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GOVERNMENT + HEALTH

Health IT Workflow Automation

BACKGROUND REPORT

Industry Lessons for Health Care

Prepared by Clinovations Government + Health (CGH) for the Office of the National Coordinator for Health Information Technology

Contract No.: HHSP233201600030I/75P00119F37001

July 29, 2020

The Office of the National Coordinator for Health Information Technology

Acknowledgements

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The authors also wish to thank Teresa Zayas Cabán, PhD and Donald Rucker, MD for their driving leadership and contributions to this project.

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Executive Summary

Inefficient health care workflows are a pervasive problem that affects providers and patients. However, the increased availability of health information technology (IT) tools and systems provides opportunities to streamline workflow through automation. Technology advancements offer new possibilities to support more efficient workflows in health care delivery and related activities, such as reimbursement, care management, and population health. Non-health sectors that broadly use automation may offer key insights into how health care processes can be automated effectively.

This report is produced for the Office of the National Coordinator for Health Information Technology (ONC) in an effort to better understand how automation facilitators and obstacles in different industries can offer examples and lessons learned to improve the quality, efficiency, and delivery of health care. This report summarizes key findings from a literature search and expert interviews to facilitate exploration of workflow automation opportunities. Key findings are grouped into *people*, *process*, and *technology* aspects and include:

Opportunities for Automation. It is critical to appropriately identify workflows that can be automated, including *what* can be automated and *why*. Workflow selection is an important component of identifying and prioritizing opportunities for automation. Findings from the literature suggested selection is typically based on the following aspects:

- People: Degree of human intervention required
- Process: Repetition of simple tasks with clear roles and responsibilities
- Technology: Tools to support a range of workflows for full or partial automation

Approaches to Automation. After determining what workflow to automate, approaches to automation found in the literature involve these steps:

- People
  - Document the roles and responsibilities of those participating in and impacted by workflow
  - Engage those involved in workflows to garner support and participation as workflows to be automated are identified, redesigned, and implemented
- Process
  - Workflow documentation: Map current-state workflow
  - Workflow analysis: Identify constraints, dependencies, information needs, and resources
  - Workflow redesign: Design new future-state automated workflows
  - Training: Create stakeholder-specific training on responsibilities and roles

- Technology
  - Identify available technologies suitable for the workflow to be automated
  - Ensure seamless interactions with other technologies across the organization

Implementing automation can also include a pilot process to automate some workflows, then applying lessons learned to broader workflow automation, in addition to performing continuous improvement activities.

Barriers and Facilitators to Automation. Barriers and facilitators to automation found in the literature search include elements related to the people involved in a given workflow, how workflows occur and interrelate within an organization, and the technology used. Common steps across industries can facilitate automation and include:

- People
  - Obtain input and ongoing feedback from those who perform workflows and are impacted by them
  - Train and re-train those who perform redesigned workflows
  - Anticipate and understand potential changes to roles and responsibilities
  - Ensure leadership support for workflow automation
- Process
  - Identify and anticipate how workflows interplay
  - Understand the role of silos across organizations
- Technology
  - Design precise alignment between technology and process
  - Promote interoperability and information sharing
  - Develop, manage, and maintain a technical infrastructure

Based on the literature search and expert interviews conducted, workflows suitable for automation are repetitive, require manual data entry, occur with high frequency, have clearly defined independent and dependent variables, and have defined roles and responsibilities. Generally, efforts to automate health care workflows have concentrated on streamlining billing, scheduling, and patient throughput. Other areas related to clinical decision making, clinical encounters and hospital stays, patient-provider interaction, population health, and safety and surveillance have experienced some, but not yet widespread, levels of automation that could generate a substantial impact on improving quality and safety of health care and reducing clinician burden.

Introduction

Across industries, automation has pushed and been accelerated by rapid technology advancement,[1, 2, 3, 4, 5, 6] expanding computing power,[7] and democratized access to information.[8] Automation has increased productivity and catalyzed the emergence of new services and products.

The public has become accustomed to many forms of automation, from the introduction of the manufacturing assembly line to appreciation for the convenience of automated banking processes.[10] In other emerging areas, such as the development of ride sharing applications (apps) and predictive analytics that personalize the consumer experience in transportation, entertainment, and hospitality, automation has been met with a mix of excitement and hesitation.

Automation is "the creation and application of technology to monitor and control the delivery of products and services."[11] It involves a number of technologies that span a variety of functions. Automation holds tremendous potential to drive efficiency in health care delivery in the United States (US), where clinical and administrative workflows are burdened by manual, repetitive tasks.

Workflow

Workflow is defined as, "the sequence of physical and mental tasks performed by various people within and between work environments."[9]

Health care delivery involves a series of interconnected clinical, administrative, and population-level workflows that occur before, during, and after a patient encounter.

INTERNET CONNECTIVITY EXPANDING ACROSS INDUSTRIES

Connectivity and democratized access to information have created the ability to obtain and use raw data to identify opportunities for improvement in the execution of business processes and delivery of services. Significant advancements in technological and digitization capabilities, alongside the emergence of the concepts of "Industry 4.0" and "Internet of Things" (IoT) support automation initiatives in a wide range of industries, including health care.[12]

Described as "the next phase in the digitization of the manufacturing sector," the concept of Industry 4.0 evolved in manufacturing and other industries. Industry 4.0 is driven by a combination of big data, advanced analytics, business intelligence capabilities, improved human-machine interfaces, and digital-to-physical transfer capabilities.[13] The connectivity advanced by Industry 4.0 holds great promise and continued application across a variety of industries.[13] In the health arena, widespread digitization of health information has the potential to identify and accelerate efficiencies by automating workflows to eliminate manual, redundant, and labor-intensive tasks. Together, these factors create opportunities to improve workflow and reduce labor-intensive tasks across clinical, administrative, and population-level workflows.

IoT emerged as a concept that describes connecting anything that can be connected and streamlining processes for personal and commercial betterment. For the health care industry, IoT has enabled the digital interconnection of devices ranging from ultrasounds and electrocardiograms to glucose monitors and smart medication dispensers to self-adjusting smart beds.[12] The global internet of medical things (Iommi) market – including platforms for delivering a multitude of cloud-based health care services – is expected to almost quadruple from $41 billion in 2017 to $158 billion in 2022.[14]

Industry 4.0

Rapid and widespread digitization across industries, based on dramatic increases in the availability of data, computational power, and connectivity in parallel to innovations in analytics and business-intelligence capabilities and technology that facilitates human-machine interaction.[13]

Internet of Things (IoT)

Movement to advance every-day device connectivity, via the internet, to form a system and network of linked and coordinated devices that send and receive data for efficiency gains.[12, 14]

Workflows Automation Spotlight on the Aviation Industry

Automation across several industries has contributed to increases in efficiency, improved safety, creation of new services and products, and enhanced value for consumers. The aviation industry's experience with automation illustrates these gains, as well as its challenges, in reaction to evolving competition, regulation, consumer expectations, and machinery and technology advancements.

Researchers studying the aviation industry have correlated its evolution with the Industrial Revolution stages, from Industry 1.0 to Industry 4.0. Automation started with visualization tools to overcome initial difficulties to build and fly a plane (Aviation 1.0). Next, it advanced to using technical analog signals to help fly planes with poor visibility and stability due to weather, as well as navigate with other planes in the same airspace (Aviation 2.0). With the introduction of more tools sending more data to pilots, digital data processing and communication automation emerged to ensure pilots could make informed decisions (Aviation 3.0). The advent of Aviation 4.0 has led the aviation industry to investigate artificial intelligence (AI) and other automation methods to explore autonomous controls. Given the importance of preventing accidents, the industry continues to investigate the spectrum of partial to full automation that relieves burden, yet preserves an appropriate degree of direct pilot control of a plane.

There are several stakeholders in the aviation field, including passengers, pilots, flight crews, schedulers, and ground and air traffic control personnel. Aviation and health care stakeholders face similar motivators and constraints that create a need for carefully designed automated workflows; some are briefly profiled below.

- Pilots and clinicians interact with a multitude of technologies and devices in their working environments to ensure safety, and they are often in the position of making quick decisions based on information generated and displayed by those technologies. While automation can reduce the burden for pilots and clinicians, the serious consequences of error – from humans or automation design – create an imperative to carefully balance full and partial automation.
- Airline companies and health care delivery organizations both face strong competition and look to automation to streamline operations and to enhance customer contact, which spans scheduling and booking, to the experience of a flight or health encounter. Airlines and health delivery organizations also deploy automation to provide safe working conditions and maintain morale across the range of teams and personnel.
- Scheduling and managing flights and crew rotations requires the automation to be flexible and adaptive to uncertainty due to factors such as plane capacity, connection times, and weather. Similarly, scheduling and managing health care appointments and procedures requires systems to take into account factors such as resources (available people, space, equipment), patient readiness (data gathered on prior tests and completion of prior authorization), and human behavior (missed, delayed, or cancelled appointments and walk-ins).

While not exhaustive, this high-level overview offers some insight into one field's experience with automation in pursuit of efficiency and value. The aviation industry continues to innovate with workflow automation approaches and determine how to apply partial and full automation, while delivering safe, efficient, high value, and people-centric services.

HEALTH IT ADOPTION GAINS TRANSLATE TO AUTOMATION OPPORTUNITIES

Health IT tools and systems have expanded into almost every aspect of health care delivery and dramatically altered health care administration and clinical practice. Although the increased adoption and use of health IT has created opportunities to more effectively leverage data and knowledge for care delivery, inefficient workflows in health care remain.[15] In addition, accounts in the popular press and peer-reviewed literature note electronic health record (EHR) usability issues and the unintended consequences of using health IT, including its contribution to inefficient workflows,[16, 17] provider burnout,[18, 19, 20, 21] and additional staffing requirements.[22] These issues highlight the need to automate workflows through the use of health IT in a manner that does not increase burden and burnout associated with documentation requirements.

As an important step toward maximizing the promise of health IT, this report seeks to better understand ways in which automation may be able to better support clinical and administrative workflows within health IT. Automation, which supports or replaces manual work with machines or computers, may help improve performance in health care. Automation can fully replace manual tasks so that they are done without human intervention, or tasks within a workflow might be partially automated using some human intervention or oversight. [23, 24, 25]

In summary, increasing digitization of health information, democratized access to digitized health information, and significant advancements in technological and digitization capabilities have created opportunities to identify and accelerate efficiencies in health care. Efforts to automate workflow through the use of health IT tools and systems should be undertaken with care to avoid unintentional increases in burden and burnout.

PURPOSE OF THIS REPORT

This report provides an analysis of current approaches in workflow automation across industries and discusses possible implications for automation of health care delivery workflows, inclusive of clinical, administrative, and population-level processes. It synthesizes evidence across targeted, peer-reviewed, and unpublished literature and references findings from expert interviews conducted in late 2019. While not exhaustive, report findings are relevant to understanding how to meet the promise of automation using health IT and, more specifically, guide their efforts as they identify and prioritize health care workflows that would most benefit from automation. This report presents information about automation fundamentals, as well as opportunities, approaches, and barriers and facilitators to automation. It concludes with examples of workflows to automate and considerations for automating workflows in health care.

Methods

LITERATURE SEARCH

The field of automation is in constant evolution, so this report is based on reviewing and synthesizing literature published in the last five years. The targeted scan of resources about automation included findings within and outside of health care from peer-reviewed journals, gray literature; issue briefs, government reports, conference proceedings and presentations, and web-based materials. Sources were limited to those published in English. A list of keywords most relevant to address the topic at hand was developed by a team of experts in health care informatics, library sciences, industrial engineering, and usability. Librarians conducted searches, and relevant articles were reviewed and analyzed. The gray or unpublished literature also included colloquial terms related to the keywords. This targeted review of resources around a specific area of focus is not an exhaustive search of the topic.

Table 1: Databases and keywords for literature review (2014-2019)

Published literature: • PubMed • Google Scholar • CINAHL • Cochrane Central Library • Business Source Corporate • Web of Science • PsycINFO • Library, Information Science and Technology Abstracts (LISTA)	**Addressing automation:** • (workflow* OR "work flow*" OR process OR processes OR (work* AND flow*)) AND automat* AND ("health IT" OR "health information technology*" OR healthcare OR "health care" OR "information system*" OR agriculture* OR "food production" OR transportation OR hospitality OR industry* OR business* OR "operations research" OR "industrial engineer*" OR "human factor*" OR ergonomic*)
Gray or unpublished literature: • Web searches based on the keywords and colloquial terms for the keywords • Search in the Cochrane Central library and Web of Science	Addressing the desire to focus on findings that feature successful automation: • success* OR solution* OR "case study" OR "case studies" OR evaluate* OR review*

Articles were screened for appropriateness and 123 were relevant for inclusion based on the focus of this project. Excluded articles did not have workflow as a central focus or were primarily focused on technology. Web-based sources were screened in a similar manner. Literature reviewed spanned a variety of disciplines and industries within and beyond health care.

To characterize the literature that was reviewed for this background report, two subject matter experts in health informatics used the Higher Education Statistics Agency (HESA) JACS 3.0 Principal subject code[26] list (highest level) to organize and count representation across disciplines. The HESA JACS codes

represent an open source higher education of higher education information for data users. The results of this are included in Table 2. Each resource was reviewed by at least one analyst. Review included extracting key points from each resource and identifying themes across resources. Project analysts also categorized specific findings from the literature as predominantly issues of *people*, *process,* or *technology.*[27] The team met regularly to discuss findings, resolve any differences in perspectives, and refine key points.

Table 2: Mapping of included literature to disciplines based on the JACS 3.0 Principal Subject Code

JACS Area	Count of Articles
Medicine and dentistry	19
Subjects allied to medicine	21
Biological sciences	7
Agriculture and related subjects	2
Computer science	35
Engineering and technology	20
Architecture, building, and planning	1
Social studies	1
Business and administrative studies	13
Mass communications and documentation	3
Education	1
TOTAL	**123**

EXPERT INTERVIEWS

This report also contains insights obtained from interviews with experts across industries and disciplines. The applied experience and/or expertise in automation of these experts made them well-suited to provide robust insight into workflow automation and its potential application to health care.

One-hour long interviews with the participants listed in the Appendix occurred between November and December 2019 and focused on the following topics:

- Automation trends in industries outside health care that may be relevant to health care
- Lessons learned from automation in industries other than health care
- Methods for evaluating the effects of workflow automation
- Workflows or processes within health care that could benefit from automation

Findings

Automation streamlines workflows for humans across industries. The literature search revealed well known automation examples in fields such as manufacturing and finance, as well as less well known and emerging examples in industries such as hospitality. While early waves of automation were characterized by the use of machines to speed the production and distribution of goods, innovation in automation now harnesses internet connectivity and data to automate more complex workflows and enhance the consumer experience with services.

The industries explored in the literature search pursue opportunities for automation based on the workflow to be automated and the degree of automation desired. A spectrum of automation ranges from low degrees, where humans remain involved to a large extent, to semi- and fully-automated workflows with little or no human involvement. Automation approaches implemented by industries other than health care offer lessons on applying automation to people, process, and technology with the aim of increasing efficiency and improving care.

OPPORTUNITIES FOR AUTOMATION

Automation Drivers

Although specific definitions and uses of automation vary across industries, automation has common goals. The degree to which automation can be accomplished is based in part on whether the industry is service- or production-based and how long an industry has used automation. Organizations pursue automation to save time, improve productivity, and enhance quality.[12]

> "Start with saving time first. If you save time, you will reduce burnout. Instead of spending 25 minutes [on administrative work], I could be spending more time with the patient."
>
> **— Dr. Randi Abramson, a practicing physician at a federally qualified health center**

Experts interviewed reiterated findings from the literature, noting that automation is pursued to improve efficiency, reduce costs, improve safety, and improve outcomes and benefits for humans. Experts noted that the motivation to innovate can drive automation and play a role in bringing new products and services to market. Entrepreneur Thomas Goetz developed an app to facilitate patient self-reported data on conditions monitored by physicians and explained the vision to enhance the care process for providers and patients: "We didn't think about it [automation] as 'what can we automate.' More so, we asked, where is there a gap or inefficiency in care?"

Although organizations that automate processes intend to make gains, they do not always achieve their goals.[28, 29] Reasons for automation failures include selection of processes unsuitable for automation, a mismatch between processes and technology, and inattention to organizational aspects of

implementation.[15] Experts interviewed articulated how, at times, the goals or drivers behind workflow automation differ – or even conflict – across stakeholders. For example, experts highlighted how workflow automation initiatives across industries such as manufacturing, hospitality, food production, and health care have allowed labor to shift into roles with less redundant tasks or take on different skillsets, but also be replaced with technology or machinery. In addition to this finding from the literature, experts interviewed spoke about the importance of using participatory, multi-disciplinary approaches to identify the stakeholders involved in a given workflow as well as the stakeholders' automation goals.

A vast range of industries use automation. Some, such as manufacturing, banking, and finance, have well-known uses of automation that the public has become accustomed to through exposure and frequent use.[30] Other industries have increasingly adopted automation into their business model as technology has evolved. For example, the legal consultation field uses predictive coding to search related case law, and the hospitality industry uses automation for personalizing hotel and entertainment experiences, managing housekeeping staffing and operations, and capacity analysis.[31, 32] Other industries have made automation central to their business model, such as ride hailing services (Uber, Lyft).[33]

Workflows for which automation has been used vary across industries. Some workflow automations were identified by literature and expert interviews as examples of automations that are now widely implemented because they save time, improve productivity, or enhance quality. Workflows for which automation has been successfully implemented include:

- Accounting functions, such as managing accounts payable and accounts receivable and tracking payments that have been received and are outstanding[34]
- Document routing based on information contained (or missing) in a document and where the document needs to go next for review[35]
- Allocating work to staff based on the task at hand, time required, complexity of the staff, and available resources, including people and physical resources[36, 37]
- Collecting data, such as completing forms, with standard data or processing information requests[38, 39]
- Physical and chemical processes, such as water treatment/desalination based on modeling in a water treatment plant[40, 41, 42]
- Biologic and laboratory pre-analytic and post-analytic activities, such as specimen or sequencing preparation[43, 44, 45, 46, 47]
- Medication dispensing and delivery, such as automated medication cabinets and pill counting[48, 49, 50, 51]

> "Consider automating workflows that are more likely to succeed: particularly reducing burden, making patients safer, and making it easier to clinicians to provide care. Technology adoption models show that these will be easier to get adopted."
>
> **— James Benneyan, professor of mechanical and industrial engineering**

- Monitoring and control, such as production auditing and quality assurance processes with alerts for human intervention based on exceptions[39, 52, 53, 54, 55, 56, 57, 58]
- Running automated reports across systems for display or review, such as population of dashboards[1] involving development of reports, identification of exceptions, and analytics[59, 60, 61, 62]
- Developing reports for human intervention with exceptions highlighted for targeted manual intervention[63]
- Supply chain management, including inventory control and supply tracking[28, 64, 65]
- Resource allocation to review demands and needs and automatically routing resources, such as people or supplies[48]

Selecting Workflows to Automate

Achieving automation goals requires selecting the appropriate workflow to automate. Findings from the literature revealed common factors for identifying workflow opportunities: characteristics of the workflow at hand, organizational environment, and technical considerations.[4]

Tasks within workflows suitable for automation typically include these characteristics:[66, 67, 68]

- Involve manual data entry
- Occur with high frequency and/or repetition
- Use clearly defined independent and dependent variables for modeling
- Have clear roles and responsibilities

For example, in the state of Maryland, Howard County officials sought to automate the process for managing citizen requests.[69] To determine which requests could receive an automated response, county officials reviewed data about previous requests. The review included identifying requests that occurred at a high volume, the degree of time and effort needed to resolve the requests, and tasks that involved consistent action by the same stakeholders for resolution. This approach to selecting workflows to automate yielded increased productivity and reduced response time.[69] Similarly, hospital administrators analyzed billing workflows to identify candidates for automation based on volume, repetition, and need for human automation. Selected workflows for coding, billing, coverage decisions, and rebilling were automated, allowing staff to focus their efforts on outliers or more complicated finance tasks.[70]

Not all workflows are suitable for automation. Several workflow characteristics make automation more difficult.[1, 7, 34, 35, 36, 44, 51, 71, 72, 73] Such workflows:

- Involve tacit knowledge that is difficult to explicate to develop clear and consistent decision-rules that support automation
- Have decision points within the workflow with complex decision-rules that are not consistently followed and require human intervention

- Include inconsistent data requirements that force human intervention to support decision-making at crucial points in the workflows
- Use independent and dependent variables that that influence decision-making within a workflow, but are not consistent for modeling
- Involve inconsistent or unclear roles and responsibilities requiring that stakeholders consult each other during crucial pieces in the workflow
- Deviate from "ideal" workflows in practice, such that automated workflows cannot accommodate deviations from ideal workflows without human intervention

Many health care workflows have the characteristics described above, making automation challenging. The experts interviewed discussed the importance of using participatory, multi-disciplinary approaches to identify automation opportunities that support the goals of automation and avoid automating workflows that do not operate efficiently.

> "The last thing you want to do is automate a process that has terrible workflow."
>
> **— Patricia Gabow, former health care executive**

While noting the importance of drawing insight from disciplines other than health care, experts interviewed also identified the characteristics that differentiate health care from other industries. In contrast to industries such as manufacturing and food production, experts emphasized that "patients aren't parts" and noted that health care providers, consumers, and other actors contribute to a "co-produced service" involving coordination, communication, and commitment to an intended health goal or status. Because the provider-patient relationship is at the center of the human experience of care delivery, experts interviewed underscored the importance of selecting workflows to automate that create and maintain trust in the humans and the technology involved.

Experts noted that variability in health care delivery across specialties, practices, and regions creates substantial challenges to standardizing processes across individuals and organizations. The distributed and non-standardized infrastructure of health care delivery organizations – including their personnel structure and technology adoption across regions, states, and national levels – makes workflow automation difficult to standardize and implement. Moreover, health outcomes are dependent on several other factors beyond health care delivery, such as social determinants of health and the environment.

In addition, experts observed that the complexity of underlying data and standards to describe and share health information requires sophisticated technology and human resources for the technical task of configuring automation. For example, provider organizations deploy significant resources to map national code structures for diagnoses, medications, allergy types, and procedures to the local codes embedded in their health information systems.

Experts noted that the scale of operations for industries with international scope for their products and services necessitates automation. In contrast, health care delivery in the US generally does not compete

internationally. This may limit the overall demand for health care automation compared to industries operating at a global scale.

Automation Continuum

Workflow automation occurs on a continuum of fully manual to fully automated workflows. Thus, selecting workflows for automation does not necessarily mean that workflows will be fully automated. Fully automated workflows do not require human intervention and typically require rote manual work. For example, one laboratory was able to fully automate processing for standard liquid-based procedures[46] because the processing followed the same sequence and had simple decision-rules. Sometimes workflows can be automated to some degree, but still require human intervention.[73, 74] These are referred to as semi-automated- or human-in-the-loop workflows.[75] One example of a semi-automated workflow is automatically generating a dashboard that must be reviewed by humans for decision-making. This means that data are automatically incorporated and calculations for the dashboard are made without human intervention, and a human must review for decision-making. One laboratory automatically generates a report of pending results, but the results must be manually released after a quality-control process.[47]

The degree of automation is linked to the complexity of a task and the sophistication of technology required to automate the task. In one semiconductor manufacturing plant, workflows across the production line were reviewed to determine which could be fully automated, semi-automated, or should remain manual.[76] Decisions about which workflows to automate at full- and partial levels were based on the complexity of the workflow, the frequency of occurrence, and the turnaround time required to support production.

Curating resources for biological databases requires document triage and information extraction, which is a highly manual process. With automated text mining, librarians can triage resources by reviewing reports from text and only manually review a fraction of the records done previously.[77]

Experts interviewed explained that partial automation with a human-in-the-loop is usually employed where an external factor creates variation and unpredictability. For example, bus or flight schedules can be “hardwired” to automatically adjust and reschedule when interruptions occur, potentially due to inclement weather, heavy traffic, “people issues” (i.e., variability from the predicted pattern of passengers, drivers/pilots, crew), and mechanical or supply delays.

> “Good flight schedules aren’t optimized assuming everything will work perfectly as scheduled, in a perfect no-variation world. Instead, they are optimized in automated scheduling routines so there is enough flexibility in terms of a plane’s capacity and connection times. In the real world, variability happens, but the flight schedules still work because of this. In health care, we tend to think deterministically. To "algorithmize" or automate some aspects of health care, instead, we need to move to tolerant automation, or a robust automation, which responds to the day-to-day chaos.”
>
> **— James Benneyan, professor of mechanical and industrial engineering**

Human-in-the-loop tasks vary by the degree of complexity of the task, types of decision-rules involved for the workflow, and human intervention needed.[78, 79, 80, 81] One human factors expert reflected that it is a

"fallacy" to equate automation with no degree of human involvement. Experts emphasized that humans are involved when they design, implement, and use the output of fully or near-fully automated systems.

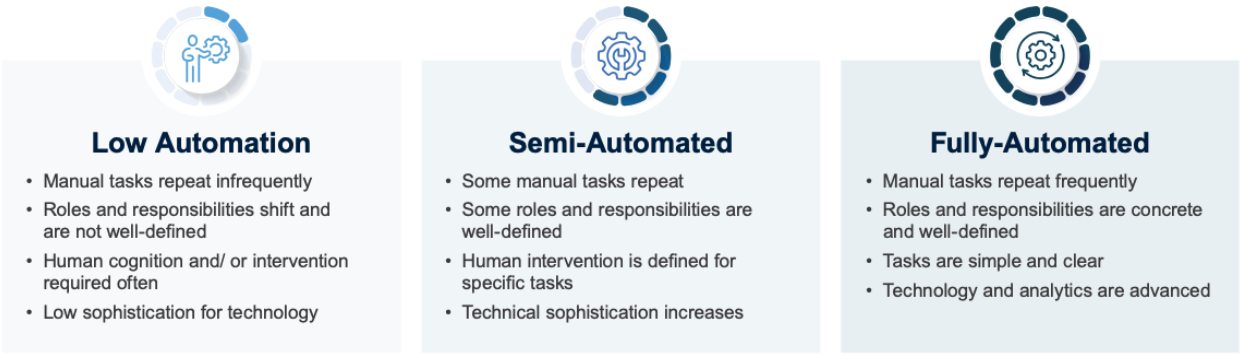
For human-in-the-loop approaches, the experts reiterated the consumer safety aspects of health care where the impact of poorly designed automation and/or human error could pose a risk to patient health and safety. While experts interviewed noted risks to automation, they characterized them as considerations to carefully evaluate and thoroughly understand when designing automation. Rather than dismiss automation broadly for health care, experts commonly provided the suggestions to 1) be very specific on the conditions and specialties suitable for automation, and those that should be excluded; 2) pinpoint the degree of risk tolerated by stakeholders involved; and 3) begin with less challenging workflows with scalability.

Technology to Support Automation Across the Continuum

A number of technologies support workflow automation across the automation continuum. The complexity of the existing workflow influences technology needed for automation. Organizations have a number of interrelated information systems with associated workflows that influence the degree of automation that is possible. Interviewed experts in engineering fields characterized workflow as a set of interrelated, sequenced tasks that may have constraints or variation depending on the output from interrelated workflows, the conditions in which the workflow occurs, and sequence of tasks in the workflow. They explained that automation must take into account how workflows interact, or are integrated, with other workflows.

Figure 1 outlines the relationship between technology and automation, where, as workflows to be automated are more complicated, more technology sophistication is needed.

Figure 1:Technology Sophistication Across the Automation Spectrum



Technology capabilities and characteristics that advance across the continuum of automation include:

- Number and type of systems housing relevant data to support workflows[17, 69, 82]
- Interoperability between systems in which relevant data are stored across types and formats[17, 69, 82, 83, 84]
- Technical infrastructure, including cloud-based capabilities, analytics, and computing power[73, 85, 86, 87, 88]
- Data visualization capabilities available for dashboards and other visual representations of data [37, 47, 84]
- Complexity of decision-rules required[24, 73, 89]
- Communication and networking considerations, such as bandwidth[2]
- Integration of automated workflow with other organizational information systems[87, 88, 90]
- Security considerations within and across systems[90]

To illustrate the interaction of workflows and processes, one industrial and systems engineer provided an example of a procedure scheduled after specific clinical criteria are analyzed. Appointment-making and clinical analyses processes must interact for a properly scheduled procedure to occur. To highlight the need for such interaction, the expert said, "The day before surgery, the hospital will discover that the patient is not ready for surgery because the patient doesn't have insurance or certain tests have not been completed. How can a hospital have both [wait times] and under-utilization at the same time? Why isn't that done by a computer?"

Several experts interviewed emphasized the contextual nature of workflows, where a process may vary depending on factors such as the people involved, timing, location, and technology. They emphasized the importance of identifying the contextual nature of workflows, particularly prior to automation.

> "You cannot take apart the action from the people and the place. You have to know who performed the action, the workstation used and whether it was located within the patient's room or in the hallway. Automation in a de-contextualized…fashion would be flawed."
>
> **-— Brian Pentland, professor of organizational routines**

In summary, opportunities for automation emerge from drivers common across industries, including improving efficiency, productivity, safety, and quality. Workflow characteristics that lend themselves to automation include replicability, complexity, frequency, and clarity of roles and responsibilities of those involved. Certain characteristics make some workflows less suitable to automate. These include, but are not limited to, workflows involving complex decision rules and inconsistent data requirements requiring human intervention, as well as workflows where human roles and responsibilities are unclear. Automation opportunities and the technologies to support them are on a continuum from fully automated to semi-automated to fully manual. Lastly, health care has unique underlying attributes that create automation challenges, including the importance of preserving the patient-provider relationship; variability in health care delivery across specialties, practices, and regions; and the role played by social determinants of health and the environment in health outcomes.

AUTOMATION APPROACHES

People, Process, and Technology Aspects

Once workflows to be automated have been selected, the next step is to develop the approach to do so. Workflow automation involves organizational changes that impact people, processes, and technologies.[27] It is important to understand who is involved in workflows, their needs, and how automation might change their work. Processes include tasks conducted, how they are completed, and how workflows relate to the overall organizational structure. Technologies are the tools used to support automation. These aspects must be addressed when approaching workflow automation.

People

People-related aspects most mentioned in the literature include identifying roles and responsibilities and how they might change with automation, and engaging those involved in workflows being considered for automation. Engaging people includes identifying those involved in and affected by workflows and including them in efforts to support workflow automation. Engaging stakeholders includes understanding their needs and asking them to review proposed workflows. In aerospace engineering, successful automation of manufacturing workflows involved asking stakeholders to review proposed workflows and incorporating their feedback before implementing automated workflows.[23] As workflow automation is implemented, stakeholder training can help ensure that staff are prepared for workflow changes. This includes identifying training needs, developing a plan, and executing the plan. As workflows are implemented, stakeholder needs might change.[35]

Process

The process aspect of workflow automation involves understanding how work will change with workflow automation. Although not explicitly stated throughout the literature, many studies used a human factors approach to address process aspects, which involves "understanding of interactions among humans and other elements of a system … that applies theory, principles, data, and other methods to design in order to optimize human well-being and overall system performance."[91] Common features of examples in the literature include documenting and mapping current workflows and analyzing them to identify opportunities for improvement that can be addressed through automation. Documenting and mapping current workflows includes reviewing current workflows and their artifacts. Data inputs include observations, event logs, and interviews with stakeholders. The output is generally a process map of a workflow.[23, 92, 93, 94]

Analyzing workflows involves reviewing current workflow to understand how tasks are performed and by whom, resources required, constraints, and dependencies. Workflow dependencies can include technical, infrastructure, sequencing, and staffing components.[6, 29, 95, 96, 97, 98, 99, 100, 101, 102] The purpose of analysis is to more fully understand workflows to optimize them. Analysis also involves identifying places where duplicate work, delays, or other inefficiencies may occur.

Redesign to support implementation includes identifying changes that need to be made to promote automation, such as to physical and technical infrastructure.[65, 72, 76, 87, 88, 96, 98, 99, 103, 104, 105, 106, 107, 108, 109, 110,

[111, 112, 113] Redesigned workflows also include the degree to which automation is appropriate and/or when human intervention might be indicated.[114] For example, in a food manufacturing and packaging plant, redesign included fully-automated and semi-automated workflows in the plant.[103] Similarly, when automating social-media marketing management, workflow redesign involved identifying places where workflows intersected. Some of the redesigned workflows were fully-automated; some were semi-automated. The semi-automated workflows had clearly defined points for human intervention.[74] Workflow redesign includes identifying roles needed at different points in the workflow to optimize the workforce.[104] Thus, higher-level staff can be reserved for more complicated functions. Redesigning workflows that cannot be clearly delineated are a challenge for mapping.[93] Elucidating workflows is also important when identifying the interplay between workflows and IT systems, particularly with design.[115]

When redesigning workflows, changes that accommodate new or modified workflows must be considered. These include possible changes to physical and technical infrastructure.[85, 101, 116] For example, when automating the assembly process of motorcycles, organizational leaders worked with stakeholders to document current workflows and elicited stakeholder input to identify candidate workflows to automate. Then they analyzed the workflows, engaged stakeholders to identify areas of improvement, optimized workflows, trained staff, and implemented. As part of redesign, some physical changes to the production line needed to be made. They found that they were able to maintain productivity goals while reducing labor costs and improving the rigor of quality control processes.[92]

Support for automated workflows and continuous quality improvement were noted across studies. Pre- and post-implementation support includes sufficient resources, leadership support, and technical support. [4, 9, 1134]

Technology

A number of technologies support workflow automation. The literature pointed to several technologies used individually or in tandem for workflow automation. Some features of technology selection include characteristics of the workflows being automated, information needed for workflows, technology availability, and other types of information available in the organization that are needed for workflow automation.[2, 25] For example, when automating manufacturing in a paper mill, organizational leaders used a combination of computing, wireless sensors, and cloud-based technologies to gather information from across the paper mill to support workflow automation.[2]

Table 3 outlines several types of technologies referenced in the literature. This is not an exhaustive list of technologies and, as computing power and functionality improves, technologies will advance.

Table 3: Technologies with associated definitions and illustrative examples

Technology	Definition	Use Example
Artificial intelligence	"The science and engineering of making intelligent machines, especially intelligent computer programs. It is related to the similar task of using computers to understand human intelligence."[116]	Automated analysis of videos based on objects and activities occurring in a video promoting smarter computerized vision[117]
Big data analytics	"A research field encompassing analysis of large amounts of data." The spectrum of big data analytics mainly includes data mining, machine learning, data science and systems, artificial intelligence, distributed computing and systems, and cloud computing.[118]	Analytics automating a chemical safety assessment processes in a laboratory setting[42]
Machine learning	"Machine learning is the study of computer algorithms that improve automatically through experience."[119]	Machine learning in a business office automating front-office tasks such as activity tracking and employee guidance[120]
Natural language processing	"Natural Language Processing is a theoretically motivated range of computational techniques for analyzing and representing naturally occurring texts at one or more levels of linguistic analysis for the purpose of achieving human-like language processing for a range of tasks or applications."[121]	Initial scanning, processing, and routing of business documents to the correct department through a sequence of steps based on automated review of structure (layout) and content (optical character recognition, keyword detection)**Error! Bookmark not defined.**
Robotics	"Robotics is the study of robot technology that makes use of disciplines such as: dynamic system modeling and analysis, mathematics, physics, biology, mechanical engineering, electrical and electronic engineering, computer science and engineering and … sensors, control and actuators."[115]	Robotic process automation in a credit union automatically identifying and assigning work to different roles, sharing relevant documents, and providing notifications of next steps[35]
Wearable sensors	"Integrated into wearable objects or directly with the body in order to help monitor health and/or provide clinically relevant data for care."[25]	Smart-home sensors interacting with other systems to provide real-time actionable data about the status of a home[6]

Regardless of the technology used, the literature pointed to the importance of using a phased approach to implement technology to support automation. Several studies conducted a pilot project or employed a phased approach.[6, 37, 39, 99, 111, 122] This typically involved automating workflows on a small scale, reviewing the implementation experience, making adjustments, and then implementing on a wider basis. For example, in aerospace engineering, stakeholders identified a workflow to automate that was highly repetitive and manual. Organizational leaders reviewed the implementation, making adjustments before automating additional workflows.[23] After initial implementation, the manufacturer used continuous quality improvement methodologies to identify automation opportunities and refine automated workflows.

BARRIERS AND FACILITATORS TO AUTOMATION

Several barriers to and facilitators of successful automation efforts were identified across industries in the literature and from the interviews, and are summarized and categorized as predominantly issues of *people*, *process,* or *technology*. These typically interact to create an environment of resistance (barriers) or support (facilitators) for innovations in workflow automation.

Identified barriers limiting the development, adoption and use of workflow automation range widely and have varying impacts. Concerns about job security, loss of quality (in work products), or limited or little improvement in productivity can end automation projects before they begin. Issues of increased cost or effort from automating can slow automation development and adoption. Innovations in automation can also be limited by data consistency problems, concerns about logic complexity, and/or interoperability challenges.

Facilitators supporting the development, adoption and use of workflow automation include eliciting ideas for automation and engaging end-users throughout the process. Implementation of automation solutions invariably represents culture change and process redesign; these require significant support, adoption, and training of end users. For example, demonstrating how a process improvement can facilitate less data entry while improving skill and morale is likely to gain traction for adoption and be successfully used.

Barriers

Addressing User Concerns

> "There are concerns about being replaced. Automation should be about freeing people to do work at the top of their training and specialty instead of throwing [automation solutions] at them, which are intended to replace them."
>
> **— James Benneyan, professor of mechanical and industrial engineering**

Reasons that stakeholders across industries may be resistant to adopting some instances of automation identified in the literature include concerns about losing the ability to interact or losing access to information or decision-making authority.[51, 67, 76, 113, 123, 124, 125] Individuals may worry that their roles may be replaced by technology,[50, 52, 59, 101, 126, 127] their input is not valued,[76, 85, 92, 108, 125, 126, 128] their role is or may become unclear or ill-defined,[29, 52, 108, 126] or

that they lack adequate training to use new tools.[52, 85, 102, 129] In addition, individuals may feel that automated solutions represent a quality, safety, privacy, or security risk.[50, 55, 85, 92, 98, 99, 101, 130]

Taken together, these factors often result in lack of motivation to adopt an automated solution.[52, 126, 127] This can be especially complicated when a solution is perceived as insensitive to organizational culture, not adding value, not adequately addressing human factors considerations, or not having bottom-up and top-down support.[12, 29, 43, 50, 76, 85, 92, 101, 102, 108, 124, 126, 128, 129, 131]

Workflow Complexity

A perception exists that some workflows are too complex and sensitive to disturbance to be successfully automated.[23, 54, 64] This is caused, in part, by lack of definition, consistency, or agreement about existing workflows or the inability to effectively model, communicate, and build corresponding systems to support workflows.[7, 23, 34, 35, 57, 68, 87, 88, 93, 96, 97, 120, 123, 132, 133] These factors can lead to interruptions in workflow, unanticipated deviations, and unintended consequences.[23, 54, 82, 86, 123]

The literature also suggested that starting from a poorly modeled workflow results in a time- and cost-intensive workflow automation activity and culminates in execution of a bad process or workflow model; this affects quality, trust, and perception of change.[23, 28, 45, 57, 82, 133] Often, goal-setting and testing parameters are nonexistent or misaligned, resulting in a poor match between intent and end result.[72, 123] Additionally, some automated systems are inflexible or difficult to customize or modify over time,[85, 123] which can be a challenge as context changes. Experts interviewed also emphasized these points and cautioned that a workflow that does not operate efficiently should not be automated.

Integration and Interoperability

The process of integrating automation is also affected by lack of interoperability or poor integration of existing information systems and data.[6, 7, 10, 23, 57, 88, 117, 122, 134, 135] This is partly due to a lack of standards and gaps in training on the use and/or availability of software.[57, 61, 83, 111, 136, 137] The current environment of separate devices and systems combined with inconsistent, unclear, or poorly designed workflows makes the challenge of automation even greater.[30, 52, 80, 81, 91, 130, 138, 139]

Data can present varied barriers to automation efforts. The underlying data may be messy, rich, and diverse and can sometimes have inconsistent quality and availability.[10, 83, 85, 98, 108, 112, 117, 135] Workflows and associated data sharing may be accompanied by complex privacy and security restrictions or limitations, standards compliance issues, and format variability.[40, 57, 61, 83, 85, 90, 137] They are often accessed via disparate systems with poorly defined system architectures or limited use of standards.[6, 10, 40, 83, 88, 104, 117, 135, 136, 139]

An IT system solution may have a dedicated workflow that must be developed, marshaled, tested and then matched to the clinical workflow.[23, 117, 124, 131] With such complexity, solutions can be difficult to customize, localize, and scale.[69, 120, 133] Although many different variables are managed when IT systems are developed, human factors considerations are often overlooked or limited.[92, 108, 111, 124, 126, 128, 129, 133, 136]

Facilitators

Integrating People, Their Work, and Technology

One of the most repeated recommendations to facilitate workflow automation is the integration of people, their work, and technology.[7, 45, 66, 76, 78, 98, 111, 114, 124, 125] Stakeholders engaged in the process of workflow automation at every level assert that workflow automation cannot happen successfully without people.[43, 126] Specific supports such as leadership engagement and buy-in, transparency, and benefit analysis are also important.[98, 122] Clear roles and responsibilities, training, and investment in culture change can smooth the introduction of workflow automation.[1, 52, 55, 106, 108] Experts interviewed reiterated these findings and encouraged a participatory, multi-disciplinary approach to identify automation opportunities.

Paramount to successful integration of automation in the workforce is paying sufficient attention to human factors features and engaging users in development and testing, including clinical and administrative review.[51, 63, 76, 126, 133] Additional key elements might include clearly establishing a gold standard for a given process using subject matter experts, providing transparency on performance goals and metrics, and using internal champions to train staff members and introduce them to new technologies.[23, 40, 43, 64, 96]

Experts interviewed encouraged approaches that capitalize on *people* as key facilitators. One engineering expert attributed success at one hospital to leadership by an executive with prior care delivery experience. The executive engaged clinicians and multiple levels of hospital staff to participate in discussions with process redesign engineers that identified opportunities based on discussion of challenges with workflow. This and several other experts emphasized the critical components of having an open-mind and using partnerships across health care and non-health care disciplines to design and implement the automated workflows.

Process

Working from a standard or, at least, a source of truth such as a workflow map, is critical for successful process redesign.[1, 29, 55, 66, 69, 72, 108, 135] This includes ensuring that change-management standards are adhered to, users are working with the same dataset, a seamless workflow is the ultimate goal, and interruptions are kept to a minimum.[29, 66, 75, 104, 130, 135, 136, 140] Changes should be as granular as possible, with an agile approach to making adjustments and abundant opportunities to course-correct and ensure support.[23, 65, 66, 82, 86, 113, 136]

> "Rather than approach it [automation] from a computer science point of view – where there is a structure or code that generates these process – I approach it from sociological, practice theory point of view to say, what is it that these people are doing, and how does the setting and their interactions affect the work."
>
> **— Brian Pentland, professor of organizational routines**

Establishing metrics for early success is important, often overlooked, and should include process and outcome measures.[43, 79, 84, 86, 113, 136, 141] Training must clearly support new workflows and be overlapping (with relevant related roles), multi-method, and multi-modal.[35, 82, 92] Other facilitators include taking time to

appropriately prepare for the change in terms of overall mindset and culture, structural workflow, and attention to change-management processes.[4, 84, 96, 113, 138] Piloting and testing prior to implementation were perceived as important elements of success, affecting both iterative development and perceived value.[23, 52, 86, 113, 133]

Technology

Facilitators for workflow efforts include systems that are flexible, interoperable, reusable, and scalable.[6, 47, 61, 81, 101, 106, 142] Key to success is development, including input from interdisciplinary teams, with a core focus on user-centered design that considers a variety of users and stakeholders.[47, 134, 135] To whatever extent possible, workflow automations can be incorporated into existing workflows to improve them while reducing workflow friction and supporting seamless workflow.[44, 69, 143] Other facilitators include ensuring that technology aligns with process definitions and integration, including dealing with what happens when the workflow varies or an unexpected result occurs.[55, 87, 123, 134] This may be an automated or semi-automated solution. Encoded clinical decision support and ensuring that rules address alert use and performance (including consequences when alerts are ignored) can also be useful.[44, 111, 130]

Next Steps to Advance Automation

Based on a review of literature across industries and interviews with automation experts, a set of key factors for selecting workflows to automate emerged. Workflows suitable for automation are repetitive, use manual data entry, occur with high frequency, have clearly defined independent and dependent variables, and have defined roles and responsibilities. Workflows unsuitable for automation have inconsistent data requirements, challenging decision rules, unstated knowledge that is difficult to articulate or explain, inconsistent and unclear roles and responsibilities, and recurring differences between the prescribed workflow and its practice.

An objective process could apply the factors above to a "menu" of workflows – provided definitions and allowable degrees for each factor were developed with a repeatable, transparent methodology – to rank workflows for automation. However, because health care is a co-produced service and largely centers on the patient-provider relationship, prioritizing health care workflows to automate becomes complex. A more subjective task requires assessing: 1) to what degree should a human be "in the loop" for a given workflow; and 2) what stakeholders derive the value from automation?

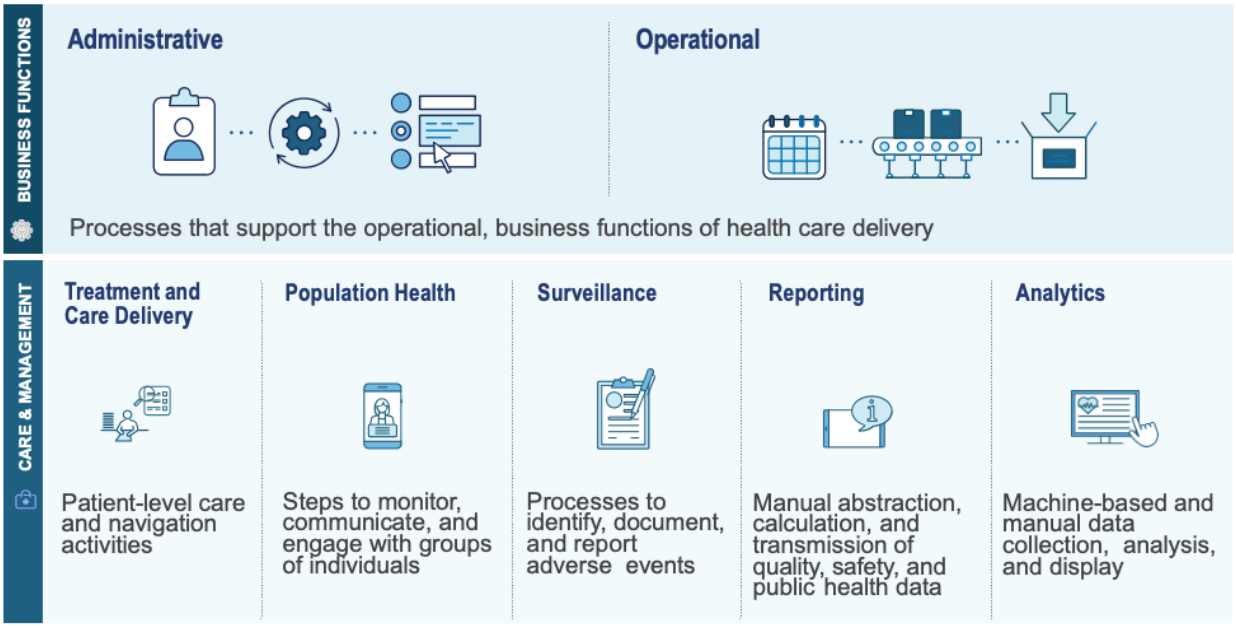
The literature identified services and technology designed to support automation for the purposes of 1) reducing or eliminating redundant, manual workflows; 2) removing waste that contributes to high costs; and 3) identifying fraud and abuse.[136, 137, 138, 144] Typically, services and technologies target administrative tasks with goals such as reducing "no-show" rates for scheduled appointments, increasing patient throughput, and reducing the burden of billing. Although these workflows alleviate challenges for administrative tasks, workflows related to clinical decision making, clinical encounters and hospital stays, patient-provider interaction, and population health have not generally seen the same widespread level of automation technology and services. Figure 2 summarizes the health care workflows that the experts interviewed suggested for automation.

Based on the literature search and expert interviews, central considerations for workflow selection and automation are listed below.

- Lessons learned from non-health care industries can inform efforts to **evaluate workflows** and identify **areas of greatest need of automation** in health care.
- There are parallels between non-health care industries that produce goods and services and health care. It may be worth considering efforts to **prioritize workflows to automate.**
- Identifying automation goals is key to design and implement successful workflow automation. However, prioritization is complicated in scenarios where automation to improve public health, population health, and chronic disease yield outcomes over long time periods. It may be useful to identify the **stakeholders necessary to design and implement workflow automation.**

- Examples emerged through expert interviews of conflicting goals where increased operational efficiency is met with decreased consumer value. When identifying opportunities for workflow automation in health care, it is important to consider **what happens when goals conflict or are prioritized differently across stakeholders** and how to craft a **framework that addresses that potential.**
- Data connectivity, analytics, and automation through machine learning and AI have advanced in sophistication such that automated systems have replaced physical entities that produced services. It is important to consider **what needs to be instrumented to support or generate automated workflows.**

Figure 2: Health Care Workflows and Tasks to Consider for Automation



Multiple stakeholders have an opportunity to apply lessons from industries outside of health care and collaborate to accelerate improvements in quality and safety of health care. With continuing concerns about the cost, quality, and safety of health care, as well as mounting provider burnout, it is important to leverage people, processes, and technology to advance automation.

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