Transformation of the US healthcare system with the advent of
wireless sensing technologies

by

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ABSTRACT

The US healthcare system is looked at from the point of view of various stakeholders and how its current structure has emerged over the years. With the shifting demographics, change in disease mix, ICT revolution and other factors at play, the system is in a state of flux. Sensor technology on the other hand has also progressed over the years to reach a point where low-cost mass-produced smart sensors are becoming omnipresent. A variety of such sensors are now available, and new ones are being developed for specific needs, like for continuous health monitoring systems. New wireless sensing technologies are redefining the care services, processes and customer expectations. This is especially true for chronic disease management and eldercare. We develop a view point to understand at a broad level how the US healthcare system is currently evolving and what role could new technologies, like wireless sensing, play in shaping its near future. These new technologies are slowly gaining foothold in the market and could possibly reach a point of inflection soon where the population starts to adopt them in masses. By creating a new mental model of how various parts in the system interact with each other, we try and develop an understanding of which factors might affect the speed of adoption of these new technologies into the system.
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CHAPTER 1: INTRODUCTION

MOTIVATION AND INTENT

There are many forces currently shaping the way healthcare is being practiced today. The entire US healthcare system seems to be in a state of transition, with changes occurring all across. We are getting to see new technologies getting adopted into the system every day, which affect not only the various stakeholders but also our very understanding of what we mean by 'care'. With every new technology, the care processes change, the benefits derived and the role of each of the stakeholders in the system metamorphs. Wireless health monitoring through various wearable devices is now becoming more common. The faster such new technologies spread and provide benefits to everyone, the more incentive they offer to the researchers and the providers involved in bringing about such changes. We want to explore the links between the properties of the system, their rates of adoption and the roles played by different parties involved in the process.

A HIGH-LEVEL VIEW OF THE US HEALTHCARE SYSTEM

Looking at the US Healthcare system, one can easily get lost in a myriad of organizations and terminologies, and feel that there is no way to fully understand the complex web of interdependencies and exchanges in such a heterogeneous system. Over the years, a number of different types of organizations have evolved and each of them play such a variety of roles that it may be difficult to do justice to all of them in this brief overview. The following depiction gives us a sense of the variety of parties involved, but is not very helpful in understanding their relationships and roles.
US Healthcare system today, is a system largely based on the concept of insurance coverage i.e. the patients generally do not pay directly to the doctor or the hospital at the time when they take their services, but rather buy 'coverage' from an 'insurer' for a period of time by paying regular 'premium' (or taxes), and in case they do fall ill, the insurer pays the bulk of the bill for treatment. This system acts like a safety net, so the patient doesn't have to worry too much about costs when he/she falls sick.

For our ease of understanding, it helps to simplify the complex relationships and the variety of parties involved. At a very broad level, let us look at the categories of the parties involved, with the help of a representation like the following:
First is the patient i.e. the consumer of the healthcare services. The hospitals, clinics, doctors etc. form the provider side i.e. the healthcare service provider. The government, employers and health insurance companies form the payer side i.e. the party that pays directly for the healthcare services delivered. This kind of a system separates the Payer from the Consumer. You may notice that, indirectly, it is the Consumer who contributes most of this money through taxes and insurance premiums, but the control of who gets paid how much, now lies in the hands of the Payer.

Beyond these three primary parties (patient, payer and providers) are some of the key controllers and influencers in the system like the regulators (e.g. FDA, a government organization) and the private technology & drug companies. The private companies help bring new innovative technologies and drugs to the market, and the regulators control and approve these while keeping the interests of the patients safe. Then there are educational and research institutions who could be privately or publicly funded. The government not only plays a role as a payer, but
also as a regulator as well as a promoter of new research. The source of funding/monetary benefits and the regulatory constraints are two of the major forces which affect the control and behavior of all organizations. Hence, it is important to understand how the system is structured in terms of these forces.

But, before we jump into the underpinnings of the system as it stands today, it is important to take a brief look at how the American healthcare system has evolved over a period of time. It is also important to note that unlike many of the developed countries, US does not have a ‘Universal Health Coverage’ or ‘Single-Payer’ system. Under such a system, typically the government is the main or ‘single’ payer, providing basic health insurance for almost everyone in the country. The quality and extent of services offered to everyone are purely need-based irrespective of social standing, religion, income, age, health status etc., and people have the freedom to choose to opt-out or buy supplemental private insurance to augment the basic health coverage provided by government.

In the US, there was historically a strong public opinion against the control of ‘big’ government, and hence the federal government had a very limited role in healthcare especially till mid twentieth century. In 1960’s only half of the hospital care in America was covered by insurance, and almost all of prescription drugs bill was paid out-of-pocket(Catlin and Cowan 1960). A majority of the medical insurance, that existed at the time, was private/employer-based and the state and federal government mostly covered only their own employees. Employer based insurance means that the employer pays the major part of the insurance premium and the individual pays a ‘deductible’ when the policy is used. This left out the unemployed, elderly and disabled people with no medical insurance security net.

In 1965, President Lyndon B. Johnson signed the Social Security Amendment and started two programs called the ‘Medicare’ and the ‘Medicaid’(Cummings n.d.). Medicare provides voluntary supplementary medical insurance for the elderly (citizens above age of 65) and Medicaid gives grants to state governments to
subsidize medical insurance to those below a certain income level. This started out the progressively increasing role of the government in funding healthcare insurance. In 1997, another program called Children's Health insurance program (CHIP) was started to provide health insurance to children in families with modest income (Randolph Fillmore n.d.). Over the years, the number of people covered, the kind of diseases and treatments and the costs borne by the US government in providing (or subsidizing) for health insurance for its citizens has surged.

MAIN GOVERNMENT ORGANIZATIONS IN THE US HEALTHCARE SYSTEM

The U.S. federal government has a hierarchical structure of organizations managing healthcare related work. The principal agency for health care services is the Department of Health and Human Services (HHS). HHS has a number of offices and organizations under it, managing different aspects:

<table>
<thead>
<tr>
<th>Organization</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centers for Medicare and Medicaid Services (CMS)</td>
<td>Manages the Medicare program and works with the state governments for Medicaid and CHIP programs</td>
</tr>
<tr>
<td>Centers for Disease Control and Prevention (CDC)</td>
<td>Conducts research and programs to protect public health and safety</td>
</tr>
<tr>
<td>National Institutes of Health (NIH)</td>
<td>Responsible for biomedical and health-related research</td>
</tr>
<tr>
<td>Indian Health Service (IHS)</td>
<td>Responsible for providing federal health services to American Indians and Alaska Natives</td>
</tr>
<tr>
<td>Health Resources and Services Administration (HRSA)</td>
<td>Supports efforts to improve health care access for people who are uninsured, isolated, or medically vulnerable</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Agency for Healthcare Research and Quality (AHRQ)</td>
<td>Conducts evidence-based research on practices, outcomes, effectiveness, clinical guidelines, safety, patient experience, health information technology, and health disparities</td>
</tr>
<tr>
<td>Food and Drug Administration (FDA)</td>
<td>Responsible for promoting public health through the regulation of food, tobacco products, pharmaceutical drugs, medical devices, and vaccines, among other products</td>
</tr>
<tr>
<td>Center for Medicare and Medicaid Innovation (CMMI)</td>
<td>Created by the Affordable Care Act (ACA) to test and disseminate promising payment and service delivery models designed to reduce spending while preserving or improving quality</td>
</tr>
<tr>
<td>Patient-Centered Outcomes Research Institute (PCORI)</td>
<td>Created by the ACA, tasked with setting national clinical comparative-effectiveness research priorities and managing research on a broad array of topics related to illness and injury</td>
</tr>
</tbody>
</table>

**TABLE 1: ORGANISATIONS UNDER HHS (SOURCE: (MOSSIALOS ET AL. 2017))**

Beyond these there are other independent non-government organizations which play important roles like advising policymakers, accrediting service providers, plans, helping formulate public opinion and lobbying for different policies. Most of these organizations are non-profits who try and maintain their independence from other organizations by seeking and securing their own sources of funding, primarily through charity or member donation and fees.
Here is a list of some of these non-government organizations and the roles they play:

<table>
<thead>
<tr>
<th>Organization</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>The National Academy of Medicine (NAM, formerly the Institute of Medicine, IoM)</td>
<td>Independent nonprofit organization that works outside of government, and acts as an adviser to policymakers and the private sector on improving the nation's health</td>
</tr>
<tr>
<td>Joint Commission</td>
<td>Independent, nonprofit organization that accredits more than 20,000 health care organizations across the country, primarily hospitals, long-term care facilities, and laboratories, using criteria that include patient treatment, governance, culture, performance, and quality improvement</td>
</tr>
<tr>
<td>National Committee for Quality Assurance (NCQA)</td>
<td>Primary accreditor of private health plans, is responsible for accrediting the plans participating in the newly created health insurance marketplaces</td>
</tr>
<tr>
<td>National Quality Forum (NQF)</td>
<td>Non-profit organization that builds consensus on national performance priorities and on standards for performance measurement and public reporting</td>
</tr>
<tr>
<td>American Medical Association (AMA)</td>
<td>Comments on and lobbies for policies affecting the health system</td>
</tr>
<tr>
<td>American Board of Medical Specialties (AMBS)</td>
<td>Physician-led specialty certification organization that certifies medical specialists in more than 150 medical specialties and subspecialties</td>
</tr>
</tbody>
</table>

**TABLE 2: NON-GOVERNMENT ORGANISATIONS IN US HEALTHCARE SYSTEM (SOURCE: (MOSSIALOS ET AL. 2017))**
Here is a schematic to help us visualize the links between various organizations involved in US healthcare:

![Schematic diagram of US healthcare system](image)

**FIGURE 3: ORGANISATION OF US HEALTHCARE SYSTEM (SOURCE: (MOSSIALOS ET AL. 2017))**
There are many factors shaping the future of healthcare system in US

1. Demographics are changing (share of elderly population is increasing)
2. Disease mix is changing (lifestyle related diseases are becoming more common)
3. Technology is advancing (ICT, Medical Imaging/Genetics, AI)
4. Socio-Political landscape shifting
   a. Healthcare is a topic high on public attention in US, given how it affects the daily lives of people as well the high share of income spent on it.
   b. Total and government spends on healthcare
Here is a formal definition of a sensor:

"An electronic device that produces electrical, optical, or digital data derived from a physical condition or event. Data produced from sensors is then electronically transformed, by another device, into information (output) that is useful in decision making done by “intelligent” devices or individuals (people)” (IEEE P1451.6 Terms &amp; Definitions Page n.d.).

There are many different types of sensors based on the kind of type of information or quality they measure.

**TYPES OF SENSORS**

Sensors are primarily categorized into two types, namely Active and Passive. Active sensors are the ones, which transmits its own energy and senses back its reflection bounced off the target. E.g. of active sensors include radar, GPS, x-ray, infrared and seismic. Passive sensors, on the other hand, receives energy from its surrounding environment through the detection of vibrations, radiations, heat etc. E.g. of passive sensors include electric field sensing, chemical, photographic etc.

Sensors can also be classified based of the different means of detection. Some of the e.g. are biological, electric, radioactive, chemical etc.

Sensors, in other way, can also be classified in the form of their conversion from input to output. For e.g., Electromagnetic, Electrochemical, Photoelectric, Thermoelectric. Thermooptic etc.

Another way of classifying sensors is to have them classified based on the outputs they produce which is analog and digital. Analog sensors are those, which produce
analog output signal against the measured quantity. Digital sensors, on the other hand, make use of discrete or digital data to convert and transmit signals.

The following table provides an illustrative list of types of sensors based on the functions they perform:

<table>
<thead>
<tr>
<th>Sensor Types</th>
<th>Sensor Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>A position sensor measures the position of an object; the position measure can either be in absolute terms (absolute position sensor) or in relative terms (displacement sensor). Position sensors can be linear, angular or multi-axis.</td>
<td>Potentiometer, inclinometer, proximity sensor</td>
</tr>
<tr>
<td>Occupancy and motion</td>
<td>Occupancy sensors detect the presence of people and animals in a surveillance area, while motion sensors detect movement of people and objects. The difference between the two is that occupancy sensors will generate a signal even when a person is stationary, while a motion sensor will not.</td>
<td>Electric eye, RADAR</td>
</tr>
<tr>
<td>Velocity and acceleration</td>
<td>Velocity (speed of motion) sensors may be linear or angular, indicating how fast an object moves along a straight line or how fast it rotates. Acceleration sensors measure changes in velocity.</td>
<td>Accelerometer, gyroscope</td>
</tr>
<tr>
<td>Force</td>
<td>Force sensors detect whether a physical force is applied and whether the magnitude of force is beyond a threshold.</td>
<td>Force gauge, viscometer, tactile sensor (touch sensor)</td>
</tr>
<tr>
<td>Pressure</td>
<td>Pressure sensors are related force sensors and measure the force applied by liquids or gases. Pressure is measured in terms of force per unit area.</td>
<td>Barometer, bourdon gauge, piezometer</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------</td>
</tr>
<tr>
<td>Flow</td>
<td>Flow sensors detect the rate of fluid flow. They measure the volume (mass flow) or rate (flow velocity) of fluid that has passed through a system in a given period of time.</td>
<td>Anemometer, mass flow sensor, water meter</td>
</tr>
<tr>
<td>Acoustic</td>
<td>Acoustic sensors measure sound levels and convert that information into digital or analog data signals.</td>
<td>Microphone, geophone, hydrophone</td>
</tr>
<tr>
<td>Humidity</td>
<td>Humidity sensors detect humidity (amount of water vapor) in the air or a mass. Humidity levels can be measured in various ways: absolute humidity, relative humidity, mass ratio, and so on.</td>
<td>Hygrometer, humistor, soil moisture sensor</td>
</tr>
<tr>
<td>Light</td>
<td>Light sensors detect the presence of light (visible or invisible)</td>
<td>Infrared sensor, photodetector, flame detector</td>
</tr>
<tr>
<td>Radiation</td>
<td>Radiation sensors detect radiation in the environment. Radiation can be sensed by scintillating or ionization detection.</td>
<td>Geiger-Müller counter, scintillator, neutron detector</td>
</tr>
</tbody>
</table>
Temperature sensors measure the amount of heat or cold that is present in a system. They can be broadly of two types: contact and non-contact. Contact temperature sensors need to be in physical contact with the object being sensed. Non-contact sensors do not need physical contact, as they measure temperature through convection and radiation.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Chemical sensors measure concentration of chemicals in a system. When subjected to a mix of chemicals, chemical sensors are typically selective for a target type of chemical (for example, a CO2 sensor senses only carbon dioxide).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical</td>
<td>Breathalyzer, olfactometer, smoke detector</td>
</tr>
<tr>
<td>Biosensors</td>
<td>Bio sensors detect various biological elements such as organisms, tissues, cells, enzymes, antibodies, and nucleic acids</td>
</tr>
<tr>
<td></td>
<td>Blood glucose, biosensor, pulse oximetry, electrocardiograph</td>
</tr>
</tbody>
</table>

**TABLE 3: TYPES OF SENSORS** (SOURCE: (DELOITTE ET AL. 2015))
EVOLUTION IN CAPABILITIES OF SENSORS OVER THE YEARS

The capabilities of wireless sensors have grown over the years. Selection of a specific kind/capability of sensor is based upon its applicability in a specific situation. Factors that should be considered while making a choice of suitability of a sensor in a particular scenario are:

1) Accuracy: is the measure for authenticity of the signal reported by the sensor
2) Repeatability: is the output produced by the signal when subjected to same input conditions multiple times
3) Range: is the defined range within which the sensor performs with accuracy. Anything outside this defined range may have cause damage to the sensors
4) Noise: is the fluctuation in the signal caused due to external disturbances
5) Resolution: is the small minute additional change in the input that sensor can read and report as a change
6) Selectivity: is to selectively sense and report the signal

All of these factors mentioned above, even though may seem generic, but they significantly affect the accuracy of the processed data and hence its value.

PAST TRENDS

Principal factors that motivated the use of sensor technology in the healthcare devices industry have been their cost, competency and size. With the transformation in the sensors from expensive to economical, basic to smarter and small to even smaller, they can be utilized for a variety of purposes and can generate wider range of data at the least cost. Explaining each of these factors in details along with relevant examples:

Economical sensors: The price of sensors has consistently fallen over the past several years are shown in figure below, and these price declines are expected to
continue into the future. For e.g., accelerometer sensor today costs less than 20% as compared to 2006. This is just an example of how sensors are becoming more affordable. Although sensors come in different price range, but a lot of them have now become economical to be able to be used for wide range of business applications.

![Graph showing sensor prices decline over 25 years](image)


**Smarter sensors:** Sensors dependent on a larger system of things like microprocessors, communication chips, power sources etc. They don’t function by themselves. Over the last two decades, microprocessors’ computational power has grown exponentially.
Smaller sensors: Cellphones and other wearable devices have led to widespread use of small sensors. A small device that combines mechanical components with digital electronics is called Micro-electro-mechanical systems sensor (MEMS). These sensors have the ability to drive broad range of applications. New kinds of biosensors could be wearable or ingestible or implantable.

DIRECTION OF RESEARCH

Sensors have come a long way in becoming adequately inexpensive, smart and small over the years, but challenges still remain. Some of the significant challenges include power consumption, data security, and interoperability.

Power consumption: Sensors are usually powered through batteries and in-line connections. While batteries are convenient to use but they run the risk of insufficient charging, replacement and overall life, especially in remote areas this may pose a significant downside. In-line connections are stable but may not be feasible rather expensive in many cases.
Power itself has two considerations:

Efficiency: Efficiencies have improved to a level that now some sensors can work on battery power for almost 10 years without replacement. With this improvement, the power required to maintain this high number of sensors has also increased. This leads to increased level of consumption of power than before due to limited financial and energy resources.

Sources: Harvesting energy from sources like solar etc. are currently very expensive and requires heavy investment (installation plus maintenance costs). Due to unreliability of associated supply of harvested alternative power, sensors mostly depend on batteries currently.

Security of sensors: Security is a major concern. Sensors do not have a lot of processing capabilities and memory available to them, but it is the best to resolve the problem of security at the source itself. Power usage limits our ability to provide security. Cryptographic algorithms help with data integrity.

Interoperability: Trademarked sensor systems designed for specific applications result in interoperability issues. Here, an important role is to be played by Communication protocols to simplify communication. Lightweight communication protocols are preferred due to various sensor level limitations such as memory capacity, power availability and low processing power. Open-source protocol like CoAP (Constrained Application Protocol) could be better as they use a format lighter than Hypertext Transfer Protocol (HTTP). While CoAP (Constrained Application Protocol) are best suited for energy constrained sensor systems, additional protocols are needed to secure communication between sensor systems as it does not come with built-in security features.

POTENTIAL FUTURE TRENDS

New techniques of mass manufacturing sensors are being invented. Semiconductor device fabrication technologies, even though primarily developed for manufacture of
electronics, led to the creation of new ways of producing very minute microelectromechanical systems (MEMS). Modified basic techniques of deposition of microscopic thin material layers and etching patterns in them by photolithography etc. were perfected to be able to produce new micro-scaled highly accurate sensors. These new technologies like MEMS led to mass scale production of a lot of new sensors like the high performance pressure sensors, accelerometers and gyroscopes. These sensors are now commonplace in our mobile phones and other daily use consumer electronics.

Some of the latest focus areas in wireless sensing technologies, especially for healthcare purposes, has been on:

1. lowering battery dependence by reducing power usage and/or energy harvesting from surroundings
2. tissue-electronics interfaces for biomedical sensing (tissue interfaces via sensing through skin, sweat, breath, blood)
3. permanence, durability and bio-safety (wearable/ implantable/ ingestible)
4. non-intrusiveness/non-contact sensing
CHAPTER 3: WIRELESS SENSING TECHNOLOGY IN HEALTH MONITORING SYSTEMS

Wireless sensing technology is set to revolutionize the healthcare industry in the near future. It is making possible the dream of automated continuous hassle-free mobile health monitoring of people. New sensors and their applications in off-the-shelf commercial devices are already changing the way consumers look to control and monitor their health. Sensors embedded in wrist watches that can monitor our heart rate, activity, etc. are becoming common. This, though, seems as just the start of a trend.

COMPONENTS OF A HEALTHCARE MONITORING SYSTEM

One way to look at a health monitoring system is to group its parts by their primary function:

![Diagram of healthcare monitoring system components](image)

FIGURE 6: PARTS OF A HEALTHCARE MONITORING SYSTEM
Communicating: With the ICT revolution, the growth and spread of infrastructure for communication and storage of data has already reached a stage where it is now almost taken for granted that it should be possible for us to be connected online and have high data bandwidths available at our fingertips almost all the time. But, for a wireless sensor to be able to communicate, especially actively, it costs energy, which, if it cannot generate or harvest from surrounding, has repercussions in terms of size and durability. Factors of data security, privacy, signal strength, range, mode of communication (NFC/Bluetooth/BLE/Cellular/GPS etc.), communication protocols and standards (ZigBee/Wireless HART/ UWB/ IETF 6LoWPAN/ ISA100) come into play here.

Reasoning: This is the area which has received a lot of attention lately with development of AI capabilities. The wealth of data generated by a sensor would be meaningless without it being processed and analyzed to get actionable insights. The raw data generated by sensor could be first evaluated at the sensor level itself before being transmitted to a network. This processing at sensor level, does not come free, and has repercussions in terms of energy usage and size. But the other choice of not processing but rather communicating all raw data also comes at the cost of more energy and bandwidth for communication.

Acting: The capability to act decisively based on inputs from a health monitoring system rests on the timeliness, accuracy and the dependability of that system. In terms of timeliness, the system many a times not only has to be real-time capable but also of storing and deciphering long term trends.

Interacting: We have been building interfaces between human and machines for almost as long as we have been building machines. These range from simple handle bars on a bicycle to the touch screens on our mobile phones, from the voice commands in our smart homes to even brain wave reading devices. The way we interact with a machine defines a major part of our experience in using that system. Our expectations from these interfaces have grown exponentially in the last decade,
and designers of machines/software applications now-a-days put in a lot of effort to make these interfaces as user friendly and intuitive as possible.

**Sensing:** Sensing function is a critical one in health monitoring systems, as the entire course of action is based upon these sensed observations. The accuracy, repeatability and sensitivity of the sensors have to kept in mind especially since this data could decide the course of future healthcare intervention. There are so many different types of sensors today that

**IMPORTANT SYSTEMIC PROPERTIES**

For a health monitoring system, the system characteristics that generally occupy the most importance are:

1. **Usability**
   a. Ease of operating/interacting
   b. Ease of wear/install
2. **Dependability**
   a. Accuracy of measurement
   b. Sensitivity in measurement
   c. Reliability
   d. Availability
3. **Safety**
   a. Clinical safety
   b. Data Security
   c. Privacy
4. **Efficiency** (energy usage, material usage, manual effort usage)
5. **Cost effectiveness**
6. **Customizability** (according to patient or situation)
7. **Interoperability**
8. **Maintainability**
9. **Sustainability**
DESIGN EVOLUTION

The challenge in terms of designing a suitable health monitoring solution lies in striking the right balance in terms of multiple features:

a. Size, weight etc. of the sensor/wearable (related to comfort in wearing/using)
b. Accuracy in observations
c. Source of energy for the sensor
d. Frequency and amount of data to be communicated
e. Safety of use (with regulatory compliance)
f. Security & privacy of data (with regulatory compliance)
g. Durability
h. Ease of use for various kinds of users (variety of patients, doctors, caregivers, medical device companies etc.)
i. Interoperability
j. Maintainability
k. Cost of production, use, maintenance
l. Design and selection of right business model to incentivize all stakeholders to adopt this new system

RISING IMPORTANCE OF WIRELESS SENSING TECHNOLOGIES AND SYSTEMS APPROACH

With such a wide array of features to balance, a systems-driven approach has started to come into focus. A deeper understanding of the needs of the patient as a consumer and other crucial stakeholders is being felt. Specifically, the healthcare customer does not seem to be in a race to buy the latest devices (a trend seen in purchase of electronics) but more interested in full solutions that take into account needs of all stakeholders.
So far, the way healthcare was practiced was based on constraints of infrequent or intermittent diagnostic data, hardly any insight into the home environment & daily living of the patient and a limited use of assistive technology. Now-a-days, with widespread connectivity and availability of high processing power at low costs, the focus seems to have shifted towards building further on these available technologies and providing new capabilities and tools to the masses. Sensor technology truly fills this gap of offering additional tools to augment connectivity and processing (reasoning) capabilities. New ‘smarter’ devices are getting introduced into the market by the dozens.

**SHIFT IN FOCUS AND CUSTOMER EXPECTATIONS**

Traditionally patients had to get all of their diagnostic tests and imaging done at a hospital or a diagnostic center. But, post the ICT revolution and with widespread availability of smart devices, people are starting to expect instant information. Patients no longer want to wait for their check-ups to find that they have a problem. The medical devices companies are now realizing that the practice of healthcare is moving away from formal healthcare facilities and into patients’ homes.

Going by the trends showing up in academic literature, there is a significant research effort being directed into this field. Articles and research papers on topics like Health-monitoring, Assistive healthcare, Technology enabled care (TEC), Telehealth, Telecare, Homecare, mobility, mobile health (a.k.a. mHealth) are being published all across. The following depiction shows how the fields of Social care, Telehealth, Smart Homes and mobility are overlapping.
We are seeing a shift of focus on value from the healthcare providers, payers, government and customer:

- From 'curative' to 'preventative'
- From 'transactional' to 'continuous'
- From 'procedure based' to 'outcome based'
- From 'life expectancy' to 'quality of life'
A number of Assistive Technologies (AT) have already made a marked difference to the quality of lives of people.

![Diagram of Assistive Technology](source)

**FIGURE 8: ASSISTIVE TECHNOLOGY (SOURCE: (ANDRICH 2012))**

There is no dearth of applications where these Assistive Technologies (AT) are being put to use:

<table>
<thead>
<tr>
<th>AT for chronic disease management</th>
<th>Medication dispensers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Customized vital sign monitors</td>
</tr>
<tr>
<td></td>
<td>Tele-health services</td>
</tr>
<tr>
<td>AT for safety and security</td>
<td>Smoke Alarms</td>
</tr>
<tr>
<td></td>
<td>Fall detectors</td>
</tr>
<tr>
<td></td>
<td>Location devices</td>
</tr>
<tr>
<td></td>
<td>Activity monitoring devices</td>
</tr>
<tr>
<td>AT to support physical functions</td>
<td>Environment modifications</td>
</tr>
<tr>
<td></td>
<td>Aid devices (hearing, walking, sight), rehabilitation equipment for physiotherapy</td>
</tr>
<tr>
<td>AT for dementia</td>
<td>Alarms, reminders, location monitor</td>
</tr>
</tbody>
</table>
These assistive technologies are serving many purposes, but the primary of these are the following:

1. Preventative care
2. Providing compensation & support to the physically challenged
3. Providing source of independence and mobility to the aged

The society is moving more and more towards independence, which involves more of self-care.
Support chronic disease management

Increase safety and security

Maintain physical and cognitive function

Supports mental well-being

Enable to follow up vital signs at home

Minimize risk of falling getting lost and accidents

Reduce burden on caregivers

Minimize the need for institutionalization

Supports independent living

Supports self-care

Increases quality of life

Reduces cost of health care

CHAPTER 4: DEEPER LOOK AT THE PACE OF ADOPTION OF NEW WIRELESS SENSOR TECH IN HEALTHCARE

Many of the wireless sensing technologies have been around and available for the last many years, but even though these have held a lot of potential and promise, their adoption has not been as fast as many predicted. We understand that it is not simply about the technical aspects of a new sensor technology that govern whether the users will find value in it and start adopting it, but also a lot about their end-experience when they use the full-system built around the technology and sensors which makes a difference to them. To take a deeper look at factors affecting the pace of adoption of Technology Enabled Care (TEC) by users in US market, we first looked at the existing models of technology adoption.

EXISTING MODELS OF RATE OF TECHNOLOGY ADOPTION

Over the years, the use and progressive adoption of technology has been studied by many people for all different kind of technologies. It has been observed that there seem to be a common observed behavior pattern A number of models have been proposed to figure out what factors play a role in determining how fast a new technology gets adopted by potential users.

Diffusion of Innovation Theory:

E.M.Rodgers had observed that the target population does not all adopt a new technology at the same time. He categorized the target population into 5 buckets:

1. Innovators
2. Early adopters
3. Early majority
4. Late majority
5. Laggards
This theory asserts that these groups differ in their behavior and hence it makes sense to use different strategies to appeal to each of these categories. Furthermore, there are five main factors that influence adoption:

1. Relative advantage
2. Compatibility
3. Complexity
4. Triability
5. Observability

Various technologies, over the years, have shown the characteristic s-curve of adoption as suggested in this theory. (It is interesting to note that technology diffusion typically happens at a much faster rate today than in 1900s)
Following is a summarized table showing a list of a number of models and what factors each were based on:

<table>
<thead>
<tr>
<th>Year</th>
<th>Theory/Model</th>
<th>Developed by</th>
<th>Constructs/ Determinants of adoption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>Diffusion of Innovation Theory</td>
<td>Everett, Roger</td>
<td>The innovation, communication channels, time and social system.</td>
</tr>
<tr>
<td>1975</td>
<td>Theory of Reasoned Action</td>
<td>Ajzen, Fishbein</td>
<td>Behavioural intention, Attitude (A), and Subjective Norm</td>
</tr>
<tr>
<td>1985</td>
<td>Theory of Planned Behaviour</td>
<td>Ajzen</td>
<td>Behavioural intention, Attitude (A), and Subjective Norm and Perceived Behavioural Control</td>
</tr>
<tr>
<td>1986</td>
<td>Social Cognitive Theory</td>
<td>Bandura</td>
<td>Affect, anxiety</td>
</tr>
<tr>
<td>1989</td>
<td>Technical Adoption</td>
<td>Fred D Davis</td>
<td>Perceived usefulness and perceived ease of use.</td>
</tr>
<tr>
<td>Year</td>
<td>Model/Model of PC Utilization</td>
<td>Author(s)</td>
<td>Factors Considered</td>
</tr>
<tr>
<td>------</td>
<td>------------------------------</td>
<td>-----------</td>
<td>--------------------</td>
</tr>
<tr>
<td>1991</td>
<td>The Motivation Model</td>
<td>Davis et al.</td>
<td>Extrinsic motivation (such as perceived usefulness, perceived ease of use, and subjective norm) and intrinsic motivation (such as perceptions of pleasure and satisfaction).</td>
</tr>
<tr>
<td>2000</td>
<td>Extended TAM2 model</td>
<td>Venkatesh and Davis</td>
<td>Social influence processes (subjective norm, voluntariness and image) and cognitive instrumental processes (job relevance, output quality, result demonstrability and perceived ease of use).</td>
</tr>
</tbody>
</table>

TABLE 5: EVOLUTION OF THEORIES AND MODELS OF TECHNOLOGY ADOPTION (SOURCE: SHARMA AND MISHRA 2014)
Without going into a lot of detail, some of the main models and their depictions are shown here for quick reference to understand the context of how such models have been evolving in the past few decades. Kindly refer to the original papers referred here for further details:

**Technology Acceptance Model (TAM):**

![Technology Acceptance Model (TAM)](SOURCE: (LAI 2017))

**Technology Acceptance Model-2 (TAM-2):**
Unified Theory of Acceptance and Use of Technology (UTAUT):

The Almere model:
All of these models mostly looked at the properties of the new technology systems from the viewpoint of the primary user. Looking more closely at the situation of users adopting new technology that enables their healthcare and caters to their health needs, we felt the need to develop a better suited model to account for the variety of perspectives of the various stakeholders. Instead of clumping together the viewpoints of two of the main users, the patient and their informal care-giver. We felt that these two groups had different needs and in fact the other stakeholders had even more different needs. Hence, we started to explore a different kind of model which takes into account the multiple factors and stages a consumer goes through before decision making.
One set of tools that came in handy in developing this new mental model were the System Dynamics (SD) concepts developed by Professor Forrester at MIT. Another such attempt of using these SD tools to improve upon the application of the technology acceptance models in technology enabled care has been made by (Lin and Chen 2012). Their mapping of the causal loops below depicts how the three dimensions of Perceived Usefulness (PU), Perceived Ease Of Use (PEOU) and Behavioral Intention (BI) are intimately linked to each other along with Subjective Norms and factors from Personal Traits, Industry, Product and Society.

![Causal Loop Diagram for Adoption of Healthcare Robot System](source: (Lin and Chen N.D.))

We further drew inspiration from the AIDA framework (Awareness, Interest, Desire, Action) prevalent in the field of marketing and advertising, and applied it to...
the process of new technology adoption. The picture grew more compete when we looked at the situation from the perspectives of the crucial stakeholders: the patient, the informal care-giver, the formal care-giver (doctor/hospital), the government and the private players.

New theoretical mental model proposed for visualization of the process of adoption of technology enabled care by a target population

This was developed purely as a theoretical mental-model to help visualize how the different parties within the healthcare system influence each other and what factors
should be taken into consideration when trying to accelerate the rate of adoption of a new technology in the consumer healthcare domain.

IDENTIFYING KEY STAKEHOLDERS, GATEKEEPERS, INFLUENCERS

DETERMINING PACE OF ADOPTION

This model highlighted to us the following:

1. The importance of roles played by the government and private players in deciding the rate of adoption of TEC by the target population
2. The crucial role played by both informal and formal care-givers, as they control the word-of-mouth based on their experience and trust factors
3. Given the multitude of factors and stakeholders, it is best that the creator of solutions should look at the complete picture in a holistic fashion. This calls for the use of systems thinking approach.

Philip Kotler had theorized that the Decision-Making-Unit (DMU) in a buying decision is made up of people playing six different roles:

1. Buyers
2. Gatekeepers
3. Users
4. Initiators
5. Influencers
6. Deciders

Borrowing the terminology developed by Kotler, we see that in the case of TEC buying behavior:

1. Patients and their care-givers (informal and formal) are the Users
2. Care-givers (informal) i.e. friends/ family members/ volunteers are playing the role of Influencers
3. Insurance Companies are playing the role of the Buyers
4. Private Players (companies) are playing the role of the Initiators
5. Government is playing the role of a Gatekeeper
6. Care-givers (formal) i.e. doctors/ hospitals/ healthcare providers are playing the role of Deciders

FUTURE DIRECTION TO BE TAKEN TO IMPROVE UPON THIS WORK

While the current exercise of making a mental model and visualizing the relations and roles of various stakeholders was very insightful, it can be improved upon. The current model is built more for the purpose of visualization of a mental model and cannot be made to simulate with actual data. This mental model could be refined and expanded to make it much more robust. Principles of System Dynamics modelling could be used to help define measurable quantities which can form the basis of a new robust practically testable model.
REFERENCES


