A Smart Healthcare Systems Framework

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This article proposes a Smart Healthcare Systems Framework for conceptualizing data-driven and mobile- and cloud-enabled smart healthcare systems. With the adoption of smart healthcare systems, healthcare organizations can provide cost-effective quality healthcare services with less IT set-up costs and reduced risks.

The world healthcare IT market is expected to grow from US$99.6 billion in 2010 to $162.2 billion in 2015,[1] fueled by increases in people's healthcare spending and organizations' IT expenditures. Healthcare spending increases reflect longer life expectancies, advances in developing countries' standard of living and the corresponding ability to afford high-quality medical treatments, and technological advances that create new possibilities for curing diseases and delivering services. IT spending increases reflect its promise to reduce healthcare costs, enhance the clinical and administrative workflow of healthcare organizations, and satisfy the huge demand for more efficient and error-free healthcare delivery.

Physicians, hospitals, insurance companies, and pharmacies are looking for ways to better understand their business practices so they can identify opportunities to reduce costs and streamline processes. Also, healthcare reform will require healthcare organizations to report quality metrics to the government as a condition for reimbursements and incentives. IT professionals in healthcare organizations need to rethink how they use IT resources instead of simply continuing to build their own internal services or purchase off-the-shelf IT products.

The convergence of various information and communications technologies—including emergent smart systems, cloud computing, social networks, and advanced sensing and data analysis techniques—is creating opportunities to organize these technologies into service relationships by configuring new healthcare service systems

 Published by the IEEE Computer Society

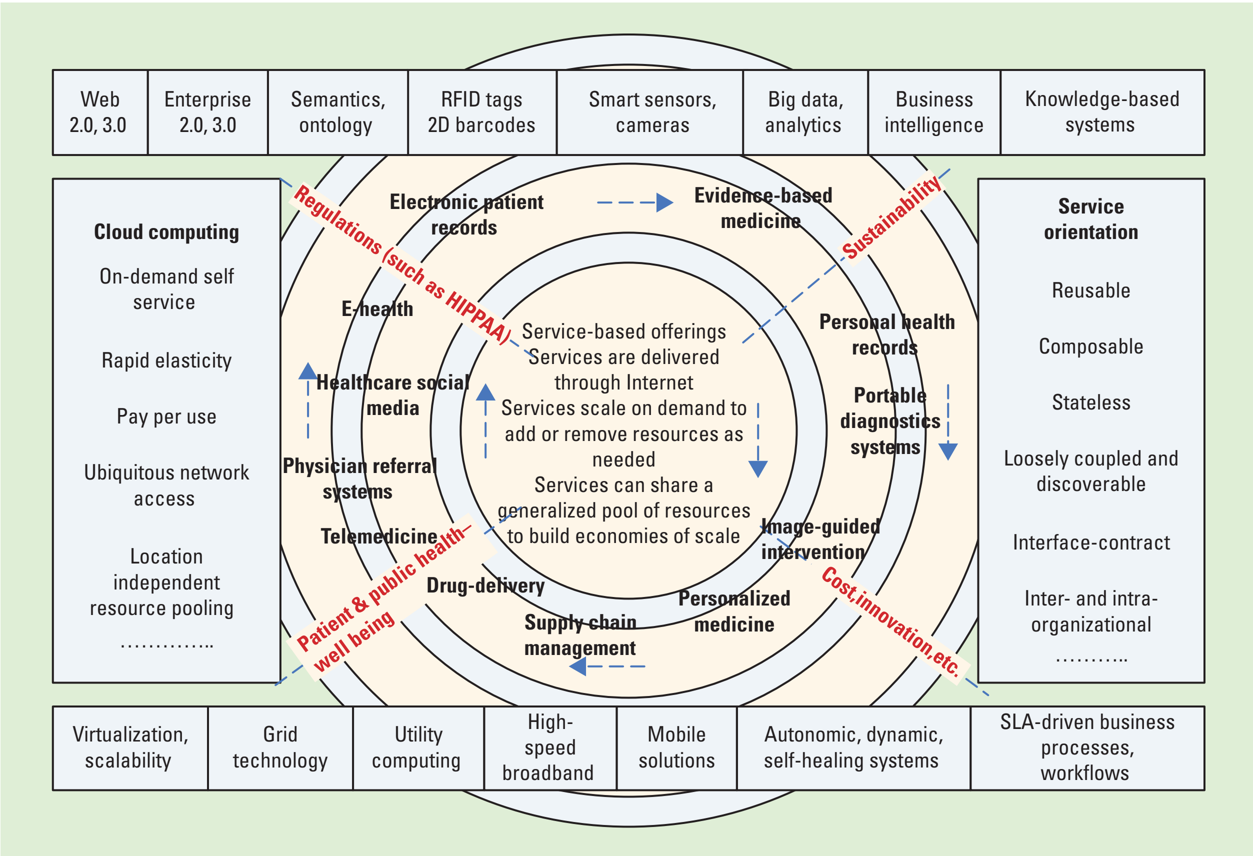

Figure 1. The convergence of information and communications technology with a sample list of some healthcare information systems.

(see Figure 1). Such systems can create new value by including people, processes, languages, laws, regulations, metrics, and models.[2] Cloud-enabled sustainable smart healthcare systems, coupled with electronic health records (big data) and emergent mobile solutions (such as novel biosensors, wearable devices, and intelligent software agents) demonstrate unprecedented potential for delivering automated, intelligent, and sustainable healthcare services.

Here, I propose the Smart Healthcare Systems Framework (SHSF), which provides opportunities for healthcare organizations to deploy platform-, technology-, and location-independent solutions with fewer risks and increased context awareness.

Challenges for Healthcare Services

Here, I review some of the numerous challenges organizations face in implementing healthcare services.

Quality Assurance

High quality is essential, given the serious consequences that could result from a mistake occurring during the sensing, controlling, or monitoring processes for healthcare-related services. Each year, patients worldwide require longer hospital stays owing to medical and medication-related errors, resulting in 2.4 million additional hospital days. Such errors also result in 32,000 deaths and \$9 billion in costs annually.[3] An estimated 1.5 million preventable adverse reactions to medications occur each year.[4]

Coordinated Care

Healthcare services must accommodate many different stakeholders. In addition to patients, doctors, and nurses, services must also support the hospitals, pharmacies, nontraditional providers, medical schools, and insurers. There are also the device manufactures; pharmaceutical, biotech, and IT companies; advocacy groups; research institutions; and government and state agencies. Consequently, the best healthcare services require interdisciplinary teams to work together (see Figure 2).

Hospitals and care providers must coordinate patient care to promote long-term wellness while

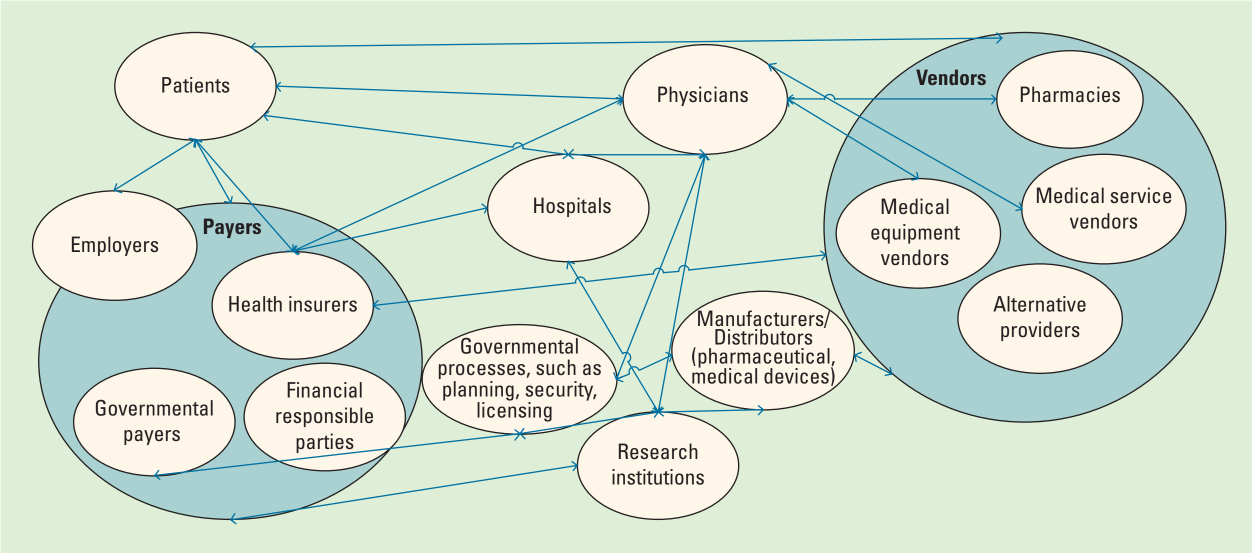

Figure 2. A sample list of healthcare value partners. Some of these partners can be grouped into certain categories, such as the payers and vendors.

remaining cost-effective. This requires comparable patient notes—in other words, integrated delivery networks that include the doctor's office, operating room, retail clinic, and patient's home or work.

Cost Reduction

Under the healthcare reform occurring in the US, hospitals must survive on what Medicare pay them, which is 87 percent of the actual cost of care. Overall, hospitals need to reduce their cost by 20 to 30 percent.[5]

Product development. In healthcare, the product development cycle is much longer and more regulated and expensive than the typical software product development cycle. Healthcare product companies must be careful about their innovation strategies and product offerings to keep costs low while addressing regulations and remaining timely.

Supply-chain management. The supply chain represents a very large portion of operating expense for most hospitals, so they also need to explore reductions in direct and indirect costs (such as costs related to error-ridden manual processes, inaccurate or incorrect data, and tracking inventory), in addition to lowering the price paid for products and services. Consolidating these processes and automating business processes can help lower costs, improve contract management, and better standardize products.

Quality and fraud management. Geographic areas with higher healthcare costs might exhibit lower quality care.[5] Much of this inconsistent quality is reinforced by a lack of transparency in the system, which makes it difficult for consumers to identify high-quality, cost-effective providers. Approximately 30 percent of healthcare spending goes toward redundant or inappropriate care,[6] and healthcare fraud accounts for more than $100 billion of the US's $2 trillion healthcare system.[7]

Energy conservation. Hospitals are among the nation's most complex and energy-intensive facilities. Using an average of 836 trillion BTUs of energy annually, hospitals have more than 2.5 times the energy intensity of commercial office buildings of similar size. This high energy consumption equates to producing 30 pounds of CO_2 for every square foot of hospital space each year.[8] Although energy costs contribute to only approximately 1 percent of a hospital's overall cost,[9] due to the size of such facilities, this accounts for $5 billion annually in energy costs alone. Of these costs, 50 percent is for cooling and heating—the rest is for other operations, including clinical and diagnostics equipment, information systems, and lighting.[8]

Coordinated Information Systems

In addition to the embedded role of IT in clinical and diagnostics equipment, information systems are positioned to produce, capture, store, process, and communicate timely information to all value partners for better coordination of healthcare.[10] Yet most health information systems have evolved in a disorganized and fragmented way as a result of administrative, economic, legal, or donor pressures, and have created many challenges for organizations.

Common languages. Healthcare service innovation affects people in their roles as providers, coproducers, and consumers of services and alters their patterns of interaction. These interactions require common languages.

System complexity. IT-based healthcare-service delivery systems that span business functions, enterprises, and geographies are becoming ever more complex and are consequently difficult to plan, govern, and adapt.

Adaptive allocation. For the most part, healthcare services can't be transported or stored, so adaptive resource and capacity allocation is required.

System integration. Electronic medical record integration becomes much harder when two or more exchange partners use IT to create joint and interpenetrating processes. Healthcare systems are expressed not only in terms of their components but also in their relationships with other value partners.

Process standardization. It's difficult to standardize delivery processes and economies of scale for healthcare services, given the nonstandardized nature of patients (with differing needs, preferences, personal characteristics, conditions, and medications), healthcare providers (with differing professional roles, training, and experience), and medical procedures and treatments (all of which converge during healthcare delivery). Novel IT system architectures that standardize inputs and processes and use platform planning and modularization to customize service offerings are needed.

Commoditization. Commoditization of hardware (for example, infrastructure as a service), software (software as a service), and business processes as services has become a major phenomenon in today's economy. Unfortunately, there's limited research on modeling commoditization decision processes, assessing the risks (such as security risks or disaster recovery), and examining the service quality associated with outsourcing options.

Interoperable systems. Today, many healthcare service providers still use paper-based medical recording processes or electronic standalone applications. There's a need for high-quality, secure, and compliance-driven interoperable systems enabled by IT in healthcare business models and efficient change management processes.

Decision-support systems. Secure, high-quality data and information exchange is essential in healthcare. Healthcare organizations face critical barriers to data-driven or analytical care decisions (such barriers include incomplete personal health data, siloed data, large amounts of structured and unstructured data, and paper-based records). Furthermore, organizations primarily use data for business reporting rather than medical decisions (evidence-based medicine). Efficient and effective operational and decision-support systems are needed for all value partners.

Stakeholder buy-in. Healthcare IT adoption is difficult because of the organizational hierarchy and powerful stakeholders—for example, physicians are primarily concerned with treating the patient, not with learning IT.

Service provisioning. Healthcare IT systems need to be defined in terms of their functions, including the direct provision of services, whether they're medical or public health services. However, such systems also require other enabling functions, such as stewardship, financing, and resource generation, and the healthcare workers.

Personalized care. Healthcare IT systems must support personalized medicine, telemedicine, home healthcare, e-health, and so on.

The Smart Healthcare Systems Framework

Many healthcare organizations attempt to improve efficiency and quality through mergers and networks that adapt the organization's resource base to changing needs and also through rapid product innovations. In other words, they attempt to manipulate what are perceived as the controllable variables in their healthcare service system. However, they often discover that these manipulations lack the necessary scope—mainly because their healthcare service system is much more complex than anticipated. Changes to the scale of healthcare service delivery can affect service quality in unanticipated ways, resulting in unnecessary costs, a staff that's unresponsiveness to patient needs, and missed opportunities for care.

Healthcare organizations are looking to adopt smart systems—that is, service-oriented cloud solutions, instrumented for monitoring health using everything from sensors to smartphones. Such solutions are interconnected through access to data that reveals patterns and algorithms that can recognize such patterns and suggest appropriate individual and collective responses from large data stores. Smart systems can thus offer agility for healthcare organizations looking to provide the best service and experience available, but can they also help reduce complexity?

SHSF Components

A fundamental premise of SHSF is that organizations can co-create their service offerings with consumers and break siloed business processes into modular, independent services that can be reused on the fly in loosely coupled dynamic business service choreographies (business processes and workflows). Furthermore, organizations can source and execute those choreographies using virtual resources. Business-to-business collaboration is a type of virtual environment with requirements for security, auditability, availability, and service-level agreements, and it requires seamless integration with existing resources and applications.

SHSF includes conceptual models of an intra- and interorganizational business process. It also includes service and resource execution architectures that contain the following: cloud services, an interorganizational supply chain, mobile smart services, big-data-enabled business-intelligence and knowledge-management services, and Web 2.0 and 3.0 solutions (see Figure 3).

The cloud services execution architecture is a three-layered intra-organizational platform that manages services relevant to each layer's role (see BP, SOA, and SOI in Figure 3). It's assumed that similar platforms exist in all organizations engaged in the business value chain. SHSF models several support processes, such as security guarantees and access controls, which ensure that certain consumers can access particular resources or specified service levels. Control and management processes outlined in the SHSF similarly ensure high availability, reliability, load balancing, and quality of service.

SHSF supports the interorganizational supply chain (which provides digital collaboration capabilities) using smart docking stations. These stations manage business-process traffic and transfer actionable interorganizational data into the appropriate intra-organizational cloud platform layer for processing. This interorganizational supply chain lets organizations conduct business through integrated distributed systems involving complex, high-volume, transactional decision activities. These systems provide transparency and help streamline the information flow. By using the Health Insurance Portability and Accountability Act (HIPAA) electronic data interchange (EDI) transactions and the Agency for Healthcare Research and Quality standards, interorganizational value-chain partners can improve interoperability.

Sample Supply Chain

Consider a multi-organizational supply chain that includes various entities, including practitioners, laboratories, payers, manufacturers, pharmacies, and research institutions requiring material, information, and knowledge or cash flow between organizations. Each entity can be an organization or can include more than one organization. The entities are all joined through a value chain with a Web-service-based agent docking station with smart service systems. With SHSF, smart systems enabled by mobile services incorporate various functions, including capturing, sensing, actuation, and control. The smart systems can identify, describe, and analyze a situation and take decisive action based on the available data in a predictive or adaptive manner.

In this configuration, serial number tracking (using RFID and 2D barcodes) can also help business address issues such drug recalls; optimized inventory management; expiry date management; financial reimbursements; and on-shelf

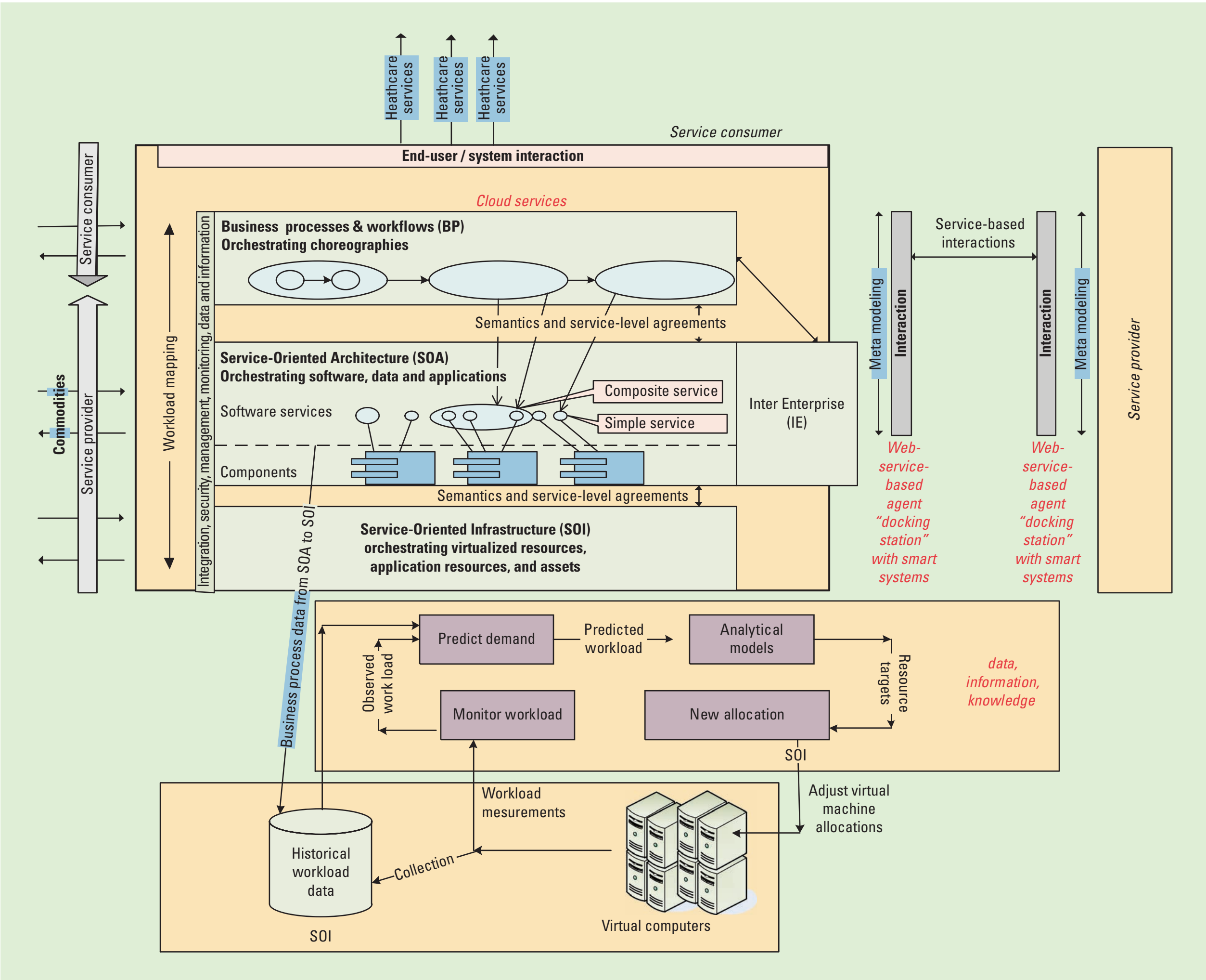

Figure 3. A sample building block of a smart healthcare system. This system includes three major layers: business process, service-oriented architecture, and service-oriented infrastructure for dynamic allocation and execution of business processes with resources.

availability for manufacturers, distributors, retailers, and pharmacies. RFID can also be used for patient tracking (by protecting patient data privacy) in hospitals, drug tracking in clinical trials, and inventory management.

Each entity can configure dynamic choreographies and orchestrate them as a black box (so processes are known internally but not externally). The Web-service-based docking station plays a middleware role for these entities, letting them communicate with each other. In the meantime, agents monitor the market and distribute the information to the various organizations. Based on changes in the market, regulations, and healthcare needs, an IT service supply chain dynamically configures different value configurations: chains (transforming input into services and products), shops (resolving customer problems), and networks (linking customers).[11]

Big-data-enabled business intelligence (BI) and knowledge-management services let organizations collect, analyze, and disseminate large amounts of structured and unstructured data for actionable decisions. BI mashups can be used to study the possible spread of various diseases. Electronic patient records can integrate several functions and provide seamless access to information for value-driven, patient-centric healthcare delivery. Personal health records and consumer profiling can be used for effective collaboration of symptom-related data (from patients) and clinical data (from laboratories). Patient records and telemedicine complement each other over television, phone, computer, or other similar media. Interaction can be in real time or via email. Text, as well as images or x-rays, can easily be forwarded and received. Data links from an ambulance to a hospital can reduce the lead time lost in preparation after a patient arrives.[12] Data mining can segment patients into different groups and then find the critical predictors for each group.

Algorithms can be developed and run automatically based on the historical information to calculate the risks for patients when they check in or when treatment is begun so the medical decisions can be driven effectively by that risk. Knowledge management in healthcare can trigger an action based on the collected data. The trigger can alert a patient or doctor in the network, provided clinical test data is logged at regular times. The system can also notify a patient of his or her risk for a particular disease by automatically testing the hypothesis using BI modules or intelligent agents working in conjunction with the healthcare information system.

Web 2.0 and 3.0 solutions are another component of this framework that enable collaborative development and the sharing of clinical decision-support systems. For example, physicians can now share medical videos using YouTube via sites such as http://askdrwiki.com.

Also, a detailed list of many healthcare wikis is available at http://davidrothman.net/list-of-medical-wikis. Healthcare professionals can use blogs to post cases and images, share information about hospital management, and build awareness about health IT. Medical blogging is allowed under HIPAA rules in the US, as long as 18 specified identifiers (including name and medical record number) aren't exposed. Social networking sites for physicians, such as www.sermo.com, are also useful, because consultation with peers prior to working on a task is of paramount importance in healthcare management. Social networking is similarly important for patients for information sharing and self-education.

Implementations

There are no clearly defined methodologies for how an organization should start adopting smart healthcare systems. Here, I review four examples, where the organizations used parts of SHSF or a similar framework.

The EU-supported SmartHealth project (www.smarthealthip.com) offers an open integrated architecture for new biodiagnostic systems to support European companies exploiting bioassays or new application concepts. The project focuses on cancer diagnostics—breast cancer recurrence monitoring; cervical cancer case-finding; and colorectal cancer diagnostics, prognostics, and theranostics. Project results show that healthcare quality increases significantly with earlier, more appropriate, and less costly treatments. Ruling out expensive treatments helps reduce costs, and implementing earlier treatments reduces complications and shortens the length of hospital stays, which is also more cost-effective.[13]

The University of Pittsburgh Medical Center's SmartRoom technology is another example of a smart healthcare system. This consists of three major components: a patient screen, which lets patients identify their caregivers, see a list of the day's activities (such as scheduled lab tests), and access educational materials. A caregiver screen gives clinicians access to essential information, including allergies and medication regimens. This system also lets nurses and aides quickly document vital signs and complete basic tasks on a touch screen. The system is intelligent enough to give different sets of patient data to different provider categories. For example, an aid responsible for turning a patient would be told that the patient is allergic to latex and get reminded to put the bed rails up. The technology is designed to eliminate 50 to 70 percent of the "unnecessary effort associated with documenting routine clinical care."[14]

The Mayo Clinic's data-driven care decisions include an algorithm to detect brain aneurysms in processed images and predict how likely it is that the images show a brain aneurism. The solution generated a 95 percent accuracy rate in detecting aneurysms, significantly improving patient outcomes.

Also, Ambient Assisted Living, a home-care mobile monitoring solution, provides efficient subscription-based services to chronic patients.[16]

Smart healthcare systems can help improve security, simplify maintenance, reduce costs, better use IT staff, and improve the user experience. However, some of the technologies deployed in these systems represent IT innovations in the healthcare industry, which makes people nervous. In implementing such systems and technologies, I suggest that organizations first

- identify the direct (for example, system and process failures) and indirect (related to data security and external service provider) risks;
- classify which manual operations have the highest potential for improved efficiency through IT;
- recognize what type of knowledge has been acquired internally—functional, industry, or internal company knowledge;
- choose service providers wisely and employ a migration company that specializes in the healthcare industry; and
- quickly determine if—and when—the external IT service provider can provide the expected service quality.

Research focused on smart healthcare systems offers an opportunity to develop new theories, models, and methods to help better design, implement, adopt, and manage these technology-based services in terms of usage and contributions to healthcare performance. IT

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