Barriers to Adoption of Information Technology in Healthcare

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ABSTRACT

Healthcare is an important pillar of society, critical for effectively responding to public health emergencies, and addressing disease, ill health, and poverty brought on by communicable disease and non communicable disease and cancer [7]. The increasing need for cost effective, time effective, and preventive healthcare is forcing radical changes in current healthcare systems, requiring them to take full advantage of capabilities of modern technology, including information technology. However, this is not straightforward. Despite constant advances in modern information technology, adoption in healthcare is very slow.

In this report, we take a systems thinking perspective to identify barriers to the application of information technology in healthcare and adoption of those advances through the prism of two use cases: electronic medical records (EMR) and remote patient monitoring (RPM) technology. Finally, we outline solutions to individual barriers and consider the negative effects those solutions might have on other barriers. We expect that our analysis of adoption of information technology in healthcare as presented in our use cases will strengthen the case for systems thinking and help requirements analysts decide on appropriate steps to boost adoption of new technology to achieve more effective and efficient next generation healthcare.

CCS CONCEPTS

•Social and professional topics →Personal health records; Remote medicine; Governmental regulations; **•Applied computing →***Health care information systems;*

KEYWORDS

Healthcare, Systems Thinking, Electronic Medical Records, Remote Patient Monitoring

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1 INTRODUCTION

Average life expectancy in OECD (Organization for Economic Cooperation and Development) countries in 2012 was 80 years, following a 5-year increase since 1990 [65]. In Canada and the United States, currently, 25% to 29% of the population is over 60 years old [74]. Worldwide, this percentage is climbing rapidly, expected to surpass 30% by 2050 [70].

Older seniors contribute to a significant portion of healthcare costs as a consequence of rising costs in the last few months of life, which intensifies even more if they belong to the minority of the population with chronic illnesses that require more intensive medical attention with age [26]. Taking into account also the steady demand for quality care from other age groups, providing healthcare services will not be affordable with current healthcare systems in the future.

As a relatively wealthy nation with a socialized healthcare system and an aging population, Canada exemplifies these challenges. Canada's population is over 36 million people, of whom nearly 11 million are seniors. Approximately a quarter of Canadian seniors have faced some sort of cognitive, physical, or sensory impairment [55]. Meanwhile, The funding gap in healthcare is steadily growing. For example, in Ontario, the funding gap is expected to reach $4 billion CAD by 2018. Other countries face similar struggle: in the United Kingdom, the NHS has reported the funding gap in healthcare will reach £30 billion by 2020 [27]. It is evident that demand for quality care is making cost and time effective healthcare a necessity.

Understanding how technology innovations can be effectively introduced in health systems and how these innovations will influence health outcomes is challenging [7]. As we will show, the many elements that make up the healthcare system have complex relationships, resulting in complex feedback loops, often with delayed effects. Healthcare systems are also hard to characterize using strict boundaries, as they are integral to a functioning society and thus well woven into multiple layers of government, industry, and society. In systems such as this, a simplistic analysis leads to situations where the most important sources of problems tend to be overlooked. There is a danger of "misperception of feedback" so that even when good data is available, the consequences of interactions cannot rapidly and correctly be deduced [34].

In this paper, we examine barriers to adoption of technology in modern healthcare using a systems thinking lens. Systems thinking focuses on the relationships between elements in complex, open-ended systems, and how those relationships produce patterns of behaviour over time, particularly the feedback loops that shape how a system responds to change. This helps anticipate rather than react to events, and to better prepare for emerging challenges [7]. By making use of systems thinking, possible consequences of policies and actions can be carefully considered. We survey the literature

on the lack of adoption of modern technology in healthcare with respect to two case studies: Electronic Medical Records (EMR) and Remote Patient Monitoring (RPM). We illustrate barriers for application of these technologies and explore solutions for overcoming those barriers, along with their potential unintended side-effects.

2 HEALTH SYSTEMS AND SYSTEMS THINKING

In this section we give a brief description of Systems Thinking and explain why it offers an appropriate framework for analysis of healthcare challenges.

2.1 Systems Thinking in Healthcare

> A systems perspective can minimize the mess; many of today's problems are because of yesterday's solutions.
>
> *Dr. Irene Akua Agyepong,*
> *Ghana Health Service, Ministry of Health, Ghana, 2009*

Systems thinking provides a set of tools for describing and analyzing complex dynamic relationships between elements of an entity. The more complex the entity (the more elements or relationships among elements that exist), the harder it is to identify, process, manipulate and predict its behavior. In such cases, people often struggle to comprehend patterns of cause-and-effect, due to non-linear feedback structures and time delays between actions [7]. Systems can be characterized in terms of their boundaries, their elements, their linkages among elements or interactions with the outside world, and their stakeholders.

Systems thinking is an appropriate methodology for approaching multiple facets of the healthcare system, particularly for analysis of technology adoption in health systems, which involve multiple "hard" and "soft" elements (i.e., variables related to human behaviour such as doctor and patient behaviour, decision drivers for institutional administration, productivity, response to incentives, etc.). Systems thinking methodologies offer insights into inter-dependencies that can cause technology solutions to create as many problems as they solve [34].

2.2 System Building Blocks, Boundaries, and Environment

The World Health Organization (WHO) defines a health system as consisting of all organizations, people, and actions whose primary intent is to promote, restore or maintain health [22]. Health systems are open systems with interlinked components that interact with the broader context in which the health system is situated, such that it is impossible to study the system in isolation from its context [7]. System elements interact and influence each other with amplifying or balancing feedback loops, making change difficult and complex [60].

The WHO identifies the following building blocks that constitute a complete health system [73]: (1) **Service delivery,** i.e., the effective, safe, and quality personal and non-personal health interventions that are provided to those in need, when and where needed (including infrastructure), with a minimal waste of resources (e.g., outpatient and inpatient care units, medical rescue and emergency services, chronic illness dispensary care, rehabilitative care, preventative care, pharmaceutical dispensing services, and the common household). (2) **Health workforce,** i.e., physicians, surgeons, specialists, nurses, paramedics, etc. The health workforce needs to be responsive, fair and efficient given available resources and circumstances, and available in sufficient numbers. (3) **Health information and technology,** i.e., the production, analysis, dissemination and use of reliable and timely information on health determinants, health systems performance and health status. Such technology covers a wide range of needs, including clinical decision support, computerized disease registries, computerized provider order entry, medical record systems, electronic prescribing, and telehealth. (4) **Medical technologies,** i.e., medical products, vaccines and other technologies of assured quality, safety, efficacy and cost-effectiveness, and their scientifically sound and cost-effective use. (5) **Health financing,** i.e., the capital required by organizations to both administer care to all in need and proceed with groundbreaking medical research. Adequate funds must be available to ensure people have access to needed services, and the costs aggregated to protect people from financial catastrophe or impoverishment associated with having to pay for them. (6) **Leadership and governance,** necessary to ensure strategic policy frameworks are combined with effective oversight, coalition building, accountability, regulations, incentives and attention to system design. Each building block does not only directly or indirectly affect the function of the system as a whole, rather also frequently it affects the function of other components as well.

Systems thinking does not come naturally to healthcare professionals, who are used to thinking on an individual scale, with the goal of maximizing their contribution. From a systems thinking perspective however, the goal of a healthcare system is to optimize the overall output of the system, rather than just maximize the output of individual building blocks or their elements [59].

Health systems can be studied at varying levels of scale. There is a tendency to study micro-systems such as a single caregiver's office or a treatment team, or macro-systems such as the organizations they belong to like hospitals or clinics. It is important however to also study health systems at a mega-system scale. This means looking at the dynamics of the building blocks of the health system in context of a province or a country. Even at this broadest scale, this is still not a closed system, as by nature it participates in the encompassing economic and social systems of the country and globally. At a micro-scale, the health system environment can be limited to a physician's office and the environment of the patient, but as we scale up, clear distinctions between the system and its environment quickly become hard to define.

2.3 Health System Stakeholders and Stakeholder Networks

Stakeholders of a system are all entities or groups of entities that are affected by system change, e.g., provincial and federal governments, healthcare practitioners (doctors, nurses, caregivers), public and private health providers, institutional administration, tax payers, patients, clinical research institutions, the healthcare IT industry, the pharmaceutical industry.

a **profit making system** from the perspective of private providers
a **distribution system** from the perspective of the pharmaceutical industry
an **employment system** from the perspective of health workers
a **market system** from the perspective of consumers and providers of health-related goods and services
a **health resource system** from the perspective of clients
a **social support system** from the perspective of local community
a **complex system** from the perspective of researchers / evaluators
a set of **policy systems** from the perspective of government
a set of **sub-systems** from the perspective of the Ministry of Health

Table 1: System stakeholder network perspectives identified by the WHO [22].

Patients view the health system as a resource system, but private providers view it as a profit making system. Those views imply very different objectives (Table 1). Knowing the varying perspectives of system stakeholders provides insights on the relationships between entities of a system, and the influence that change in one building block of a system has in another.

We will focus on Electronic Medical Records (EMRs) and Remote Patient Monitoring (RPM) to discuss adoption of technology in healthcare. Both technologies have been adopted to an extent and contribute to a growing estimate of aggregate benefits each year. However, there is still a lot of untapped potential and unexplored barriers limiting further adoption. We chose these two technologies for their different adoption rates and barriers to adoption, and we will analyze these barriers with more details in the following sections.

3 USE CASE: ADOPTION OF ELECTRONIC MEDICAL RECORDS (EMRS)

Electronic Medical Records (EMRs) are repositories of standard medical and clinical data gathered in one provider's office, and Electronic Health Records (EHRs) are designed to contain and share information from all providers involved in a patient's care. However, they are sometimes both referred to as EMR technology, which is the terminology we will use in this analysis. We list the most important benefits of EMR technology.

- Maximized Cost-Efficiency: EMR use eliminates time spent tracking down and maintaining paper based records, and enables digital information sharing with other professionals. This practice reduces orders of duplicate diagnostic testing that can be costly, painful, or time consuming. With 9% of all lab tests and 10% of diagnostic imaging tests found to be redundant, EMRs can reduce duplicate testing by maintaining a searchable record of all past patient tests [8, 76]. A PwC study estimated the economic benefit of EMR use to be $99 million [51]. The study estimates that among 444 million annual lab tests in Canada, 29 million of those tests can be considered duplicates and redundant.

- Chronic disease management and preventative care: EMRs can help in early identification of people with active or potential chronic diseases and target service to patients based on their level of risk. Frequency of patient screening and testing can be monitored and physicians can be reminded when to check up on patients [51]. A Canadian study found that practices using EMRs had far superior prevention scores for patients concerning diseases such as various forms of cancer and audio or visual impairment screenings [21].

- Long term data monitoring: Patient data can be tracked and monitored over time, providing insight into quality of care, and patient improvement, and allowing associations between points in a patient's disease history.

- Improved immunization rates: EMR adoption greatly increases the timely identification of patients in need of immunization and helps remind physicians to schedule appointments [15, 36], saving tens of thousands of lives and over $900 million in the US per year [51].

- Standardization of care: Handwritten patient files are prone to illegible handwriting, misspellings and inconsistent terminology. Digitization of records can enforce standards and eliminate inconsistencies.

3.1 Rate of adoption of EMRs

Larry Weed first introduced the concept of electronically maintaining patient records into medical practice in the late 1960's with Problem Oriented Medical Record [69]. Adoption of EMR systems however was at best limited until the 1990's, when personal computers were becoming more affordable. However, even today, many medical practitioners still use paper records. The percentage of Canadian physicians using electronic medical records (EMRs) has tripled over the past seven years, increasing from about one-quarter of doctors in 2007 to three-quarters in 2014 [17].

Canada achieved a number of significant milestones in digital health in 2014-2015 with over 91,000 clinicians now using electronic medical record technology. This is remarkable given that many components of current EMRs were not even digital a decade ago. Investments in EMRs, diagnostic imaging, drug information systems and telehealth have produced an estimated 13 billion dollar in benefits since 2007 [2]. While some provinces like British Columbia, Alberta and Ontario are committed to adoption of EMR solutions (reported EMR adoption ranging between 75-85% in 2012), it is clear that there is significant room for improvement in others (reported EMR adoption ranging between 15-45%) [14].

3.2 Barriers for adoption of EMRs

While it is evident that the technology of electronic medical records has a significant adoption rate in healthcare (currently over 75% in Canada), it is still a troubling fact that many physicians and smaller clinics still have not moved on from paper records, and barriers to

adoption of this technology evidently remain. We identify the most important barriers to adoption of EMR technology next, but a more comprehensive list can be found in [4].

1) Economic barriers

Time: Choosing an EMR system and learning how to use it takes time [37]. The EMR market is extremely saturated, and navigating options and comparing costs and features is an overhead many family physicians do not have the time for. In addition to that, once an EMR system has been selected, use of it requires training, something some physicians do not feel they can afford extra time for.

Cost: Physicians must choose between purchasing an EMR system from a vendor or commissioning custom systems for their practices. Either way, use and maintenance of an EMR system accumulates costs that come not only from the system purchase, but also from training, maintenance, IT support, system upgrade and data storage, governance and migration costs. Therefore for small and medium sized practices, these costs accumulate to create a significant barrier for adoption of the technology, as benefits of EMR adoption would take too long to reap [41, 54].

2) Barriers to adoption for clinicians

Poor design: The majority of legacy EMR systems in North America were designed with the primary functionality of record keeping for billing patients. Thus the primary functionality is not designed to assist a physician in best possible patient care, leading to frustrating and time consuming interactions between system and physician. In addition, vendors tend to underestimate complexity of patient assessment and care workflows and procedures. Interviewing and administering care to patients is a very delicate interaction, and the added overhead of interacting with complex interfaces to record information is often hindering [10, 13]. Some physicians reported that they sometimes stop using EMRs because hunting for menus and buttons disrupts the clinical encounter and hinders doctor-patient interaction [37].

Lack of customizability: Physicians often avoid adoption of EMR solutions as every practice has different processes and workflows that work, and physicians do not want to be constrained by rigid software systems [23].

3) Infrastructure and regulations

Privacy & security: Non adopters of EMR technology often still believe that use of EMR solutions endangers patient privacy [39]. This is not an entirely unfounded belief, as Forbes reports that in 2015 alone there were over 112 million data breaches in healthcare records in the United States alone [43].

System reliability: Physicians need reliable access to their patients data at all times, and they worry that patient data can be temporarily unavailable at a critical moment or even lost if computers crash, viruses attack, or the power fails [53].

Despite these barriers, adoption of EMR technology by physicians and health organizations such as hospitals and clinics is steadily increasing. This often occurs due to pressure from administration or government to modernize care, and not because barriers for technology adoption by physicians have been overcome. Physicians are forced to use products that they find time consuming or disruptive of patient care, leaving many with a distaste and distrust for the technology.

3.3 EMRs and interoperability

> All the money spent on electronic health records has yielded only a fraction of the value of getting interoperability. It's like giving everyone cellphones and not putting up a cell tower.
>
> David Kendrick, head of Oklahoma's health information exchange [6]

With the steady adoption of EMR technology new problems arise. High adoption rates do not equate to effective or efficient use of EMRs. The focus in the industry has now shifted to issues such as interoperability, standardizing data formats and integrating e-prescribing into record systems [17]. While EMR solutions improve patient care within a practice, across locations there is chaos. Information stored in EMRs is not easily shared with providers outside of a practice. Often patient records have to be printed out and delivered by mail to specialists and other members of the care team. This becomes a problem particularly in large cities where a patient is often seen by multiple institutions. Moreover, even within single institutions that are large in size, different departments often use specialized EMR software, that do not support information sharing. Thus concern is not only that of adopting EMR solutions, but also achieving information integration and interoperability that enables global patient care.

Canada Health Infoway [11] is an independent, not-for-profit corporation, formed through a partnership of federal, provincial, and territorial governments and funded by the federal government. Its members are the deputy ministers of health from across the country. There are provincial government initiatives in Ontario and Alberta (eHealth Ontario [24] and Netcare [5]) that have invested heavily in EMR interoperability and have developed specifications for EMRs to this end. A recent federal and provincial audit estimated the total cost of implementing EMRs Canada-wide at over $10 billion and the total annual benefits at $6 billion [45]. The United States Office of the National Coordinator (ONC) for health information technology has compiled a report to serve as a road map for nationwide EMR interoperability within the next nine years [47]. Benefits of EMR interoperability include:

- **Effective patient care:** Coordinated care between departments of a healthcare center or across care centers is often a matter of life or death. Machine readable patient data becomes accessible to authorized providers across departments, institutions and locations without delay.

- **Reduced costs:** Reduced risk of miscommunication that could lead to failed patient care and malpractice lawsuits. Reduced number of duplicate tests across organizations. Less time spent faxing, scanning or physically transferring documents that then need to be analyzed by a human for relevant information.

- **Efficient patient care:** Minimizing redundant paperwork, as patients need only fill out medical history paperwork once. Minimizing redundant tests that are not only costly but could also be invasive or painful to patients.

- **Large scale data driven clinical research:** Data for public health monitoring and clinical research is produced at volumes that benefit analysis.

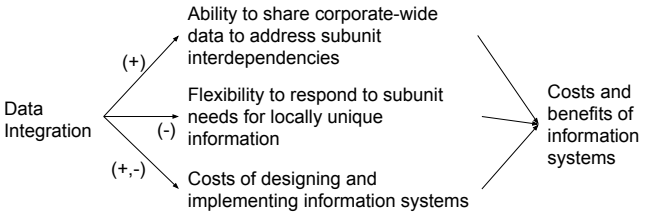

Figure 1: The impact of data integration on costs and benefits of IT systems adapted from Goodhue et. al [30].

3.4 Barriers for EMR interoperability

Research in information integration [35, 49, 52, 68] and system interoperability [12, 50, 62, 75] is rich and has a history of over three decades. Information integration facilitates the collection, comparison, and aggregation of data from various parts of the organization, leading to better understanding and decision making when there are complex, interdependent problems [30]. The impact of data integration on an information system can be both positive and negative (see Figure 1). Information integration is costly, and it is important that effectiveness of complex information processing mechanisms are balanced against great costs [30]. We next analyze the barriers we identify as the most critical.

1) Infrastructure and regulations

Siloed data: EMR providers often achieve customer lock in by making it too expensive or difficult to migrate data from one software to another. Siloed data has proven to be healthcare's biggest flaw. Vendors increasingly engage in "information blocking" in order to charge data exchange fees. In fact, some vendors charge $5,000 to $50,000 to set up connections for sending and receiving patient information to other systems [38]. This is the biggest barrier to interoperable electronic medical records, and was recently widely addressed in an extensive report to congress in 2015 [46].

Privacy concerns: A patient's record belongs to the patient. The doctor that administered care has access to it, but it should not be freely available for other doctors to access without patient consent. In addition, health related data has increasingly become a target for hackers [31, 33], with over 100 million healthcare records stolen last year alone [18]. Patients worried about the integrity of their information may conceal information due to lack of confidence in the security of the system having their data, compromising their treatment [48].

Lack of standards: Sharing electronic patient records currently means printing, scanning and mailing a copy of the record. In some cases, vendors comply with a standard that allows electronic faxing of medical records. However this is more of a band-aid solution, as there are no strong standards for EMR interoperability [29].

Lack of incentives: Vendors have not been incentivized to make interoperability with competing software a key capability in their software [56].

Lack of knowledgeable support personnel: Data integration does not have a one-size-fits-all solution and requires weeks or months of engineering to establish a connection between platforms [6].

2) Economic barriers

Cost: While the benefits of EMR interoperability are undisputed, the investment required to achieve it is a huge deterrent. Every EMR software used needs multiple customized interfaces to work with other platforms, and those costs have to be paid by either the organizations using the software, or by government funds, or by the providers themselves [29].

3) Technical barriers

Market saturation: There are hundreds of vendors supplying hospitals clinics and private practices with EMR software in North America. The four biggest healthcare IT providers are Agfa-Gevaert, Cerner, GE Healthcare and McKesson. In fact, the impressive rates of adoption of EMRs so far might even be a reason for lack of interoperability, as the industry did not have time to create necessary compliance standards [64].

Legacy systems: Countries with a healthcare infrastructure that adopted EMR solutions early are now faced with the dilemma of investing in painful and costly integration solutions over legacy systems or investing in new infrastructure.

4 USE CASE: ADOPTION OF REMOTE PATIENT MONITORING (RPM)

Telehealth is a combination of electronic information and telecommunication technologies which enables patient/clinician contact and care, education, intervention, monitoring and remote admissions [61]. Remote patient monitoring (RPM) is a telehealth component that involves the application of technology to enable monitoring of patients and reporting their health data, outside of conventional clinical settings (e.g., in the home). The process of RPM can be described in the following four steps [28]. Data (such as vital signs) is passively or actively collected through appropriate interactions with patients. Collected data is transmitted between family caregivers and organizations by providers. The data is evaluated by algorithms or human resources to find out if something in their physical condition needs to be considered. After data evaluation family caregivers and clinicians or even patient themselves might need to be notified.

After transmission, patient data is evaluated by the appropriate RPM program. These programs, based on their technological complexity can be categorized into four different streams [25]. *Enabling* systems give patients web access to their medical information through portals, mobile applications and different software. *Self-monitoring* systems let patients share their health information with their care provider within well-ordered intervals. *Assisted monitoring* systems enable community care professionals to monitor and coach complex patients after their discharge from hospital care. *Environmental monitoring* systems are designed for patients with complicated physical situation such as patients with physical disabilities or chronic conditions. Such systems involve installed devices for monitoring and collecting data from patient.

Multiple studies have demonstrated the benefits and outcomes of using RPM technology [25], especially in terms of cost and quality of care [9, 16, 19, 28, 58, 66]. We identify the most important advantages of RPM deployment:

- Reduced personal and institution costs: Length of stay for patients decreases, as does cost of care per capita. Emergency hospital service use by older adults decreases as complications and

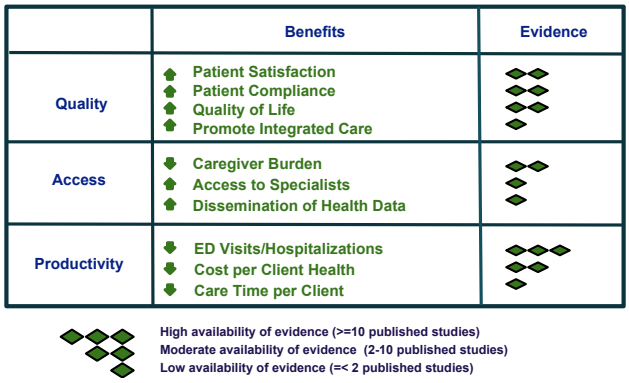

Figure 2: State of the art in remote patient monitoring technologies [25].

deterioration of health are prevented early, eliminating extended or repeated emergency department visits and hospitalization.

- Rise in quality of experience: Patients maintain independence, live at home and work in their preferred setting as the need of moving to a clinical, high cost, intensive setting reduces. Familiarity with their health status makes patients more likely to embrace caregiver's recommendations rather than resist them.

- Effective mental health care: Remote monitoring and trend analysis of psychological parameters makes care less intrusive and easier, (e.g., tracking patients with illnesses like dementia).

- Improved quality of care: RPM connects clinicians virtually instantly with their patients with relevant patient data making daily routines more efficient. This increases the capacity of physicians to treat more patients, while patients can become more engaged and accountable for their health.

4.1 Rate of RPM adoption

Remote patient monitoring has been available for decades in different forms such as cardiac monitoring. Initially RPM devices were simple, however, since 2000 they have significantly improved in terms of accuracy, speed and use of state of the art technology [20]. A recent study from Canada Health Infoway (2014-2015) showed that RPM activity is growing in Canada [2]. The same study showed that the growth in use of telehealth devices is especially important for First Nations communities and people in rural areas, as they often cannot otherwise afford the cost and time of traveling great distances to see specialists. By end of 2010, 1% of Canadians used medical devices for electronically capturing and transmitting data to their healthcare providers (via Internet or SMS). This data was used for post-surgical monitoring or chronic disease monitoring. The 2013 Canadian Telehealth Report showed that about 5,000 patients participated in 19 different streams of RPM programs among 7 provinces and territories, which is more evidence of continuing 15-20% yearly growth of remote patient monitoring across Canada [25]. In 2014, Canada Health Infoway reported an increase of more than 180% in telehealth events since 2010. The number of patients who use devices in their homes to electronically transmit data to specialists and healthcare providers for monitoring and support is growing fast. Approximately 3,800 patients were enrolled in provincial and territorial programs actively in 2014 which is an increase of more than 50% (from about 2,500 patients in 2010).

4.2 Barriers of RPM adoption

Between 2007 and 2010 telehealth has resulted in $125 million worth of cost benefits for patients and the healthcare system [32]. Reports show that more than 80% of Canadians are willing to take advantage of digital health solutions like RPM and 76% of Canadians think digital health can make accessing healthcare services easier and more convenient [3]. Despite this, the adoption of this technology is still extremely slow and limited. Contributing barriers to slow adoption are dependent on each other but can be classified in distinct categories [44, 72]. We discuss the most important contributing barriers next.

1) Economic barriers

High cost of RPMs: Many devices supporting RPM now cost thousands of dollars, but for extensive and widespread use, costs must come down [28, 40].

Lack of scalable business models: Increasing concern in accountability and liability or RPM systems makes providers are uncertain and anxious about investing in RPM programs [44].

2) Infrastructure challenges

Wireless Network: RPM systems are highly dependent on a powerful and extensive wireless telecommunication infrastructure as they rely on reliable and efficient data transmission. Extensive telecommunication infrastructure may not be available in undeveloped and rural areas, hindering RPM deployment [72].

Efficient systems: The continuous incoming flow of patient data requires efficient and effective analysis and evaluation from a dedicated team of healthcare providers. As a result, although the intention behind RPM technology is increased efficiency, it can become a barrier to healthcare providers that are not technology savvy [63].

Lack of sufficient data: Developing and evaluating accurate and reliable complex systems requires a wide variety of appropriate real world data. Collection and dissemination of this data for research purposes requires a long complex ethics approval process [22]. Furthermore, current basic data collection infrastructure is still weak in most countries and often the stored data is limited, incomplete and of low quality. Finally, collecting data from adults, especially older adults with a chronic disease is a difficult, costly and time-consuming process because of their poor physical condition.

3) Barriers to adoption for patients

Patient training: Patients and their caregivers require training sessions to effectively use each different device. In addition, many are often not well equipped to check or troubleshoot the problems arising from lack of infrastructure of failing infrastructure such as the wireless network of the RPM interface to the network.

Patients willingness: RPM programs fail without active patient participation. While reports show over 80% of Canadians are willing to take advantage of telehealth programs, they also show a concern regarding collection and handling of sensitive personal information [3].

4) Barriers to adoption for clinicians

Burden of new technologies: Practitioners and clinicians are already exhausted with increased documentation burdens and pressure of learning the state of the art technologies in their field. They often assume that RPM platforms will increase this load and as a result their collaboration will become more difficult, making adoption more complicated [44].

Data unreliability: Data transmitted by RPM systems may be incomplete or noisy due to network issues or issues related to RPM devices in patient homes.

5) Barriers to adoption for institutions

Poor integration: Lack of regulations resulted in poor integration of software and processes of different institutions and organizations [44].

RPM deployment issues: There are different challenges for deploying RPM systems, such as tool delivery, tool installation and patient and care giver training. RPM providers are responsible for training patients and their care givers on how to efficiently use RPM devices and software. Verification and validation of collected patient data is another challenge of deploying RPM since for ensuring accuracy and security in the system, as providers often use heuristics such as demographic data to correctly identify patients.

6) Barriers created by legal and regulatory issues

Privacy and Security: Transmission of sensitive patient data happens across telecommunication networks and wireless carriers. Such mediums have the ability to read information from these devices, creating an information security concern for RPM systems [63].

Accountability and Liability: Adoption of RPM technologies brings about a shift in accountability that can cause liability confusion. While health delivery organizations maintain their custodial responsibilities, in RPM settings they will not have sole control over patients health information, thus sharing accountability with patients or caregivers (e.g., a family member). Additionally there are no guidelines to specifying if clinicians should intervene when they receive an alert without considering the extent of urgency [1, 63]. This uncertainty makes health providers leery of participating in RPM settings.

7) Barriers created by reimbursement issues

Reimbursement Guidelines: Incorporation of RPM services into clinical practice requires clear reimbursement guidelines. The current lack of these guidelines may prove to be a significant barrier [63].

5 SOLUTIONS

Having outlined the barriers to adoption of technology in healthcare in two case studies, we can now discuss actions that can be taken to overcome those barriers. However, as with any complex system, while introducing change in the healthcare system to overcome one barrier to adoption, we might actually strengthen another barrier, as discussed below. We illustrate examples in Figures 3 through 8, with red arrows depicting negative effect of solutions on barriers and green arrows depicting positive effect, while plus and minus depict increase or decrease of the effect. Therefore for every solution given, it is important to predict and identify such unintended change. Only after such a comprehensive analysis can we weigh trade-offs and decide which solutions to implement.

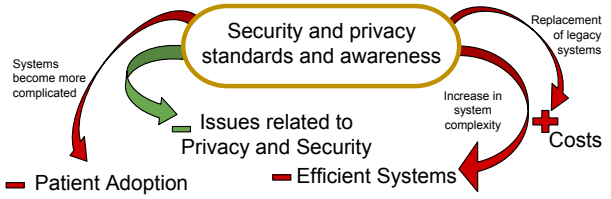

Figure 3: Effect of security and privacy standards on barriers to adoption of technology in healthcare.

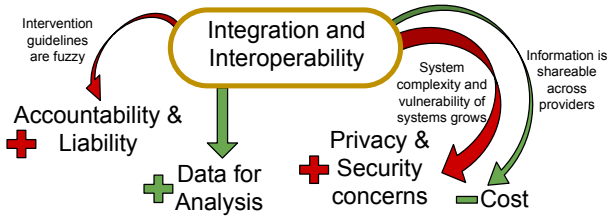

Figure 4: Effect of system integration initiatives and standards on barriers to adoption of technology in healthcare.

1) Security and privacy standards and awareness. Patient medical data must be treated with very high privacy and security standards, whether in EMRs or RPMs. Currently, while EMR solutions typically employ high security standards, many RPMs are still lacking. Obvious solutions for both include passwords and firewalls, but more sophisticated solutions are needed, such as data encryption in data base layers [44], multiple layers of authentication, etc. Equally important are security standards in caregivers and patient behaviour. Caregivers and patients using RPM systems for instance must be educated on the type of data being collected, how it is being collected and the expected use, visibility, and access protocols of the data.

Governments must clearly outline and enforce privacy expectations and healthcare providers must communicate their privacy requirements clearly to supporting carriers [1]. While increased security efforts address privacy concerns, they also create barriers to adoption of such technologies. Elderly patients may find added complexity confusing in RPMs, cost of infrastructure in both RPMs and EMRs will rise, particularly for large scale deployment, and systems run the risk of becoming less efficient as load increases.

2) Integration and interoperability standards. Private and public sectors need to work together to develop and drive the consistent specification and implementation of standards that enable interoperability and ensure data security in both EMR [46] and RPM technologies [44]. Such standards clarify the requirements and expectations for secure and trusted exchange of data and enable developers to integrate different software solutions faster and more cost effectively than before. However, interoperability of software systems exposes them to more security vulnerability, increases strain on accountability and liability barriers. Finally, implementation of interoperability or replacement of legacy systems will accumulate tremendous cost, but over time the overall cost of the ecosystem goes down, providing more effective care.

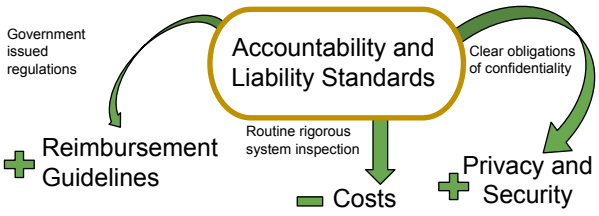

Figure 5: Effect of accountability and liability standard creation on barriers to adoption of technology in healthcare.

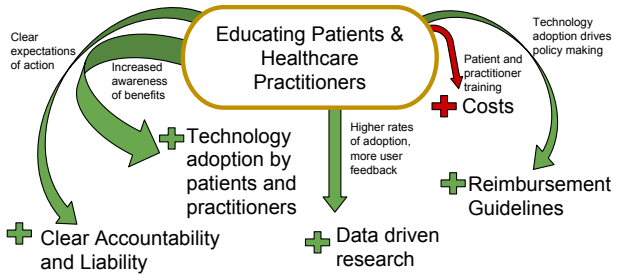

Figure 6: Effect of patient and practitioner education on barriers to adoption of technology in healthcare.

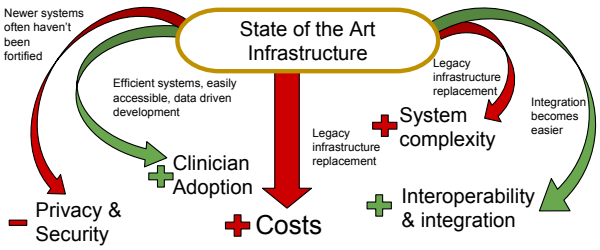

Figure 7: Effect of use of state of the art infrastructure on barriers to adoption of technology in healthcare.

3) Accountability and liability standards. The rising accountability and liability concerns for RPM systems can be mainly addressed with either government regulations, or by following clear guidelines for formally defining and communicating responsibilities and liabilities vendors and caregivers are willing to accept and those they expect patients to accept [1]. In addition to this, devices should be routinely evaluated to account for data errors introduced as a result of user (patient and/or caregiver) error or misuse. Reliability of data will improve the assessment process and will enable practitioners to be better partners to their patients [44]. Finally, all parties involved in deployment, management and use of RPMs must be bound to the same obligation of patient confidentiality. Such standards will increase privacy and security of systems, lower secondary costs (i.e., lawsuits, etc.), and help reduce barriers to adoption created by the lack of reimbursement guidelines.

4) Health IT certification surveillance. All technology used in healthcare settings is strictly government regulated and must be certified. Some industry leaders have responded to federal calls for interoperability, and are beginning to adhere to standards that make their products certifiable. EMR vendors that don't apply to standards (e.g., impose contractual or technological restrictions on use or access of patient data), risk being de-certified as vendors [67]. Both Health Canada and the U.S. Food and Drug Administration set guidelines for RPM devices [1], but currently there aren't strict enforcement procedures for enforcement. Enforcement of all above guidelines is crucial for overcoming many of the barriers to adoption (such as accountability, liability, data reliability, lack of integration, and difficulty of software deployment like EMRs and RPMs), however it also increases cost as devoted agencies are needed to enforce these standards.

5) Setting performance incentives and mandates. It has been found that financial payback to practices for achieving quality improvement or mandates for IT use increases the adoption and use of EMRs [42]. This speeds up adoption by reducing costs and potentially also encourages interoperability and integration.

6) Personalization of software. Many practises or hospitals do not use full capabilities of their EMR software as they are inflexible or do not align with processes and workflows followed by healthcare personnel [42]. Allowing personalization of software, while expensive, will ensure higher and more thorough adoption of EMRs, unleashing their full potential. While this is expensive, makes system deployment and maintenance more difficult, and creates extra burdens of new technology, it also increases patient and physician adoption.

7) Educating patients and practitioners. While EMR adoption is currently on the rise, RPM systems are still new. Education of physicians and patients through seminars, and training sessions would help in adopting such technology, as they increase awareness and motivation of use. Educating patients on the benefits of their data being available and the security infrastructure protecting their data is key to accelerating acceptance and adoption of such systems. Such efforts can be costly, driving up the cost barrier to adoption. As practitioners and patients become more motivated to use RPMs, we expect to see more involvement in accountability, liability and reimbursement guidelines standards generation. In addition, with more widespread use of such systems, data collected for informing system design increases, leading to better informed next generation systems.

8) Make healthcare practitioners first class citizens. Requirement driven design of EMRs and RPMs by healthcare practitioners and patients is necessary to design software that will be used to full capability. This requires an iterative design process with constant feedback. While costs will increase due to a more complicated design process, the benefits are definitely incomparable, as systems are more likely to be used to their full potential, and data collected will be richer and more useful.

9) State of the art infrastructure. Physician expectation for constantly reliable and available infrastructure can be met with cloud services and multiple interface design. This will spearhead clinician adoption and help make systems more integration friendly, but it also creates necessary cost and complexity on infrastructure (i.e., security, network connectivity, data encryption, trained personnel, etc.). In addition, state of the art systems in their infancy might be more vulnerable, creating added concern on data privacy.

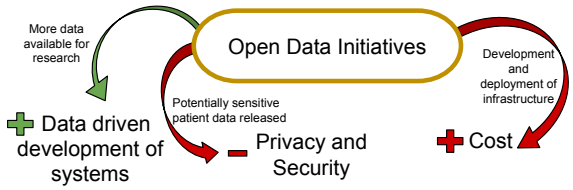

Figure 8: Effect of Open Data Initiatives on barriers to adoption of technology in healthcare.

10) Open data initiatives. As privacy is a primary concern in healthcare, researchers often complain of lack of patient data to drive next generation research and development and evaluating current systems. The WHO recognizes these concerns and states that investing in data availability, quality and use is a long term prospect but crucial to efficient and coordinated efforts in improving health and health systems [22]. Such initiatives obviously will make more healthcare data available for research validation, but costs and privacy and security concerns will rise.

6 DISCUSSION

In this paper, we analyzed the healthcare sector as a complex system, and applied systems thinking tools to identify causal relationships across the system. We identified the elements comprising a healthcare system and gave examples of the complex web of relationships that emerge between those elements. We then discussed information technology adoption in healthcare as seen in two use cases; Electronic Medical Records and Remote Patient Monitoring. For each use case, we illustrated the barriers for adoption and we gave an analysis of solutions per barrier. This analysis is valuable for understanding unexpected side effects and for deciding on trade-offs.

The complexity and intricacy of relationships among barriers for adoption show that it is immensely difficult to solve the barriers for adoption of technology in healthcare, as shown in our analysis of Electronic Medical Records and Remote Patient Monitoring. Examining the problem from a systems thinking approach provides a birds eye view of the problem, and clearly defines individual barriers, individual solutions, and most importantly, trade-offs that need to be made. It becomes clear that to achieve effective large scale adoption of technology such as EMRs and RPMs public and private policy interventions are necessary. Improvement of EMRs for increased adoption and effectiveness is going to be costly and difficult, and solutions for accelerating that adoption are not straightforward or easy to implement.

Further work is needed to broaden our analysis of barriers to adoption, to explore the aggregated effect of multiple solutions to these barriers, to determine whether a combination of strategies will mitigate one another's weaknesses, or exacerbate them. In the future, we would like to investigate patterns of adoption of information technology in healthcare as it compares to other sectors, using the innovation diffusion life cycle [57, 71] as a basis for identifying the longer term processes of adoption and the second- and third-order effect of these technologies. In addition, the adoption of big data technology and services are currently generating tremendous interest for their potential to improve healthcare systems, but a similar analysis to the one we present in this paper is needed to explore the likely negative impacts of these technologies, and the trade-offs involved in attempting to mitigate these impacts.

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