The Evolving Internet of Things (IoT) in Healthcare

The impact of IoT and communication technology on health care services

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Introduction

The healthcare industry is in a technological crossroad where innovation in digital communication and Internet-of-Things (IoT) technologies are intersecting thereby changing the relationships between medical care providers, patients, health care systems, and the government. Advancements in digital and communications technology have caused doctors, hospitals, and health systems to evaluate the impact of these devices in the complex milieu of administrative process, regulatory compliance, and clinical communications. The world of technology continues to benefit from miniaturized form-factors, such as, improving accuracy, growing functionality, and accelerating speed. Meanwhile, the administrative and operational requirements in the healthcare space are complex, multi-faceted, and shaped by regulatory oversight. This chapter considers the impact of advancing digital communication technology on the delivery of healthcare services by individual healthcare providers and organizational healthcare systems.

Today's Healthcare IoT

Standard business practices in the communications industry has resulted in mass-marketing of increasingly powerful computational and communication devices such as touch screen-enabled phones and tablets. Developers of various health-related devices and software market these wellness products as "intelligent" or "smart". Application of these health-monitoring tools and wearable devices by patients is in progress in many clinical settings. Consumer-grade devices possess the potential to increase the adoption of these technologies but there are concerns these devices can produce data with uncertain accuracy and therefore present a potential negative clinical risk.

Evaluation of the safety of the consumer digital medical device for use with patients having specific medical conditions is the first step toward understanding and reducing these risks. Additionally, subsequent studies that ascertain the impact of the device under controlled observation by a medical professional must be implemented. Evaluation of the accuracy of these consumer devices to prognosticate clinical outcome or benefit to the patient requires longitudinal analysis that takes time to complete. Until such longitudinal clinical outcome studies materialize, management protocols will retain existing care paradigms. Clinical research of patients with specific medical diagnoses or conditions requires careful review in clinical validation studies. Without these validation studies, licensees may have difficulty prognosticating precise outcomes utilizing consumer-grade devices.

In addition to the clinical and scientific questions, administrative operational requirements exist. Healthcare systems and medical centers maintain internal procedures and policies which define work flow and protocol for communication. These internal regulations reflect prior experiences in dealing with healthcare issues within those communities and medical centers. Sometimes these procedures have been based upon legacy paper and pen processes. Certainly, many of these healthcare system and medical center policies fail to contemplate integration of information flow from environments outside the traditional hospital or medical office examination room. Security, privacy, and regulatory compliance measures have begun to emerge as important concerns that are impacting policy with risks being mitigated by administrative review. Reception of the information by the health care system requires insight to care provider work flow and the corporate responsibilities internal to the healthcare operation. Therefore, integration of consumer devices into the workflow utilized by the healthcare system and constituent licensees requires investment of time and resources that may be outside the existing budget for many medical institutions and systems.

Digital communication networks interconnecting these smart devices are proliferating with growing capability, easier access, and decreasing expense to consumers. Reference databases, artificial intelligence, man-machine interface systems (MMI), and cloud services are adding utility and capability to these pervasive networks. When applied to the healthcare field, the combination of smart device and instantaneous digital networking suggests a future where individual patients can communicate medical and health related information on a 24x7 basis with caregivers and providers. This optimistically presents a future where the health care system, specific medical facilities, and care providers can show improved outcomes for challenging patient populations.

However, progress in communication technology is already impacting the delivery of healthcare services today with concomitant expenses and risks. Improved communications have the potential to improve healthcare efficiencies but they also increase the need to safeguard protected health information, ensure data integrity and security, and meet adhere to new regulatory regulations.

These technology-enabled improvements may appear if healthcare providers rethink their current perceptions of the healthcare industry. The understanding of outcomes and metrics are shifting from facility and provider based measures to patient-centric measures that require a much larger ecosystem of participating partners. The idea of a hospital as an isolated institution transforms to a community-centric ecosystem of care delivery and management. As a technology, IoT will play a critical role in this transition, but other technologies and factors must also play a role. The cultural change in the definition of healthcare across a community will occur as community-wide networks develop and information management matures. Ultimately healthcare becomes less about tactically managing one illness and more about strategically managing communities to gain a larger vision of wellness across the populations served.

This forward looking view of healthcare as an efficient, community centric, participatory ecosystem is transformative. This vision will evolve over time enabled by technology, and implemented over a series of digital transformation projects. Ultimately, many such digital transformation projects are required and the order and speed at which they are pursued will vary widely as each community seeks to optimize the evolutionary process to meet local needs.

This should not be taken to imply that the application of these advanced technologies is ready for mass market deployment, but evidence suggests that healthcare institutions across the world are deploying and testing components of critical elements necessary to allow the healthcare industry to take the next step.

Challenges in the Healthcare Implementation of IoT Devices

While the capabilities of these cutting edge technology systems are truly inspiring and offers the potential to improve healthcare outcomes while reducing systemic costs, it has to be understood that technology is a tool. How that tool is applied by institutions with access to it, determines which outcomes will be realized.

Healthcare institutions are built utilizing equipment from a variety of suppliers and thus maintenance of this complicated system must occur in a multi-vendor environment. While an individual vendor can achieve wonders with technology they often struggle to introduce that same technology to an environment that supports a combination of vendors in a configuration that has not previously been encountered. Typically, this mix of vendors are in competition with each other, often leaving the healthcare IT teams in the middle. Moreover, once the system is installed and certified for operations, the healthcare IT staff typically continue to struggle in an effort to maintain a complicated infrastructure that is unique to their institution.

Data security is increasingly in the news as the media focus on "mischief makers" seeking to gain access to network structures that are intended to be secure. These threats are carried out for bragging rights and sometime for the sinister purpose of causing harm. While most reputable institutions take action to detect and thwart such activities, it is impossible to prevent each possible effort. Complicating matters further, some of these activities are simply the result of human, but well intentioned, error.

Tangentially related to these data security issues are data privacy issues. Security relates to ensuring that the data is properly protected from external parties. Privacy relates to assurances that the data use is limited to the purposes intended by the patient. Patients generally trust their doctor and want to provide their doctor with the best data they can to ensure the highest level of healthcare. This does not suggest that same level of trust applies to the administrators or the support structures that assist the doctor. Patients want to have an active voice in determining when and how their healthcare data is utilized by the larger healthcare community.

The healthcare environment is fluid. Patients change doctors, see specialists, change insurance carriers, go to clinics, and go to different hospitals. At the same time, doctors change hospital affiliations, alter partnerships, and change insurance company relationships. The healthcare system is structured with the expectation that the logical linkages within the healthcare ecosystem will evolve over time and in a data centric world this will force the data within the ecosystem to move. Moving forward, as new devices and capabilities come on line, these new sources of data must be integrated with historic records.

Technology, particularly when it is first introduced, is expensive to develop, deploy, train, and build processes. It often obsoletes existing equipment or forces expensive upgrade procedures onto legacy systems needed to maintain system-level compatibility. These management and administrative challenges are compounded by the pace of regulatory change and by tightening budgets due to decreases in reimbursement for services. Requests from third-party and government agency payers continue to demand expansion of services with decoupling of services from reimbursement. The health systems are requested to bear higher acuity stress and loads with shrinking bed capacity and an aging population. .

Stacking Engineering Progress for IoT Implementation in Healthcare

Technology can be considered as a tool that is an enabler of new services and approaches to communication while disrupting slower and less responsive healthcare paradigms. The information superhighway carrying medical traffic must be engineered with specific routing of traffic, rights of priority in traffic lanes, and assured velocities of travel. And, to complicate this consideration, historic progress can make progress more difficult because incremental gains are more complicated than historic gains.

Innovation in digital technology and communications devices continues to improve speed, decrease power consumption, shrink microprocessor chip sets, and increase memory storage. A stack of technological effects relevant to healthcare can be described.

1. IoT Device Physical Factors: The semiconductor and device industry continues to reduce the size and power footprint of IoT devices. This serves to reduce the cost of the devices while simultaneously increasing the amount of data produced. In the healthcare space this leads to improving performance, accuracy of measurement, and sensor diversity of the patient. The emergence of devices continues internationally at a pace that was not contemplated during the prior generation of communications tools. As use of consumer-level health tracking and fitness

devices grows, health care applications will appear with reduced latency, lower costs, greater quantities of data, and growing reliability in obtaining automatic physiologic measurements.

2. Network Communication Velocities: The emergence of wi-fi, 4G, LTE, and 5G mobile network protocols offer increasing digital bandwidth available to host mobile communication devices. When applied to medical communications, users can be spread over an increasing range of geographies and environments while maintaining digital communication.

3. Data Warehousing and Inventory: The real-time recording of large quantities of information from multiple sources requires warehousing in centralized databases on the cloud. Enabling technologies have appeared in data warehousing and centralized database administration to improve the experience of building, operating, and maintaining large quantities of secure health and medical information for research and reference purposes. While university-level affiliated medical centers and healthcare organizations presently utilize these systems for research purposes, these capabilities will soon reach community-level primary care providers, ancillary caregivers, and the patient.

4. Patient Transport Process: Rather than requiring the transport of all patients to a physically present healthcare facility prior to assessment, personal health and medical information can be presented to the healthcare team prior to transporting the patient. This allows efficient routing of the patient to match patient need to the facility acuity level. Efficiencies can also be realized by freeing the practice of healthcare from inventories of specialized medical equipment that are tied to a specific location and pushing lower cost devices to lower acuity levels of care.

5. Local and Global Intelligence: A wealth of insight will soon become available to support individual and community level healthcare decisions. The application of machine learning and artificial intelligence processes to extremely large datasets may reveal relationships in community-level, population-wide datasets that individual healthcare practitioners will otherwise be unable to observe. Progress is being made in the automation of data analysis, machine-learning, and artificial Intelligence (AI) to transform voluminous data into actionable metrics. As wireless networks proliferate globally, previously underserved populations will have easier access to medical knowledge and health education content. At a physical level, these data will allow more accurate and timely communication with individual users gaining mobility and access to care. Healthcare services will have mobility instead of being fixed to specific offices or locations.

Objectives in Applying the Internet of Things to Health Care Services and Delivery

As the effects of these interactive technological innovations build, objectives in application of the technology to health care services must be considered. As a general observation, it is expected that IOT and technology in general may enable gains in the healthcare industry by addressing one or more of the following objectives:

1. Identification of Health Trends and Medical Needs for the Individual User: Communication technology will assist in identifying individuals with changes to physical function and, perhaps, the need for medical assistance, support, and care. Technology can also assist defining the types of health care services required in terms of urgency, procedure type, and the location for that care. Advancements in technology, when applied in healthcare, will continue the shift from a triage and response paradigm to a predictive and preventive model by empowering individual patients, care providers, and health systems with population wide insight.
2. Matching the Individual to Health System Service Resources: Technology will improve communication between healthcare resources and individuals with the need for assistance, support, and care. Once identified, users can locate and communicate with networks of healthcare

professionals with a wide range of healthcare affiliated resources, including sub-specialists, primary care, pharmacies, nursing care, transportation services, social workers, community resources, and caregivers.

3. Monitoring of Community and Population-wide Health Metrics and Analysis: Advances in technology will improve preventive health care services provided on a community-wide level. Moreover, progress in the personalization of healthcare delivery cannot be achieved without equal progress on a community and population-wide basis.
4. Monitoring of Efficient Use and Quality of Health Care Services: Healthcare institutions continuing to make progress to improve the efficiencies of their specific institutions. While laudable progress has been made, technology can be utilized to drive these efficiencies to a larger stage by use of data services to interoperate between health care centers and systems.
5. Personalization of Community Environmental Metrics: It has been widely accepted that health issues are often driven by the environment. But healthcare institutions do not, as a matter of course, collect environmental data about how patients live their lives and include that data as part of health records. If the healthcare professional had information focused on individual environments, personalized treatment plans can include recommendations tailored to environmental factors impacting patient well-being.

Examples of Next-Generation IoT Integration Impacting Healthcare

Next-generation, health care systems will be based on platform architectures that clearly segment the infrastructure, applications, devices, and communications systems into different logical layers. The following examples describe a cross section of evolutionary programs that illustrate efforts to create forward looking systems that meet current needs while simultaneously providing a path for forward growth.

Examples of Identification of Health Trends and Medical Needs for the Individual User

Some IoT devices require patients to self-monitor and self-manage their health while at home. The simple fact that a part of the population is motivated to participate in the healthcare process is a positive step forward for healthcare in general; however, the home health technology environment is not always HIPPA compliant. This should raise questions about data authenticity, quality, and privacy as this data passes through a gateway into a HIPPA compliant domain. Additionally, the home-health care device market often does not receive FDA approval, which means the data from these devices are not calibrated or tested against an industry standard; the same data from different devices might be calibrated or measured differently making the reported data (and healthcare integration efforts) vendor dependent.

In another example of physiologic observation of individual users, a team of researchers from the Massachusetts Institute of Technology in Cambridge created RF-Pose, a wireless smart-home system that employs artificial intelligence to sense people's movements through walls (http://news.mit.edu/2018/artificial-intelligence-senses-people-through-walls-0612). The development team utilized a neural network to analyze how radio signals bounce off people's bodies — even when they're on the opposite side of a wall. During a recent research study, the neural network was able to successfully extrapolate these findings to sense a subject's postures and movements. The researchers are using this sensor technology, coupled with AI intelligence, to work with physicians to allow physicians to monitor patients with conditions like Parkinson's Disease or Multiple Sclerosis. The goal is to assist the physicians understanding of the disease progression, without requiring a patient to wear personal sensors. Dina Katabi, team leader and professor in MIT's Computer Science and Artificial Intelligence Laboratory reported, "We've seen that monitoring patients' walking speed and ability to do basic activities on their own gives healthcare providers a window into their lives that they didn't have before, which could be meaningful for a whole range of diseases. " The researchers intend to implement a consent mechanism for RF-Pose before deploying other "real-world" applications as well. These mechanisms require the participant to simply perform a specific set of movements prior to the system monitoring the environment to obtain a baseline set of data on which to compare the ongoing surveillance by the AI system.

Northwestern Medicine, a Chicago based health care system, is launching an artificial intelligence center focused on cardiovascular disease with funding from a $25 million charitable donation (https://www.prnewswire.com/news-releases/northwestern-medicine-receives-transformative-25-million-gift-from-the-bluhm-family-charitable-foundation-300671938.html). The Bluhm Family Charitable Foundation's gift builds on the foundation's previous financial donations to Northwestern Medicine. In 2005, the foundation — formed by Chicago philanthropist and real estate developer Neil G. Bluhm — established the Northwestern Medicine Bluhm Cardiovascular Institute. The new gift will support the investigation into how advancements in artificial intelligence and machine learning can help improve cardiovascular disease diagnosis, treatment, and research. According to Patrick M. McCarthy, MD, executive director of the cardiovascular institute, "Artificial intelligence is the next frontier in breakthrough medicine, and Northwestern Medicine is leading the way by incorporating this emerging technology throughout its cardiovascular programs."

Medtronic created an application based diabetes management assistant, called Sugar.iQ (http://newsroom.ibm.com/announcements?item=122916). The Sugar.IQ application, which is now available to users of Medtronic's Guardian Connect continuous glucose monitoring system via Apple's App Store, employs artificial intelligence and analytics from IBM Watson Health to analyze how certain foods, insulin dosages and daily routines influence glucose levels. The Medtronic and IBM Watson Health's goal for the application is to provide patients with personalized guidance addressing how best to control their glucose levels. Patients who used the Sugar.IQ app spent 36 more minutes per day in the healthy glucose range than they did prior to downloading the application, according to research presented at the 78th Scientific Sessions of the American Diabetes Association.

A research team from the University of Waterloo in Ontario, Canada, is developing a new method to detect changes in diabetes patients' glucose levels without the need for an invasive blood draw (https://eurekalert.org/pub_releases/2018-06/uow-aar062718.php). Traditionally, diabetes patients must monitor their blood glucose levels by drawing blood via a finger prick several times a day. To avoid the need for frequent blood draws, the researchers are working with Google and the German hardware company Infineon to utilize radar and artificial intelligence technologies to detect changes in patients' blood glucose levels. Initial tests indicate these technologies were 85 percent as accurate as traditional blood analysis. The project employs radar to send high-frequency radio waves into a patient's blood sample and the returned radio waves contain information about the patient's glucose levels. Researchers proceed to analyze this information with AI algorithms that detect glucose changes based on 500-plus wave characteristics, such as how long the radio waves take to "bounce back" to the device sensor. George Shaker, PhD, an adjunct assistant professor of electrical and computer engineering at the University of Waterloo and leader of the research team, envisions a day when there will be the ability to analyze blood conditions inside the body without actually having to sample any fluid. Continued research efforts are expected to improve sensor sensitivity and ultimately allow these advanced detectors to obtain results through a patient's skin. In the future, it may be possible to build the technology into a smartwatch type device to actively monitor a patient's health in hospital quality data.

The University of Iowa Health Care in Iowa City is using IDx's AI diagnostic system in the diabetes care setting (https://www.prnewswire.com/news-releases/university-of-iowa-health-care-first-to-adopt-idx-dr-in-a-diabetes-care-setting-300672070.html). The system, called IDx-DR, utilizes artificial intelligence to detect diabetic retinopathy, and has been approved by the FDA to provide screening decisions without requiring a specialist to interpret the results. To use the IDx-DR software, a provider uploads digital images of a patient's eyes, taken with a specialized retinal camera, to a cloud based database server. On the server, IDx-DR applies an AI algorithm to analyze the images and determine whether the patient has more than a mild case of diabetic retinopathy. Diabetic retinopathy, a diabetes-related eye disease, is the most common cause of vision loss among diabetes patients in the U.S. If the software detects more than mild diabetic retinopathy, it refers the patient to an eye care professional for a more in-depth diagnostic evaluation. If IDx-DR does not detect the condition, it recommends the diabetes patient undergo a routine rescreen in 12 months. For the University of Iowa Health Care, the device allows providers at the diabetes and endocrinology center at UI Health Care-Iowa River Landing in Coralville — who aren't typically involved in eye care — to employ the device to complete patients' annual diabetic retinopathy screenings. According to E. Dale Abel, MD, PhD, director of the division of endocrinology and metabolism at UI Health Care, "early detection of diabetic retinopathy is an essential component of comprehensive diabetes care. This innovation further strengthens the ability to provide state-of-the-art care for patients with diabetes."

Examples of Matching of Individual Needs to Health System Service Resources

An example of communication technology intersecting with medical devices occurs daily when paramedics utilize digital communication technologies to share medical data from devices in the field with supporting emergency rooms during emergency response. This allows the first-responders to provide rapid diagnostics and immediate medical interventions in the field or during patient transport. Additionally, medical personnel in the ER can be notified of the pending arrival of a patient in distress and prepare emergency care resources prior to arrival of the patient. This same concept can also be employed to permit individuals to send personal healthcare information to their doctor before less acute needs arise.

For several years, there have been publications of specific use cases when digital communication technology is applied to post-operative monitoring of patients upon discharge from the hospital. This monitoring of patient out-comes is helpful to address government mandated metrics reported by hospitals to regulators.

Geisinger's Steele Institute for Healthcare Innovation is deploying an artificial intelligence tool at Geisinger Medical Center in Danville. (https://jvion.com/news/press/geisinger-s-steele-institute-for-healthcare-innovation-selects-jvion-s-ai-to-help-transform-care-delivery). The AI tool, which Jvion brands as its "cognitive clinical success machine" solution, will aid Geisinger Medical Center in reducing avoidable readmissions related to chronic obstructive pulmonary disease, a group of lung diseases.

Examples of Monitoring of Community and Population-wide Health Metrics and Analysis

An example of community-wide healthcare technology being used to help monitor risk for future disease is the monitoring of vaccination rates in California schools. State-mandated reporting of the immunization status of children was previously handled by way of primary care physicians completing hand-signed paper-based forms. Previously, these manually completed forms conveyed dates of each vaccine for each pupil. However, processing of these forms by primary care offices, school district personnel, and school nurses was manual and time-consuming. Development of digital vaccine registries and district-wide, student health databases and applications permit sharing of data with district-wide analysis across the population of students in each school site in a community.

Previously published clinical research on "herd-immunity" defines the vaccination-rates required in a community to protect children from vaccine-preventable infectious disease. Therefore, the population-specific data which is calculable from school district based student health metrics provides an assessment of the risk of contagion and spread of vaccine preventable infectious disease in schools.

Compliance by healthcare providers in a community with public health recommendations is visible on a geographic basis. These metrics can also provide temporal insight to characterize the effect of public health messages on vulnerable populations. Expansion of these capabilities will make use of metrics to reveal issues impacting delivery of care, including the alignment and implementation of regional public health recommendations by community-level health care providers. Advancement in the communication technology will allow revision of these recommendations on a timelier basis.

Examples of Monitoring of Efficiencies within and the Quality of Health Care Services

Healthcare professionals have constraints on their time spent per patient encounter. Consider an 8-hour work shift, not including required break time with a ratio of 1 nurse to 8 patients. This leaves the nurse 60 minutes to care for one patient per 8-hour shift. This does not include the time to interface with digital documentation systems. Assuming the nurse logs in and reviews existing health care records for the first 10 minutes of the patient intake process and then spends 20 minutes at the end of each patient visit updating the records, a mere 30 minutes is left to interact with the patient. As IoT increases the amount of data in the records, the amount of time required for records review will increase and face-to-face patient time will logically decrease.

One challenge facing IoT deployments relates to the need that IoT data be self-organizing. The increased volumes of data cannot be allowed to reduce doctor-patient time and should be targeted to increasing patient time compared to today's current practice. To do this, as IoT devices generate patient specific data, the data must be automatically logged into the patient's medical record to minimize the human time required for data management. Further, the patient's record must be self-organizing (based on AI) so the most important data is prioritized in presentation to medical staff. Perhaps the default setting should be that patient records are presented to the medical staff in terms of priority with the most critical points being presented ahead of lower priority data.

Fortunately, several of the top EHR vendors are nearing the release of IOT based AI systems that will assist clinicians with the basic input of data. A major complaint by physicians and care givers is the increased time to complete the electronic record, and decreased time with the patient and their family. By restructuring a patient visit and utilizing IOT and AI, many aspects of this challenge can be overcome. At least one EHR vendor has a prototype of this patient visit workflow redesign. It consists of various IOT devices that gather information prior to the visit, then uploads this to the patients EHR at the time of the visit. Once the doctor walks into the patient room, two video and audio arrays monitor and track the conversation and exam. The EHR is populated with the IOT device information, as well as the conversation and exam. Medications, orders, diagnosis, and many other elements are populated in the EHR prior to and during the visit. This saves clinicians both time and effort.

A group of researchers from the Center for Robotic Simulation and Education at the Los Angeles-based Keck School of Medicine at the University of Southern California have implemented artificial intelligence to measure surgeons' performance and described their experiences in an article for JAMA Surgery (https://jamanetwork.com/journals/jamasurgery/article-abstract/2685266). The current standard for evaluating surgeons is peer review by an expert evaluator, either during surgery or from video footage following the procedure. To improve the accuracy of the process and decrease the need for expert evaluators, the researchers developed a method to automatically analyze data captured by surgical robots. Robots represent high end IOT devices that can feed data to AI based learning systems to analyze performance and then actively learn from the process. The researchers employed a Da Vinci System to collect performance metrics and then used AI algorithms to recognize patterns in a surgeons' performance. They found the algorithms could "objectively measure surgeon performance and anticipate patient outcomes." "Systems data captured directly from the robot provide an opportunity to more accurately and objectively measure surgeon performance." Similar types of technology are expected to be applicable to support personalized surgeon training as well.

Efficient use of health care space is also helped by the development of algorithms that are capable of monitoring the duration of time required to complete procedures. This allows equipment inventory to efficiently manage sterilization procedures, decrease idle time in key areas, and improve the ability of support staff to prepare equipment and rooms for subsequent use.

Innovation in the use of digital communication devices impacts how medical care is rendered. The growth of telemedicine services across the United States over the past twenty years has helped to address access to care issues in rural communities. These same technologies also assist urban medical centers when consulting with specialty physicians who may be on-call for multiple centers. These panels assist in situations requiring higher levels of medical expertise to diagnose and treat patients with complex illnesses. The communication network becomes a force multiplier for the region.

In many medical centers across the nation, radiologists remotely review and report results of radiographic procedures. Electrocardiograms (EKG's), Echocardiograms, and some radiographic procedures (x-rays, CT scans, and MRI scans) are examples of medical procedures which can be ordered on an emergency basis from a major hospital ER and where the review of the results can be reported by physicians that are distant to the site of care. The ability to gain immediate and mobile access to rich, high-definition video content by these licensees may significantly impact their quality of work, care, and life.
There are some medical centers where "on-call" radiologists are available in very distant locations, including outside the borders of the United States. This allows night-time emergency procedures to be reviewed by physicians working a day shift in another time zone. This time shifting of work is relevant to the accuracy and speed of reporting and in the well-being of physician specialists and the patients served.

In another example of digital technology helping to address efficiencies in patient care, the "eICU" project at Emory University's medical center built the ability to supplement on-site critical care medical personnel with similar personnel situated in a communications center on the opposite side of the world. By building this "eICU" capability, night-shift management of patients in Atlanta is assisted by day-shift critical care physicians in Perth, Australia. This is an example of how medical device data can be shared through a digital network to improve the well-being of patients while improving efficiencies in the healthcare workforce.

Example of Personalization of Community Environmental Metrics
In 2012, the Air Louisville project partnered local funders, the city of Louisville, and Propeller Health to deploy 300 asthma inhaler sensors that track administration of each use of asthma medication from the inhaler. Scaling of the program to over 1000 sensors and patients was funded by the Robert Woods Johnson Foundation. This program aligned these new devices with public health interests in controlling asthma on the municipal level. Although the project did not personalize environmental air-quality measurement, it did personalize the monitoring and tracking of asthma inhaler use and asthma intervention. Heat mapping generated by inhaler use data illustrated areas of higher inhaler use while different mapped regions correlated to higher hospitalization rates, suggesting that higher incidence of hospitalizations for asthma occur in areas of less compliance with asthma interventions. This complex project involves calibration of sensor data to maps and other environmental data from the city of Louisville. The project can be reviewed at www.airlouisville.com.

Technology Enabled Capabilities and Issues

Calibration, testing, and tracking of home-healthcare devices is expensive and drives the price of many home-health care tools outside the reach of many consumers. As an alternative, given that the ability to process data is increasing at such a rapid rate, information reported by a specific class of medical devices might be aligned to an industry standard protocol. Several candidate protocols currently exist.

The effort required to organize data to draw a medical technician's attention to the most important information can be a simple or complicated process. Some organizational rules in healthcare are standardized through medical training. For example, the heart rate, temperature, and blood pressure are universally recorded and should be reported as one of the first records of any electronic healthcare record. Many of the current EHRs allow for the customization of the record now, with new decision support algorithms also being created regularly.

Other indicators are more nuanced and their priority depends upon other data records. By analogy, over-the-horizon early-warning systems deployed by defense agencies quantify risk of attack by utilizing radar. In those monitoring systems, the impending danger is determined based on the existence of a complex set of trigger warnings. If conditions in a trigger situation are met, an alert or automated response is transmitted to an appropriate authority. In the case of medical care, physiologists and physicians are aware that specific physiologic measurements are a potential indicator of concern warranting closer evaluation. Those conditions cause the monitoring process to message warnings. Different medical specialties may be characterized differently in the expert system, allowing a specific doctor to have their issues uniquely flagged. Moreover, one doctor will be able to observe the issues that have been raised to other doctors, thereby improving doctor-to-doctor coordination.

In the United States, the majority of the healthcare needs are supported by insurance companies and overseen by regulators. Most patients are supportive of any advances in healthcare that improve the level of healthcare or reduce the cost of services, however, there is significant concern that the same data that allows improvement in the diagnostic/treatment processes will be employed by insurance companies to identify higher risk individuals to influence coverage decisions or alter monthly premiums. Despite promises from the insurers this will not occur, consumers are wary that the potential exists. The existence of a promise from an untrusted financial stakeholder with profit incentives are not comforting. Regulators have been positioned to serve as a check and balance against the insurance industry but regulators move slowly compared to ever-evolving technologies.

Economics represents another issue facing the industry. The cost of deploying IoT systems in a sufficient density to create a sufficiently significant blanket of data is staggering. Making use of incentives would shift some of the burden of creating this ‘fabric’ of IoT devices from the healthcare institutions to the general public. For example, if healthcare providers gather environmental data from privately deployed IoT devices, it means the healthcare industry does not need to duplicate that investment with industry owned IOT devices. Incentives can increase deployment in areas with economic means, but targeting specific areas would allow costs to be targeted yet will also contribute to a growing medical data divide where those with the economic means will have better healthcare than others. Ultimately insurance companies and/or government agencies must play an increased role in deploying these IoT systems to ensure the data coverage (and data driven healthcare in general) is not rationed.

The described concerns are problematic in today’s healthcare environment and addressing these concerns may improve healthcare efficiencies in the near term. However, longer term, as these kinds of monitoring devices become pervasive, these issues will grow in magnitude and solutions will become harder to adopt. After all, it is easier to repair a plane while it is on the ground compared to in flight.

As IoT systems are expanded, the volume of data produced by the IoT devices will grow exponentially. The real-time nature of the data allows response time improvements and also improve the ability to predict future health issues. However, predictions rely on historic data which implies a need to retain these vast volumes of real-time data as legacy records that can be incorporated into predictive analytics. The growing volume of IOT devices and the increased need for retention of historic data creates an expanding data management problem. There are alternative proposals that suggest placing intelligence at the edge of a network to filter the data thereby reducing the amount of data managed centrally. However, inherent in such proposals is the implication that the need for data is well understood. While reducing the data volume at the edge saves on storage and communication cost, it also reduces the amount of data that can drive predictive health care analytics. In many ways, data is like an investment and filtering data at the edge may save costs near term but also reduces the potential that can be derived from the data. Given that network communications and data storage costs continue to plummet, the tipping point that determines whether data should be saved or discarded will continue to shift from filter based proposals toward centralized data repositories.

Centralization or decentralization of data represents another area of potential activity. Centralized repositories have been the industry norm for approaching data management issues. While distributed database systems have been in existence for many years, the appearance of blockchain as a community managed alternative to the centralized system have drawn increased interest. It is difficult to discuss blockchain systems as a whole because there are so many incompatible variations of blockchain making it a challenge to compare data management alternatives. In general blockchain was developed as a means of conducting data transfers in an environment where there is no trusted central authority. In blockchain, a community agrees to work together to support a shared data repository. The coordination required between the involved carries the baggage of reduced performance. But this overhead allows improved privacy and security if a central authority cannot be trusted. What is unclear is whether blockchain eliminates the need for a trusted relationship, whether it fills an operational need until a trusted relationship can be built, or whether the performance penalty that comes with current blockchain systems melts away as communications costs continue to fall.

Environment data, such as weather data, includes data such as pollen counts. This data is typically created from digital models rather than actual sensor readings. While this data is useful, it lacks the clinical significance of data that is generated from a network of local sensors. Some state and local agencies have deployed sensors that measure ozone, carbon monoxide, nitrogen dioxide, and sulfur dioxide (components of smog) for research purposes in limited areas. Real-time data from these systems is utilized by some commercial organizations (e.g. purpleair.com, airbeam, ..) as low accuracy data streams. While these systems provide real-time data, the nature of the data collection methodology is often not well documented which limits the usefulness of the data in a healthcare setting. For example, some of these systems fail to distinguish indoor from outdoor air quality or clearly identify mobile from fixed-site data collection. Moreover, the accuracy of air-quality sensors is sometimes related to the quality of the detection sensors but the specifications of the specific sensors are often not disclosed. Organizations such as The South Coast Air Quality Management District looks at these early system as a first step and is continuing their efforts to build and expand on the capabilities and assessments.

To date, there have been many proposals that suggest that Machine Learning and AI algorithms can be directly applied to assist emergency services personnel during times of crisis; these same systems can be made available to citizens for improved information access while emergency services are en-route. The capabilities of these AI driven systems are proportional to the amount of data available to them. While the capabilities of these systems are already impressive, the data ingested to date is largely professional quality data which implies they could be doing demonstrably more if they were able to tap the full extent of the digital world.

In a note of caution, researchers at the Massachusetts Institute of Technology in Boston created what they've dubbed the "world's first psychopath AI." (http://time.com/5304762/psychopath-robot-reactions/) The artificial intelligence algorithm, nicknamed "Norman" after the character Norman Bates in Alfred Hitchcock's film “Psycho”, generates captions for Rorschach-style inkblot psychological tests. Because the researchers trained the algorithm on violent content from what they call "the darkest corners of Reddit," Norman applied more disturbing descriptions than industry standard image captioning models. In one example, a standard image captioning model described an inkblot as "a group of birds sitting on top of a tree branch.” However, Norman provided the caption "a man is electrocuted and catches to death." The researchers stressed their reason for developing Norman was to underscore a foundational principle of AI — use of AI to achieve better treatment of mental disorders is highly dependent on the data that drive the AI engine. The MIT research further demonstrated that data employed to teach a machine learning algorithm can significantly influence its future behavior. This also suggested that the some mental disorders can be exacerbated by exposure to biased data and perhaps a possible treatment might be influenced by altering the prevailing data.

The Road Forward

There is a consensus understanding that increased volumes of data can improve healthcare outcomes while also lowering costs. However, the operational structures that evolved to ensure health care quality cannot be extended to cover all the data that might have a positive impact on healthcare outcomes. The current trend is to ask consumers to contribute their generated data into an ecosystem managed by the healthcare and insurance industry. Unfortunately, this evolutionary push will be impeded by consumer trust issues given that the healthcare industry is overseen by insurance and various governmental agencies.

Further complicating this issue is the fact that the healthcare industry, including hospitals, medical centers, pharmacies, and third-party medical management companies) do not have the staff or insight into the dramatic expansion coming to reality in data and communication technologies (big data, artificial intelligence, Internet-of-Things, and more). Delegating or outsourcing efforts to manage the growing number of data driven healthcare processes to external services has limits unless these companies are willing to assume liability for automated healthcare decision making processes.

A new path forward is necessary to support a healthcare system that is able to incorporate all data that might serve to improve healthcare outcomes. Patients will not be satisfied releasing their personal data to a managed healthcare ecosystem unless they are provided direct involvement in the use of their data. Personal involvement in data decision making implies patients may also wish to make that same data available to parties outside the traditional healthcare ecosystem. Data is data and it does not become healthcare data until it is put into a managed data infrastructure; that same data can be processed for purposes outside the HIPPA managed bubble with the user being directly involved in the process. It is possible that a manager of these data structures can refuse to accept data from devices which they consider to be unacceptable. Device manufacturers may seek to have their devices certified by one or more of these ecosystem managers. Data infrastructure managers, data producing devices, and healthcare applications can exist outside the managed environment to provide guidance for external patient advice portals. These external system can be bound by geography, insurance coverage, or political designations. Effectively there are multiple healthcare ecosystems, some with industry/government oversight and control while others do not. Both the regulated and unregulated environments should be accessible to the greater medical community, with researchers and public health personnel, possibly having access to all of the data.

It is possible that the role of a primary care physician in the near-future will begin to shift from that of hands-on care at a designated office appointment to a personal healthcare advisor. Perhaps, as part of the appointment process, the patient is first asked to visit one or more healthcare AI service so the patient and doctor start the consultation process from an informed state. A tele-medicine consultation process serves as a first step before the patient sits with the doctor so more of the doctor's time is spent with the patient's concerns and less with the preliminaries. While such a preliminary referral might not be an absolute requirement (not everyone will be comfortable with such a process), it is possible the insurance company might waive or reduce the copay in exchange for the patients efforts to actively participate in the healthcare process.

For example, the I3 Consortium (i3.usc.edu) is creating a data architecture where patients can manage how their healthcare data is broadcast and who has access to the IOT data they generate. Consumers who are concerned with community health issues will have the option to contribute certain aspects of their healthcare data to officials at the public health departments. Some patients will want to turn these data feeds on during flu season and turn them off at other times, while some others with security concerns will opt against participation. Independently, citizens will have the option to send the same data to their local physician for preventative purposes, or they will opt to release the data to insurance companies for a lower premium, and maybe they will release the data to a personal service that monitors their health and well-being outside the managed healthcare environment.

In times of healthcare crises, it will be imperative to have the capability for citizens, healthcare professionals, and government agencies to rapidly reconfigure the data driven healthcare infrastructure and systems through initiatives such as I3 (A consortium developing an opensouce Internet-of-Things data governance system based on research from USC-Marshall's Institute for Communications Technology Management and USC's Viterbi School of Engineering), which are positioning themselves to fill that need.

With these systems in place, it is possible that in addition to empowering citizens to be more actively involved in the healthcare data ecosystem, it is possible that some of these data processing needs can be moved outside of the already overtaxed government/insurance managed healthcare system.

Generally speaking, most technology driven advances occur in compartmentalized and independent bubbles; progress achieved in one sector serves as an enabler for progress in another. Properly implemented, technologies like smartphones, EHRs (Electronic Health Records), and even Wi-Fi, have allowed the healthcare industry to improve the level of care for patients, efficiencies for administrators, and returns for shareholders.

For example, building an automated inpatient monitoring system for the hospital can improve operating efficiencies while improving patient care, but more can be accomplished if data from other administrative domains and consumer devices could be integrated to create a more holistic perspective. Capitalizing on this untapped data to bring incremental value to the healthcare industry is exceedingly difficult when these systems are run by different administrations who have made independent solution purchasing decisions. Further, integration complexity problems can be expected to increase dramatically as the industry continues to shift to data-driven patient management paradigms. Consider a medical device developer who has created a next generation device that gives rise to a plethora of patient monitoring data. Practically speaking, it is almost impossible for an IOT device developer to contemplate all the different ways the data can be utilized by a healthcare professional. If, instead, data collection devices were independent from applications, a single device can drive multiple different diagnostic applications and the issue becomes one of connecting data generators with data consumers. Concepts like VNA (Vendor Neutral Archives) have begun to move the industry in the right direction by allowing medical images to be filed with EMR systems for independent access by various applications; but this concept must be extended to include other IOT devices as well.

Given the lack of an IOT VNA, today's practice considers an IOT application and the associated IOT devices as a complete system. This practice couples IOT devices to specific applications. However, by linking devices to applications, the net effect is to create a series of IOT application silos that are individually managed. Operationally, this is a complex proposition because staff must be dedicated to each silo or staff members need to become operational generalists that provide basic support to a larger number of applications. This same siloed architecture also limits the healthcare professional's ability to leverage data across a broad infrastructure. If certain applications are only aware of a limited number of IOT devices, it may be necessary to duplicate IOT device deployments if a deployed device is incompatible with a new application.

Some IOT application providers have attempted to solve this dilemma by creating application layer APIs which allows their application to link with another, as long as the other application is willing to accept data from a 3rd party. This creates a manageable hierarchy assuming the number of applications remains small. However, such an architecture begins to operationally suffer as the system scales to support a larger number of applications. Moreover, because the connectivity is dependent on the behavior of the applications, each application can become a reliability/performance choke point. Such stop-gap measures can be expected to proliferate until a VNA-type vision is applied to healthcare IOT.

While VNA philosophies can be utilized to reduce the IOT application silos, they will likely not be able to incorporate consumer-targeted medical data into their archives as native data. Consumer IOT devices do not generally live up to medical device quality standards. Comparing a medical halter monitor to data generated by a consumer device will likely lead to confusion unless the healthcare professional knows the source of the data and the validity/reliability of the data sourced from such a device. Additionally, the behavioral dynamics that govern consumer use of a monitor provided by the doctor for temporary use is far different from the behavioral dynamics at play when a consumer purchased IOT device is continually providing data to a third party. Consumers may expect incentives, direct control, and other benefits to accrue from these devices personally procured from outside the healthcare industry. As an additional complication, these independent devices add another dimension to the security conversation given the open nature of these markets.

The creation of an evolved architecture that allows vendor neutral data stores and integration of consumer and medical data into one repository may require additional extensions to current practices. VNA systems can be integrated into medical record management systems at different points in the information flow. However, inclusion of consumer data into medical data flows implies a need for a tool that can serve to route the IOT data into the medical data space AND also route it to one or more consumer-friendly applications. Given that the system needs to support data flows between a variety of end-points, the routing mechanism must be security aware so that misbehaving IOT devices (and applications) can be identified and isolated from the network. In addition, the system must support the creation and management of trusted relationships between data end-points with an appreciation for the fact that trust is a dynamic and very personalized expression of acceptability.

The forces that will drive the shift from an application-centric IOT environment to an infrastructure-centric environment are the same as those that drove the evolution of the Internet, with the only tangible uncertainty being the velocity which drives such changes. It can be argued that the lack of an open IOT infrastructure will confine the majority of health care IOT by the IT department's span of control. That is, if an IT department can enforce specific device and application deployment decisions, the need for an open IOT architecture can be reduced. However, such a dictated IOT support plan limits ecosystem partnerships (linkages to independent clinics, surgery centers, ambulances, etc.), and impedes patient-centric participation (unless the hospital provides all needed IOT devices and support).

In an effort to expand the health care paradigm, it becomes important to look at healthcare in the context of the patient. Rather than diagnosing the patient based on information gathered at the doctor's office, the patient should be able to provide the doctor with information about the environment where they reside, work, and transit. Environmental data, including data from consumer quality IOT devices would allow the doctor to makes much more informed healthcare decisions. Further, as healthcare-focused artificial intelligence applications become common place, applying data analytics to the wealth of real-time data about individual patients will become common practice.

The reality of this vision is technologically attainable; however, there are many non-technology driven issues that must be faced and conquered before it can be realized. First, all entities must accept the privacy and manageability of such a system – this is not to say that consumers must change but instead means that systems must evolve to accept working within the individual's privacy domain. This is not an easy or straightforward task in that those who generate this data (via their devices) must be comfortable with the fact that they have control over who can see their data and that they can easily extend or rescind data permissions based on their self-interest. In such a data centric word, patients must be treated as health-care partners where they are providing data in exchange for services; this is a give and take relationship like any other partnership. And, like any such partnership, the amount of sharing that occurs is proportional to the level of trust that exists between the parties, and this trust must be developed and maintained over time for the partnership to be successful.

Conclusion

In conclusion, data driven medicine is forcing the industry to step past the concept where the healthcare industry is a closed, regulated industry. If certified healthcare professionals are limited and can consider only management by certified infrastructure managers, their ability to make the best possible recommendations will be limited. The concept of a healthcare ecosystem must be expanded to include a broad spectrum of contributors and user groups. This future healthcare ecosystem should encourage data submission from a wide range of sources provided that the provenance of the data is confirmed and documented. Maximizing the use of the data by providers, health systems, and others while protecting the privacy rights of users is a challenge.

While data from IOT-enabled devices and other sources has the potential to improve outcomes, reduce cost of care, and improve the personalization of medical treatment in developed countries, the global impact of this technical trend is even more compelling. In developing nations, as telecom companies expand bandwidth and speed globally, it is possible for international NGO's to begin projecting medical expertise into developing nations.

Future health care digital networks and physical systems must be accessible both digitally and economically while protecting security and accuracy. These communication technology driven health devices and networks can improve personal and community-wide health and well-being, regardless of diagnosis, disability, health condition, socio-economic, demographic, or other personal privacy concerns. The on-ramp to improving use of IOT systems for healthcare lies in the creation of a big multi-lane, high-speed, digital on-ramp to the medical information superhighway of the future.