interdependent. Thus, it is possible for large system dysfunction to be reduced through processes that provide technological and organizational innovation mechanisms that are rooted in continuous, detailed analysis. As a result, access, cost, and quality do not have to be traded off against each other for us to see improvement in the healthcare system.

Improving healthcare by applying principles of operations management certainly is an ambitious task. Some work has been done, but most of the journey still lies ahead. The purpose of this review article is to take stock of the operations management research in healthcare. We then synthesize this research by articulating a set of five findings that, in our view, summarize the present understanding that the field of operations management has empirically established in the domain of healthcare. Finally, we conclude by describing where we see the biggest gaps

[1] https://www.cms.gov/research-statistics-data-and-systems/statistics-trends-and-reports/nationalhealthexpenddata/nhe-fact-sheet.html

between what we know and what we feel is needed. The focus of this review is entirely on empirical work in healthcare operations and we direct the reader to the accompanying article by Keskinocak and Savva (2019) on mathematical models of healthcare operations.

2. Past Research

The goal of healthcare operations management is to create and manage a system that provides a population with the right professional service at the right time and place so that individuals remain as healthy as possible for as long as possible, and at the lowest possible cost to society. In evaluating the performance of healthcare systems, the key outcomes of interest are access, costs, and quality. To that end, the healthcare operations management literature focuses on the efficient allocation of critical resources, the design and organization of effective delivery systems, and the use of technology in enabling new innovative models of care delivery.

2.1. The Unique Approach of Healthcare Operations

The earliest papers in healthcare operations management typically involved the re-application of existing models from manufacturing and services to the healthcare setting. Examples include capacity sizing, patient scheduling, and process flow improvements applied to patient flow in hospitals. However, recent papers, especially empirical ones, have focused on challenges unique to the healthcare domain. As a result, the emerging work in healthcare operations bears some similarities with the fields of clinical research, health services research, and health economics. Yet, healthcare operations management differs from these other streams of inquiry in three important ways.

1. Healthcare operations management tends to focus on operational and organizational variables (e.g. workforce, design of work, resources, process flow), rather than clinical variables that the medical professional has historically studied.

2. Unlike medical papers, healthcare operations management is not only concerned with evaluations of interventions (e.g. does using a blood-glucose app help control diabetes?) but is also deeply interested in the underlying mechanisms in the care process that affect or moderate its effectiveness.

3. The goal of research in healthcare operations is not only to develop managerial and economic insights, but to also formulate prescriptive solutions.

2.2. Rapid Growth in Research

The empirical analysis of healthcare operations management has become increasingly popular in the top journals of operations management. According to a database tracking empirical research in operations management across all industries (Terwiesch et al. 2019), prior to 2005, the journals *Management Science, Manufacturing and Service Operations Management*, and *Production and Operations Management* together published roughly one empirical healthcare operations article every other year. That number grew to one article per year from 2006 to 2010 and since then has risen sharply, with the years 2016 and 2017 seeing eight empirical articles each. A key driver behind this explosive growth has been data availability. Early papers had little data available as far as the actual process dynamics involved in the care delivery. Data such as patient waiting times or processing times of providers were typically not available and, if they were, they had to be manually connected with the patient medical record.

This changed fundamentally with the introduction of patient tracking systems. Though these systems were primarily designed to facilitate the day-to-day operations, their time stamped format, which tracks each patient from arrival to discharge, provided researchers with granularity of information that had not existed before. This enabled two types of new research studies in healthcare operations:

- The length of stay of a patient could be decomposed into various elements and the flow of patients, including waiting times and patients bouncing back to a prior unit, could be analyzed.

- The time stamps for the key flow events of all patients enabled a researcher to retrospectively determine the census of a unit or a hospital at any moment of time. Such census information can be used as an important driver of outcomes.

As hospitals continue to advance their implementation of tracking technologies, new types of datasets emerge. For example, Staats et al. (2016) employ monitoring technology data to determine if providers followed the handwashing protocol when entering a patient room, and Kim et al. (2017) observe the temporal changes in acuity levels for patients in the ICU. At an even more granular level, Meng et al. (2019) analyze a database in which each nurse's exact location in an emergency department was recorded every few seconds, enabling the authors to measure nurse walking behavior and how quickly nurses responded to patient calls. In sum, it appears that the constraint of data availability has been greatly relaxed.

This growth in publication parallels other trends. The Healthcare Operations Management Special Interest Group (SIG), which did not exist over a decade ago, is now one of the largest groups at the annual Manufacturing and Services Operations Management (MSOM) conference. A few years ago, INFORMS began an annual healthcare conference, which now hosts around 500 talks and posters annually. Moreover, empirical healthcare operations is a popular topic amongst doctoral students and recent graduates of many operations management programs, indicating that interest in healthcare operations management is likely to grow.

3. Our Present Understanding

Looking at the journals (*Management Science*, *Manufacturing and Service Operations Management*, and *Production and Operations Management*), we have identified a set of over 70 empirical papers in healthcare operations. We focus our review on these three journals, but certainly want to acknowledge that more work has been done in other journals and the previously mentioned adjacent research communities.

We synthesized the results of prior work into five findings. Each finding is, by design, rather broad and the reviewed articles might fit to multiple findings. Nevertheless, we find that the structure we impose makes it easier for the novice reader to navigate this exciting field.

3.1. Importance of Operational Variables

Understanding the drivers of patient outcome is critical to the advancement of medicine. However, prior research in medicine has primarily focused on patient level clinical variables (such as socio-demographic data, comorbidities, risk scores, etc.) in influencing outcomes. An important line of work in healthcare operations has shown that even after accounting for patient level medical risk, operational factors directly impact patient outcomes, sometimes more significantly than well-known medical variables.

Consider for example the role of system level utilization. As utilization rises, providers get busy and fatigued, beds are filled, and response times for tests increase. Does it matter for the medical outcomes of a patient whether she arrives to a busy hospital? A number of healthcare operations management articles have demonstrated that operational variables such as workload, arrival times, or the day of week impact care delivery pathways and patient outcome. KC and Terwiesch (2009) show how care is accelerated for patients that are treated in a busy system. In a large, multi-site study of 83 German hospitals, Kuntz et al. (2014) provide empirical evidence for the existence of safety tipping points, which are levels of system utilization beyond which patients are exposed to an increase in mortality risks. KC and Terwiesch (2012) and Kim et al. (2015) examine patient flow through a hospital's intensive care unit (ICU) and find that high levels of bed occupancy were more likely to lead to patients being discharged prematurely or not being admitted to the ICU at all, both of which can increase the risk for revisits (or bounce-backs) of patients into the ICU at future times. Berry Jaeker and Tucker (2016) find a non-linear N-shaped effect of utilization on the length of stay for patients being discharged from the hospital.

Lack of available resources can also greatly impact the types of treatment offered to patients. For example, Freeman et al. (2016) find that a high level of workload for midwives leads to a greater likelihood of complex patients being referred to specialists. The effects of downstream utilization can also be felt in the hospital's emergency department (ED); Allon et al. (2013) show that bed shortage in the hospital inpatient units can drive increased congestion in the ED, leading to increased rates of ambulance diversions.

Operational variables such as the time of treatment also have a surprising and significant impact on clinical outcomes. For example, Anderson et al. (2014) find that trauma patients who arrive to the hospital during off-hours receive inferior care, resulting in worse clinical outcomes. KC (2019) finds that heuristics based on the hour of admission can have a significant effect on the patient length of stay, with important implications for operating costs and capacity availability. Bartell et al. (2019) find that the day of week of admission can impact whether the patient incurs a weekend hospital stay, resulting in patient length of stay and clinical outcome implications. Similarly, Batt et al. (2017) find that emergency room patients are impacted by the time-in-shift of the treating physician. In particular, patients who are assigned towards the end of a doctor's shift are more likely to be handed off to a physician beginning the next shift, resulting in a notable impact on service quality as evidenced by increased hospital length of stay and a likelihood of a hospital revisit. Deo and Jain (2018) similarly find temporal heterogeneity in service rates in an outpatient clinic setting; patients arriving later in the day experience a shorter length of stay compared to those arriving earlier. We thus summarize the first finding as:

Finding 1: Operational characteristics play an important role in influencing patient outcomes, and warrant just as much attention as patient-level clinical characteristics (e.g., *socio-demographics, comorbidities, risk scores, etc.), which have been the primary focus of prior research in medicine.*

3.2. The Importance of Volume

A stream of literature in healthcare operations has studied the effect of volume of clinical activity on outcomes, service times and costs. Volume of activity can be measured in at least three different but correlated ways: First, it can be measured as the overall *cumulative* volume of past activity at a certain point in time. Second, it can be measured as the volume of activity per period of time and, third, it can be measured in relative terms as the percentage volume of a specific activity relative to all other activities performed by a provider or organization.

Cumulative volume relates to learning curve, often referred to as the "volume-outcome" effects in the medical literature: Outcomes achieved for a specific procedure by hospitals and individual doctors improve as their cumulative patient volume in that procedure increases. In one of the earliest empirical healthcare operations papers, Pisano et al. (2001) demonstrate that rates of learning for the same cardiac surgery procedure vary significantly between hospitals. Subsequent work has unpacked the drivers of learning to understand the cause of this variation, establishing firm-specificity (Huckman and Pisano 2006, Theokary and Ren 2011) , team-specificity (Avgerinos and Gokpinar 2016; Reagans et al. 2005), variety-of-experience specificity (KC and Staats 2012, Ramdas et al. 2017) , the dependence on successes and failures (KC et al. 2013), and the role of new information (Staats et al. 2017) as moderators of learning.

Period-specific volume effects relate to the actual scale of activity. Using the context of cardiac surgery, KC and Terwiesch (2011) study how changes in relative scale of an activity, also referred to as focus, affect length of stay in a hospital. They emphasize that focus can be measured at different levels within the hospital, at the hospital level, the department level or the process level and show that the lower level focus variables are more robustly associated with reduced length of stay. Clark and Huckman(2012) find that hospitals that are more focused on cardiac surgery have lower mortality rates and that the association is more pronounced when complementary services are present in the hospital. This warns against a narrow specialization from a quality perspective and is confirmed by a mortality study by Kuntz et al. (2019) who find that routine elective patients benefit most from their hospital's focus on their disease segment, while emergency patients with significant comorbidities see no benefit.

Economies of scale effects in hospitals have been explored at length in the health economics literature (see e.g. Giancotti et al. 2017 for a recent survey). However, although the majority of studies find evidence of the existence of economies of scale, their magnitude and moderating circumstances remain subjects of debate. Exploring scale spillover effects between services, Freeman et al. (2019) find that an increase in the volume of elective activity in a focal specialty tends to make emergency care in the focal specialty more expensive, while an increase in volume of emergency activity in another, non-focal specialty tends to make emergency care in the focal specialty less expensive.

A key mechanism through which scale improves outcomes and productivity is task specialization, as division of labor becomes only economic at scale. However, a large number of specialists also mean that there will be multiple handoffs among key stakeholders, leading to increased coordination and communication costs. In managing this tradeoff, healthcare providers and physician practices may choose to maintain fewer levels of staff (Dobson et al. 2009). Similarly, White et al. (2017) note that although the use of mid-level care providers to perform some of the tasks is an increasing trend, there are a range of scenarios where not hiring a mid-level provider (i.e., the physician works alone) is likely to be most profitable for the clinic. Similarly Lu and Lu (2016) find that laws limiting overtime for permanent workers lead to greater use of temporary workers (an operational flexibility response), to the detriment of quality of care. We summarize our second finding as:

Finding 2: Care processes improve with cumulative volume (a result known as the learning curve) and the learning rate is affected by organizational factors. Care processes benefit from scale (volume per period), but changes in the scale of a specific service can have spillover effects to other services that can be positive or negative.

3.3. Routing Patients through Healthcare Systems

In a focused care process, a healthcare system avoids the challenge of dealing with a heterogeneous patient population. But, if each resource in the healthcare system is focusing on a given indication, the routing of patients through the system becomes critical. Getting the right patient to the right clinicians at the right time and place is a fundamental day-to-day challenge in healthcare operations. In other words, it is not enough to just study individual resources, but one has to analyze the larger network.

For example, a researcher modeling the demand for an emergency room might simply look at the number of cases arriving in a given time period as exogenous demand. However, such modeling approach hides the fact that the patients arriving in the ER might have been cared for before (Bavafa et al. 2019). If a primary care appointment had been easily available at the time the patient experienced the first symptoms, maybe the ER visit could have been avoided. Moreover, if the waiting times in the ER are getting too long, the patient might decide to delay or shorten her reception of care in the ER. Such an incomplete treatment might come at the expense of worse health and more clinical needs in the future (KC and Kim 2019).

This example illustrates four interdependencies among resources in the healthcare network. First, we need to understand the routing decisions of providers, who are not just care resources but also the ones referring to other resources. Consider for example the decision to admit a critical care patient to the ICU. Kim et al. (2015) find that available ICU capacity significantly influences whether the patient is admitted to the appropriate ICU. Such access to care decisions have been studied in the hospital patient admission from the emergency department (KC and Terwiesch 2017), where high levels of inpatient bed occupancy lead to fewer patients admitted as inpatients from the ED, even after accounting for their medical conditions; in maternity care decisions, the lack of available resources have also been found to influence patient care pathways (Freeman et al. 2016). Lu and Lu (2018) study the inter-hospital transfer of patients and find that the routing decisions by providers are more significantly affected by hospital relationships than by travel distance or quality of providers.

Second, some routing decisions are made by the patients. This includes abandoning the wait for a resource as well as the decision to seek out resources in the first place. For example, Batt and Terwiesch (2015) find that queue length and the perceived increase in the waiting time lead to patients abandoning the emergency department. Moreover, patients in a healthcare network take into account information in delay announcements in choosing emergency care providers (Dong et al. 2018). The decision to seek care has also been found to be influenced by various factors including physician ratings and time to appointment (Liu et al. 2017, Osadchiy and KC 2017, Salzarulo et al. 2016, Liu et al. 2019); online physician ratings can provide valuable information source for patients to learn about physician quality (Lu and Rui 2017).

Third, often times, routing happens in the form of an escalation. As one resource has failed in providing the care, the patient's health deteriorates and now needs to be handled at a more sophisticated (and expensive) resource. Chan et al. (2016) find that delays in admitting patients to the ICU can negatively impact subsequent quality of care in the ICU, as evidenced by increased ICU length of stay. Escalations due to quality of care issues have been described in cases of patients bouncing back to the ICU and impeding patient flow (Chan et al 2014, KC and Terwiesch 2012, Long and Matthews 2018). Escalations can also take the form of bounce-backs of patients to the hospital once they have been discharged. For example, governmental policies (Zhang et al. 2016) as well as conformance to care delivery standards (Senot et al. 2015) have been found to be strong predictors of post-discharge hospital revisits. Relatedly, Andritsos and Tang (2014) find that standardization of care achieved from implementation of medical guidelines leads to lower resource usage (indicated by length of stay reduction), especially in less focused environments.

Finally, in light of these multiple channels through which care can be delivered, system design decisions are critical. In particular, coordination activities amongst providers in healthcare coalitions can have a significant effect on rapid response to emergency and mass-casualty events (Mills et al. 2018). Similarly, managing the inpatient scheduling process to smooth out bed availability can help to improve bed availability for patients who present in the ED (KC and Terwiesch 2017). Early task initiation (Batt and Terwiesch 2016) can also help to mitigate the effects of congestion on performance of the ED. Finally, having an appropriate level of community based primary care services has also been found to improve population health (Zepeda and Sinha 2016). We thus summarize our third finding as:

Finding 3: To get the right patient to the right provider at the right time requires informed routing decisions and an appropriate overall design of the system

3.4. To Err is Human

In 1999, the Institute of Medicine published "To Err is Human" a report based on a multi-year study examining the state of care delivery in the US highlighting the importance of human fallibility in the provision of care. Operations management is uniquely suited to study errors and failure, having developed numerous methods and tools geared towards process analysis and the identification and management of points of failure.

The advent of micro-level transactional data from healthcare has further allowed researchers to examine care delivery at a more granular level, and to explore the human elements of failure.

For example, Staats et al. (2016) examine a well-understood clinical practice – hand hygiene, and find that providers often systematically deviate from best practices. Relatedly, lack of observability can also lead to providers misreporting incidences of hospital acquired infections, in order to improve their reimbursements (Bastani et al. 2018).

Often times, healthcare workers have a large amount of discretion in their work, i.e., there is no clear standard. For example, a form of discretion in work is the pickup of patients in the emergency department; the number of patients concurrently seen by a given physician at any point in time in the emergency department can vary significantly. However, this variation in the level of multitasking (KC 2013) can dramatically affect service quality. Such variations in workload also have a direct effect on hospital revenues (Powell et al. 2012). An important form of discretion for knowledge workers confronted with several different tasks is which task to complete first. Ibanez et al. (2017) have found that workers often deviate systematically from the prescribed task sequence. In particular, doctors prioritize similar tasks (batching) and those tasks they expect to complete faster. KC et al. (2019) also find evidence of task completion bias (TCB) towards completing easier tasks during periods of high workload; they find that although TCB leads to increased performance in the short term, it can impede longer-term learning effects.

Peer effects have also been found to be salient. For example, Song et al. (2015) find that pooling of doctors surprisingly has negative effect on the productivity of the ED, as the effects of free-riding dominated the beneficial effects of queue pooling. Peer effects also influence how individual providers utilize past experiences in generating improvement over time KC et al. (2013). We summarize this by stating:

Finding 4: Behavioral factors contribute to a large gap between the medical standards of care and the care that is provided at the bedside.

3.5. Managing Process Improvement

The previously mentioned studies of learning all report a large degree of heterogeneity across the learning rates. Beyond system design level decisions such as volume, it has been shown that the process of learning can be actively managed. We find it helpful to distinguish between articles that focus on the organizational dynamics of this improvement process and those that present specific operational models.

3.5.1 Organizational

In general, although operational improvement in hospitals is perceived as a challenge there are various organizational interventions and policy levers that can greatly aid process improvement. For example, management by walking around, where senior employees observe frontline workers at work (Tucker and Singer 2015, Tucker 2007) has been found to aid process improvement. Creating a culture that supports psychological safety (Tucker et al. 2007), providing public feedback (Song et al. 2017), and maintaining an appropriate level of administrative oversight (Senot et al. 2016) have also been found to be crucial in improving care delivery.

Some of this work has examined the moderating role of technology in the improvement of care processes. For example, Hydari et al. (2018) find that the use of electronic medical records led to a 17.5% decline in patient safety events. Lu et al. (2017) find that the adoption of health IT can enhance the automation of nursing tasks, particularly at high-end nursing homes, resulting in reduced staffing levels and improved clinical quality. Angst et al. (2011) further find that the sequence of adoption of the types of healthcare IT also matters; in particular, hospitals that integrated foundational technologies first tend to generate better performance outcomes. At the system level, Ayer et al. (2017) find that the adoption of health information exchanges led to over 10% reduction in length of stay in emergency departments. Laker et al. (2018) find, however, that the easy access to clinical information in the form of electronic health records can lead to information overload, compromising productivity and quality of care. However, stressing key aspects of the information to decision makers was found to improve the quality of care.

Finally, the development and implementation of process compliance has been found to also improve clinical outcomes. For example, improvements in internal service quality measures (Zheng et al. 2018) and the improvement of process conformance have been found to directly impact patient quality of care (Chandrasekaran et al. 2012, Senot et al.2016). Workarounds and first-order problem solving have been found to deter operational improvement; Tucker (2015) finds that making workarounds more difficult to implement, and providing frontline works with greater access to process owners can lead to increased communication about operational failures.

3.5.2 Operational Models

The field of operations management has developed a number of analytical tools to help determine how much capacity is needed to manage uncertain demand. For example, the newsvendor model has been used for evaluating the trade-off in allocation of operating room capacity (Olivares et al. 2008, He et al. 2012) and in nurse staffing decisions (Green et al. 2013). Some of this work involves using detailed patient level data to improve appointment scheduling (Salzarulo et al. 2016) or to match patients to providers more effectively (Wang et al. 2018).

Some of the research has also examined the effect of changes to the patient flow process on the overall throughput rates as well as quality of care. For example, Hu et al. (2018) consider the effect of early transfers of patients to the ICU based on their medical risk scores; Chan et al. (2018) similarly consider the effect of step-down units on overall patient throughput from the ICU. KC and Terwiesch (2017) find that smoothing inpatient schedules can greatly aid patient access from the emergency department. In the emergency department, early task initiation in anticipation of future resource demands, constitutes a form of demand smoothing, helping to match supply with demand more effectively (Batt and Terwiesch 2016). We thus summarize our fifth finding as:

Finding 5: The rate of improvement is not exogenous, but it can be improved through good micro level organizational design and the use of operational models.

4. Exciting Areas for Future Research

So far, we have described five streams of research. Each of the streams has established a set of findings that we broadly synthesized above. By articulating these findings, we do not imply that these research streams have converged or have come to a dead end. To the contrary – a substantial amount of future research is needed to refine these findings so that they can be applied with the same degree of confidence that models of inventory management models are now applied in supply chain settings.

As we think about the future of healthcare operations, however, it is important for us to realize that the field of medicine itself is going through a transformation. New payment systems, the possibilities associated with digital and connected technologies, and scientific breakthroughs all will have dramatic effects on the delivery of clinical care. In light of these changes, insights from Operations Management are needed more than ever to help design new care delivery models that provide access to high quality care at affordable costs to society.

4.1. New payment systems: Value-based healthcare and service integration

The dominant hospital reimbursement system today, co-developed by the late Professor Robert Fetter of Yale's OR department in the 1970's, is based on so-called diagnosis-related groups (DRG). In a nutshell, Fetter's work defined the range of products that hospitals produce. In a DRG system, hospitals are paid according to a national tariff for each patient within a given DRG. However, DRG-based reimbursement comes with some challenges which include incentivizing the overproduction of high margin DRGs even if not in the interest of the patient, cutting corners and externalizing quality problems (e.g. from the hospital to the community), or cherry-picking less costly patients within a DRG category. . Ever since the introduction of DRGs, hospital regulators have been refining the system which has rendered the system highly complex but has not addressed the root-cause of these problems: DRG systems do not reimburse for quality; they are based on counting activity – the amount of *healthcare* provided rather than the amount of *health* the patient population enjoys.

Value-based healthcare (Porter and Teisberg 2006) aims to pay for "outcomes that matter to patients". Outcomes are defined at the level of a condition or a procedure. In a recent NEJM Catalyst survey, 42% of 552 responding clinical leaders, clinicians, and executives of US healthcare organizations agreed with the statement that value-based healthcare will become the primary revenue model for their organization[2]. While the clinical and economic principles of value-based healthcare are sound and relatively well understood, its operationalization is still in its infancy. A core challenge of outcome-based reimbursement is that if we pay hospitals for outcomes, hospitals will need to control what happens to the patient after discharge. Value-based healthcare is thus predicated on the careful integration of a range of different healthcare providers, who are rarely in the same organization. This integration effort is the fundamental operational challenge of value-based healthcare.

A bewildering array of different integration models are being tested across the world. Prominent examples are the nearly 1,000 Accountable Care Organizations (ACO) in the US. These organizations are not reimbursed on their level of activity. Instead they receive an annual capitation payment for a clearly specified population to provide a clearly defined range of services against specific quality targets. What makes some integration models work and others not? What advice can we, as operations management researchers, offer on the operationalization

[2] https://catalyst.nejm.org/transitioning-fee-for-service-value-based-care/

of such integration efforts? How should make-or-buy decisions be made by provider organizations? What kinds of contracts lead to improved outcomes? Which population characteristics affect the relative effectiveness of different integration models? Answering these questions requires empirical work that accurately captures clinical and operating considerations.

4.2. Digitization and Connected Health

Digitization is fundamentally changing how healthcare is delivered and this change in itself provides a very rich and exciting research context for operations management scholars. At the same time, digitization provides a step-change in our ability to do empirical research as modern electronic medical records offer incredibly granular maps of care processes at the patient level.

The digital revolution in healthcare is changing clinical workflows. The ward, where paper notes and patients were traditionally collocated, is no longer the natural adjourning location for physicians, who shift their time from the bedside to computer screens. This reduction of face-to-face contacts between clinicians and their patients comes with challenges. As operations management scholars, we are well equipped to study these work patterns.

Technology also allows providers to track their patients who are currently not in the hospital. Patients make decisions related to diet, exercise regimen, or medication adherence without the involvement of care providers at times when they are unconnected to the healthcare system. The nascent field of Connected Healthcare is concerned with designing care processes that take advantage of technologies such as connected scales, pill bottles, glucose meters, wearable devices, and even implantable devices to "hover over" patients during the time when they are not in the hospital. The advent of connected health also enables the delivery of care in non-institutional settings, such as the patient's home or long-term care facility more conveniently and cost-effectively.

More connections, however, do not automatically translate into better care. Providers are already busy with their traditional duties of helping the patients they see in the clinics. When in the future they will receive countless emails and message alerts from their patients outside the clinic, workflows and operations have to be redesigned. Bavafa et al. (2018) show that when patients have easy email connections to their provider, system productivity is decreased rather than increased. This creates a "productivity paradox" of information technology investments that deserves further attention.

4.3. Scientific Breakthroughs: Precision Medicine and Personalized Medicine

At present, it is difficult for doctors to predict which treatment will be best for a specific patient at a specific time. Available evidence is based on average treatment effects on narrowly defined clinical endpoints in randomized control trials across large patient samples satisfying a specific range of inclusion criteria. The treatment is known to improve specific measures more often than not in this defined population, but is not known if the treatment is the best one for the patient at hand.

Precision medicine, sometimes also referred to as personalized medicine, replaces the traditional "one-size-fits-all" approach of disease management by a more targeted approach, based on the use of data and prediction technologies that advise doctors which medical treatment will be safe and effective for an individual patient, based on patient-level information, including genetic, epigenomic, clinical and non-clinical information.

Precision medicine is not a panacea and predictions will remain imperfect. The value of that imperfect information will depend on how the technology is integrated into the complex healthcare service delivery system. Operations management scholars are well placed to help the medical community understand how to customize care delivery by integrating prediction technology into complex healthcare service systems and combine the predictive power of analytics with patient preferences to achieve more satisfying outcomes for patients.

5. Conclusion and Call to Action

The complexity of healthcare operations attracts scholars with diverse interests who cover a wide spectrum of research projects, drawing on the full range of research in management, economics and, not least, medicine. But at the same time, this diversity provides a challenge because it can lead to fragmentation of scholarship, making our impact as a field difficult. What can be done to leverage the diversity, avoid fragmentation and create impact with our research? We propose three remedies.

First, to impact healthcare services with our research, we need to follow the lead of medical journals and publish papers that are accessible to a wide academic and non-academic audience. The most impactful medical journals publish short and focused papers written for an educated non-specialist audience. These journals achieve their impact by separating the assessment of a paper's rigor (the referees' job) from the paper's story. While the published paper focuses on communicating the story, the detailed material that is necessary for an in-depth assessment of the rigor and strength of the evidence is provided in an appendix or an online supplement. If we want people in the industry to act on our insights and implement change, we need to change our publication habits and align them with the leading medical journals.

Second, we need to complement the predominant retrospective observational studies with carefully designed prospective field studies, where research teams implement research findings in practice and then observe outcomes and assess impact. When conducting retrospective studies used on archival data, we need to continue with careful research designs that employ appropriate identification strategies for establishing causality.

Third, like medicine, we need regular systematic reviews to organize and summarize the state of knowledge of healthcare operations. These reviews should focus on specific topics and should be written by a group of academic and practitioner experts with a view of facilitating evidence-based practice. Notably, reviews should incorporate not only the operations management literature but all relevant literature published in medical journals and other cognate fields, such as organizational behavior or economics. We must find space for such reviews in our leading journals.

While the field of healthcare operations is still nascent, a lot of excellent research has been produced over the past decade. A vibrant and expanding community of young operations scholars is beginning to identify with the emerging field and committed to developing knowledge that helps the world deal with the immense challenges of aging populations and rising healthcare costs. This is a golden age for healthcare operations scholars and a great opportunity to make a significant impact with our research.

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