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HEALTHCARE: A COMPLEX SERVICE SYSTEM

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Abstract

Healthcare is indeed a complex service system, one requiring the technobiology approach of systems engineering to underpin its development as an integrated and adaptive system. In general, healthcare services are carried out with knowledge-intensive agents or components which work together as providers and consumers to create or co-produce value. Indeed, the engineering design of a healthcare system must recognize the fact that it is actually a complex integration of human-centered activities that is increasingly dependent on information technology and knowledge. Like any service system, healthcare can be considered to be a combination or recombination of three essential components – people (characterized by behaviors, values, knowledge, etc.), processes (characterized by collaboration, customization, etc.) and products (characterized by software, hardware, infrastructures, etc.). Thus, a healthcare system is an integrated and adaptive set of people, processes and products. It is, in essence, a system of systems which objectives are to enhance its efficiency (leading to greater interdependency) and effectiveness (leading to improved health). Integration occurs over the physical, temporal, organizational and functional dimensions, while adaptation occurs over the monitoring, feedback, cybernetic and learning dimensions. In sum, such service systems as healthcare are indeed complex, especially due to the uncertainties associated with the human-centered aspects of these systems. Moreover, the system complexities can only be dealt with methods that enhance system integration and adaptation.

Keywords: Services, healthcare, system integration, system adaptation, system complexity, system of systems, customization, co-production, decision informatics, real-time decision making

1. Healthcare as an Engineering Focus

Healthcare refers to the treatment and management of illness, and the preservation of health through services offered by the medical, dental, pharmaceutical, clinical laboratory sciences, nursing, and allied health professions. Healthcare embraces all the goods and services designed to promote health, including "preventive, curative and palliative interventions, whether directed to individuals or to populations" (WHO 2000).

Clearly, engineering – the application of technical, scientific and mathematical knowledge to help design and implement materials, structures, machines, devices, systems, and processes that can achieve a desired objective – has and will continue to have a critical impact on healthcare. Indeed, as identified in Table 1, every engineering discipline or technology has potential applications to biology; a number of such

Table 1 Engineering healthcare: technobiology examples

Discipline	Examples	Scope
Biomedical	1. PillCam 2. Neurostimulator 3. Hypothermia 4. Stem Cells from Adult Cells 5. Personalized Medicine	1. Swallowed pill can capture 50K gastrointestinal images 2. Nerve stimulation to treat migraine headaches, etc. 3. Lowering body temperature to 91.5 degrees to stem harmful chemical reactions when oxygen is restored following cardiac arrest 4. Employ 4 embryonic genes to induce stem cell growth 5. Tailor medicine through genetic profiling chips/sensors
Chemical	1. Tissues 2. Diagnostic 3. Microcyn	1. Regenerative medicine: engineering induced pluripotent stem (iPS) cells to create skin, muscle, bone, cartilage, fat, blood vessel, nerve, heart, liver, bladder, kidney, etc. 2. Tests that identify gene variations which can predict Lou Gehrig's disease, Parkinson's, Alzheimer, etc. 3. Electronically charged, super-oxidized water-based solution that attacks proteins in infectious agents of a wound, reducing need for antibiotics
Electrical	1. Bioimaging 2. Robotic 3. Bioinformatics 4. Ultrasound	1. High-definition laparoscope for colonoscopies, etc. 2. Automated assist in walking, moving, etc. 3. Large scale analysis of data for drug discovery, etc. 4. Focused-ultrasound surgery on fibroid tumors, prostates
Environmental	1. Sunshine Vitamin 2. Hearing Pill	1. Sunlight spurs body's production of vitamin D which can reduce instances of cancer, autoimmune disease, high blood pressure, heart disease, and diabetes 2. Naturally occurring substance called N-acetylcysteine (NAC) helps prevent hearing loss due to loud noise by helping body produce more glutathione
Industrial	1. Evidence-Based Protocols, Including False-Discovery-Rate 2. Adaptive Clinical Trials 3. E-Care 4. Concierge Care 5. Preventive Care 6. Personalized Care	1. Data mining and analysis of past treatments can point to effective protocols, including minimization of false positives linking diseases and DNA genes 2. Design and success criteria adjusted as clinical results are obtained 3. Integrated digital records and wearable wireless devices 4. VIP/premium services 5. Biomarkers/diagnostic tools allow for predictive care 6. Genomics-based adaptive, customized care
Material	1. Nanoparticle Medicine 2. Drug Delivery 3. Surgical Tape	1. Focused cancer treatment by targeting special nanoparticles which attach to cancerous cells 2. New drug delivery material with timed release 3. Biodegradable elastic polymer to close incisions or cuts
Mechanical	1. Haptics 2. Exoskeleton 3. Prosthetic 4. Artificial Disc 5. Asthma Mitigation	1. Sensing/manipulating of objects through touch 2. External anatomical feature that supports/protects a body 3. Orthopedic or bionic device for mobility impaired 4. Replaced neck disc, resulting in less pain and swelling 5. Alair System uses radio-frequency energy to warm the airway in asthma patients; keeps muscles from constricting

"technobiology" examples (i.e., through the application of technology-based techniques to biological problems) are cited and briefly described. (More specifically, technolobiology is to be differentiated from "biotechnology" which is about the application of biology-based techniques to technological problems; such techniques include neural networks, genetic algorithms and systems biology.) The Table 1 technolobiology examples highlight the technological focus; they include biomedical, chemical, electrical, environmental, industrial, material and mechanical devices, approaches, and processes.

An overarching engineering approach that underpins many of the Table 1 examples concerns addressing each biological problem from a systems perspective. In this regard, Grossman (2008) has identified several disruptive engineering innovations that could change the way healthcare is organized, paid for, and delivered, including precision diagnostics and therapies (i.e., evidence-based medicine), advances in information/communication technologies (i.e., personal health record) and new business models (i.e., overcoming the cottage-industry structure and the dysfunctional reimbursement and regulatory framework). Continuing in the same vein, the contents of this paper are primarily focused on applying systems engineering to the development of a healthcare service system that is both integrated and adaptive. Thus, the paper builds on both a presentation by one of the authors at a recent healthcare workshop (Tien & Goldschmidt-Clermont 2009) and a recent paper on complex service systems (Tien 2008).

The remaining Sections 2 through 5 of this paper, respectively, considers healthcare as a service, as an integrated system, as an adaptive system, and as a complex system, followed by several concluding insights in Section 6. The purpose of this paper, then, is to highlight the critical importance of integration and adaptation when designing, operating or refining a complex service system like healthcare.

2. Healthcare as a Service

As detailed in Tien & Berg (1995, 2003, 2006, 2007), the importance of the services sector cannot be overstated; it employs a large and growing proportion of workers in the developed nations. As reflected in Table 2, the services sector includes a number of large industries; indeed, services employment in the U.S. is at 82.1 percent, while the remaining four economic sectors (i.e., manufacturing, agriculture, construction, and mining), which together can be considered to be the physical "goods" sector, employ the remaining 17.9 percent. Healthcare – which employs 10.8% of the U.S. workforce – is, of course, one of the largest industries in the services sector. Yet, as Tien & Berg (2006) augur, engineering research and education have not followed suit; the majority of research is still manufacturing- or hardware-oriented and degree programs are still in those traditional disciplines that were established in the early 1900s. On the other hand, medical research and education are somewhat more sensitive to the services need of healthcare; for example, evidence-based protocols are becoming more prevalent in the practice of medicine. Nevertheless, Hipel et al. (2007) maintain that services research and education deserve more attention and support in this 21st

Century when the computer chip, the information technology, the Internet and the flattening of the world (Friedman 2005) have all combined to make services – and services innovation – the new engine for global economic growth.

What constitutes the services sector? It can be considered "to include all economic activities whose output is not a physical product or construction, is generally consumed at the time it is produced and provides added value in forms (such as convenience, amusement, timeliness, comfort or health) that are essentially intangible…" (Quinn et al. 1987). Implicit in this definition is the recognition that services production and services delivery are so integrated that they can be considered to be a single, combined stage in the services value chain, whereas the goods sector has a value chain that includes supplier, manufacturer, assembler, retailer, and customer. Alternatively, services can be considered to be knowledge-intensive agents or components which work together as providers and consumers to create or co-produce value (Maglio et al. 2006).

Unfortunately, the U.S. healthcare system is a good example of a people-intensive service system that is in disarray. It is the most expensive and, yet, among the least effective system for a developed country; a minority of the population receives excellent care, while an equal minority receives inadequate care (National Academies 2006). This situation is not due to a lack of well-trained health professionals or to a lack of innovative technologies; it is due to the fact that it is based on a fragmented group of mostly small, independent providers driven by cost-obsessed insurance companies – clearly, it is, at best, a non-system (Rouse 2008). As a consequence, an integrated and adaptive healthcare system must be designed and implemented, one requiring the participation and support of a large number of stakeholders (i.e., consumers, doctors, hospitals, insurance companies, etc.). For example, patients must take increased responsibility for their own healthcare in terms of access and use of validated information.

Table 2 Scope and size of U.S. employment

Industries	Employment (M)	Percent
Trade, Transportation & Utilities	26.1M	19.0%
Professional & Business	17.2	12.6
Health Care	14.8	10.8
Leisure & Hospitality	13.0	9.5
Education	13.0	9.5
Government (Except Education)	11.7	8.5
Finance, Insurance & Real Estate	8.3	6.1
Information & Telecommunication	3.1	2.2
Other	5.4	3.9
SERVICES SECTOR	112.6	82.1
Manufacturing	14.3	10.3
Construction	7.5	5.5
Agriculture	2.2	1.6
Mining	0.7	0.5
GOODS SECTOR	24.7	17.9
TOTAL	137.3	100.0

Source: Bureau of Labor Statistics, April 2006

In the remainder of this introductory section on services, it would be helpful to highlight three overarching influences. First, the emergence of e(lectronic) services is totally dependent on information technology; they include, as examples, medical records, financial services, banking, airline reservation systems, and consumer goods marketing. As discussed by Tien & Berg (2003), e-service enterprises interact or "co-produce" with their customers in a digital (including e-mail and Internet) medium, as compared to the physical environment in which traditional or bricks-and-mortar service enterprises interact with their customers. Similarly, in contrast to traditional services which include low-wage "hamburger flippers", e-services typically employ high-wage earners and services that are more demanding in their requirements for self-service, transaction speed, and computation. In regard to data input that could be processed to produce information that, in turn, could be used to help make informed service decisions, it should be noted that both sets of services rely on multiple data sources; however, traditional services typically require homogeneous (mostly quantitative) data input, while e-services increasingly require non-homogeneous (i.e., both quantitative and qualitative) data input. Paradoxically, the traditional service enterprises have been driven by data, although data availability and accuracy have been limited (especially before the pervasive use of the Universal Product Code – UPC – and the more recent deployment of radio frequency location and identification – RFLID – tags). Likewise, the emerging e-service enterprises have been driven by information (i.e., processed data), although information availability and accuracy have been limited, due to a data rich, information poor (DRIP) conundrum (Tien 2003).

Consequently, while traditional services – like traditional manufacturing – are based on economies of scale and a standardized approach, electronic services – like electronic manufacturing – emphasize economies of expertise or knowledge and an adaptive approach. Another critical distinction between traditional and electronic services is that, although all services require decisions to be made, traditional services are typically based on predetermined decision rules, while electronic services require real-time, adaptive decision making; that is why Tien (2003) has advanced a decision informatics paradigm, one that relies on both information and decision technologies from a real-time perspective. High-speed Internet access, low-cost computing, wireless networks, electronic sensors and ever-smarter software are the tools for building a global services economy. Thus, in e-commerce, a sophisticated and integrated service system combines product (i.e., good and/or service) selection, order taking, payment processing, order fulfillment and delivery scheduling into a seamless system, all provided by distinct service providers; in this regard, it can be considered to be a system of – different – systems.

The second influence on services is its relationship to manufacturing. The interdependences, similarities and complementarities of services and manufacturing are significant. Indeed, many of the recent innovations in manufacturing are relevant to the service industries. Concepts and processes such as cycle time, total quality management, quality circles, six-sigma, design-for-assembly, design-for-manufacturability, design-for-recycling, small-batch production, concurrent engineering, just-in-time manufacturing, rapid prototyping, flexible manufacturing, agile manufacturing, distributed manufacturing, and environmentally-sound manufacturing can, for the most part, be recast in services-related terms. Thus, many of the engineering and management concepts and processes employed in manufacturing can likewise be employed to deal with problems and issues arising in the services sector.

Nonetheless, there are considerable differences between goods and services. Tien & Berg (2003) provide a comparison between the goods and services sectors. The goods sector requires material as input, is physical in nature, involves the customer at the design stage, and employs mostly quantitative measures to assess its performance. On the other hand, the services sector requires information as input, is virtual in nature, involves the customer at both the production and delivery stages, and employs mostly qualitative measures to assess its performance. Of course, even when there are similarities, it is critical that the co-producing nature of services be carefully taken into consideration. For example, in manufacturing, physical parameters, statistics of production and quality can be more precisely quantified; on the other hand, since a services operation depends on an interaction between the recipient and the process of producing and delivering, the characterization is necessarily more subjective and different.

A more insightful approach to understanding and advancing services research is to explicitly consider the differences between services and manufactured goods. As identified in Table 3, services are, by definition, co-produced; quite variable or heterogeneous in their production and delivery; physically intangible; perishable if not consumed as it is being produced or by a certain time (e.g., before a flight's departure); focused on being "personalizable"; expectation-related in terms of customer satisfaction; and reusable in its entirety. On the other hand, manufactured goods are pre-produced; quite identical or standardized in their production and use; physically tangible; "inventoryable" if not consumed; focused on being reliable; utility-related in terms of customer satisfaction; and recyclable in regard to its parts. In mnemonic terms and referring to Table 3, services can be considered to be "chipper", while manufactured goods are a "pitirur".

Although the comparison between services and manufacturing highlights some obvious methodological differences, it is interesting to note that the physical manufactured assets depreciate with use and time, while the virtual service assets are generally reusable, and may in fact increase in value with repeated use and over time. The latter assets are predominantly processes and associated human resources that build on the skill and knowledge base accumulated by repeated interactions with the service receiver, who is involved in the co-production of the service. Thus, for example, a surgeon should get better over time, especially if the same type of surgery is repeated. Indeed, clinical productivity increases for an average physician, from the dawn of a career to almost the end of a career, with a slight slowing down

Table 3 Services versus manufactured goods

FOCUS	SERVICES	GOODS
Production	***C***o-Produced	***P***re-Produced
Variability	***H***eterogeneous	***I***dentical
Physicality	***I***ntangible	***T***angible
Product	***P***erishable	"***I***nventoryable"
Objective	***P***ersonalizable	***R***eliable
Satisfaction	***E***xpectation-Related	***U***tility-Related
Life Cycle	***R***eusable	***R***ecyclable
OVERALL	***CHIPPER***	***PITIRUR***

towards the end. Likewise, while most U.S. physicians practice at a financial loss over the first few years, they progressively improve their financial standing over the course of their career.

In services, automation-driven software algorithms have transformed human resource-laden, co-producing service systems to software algorithm-laden, self-producing services. Thus, extensive manpower would be required to manually co-produce the services if automation were not available. Although automation has certainly improved productivity and decreased costs in some services (e.g., telecommunications, Internet commerce, etc.), it has not yet had a similar impact on other labor-intensive services like healthcare. However, with new multimedia and broadband technologies, some hospitals are customizing or personalizing their treatment of patients, including the sharing of electronic records with their patients. In this manner, patients can take increased responsibility for their own healthcare.

A third critical influence on services is the computational-driven move towards mass customization. "Customization" implies meeting the needs of a customer market that is partitioned into an appropriate number of segments, each with similar needs (e.g., Amazon.com targets their marketing of a new book to an entire market segment if several members of the segment act to acquire the book). "Mass customization" implies meeting the needs of a segmented customer market, with each segment being a single individual (e.g., a tailor who laser scans an individual's upper torso and then delivers a uniquely fitted jacket). And "real-time mass customization" implies meeting the needs of an individualized customer market on a real-time basis (e.g., a tailor who laser scans an individual's upper torso and then delivers a uniquely fitted jacket within a reasonable period, while the individual is waiting).

It is interesting to note that in regard to customization and in relation to the late 1700s, the U.S. is in some respects going "back-to-the-future"; thus, advanced technologies are not only empowering the individual but are also allowing for individualized or customized goods and services. For example, e-education reflects a return to individual-centered learning (Tien 2000), much like home schooling in a previous century. Moreover, when mass customization occurs, it is difficult to say whether a service or a good is being delivered; that is, a uniquely fitted jacket can be considered to be a co-produced service/good or “servgood”. The implication of real-time mass customization, then, is that the resultant, co-produced “servgood” must be carried out locally, although the intelligence underpinning the co-production could be residing at a distant server and delivered like a utility. Thus, while manufacturing jobs have already been mostly relocated overseas (with only about 10.3 percent of all U.S. employees still involved in manufacturing) and service jobs (which now comprise about 82.1 percent of all U.S. jobs) are beginning to be relocated overseas, real-time mass customization should help stem job outflow, if not reverse the trend. In this regard, real-time mass customization should be regarded as a matter of national priority.

Clearly, healthcare needs to transition from being a traditional (although high-wage) service to an electronic-based service industry, one relying on digital media for such activities as real-time access to patient records. (Some digitally-based medical approaches need further assessment and improvement; thus, while robotic surgery is quite helpful in the repair of small nerves and blood vessels, its overall efficacy is still under debate – nevertheless, as robotic surgery is further refined, it will undoubtedly become a standard technique in the surgeon’s arsenal of tools.) Additionally, healthcare must adopt some of the methods that have enabled manufacturing to be efficient (e.g., reduced cycle time, improved quality, etc.), while focusing on service effectiveness (e.g., maintaining a high standard of co-production, meeting consumer expectation, etc.). Most importantly, healthcare must be adaptive and must customize their treatments to the needs of their patients, ranging from evidence-based protocols to “servgood” or personalized medications.

3. Healthcare as an Integrated System

A service system like healthcare is actually an integration or combination of three essential components – people, processes and products. In particular, people can be grouped into those demanding services (i.e., consumers, users, patients, buyers, organizations, etc.) and those supplying the services (i.e., suppliers, providers, clinicians, servers, sellers, organizations, etc.); processes can be procedural (i.e., standardized, evolving, decision-focused, network-oriented, etc.) and/or algorithmic (i.e., data mining, decision modeling, systems engineering, etc.) in structure; and products can be physical (i.e., facilities, sensors, information technologies, etc.) or virtual (i.e., e-commerce, simulations, e-collaboration, etc.) in form.

Given the co-producing nature of services, it is obvious that people constitute the most critical component or element of a service system. In turn, because people are so unpredictable in their values, behaviors, attitudes, expectations, and knowledge, they invariably raise the complexity of a service system. Moreover, the multi-stakeholder – and related multi-objective – nature of such systems serve to only intensify the complexity level and may render the system to be indefinable, if not unmanageable. Human performance, social networks and interpersonal interactions combine to further aggravate the situation. While people-oriented, decision-focused methods are further considered in Section 4, it is interesting to note that sometimes systems are too big to manage or, alternatively, to let fail. Thus, although in the 2008 economic disaster, the U.S. Federal Government allowed Lehman Brothers to fail, it could not let either the insurance conglomerate American International Group or the giant Citigroup holding company go bankrupt. In fact, federal regulators across the globe are now – in 2009 – trying to ensure that such disasters do not happen again, perhaps by breaking up too-big-to-fail international firms so that they could fit and operate within national borders.

Processes which underpin system integration include standards, procedures, protocols, and algorithms. By combining or integrating service processes, one could, for example, enhance a "one-stop shopping" approach, a highly desirable situation for the consumer or customer. Integration of financial services has resulted in giant banks (e.g., the above-mentioned Citigroup); integration of home building goods and services has resulted in super stores (e.g., Home Depot); and integration of software services has resulted in complex software packages (e.g., Microsoft Office). Integration also enhances system efficiency, if not its effectiveness. For example, the radio frequency location and identification (RFLID) tag – or computer chip with a transmitter – serves to integrate the supply chain. However, as supply chains become more electronically integrated and interdependent, cyber security becomes more problematic (Donofrio 2008).

In regard to service-related products, one can group them into two categories. First, there are those physical products or goods (e.g., autos, aircrafts, satellites, computers, etc.) which, as indicated in Section 2, enable the delivery of effective and high-quality services (e.g., road travel, air travel, global positioning, electronic services, etc.). Second, there are those more virtual products or services, including e-commerce.

More importantly and as detailed in Table 4, service system integration can occur over the physical, temporal, organizational and functional dimensions. Physical integration can be defined by the degree of systems co-location in the natural (i.e., closed, open, hybrid), constructed (i.e., goods, structure, systems) or virtual (i.e., service, simulated, e-commerce) environment. An urban center's infrastructures (e.g., emergency services, health services, financial services, etc.) are examples of a constructed environment. Over time and with advances in information technology and the necessity for improved efficiency and effectiveness, these infrastructures have become increasingly automated and interlinked or interdependent. In fact, because the information technology revolution has changed the way business is transacted, government is operated, and national defense is conducted, the U.S. President (2001) singled it out as the most critical infrastructure to protect following 9/11. Thus, while the U.S. is considered a superpower because of its military strength and economic prowess, non-traditional attacks on its interdependent and cyber-underpinned infrastructures could significantly harm both the nation's military power and economy. Clearly, infrastructures, especially the information infrastructure, are among the nation's weakest links; they are vulnerable to willful acts of sabotage, if not invasions of privacy. Moreover, as indicated earlier, this interdependency contributed significantly to the 2008 economic disaster or recession. Recent

Table 4 System integration: Dimensions

Dimension	Definition	Characteristics	Elements
Physical	Degree of Systems Co-Location	Natural Constructed Virtual	Closed; Open; Hybrid Goods; Structures; Systems Services; Simulation; E-Commerce
Temporal	Degree of Systems Co-Timing	Strategic Tactical Operational	Analytical; Procedural; Political Simulation; Distribution; Allocation Cognition; Visualization; Expectation
Organizational	Degree of Systems Co-Management	Resources Economics Management	People; Processes; Products Supply; Demand; Revenue Centralized; Decentralized; Distributed
Functional	Degree of Systems Co-Functioning	Input Process Output	Location; Allocation; Re-Allocation Informatics; Feedback; Control Efficiency; Effectiveness

efforts at imbuing infrastructures with “intelligence” make it increasingly feasible to address the safety and security concerns, allowing for the continuous monitoring and real-time control of critical infrastructures.

Temporal integration can be defined by the degree of systems co-timing from a strategic (i.e., analytical, procedural, political), tactical (i.e., simulation, distribution, allocation), and operational (i.e., cognition, visualization, expectation) perspective. Expectation, for example, is a critical temporal issue in the delivery of services. More specifically, since services are to a large extent subject to customer satisfaction and since, as Tien & Cahn (1981) postulated and validated, “satisfaction is a function of expectation,” service performance or satisfaction can be enhanced through the effective "management" of expectation. When applied to healthcare, however, it may be difficult, if not impossible, to manage a patient’s expectation under certain emergency situations.

Organizational integration can be defined by the degree of systems co-management of resources (i.e., people, processes, products), economics (i.e., supply, demand, revenue), and management (i.e., centralized, decentralized, distributed). In regard to management integration, Tien et al. (2004) provide a consistent approach to considering the management of both goods and services – by first defining a value chain and then showing how it can be partitioned into supply and demand chains, which, in turn, can be appropriately managed. Of course, the key purpose for the management of supply and demand chains is to smooth-out the peaks and valleys commonly seen in many supply and demand patterns, respectively. Moreover, real-time mass customization occurs when both supply and demand chains are simultaneously managed. The shift in focus from mass production to mass customization (whereby a service is produced and delivered in response to a customer's stated or imputed needs) is intended to provide superior value to customers by meeting their unique needs. It is in this area of customization – where customer involvement is not only at the goods design stage but also at the manufacturing or co-production stage – that services and manufacturing are merging in concept (Tien & Berg 2006), resulting in a "servgood". The simultaneous, real-time customized management of both the supply and demand chains is further considered in Section 5.

Functional integration can be defined by the degree of systems co-functioning in regard to input (i.e., location, allocation, re-allocation), process (i.e., informatics, feedback, control), and output (i.e., efficiency, effectiveness). From an output perspective, for example, it is obvious that a system should be about integrating and enhancing efficiency and effectiveness, the twin pillars of productivity. However, it should be noted that timely manufactured goods are primarily a result of an efficient supply chain, while quality services are primarily a result of an effective demand chain.

Again, healthcare – as a service system – must be integrated in regard to people, processes and products, as well as over the physical, temporal, organizational and functional dimensions. It is obvious that designing an efficient and effective healthcare system is not easily accomplished; socialistic systems like Sweden's cost too much, while capitalistic systems like the U.S.'s are both high cost and unfair. New design approaches are required. The information technology revolution has permitted the analysis part of system design to be largely undertaken by computers; it allows for a simulated and collaborative redesign process to occur – until a satisfactory design is achieved which meets specified performance (e.g., morbidity, mortality, cost, etc.) criteria. The resultant and integrated healthcare system must be a comprehensive, interoperable system of systems. Perhaps the best example of an integrated healthcare system is that proposed by Goldschmidt-Clermont et al. (Undated); based on the autonomic computing initiative, they propose an autonomic healthcare system that combine the existing hospital information technology with operational processes to bring down the barriers among different specialties and to improve the quality of care being provided. As a final point, it should be noted that the human body is itself an amazingly integrated system of systems, one that should not be perturbed by surgeries and other intrusive treatments; indeed, the clinical specialist that should command the highest salary is one who focuses on the body as a system of systems.

4. Healthcare as an Adaptive System

Because a service system is, by definition, a co-producing system, it must be adaptive. Adaptation is a uniquely human characteristic, based on a combination of three essential components – decision making, decision informatics, and human interface. (Indeed, designing a healthcare system is about making decisions or choices about the system's characteristics or attributes.) Figure 1 provides a framework for decision making. To begin, it is helpful to underscore the difference between data and information, especially from a decision making perspective. Data represent basic transactions captured during operations, while information represents processed data (e.g., derivations, groupings, patterns, etc.). Clearly, except for simple operational decisions, decision making at the tactical or higher levels requires, at a minimum, appropriate information or processed data. Figure 1 also identifies knowledge as processed information (together with experiences, beliefs, values, cultures, etc.), and wisdom, in turn, as processed knowledge (together with insights, theories, etc.). Thus, strategic decisions can be made with knowledge, while systemic decisions can be made with wisdom. Unfortunately, for the most part, the literature does not distinguish between data and information; indeed, economists claim that because of the astounding growth in information – really, data – technology, the U.S. and other developed countries are now a part of the global "knowledge economy". Although electronic data technology has transformed large-scale information systems from being the "glue" that holds the various units of an organization together to being the strategic asset that provides the organization with its competitive advantage, the U.S. is far from being a knowledge economy. In the continuum of data, information, knowledge, and wisdom, the U.S. – together with other advanced economies – is, at best, at the beginning of a data rich, information poor (DRIP) conundrum, as identified in Section 2.

The fact remains that data – both quantitative and qualitative – need to be effectively and efficiently fused and analyzed in order to yield appropriate information for informed or intelligent decision making in regard to the design, production and delivery of goods and services, including healthcare. As depicted in Figure 2, the nature of the required real-time decision (regarding the production and/or delivery of a service) determines, where appropriate and from a systems engineering perspective, the data to be collected (possibly, from multiple, non-homogeneous sources) and the real-time fusion and analysis to be undertaken to obtain the needed information for input to the modeling effort which, in turn, provides the knowledge to identify and support the required decision in a timely manner. Clearly, methods must be developed that can fuse and analyze a steady stream of non-homogeneous (i.e., quantitative and qualitative) data – this is especially true for healthcare, where quantitative data from monitoring devices must be complemented with the patient's qualitative assessments before the clinician can recommend an appropriate treatment. The feedback loops in Figure 2 are within the context of systems engineering; they serve to refine the analysis and modeling steps.

Continuing with the decision informatics paradigm in Figure 2, it should be noted that decision modeling constitutes the information-based modeling and analysis of alternative decision scenarios; they include operations research, decision science, computer science, industrial engineering and, more recently, business analytics. At present, decision modeling methods suffer from two shortcomings. First, most of the available – especially optimization – methods are only applicable in a steady state environment, whereas in the real-world, all systems are in transition. (Note that steady-state, like average, is an analytical concept that allows for a tractable, if not manageable, analysis.) Second, most of the available methods are unable to cope with changing circumstances; instead, we need methods that are adaptive so that decisions can be made in real-time, as is required in most healthcare situations. Thus, non steady-state, adaptive decision methods are required. More importantly, real-time decision modeling is not just about speeding up the models and solution algorithms; it, like real-time data fusion and analysis, also requires additional research and development.

The systems engineering methods implicit in Figure 2 concern the integration of people, processes, and products from a systems perspective; they include electrical engineering, human-machine systems, system performance and system biology. Again, the real-time nature of co-producing services – especially human-centered services that are computationally-intensive and intelligence- oriented – requires a real-time, systems engineering approach. Ethnography, a branch of anthropology that can help identify a consumer's unmet needs, is being used to spot breakthrough product and service innovations. Another critical aspect of systems engineering is system performance; it provides an essential framework for assessing the decisions made – in terms of such issues as satisfaction, convenience, privacy, security, equity, quality, productivity, safety and reliability. Similarly, undertaking systems engineering within a real-time environment will require additional thought and research.

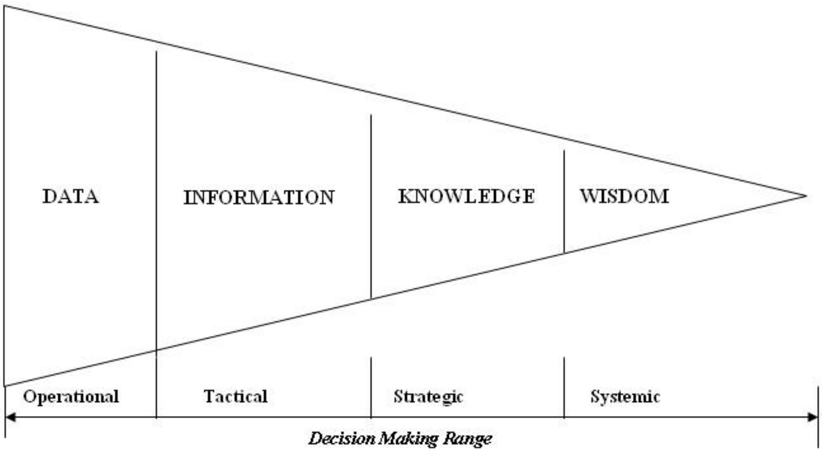

Figure 1 System adaptation: Decision making framework

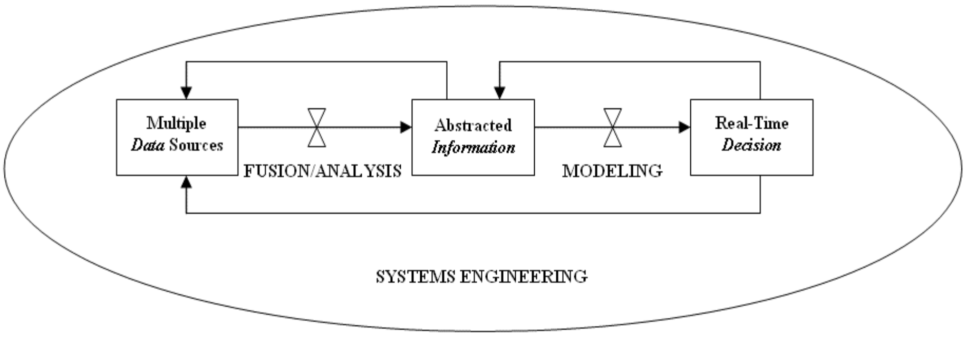

Figure 2 System adaptation: A decision informatics paradigm

Human interface is another essential element of an adaptive service system; it is actually a critical tool in systems engineering. Such interface could include the interactions between and among humans and software agents, machines, sub-systems, and systems of systems. Human factors constitute a discipline that deals with many of these interactions. However, another critical interface concerns how humans interact with data and information. In developing appropriate human-information interfaces, one must pay careful attention to a number of factors. First, human-information interfaces are actually a part of any decision support model; they structure the manner in which the model output or information is provided to the decision maker. Cognition represents the point of interface between the human and the information presented. The presentation must enhance the cognitive process of mental visualization, capable of creating images from complex multidimensional data, including structured and unstructured text documents, measurements, images and video. Second, constructing and communicating a mental image common to a team of, say, clinicians and nurses could facilitate collaboration and could lead to more effective decision making at all levels, from operational to tactical to strategic. Nevertheless, cognitive facilitation is especially necessary in operational settings which are under high stress. Third, cognitive modeling and decision making must combine machine learning technology with a priori knowledge in a probabilistic data mining framework to develop models of, say, a nurse's tasks, goals, and objectives. These user-behavior models must be designed to adapt to the individual decision maker so as to promote better understanding of the needs and actions of the individual, including adversarial behaviors and intents.

More importantly and as detailed in Table 5, service system adaptation can occur over the monitoring, feedback, cybernetic and learning dimensions. Monitoring adaptation can be defined by the degree of sensed actions in regard to data collection (i.e., sensors, agents, swarms), data analysis (i.e., structuring, processing, mining), and information abstraction (i.e., derivations, groupings, patterns). Data are acquired by sensors, which could be in the form of humans, robotic networks, aerial images, radio frequency signals, and other measures and signatures. In regard to patients, for example, sensors which monitor their vital signs are essential, as are verbal inputs from the patients themselves. More recently, data warehouses are proliferating and data mining techniques are gaining in popularity. However, no matter how large a data warehouse and how sophisticated a data mining technique, problems can occur if the data do not possess the desirable attributes of measurability, availability, consistency, validity, reliability, stability, accuracy, independence, robustness and completeness.

Moreover, in most situations, data alone are useless unless access to and analysis of the data are in real-time. In developing real-time, adaptive data processors, one must consider several critical issues. First, as depicted in Figure 2, these data processors must be able to combine (i.e., fuse and analyze) streaming data from sensors and other appropriate input from knowledge bases (including output from tactical and strategic databases) in order to generate

Table 5 System adaptation: Dimensions

Dimension	Definition	Characteristics	Elements
Monitoring	Degree of Sensed Actions	Data Collection Data Analysis Information Abstraction	Sensors; Agents; Swarms Structuring; Processing; Mining Derivations; Groupings; Patterns
Feedback	Degree of Expected Actions	Standardized Procedural Algorithmic	Pre-Structured; Pre-Planned Policies; Standard Operating Procedures Optimized; Bayesian
Cybernetic	Degree of Reactive Actions	Deterministic Dynamic Adaptive	Known States; Deterministic Actions Known State Distributions; Dynamic Actions Unknown States; Adaptive Actions
Learning	Degree of Unstructured Actions	Cognition Evidence Improvisation	Recognition-Based; Behavioral Information-Based; Genetic Experience-Based; Evolutionary

information that could serve as input to operational decision support models and/or provide the basis for making informed decisions. Second, as also indicated in Figure 2, the type of data to collect and how to process it depend on what decision is to be made; these dependencies highlight the difficulty of developing effective and adaptive data processors or data miners. Further, once a decision is made, it may constrain subsequent decisions which, in turn, may change future data requirements and information needs. Third, inasmuch as the data processors must function in real-time and be adaptable to an ongoing stream of data, genetic algorithms, which equations can mutate repeatedly in an evolutionary manner until a solution emerges that best fit the observed data, are becoming the tools of choice in this area.

Feedback adaptation can be defined by the degree of expected actions based on standardized (i.e., pre-structured, pre-planned), procedural (i.e., policies, standard operating procedures), and algorithmic (i.e., optimized, Bayesian) approaches. In general, models underpin these approaches. As an example, Kaplan et al. (2002) have developed a set of complex models to demonstrate that the best prevention approach to a smallpox attack would be to undertake immediate and widespread vaccination. Unfortunately, models, including simulations, dealing with multiple systems are still relatively immature and must be the focus of additional research and development. Such system of systems models are quite complex and will require a multidisciplinary approach.

Cybernetic adaptation can be defined by the degree of reactive actions that could be deterministic (i.e., known states, deterministic actions), dynamic (i.e., known state distributions, dynamic actions), or adaptive (i.e., unknown states, adaptive actions). Cybernetics is derived from the Greek word “kybernetics”, which refers to a steersman or governor. Within a system, cybernetics is about feedback (through evaluation of performance relative to stated objectives) and control (through communication, self-regulation, adaptation, optimization, and/or management); thus, cybernetic adaptation refers to actions that are undertaken based on an assessment of the feedback signals and then taking corrective steps to control the system so as to achieve the desired system objectives. A system is defined by state variables that are known in a deterministic manner (resulting in deterministic feedback or cybernetic actions); that are known in a probabilistic or distributional manner (resulting in dynamic feedback or cybernetic actions); or that are unknown (resulting in adaptive feedback or cybernetic actions). As an example, autopilots – which are programmed to deal with deterministic and dynamic situations – can, for the most part, take off, fly and land a plane; yet, usually two human pilots are also on the plane, just in case an unknown state occurs and the adaptive judgment of a human pilot is required. Clearly, a trained human – like a clinician or surgeon – is still the most adaptive controller, although machines are becoming more 'intelligent' through adaptive learning algorithms.

System control is perhaps the most critical challenge facing system of systems (SoS) designers. Due to the difficulty, if not impossibility, of developing a comprehensive SoS model, either analytically or through simulation, SoS control remains an open problem and is, of course, uniquely challenging for each application domain. Moreover, real-time control – which is required in almost all application domains – of interdependent systems poses an especially difficult problem. The cooperative control of an SoS assumes that it can be characterized by a set of interconnected systems or agents with a common goal. Classical techniques of control, optimization and estimation could be used to create parallel architectures for, as an example, coordinating numerous sensors. However, many issues dealing with real-time cooperative control have not been addressed, even in non-SoS structures. For example, one issue concerns the control of an SoS in the presence of communication delays among the SoS sub-systems.

Finally, learning adaptation can be defined by the degree of unstructured actions based on cognition (i.e., recognition-based, behavioral), evidence (i.e., information-based, genetic), and improvisation (i.e., experience-based, evolutionary). Learning adaptation is mostly about real-time decision making at the operational level. In such a situation and as indicated earlier, it is not just about speeding up steady-state models and their solution algorithms; in fact, steady-state models become irrelevant in real-time environments. In essence, it concerns reasoning under both uncertainty and severe time constraints. The development of operational decision support models must recognize several critical issues. First, in addition to defining what data to collect and how they should be fused and analyzed, decisions also drive what kind of models or simulations are needed. These operational models are, in turn, based on abstracted information and output from tactical and strategic decision support models. The models must capture changing behaviors and conditions and adaptively – usually, by employing Bayesian networks – be responsive within the changing environment. Second, most adaptive models are closely aligned with evolutionary models, also known as genetic algorithms; thus, they function in a manner similar to biological evolution or natural selection. Today, computationally-intensive evolutionary algorithms have been employed to develop sophisticated, real-time pricing schemes to minimize traffic congestion (Sussman 2008), to enhance autonomous operations in unmanned aircrafts, and to determine sniper locations in modern day warfare (e.g., in Iraq). Third, computational improvisation is another operational modeling approach that can be employed when one cannot predict and plan for every possible contingency. (Indeed, much of what happened on 9/11 was improvised, based on the ingenuity of the responders.) Improvisation involves learning by re-examining and re-organizing past knowledge in time to meet the requirements of an unexpected situation; it may be conceptualized as a search and assembly problem, influenced by such factors as time available for planning, prevailing risk, and constraints imposed by prior decisions (Mendonca & Wallace 2004). The rise of cloud computing – whereby the vast array of machines (including laptops and smartphones) can be connected to data and algorithms almost anytime and anywhere – is becoming an essential tool to computational decision making, including improvisation.

Again, healthcare – as a service system – must be adaptive in regard to decision making, decision informatics, and human interface, as well as over the monitoring, feedback, cybernetic and learning dimensions. At all levels of healthcare decision making, there are a spectrum of possible methods that can be utilized, ranging from adopting adaptive – instead of randomized – medical trials, to autonomous control, to virtual-touch tools, to genetic algorithms, to improvisation, all able to cope with imprecision, uncertainties and partial truth (Zadeh 1996). As an example, shared or informed decision making is becoming more popular and, as a result, patients are electing to have fewer surgeries for clogged arteries (when they are informed that, except for reducing chest pains, drugs are just as effective as angioplasty surgeries – with balloons and stents – in preventing heart attacks and death), prostate cancer (when they are informed that 97 percent of men with prostate cancer die of some other cause), and herniated discs (when they are informed that the outcomes are the same when they have surgery or not). Moreover, the methods can be used to process information, take into account changing conditions, and learn from the environment; thus, they are adaptive and, to a large extent, responsive to a data stream of real-time input. In a fully integrated and adaptive system of systems (SoS), each system must be able to communicate and interact with the entire SoS, without any compatibility issues. On a less global scale, personalized medicine development (Aspinall & Hamermesh 2007) and delivery (Mitragoti 2008) reflect healthcare adaptation at its finest.

5. Healthcare as a Complex System

Service systems can indeed be complex, requiring both integrative and adaptive approaches to deal with their complexity. There are a number of ways of identifying the complexity of a system (Rouse 2007), especially a service system. Table 6 lists seven system stages that underpin the complexity of a healthcare service system and that require integrative and adaptive methods to mitigate, if not to handle, the complexity.

First, the system's purpose is hard to define, given the many stakeholders (i.e., patients, clinicians, insurers, etc.) involved, the multiple objectives (i.e., wellness care, emergency care, acute care, etc.) of each stakeholder, and the overarching business model (i.e., revenues, expenditures, endowments, etc.). How one combines all these divergent viewpoints into a consistent and viable purpose is an almost impossible task. Second, the system's boundary is, at best, ill-defined and shifting; the spatial (i.e., offices, clinics, hospitals, etc.), temporal (i.e., schedules, activities, resources, etc.), and interdependent (i.e., infrastructures, supply chains, demand chains, etc.) relationships are difficult to ascertain. Third, the system's design must be robust (i.e., to insure reliability, quality, integrity, etc.), efficient (i.e., to minimize cost, inventory, waste, etc.), and effective (i.e., to maximize usefulness, satisfaction, pervasiveness, etc.). Fourth, the system's development must be based on models (i.e., gedanken experiments, simulations, networks, etc.), scalability (i.e., multi-scale, multi-level, multi-temporal, etc.), and sustainability (i.e., over time, space, culture, etc.). Fifth, the system's deployment must be with minimal risk (i.e., morbidity, co-morbidity, mortality, etc.), uncertainty (i.e., unexpected attitude, behavior, performance, etc.), and unintended consequences (i.e., delays, bad side effects, deteriorating vital signs, etc.). Sixth, the system's operation must be flexible (i.e., agile, transparent, redundant, etc.), safe (i.e., with minimal natural accidents, human failures, unforeseen disruptions, etc.), and secure (i.e., with minimal system viruses, system crashes, privacy intrusions, etc.). Seventh, the system's life cycle must be predictable (i.e., in regard to inputs, processes, outcomes, etc.), controllable (i.e., with appropriate sensors, feedback, cybernetics, etc.), and evolutionary (i.e., with learning capabilities, timely recoveries, intelligent growth, etc.).

System complexity can also be characterized by a simple two-by-two, supply versus demand, matrix (Tien et al. 2004); Table 7 provides an insightful understanding of supply chain management (SCM, which can occur when demand is fixed and supply is flexible and therefore manageable), demand chain management (DCM, which can occur when supply is fixed and demand is flexible and therefore manageable), and real-time customized management (RTCM, which can occur when both demand and supply are flexible and therefore manageable or allowing for real-time mass customization). Table 7 identifies several example SCM, DCM and RTCM methods. The literature is overwhelmed with SCM findings (especially in regard to manufacturing), is only recently focusing on DCM methods (especially in regard to revenue management), and is devoid of RTCM considerations, except for a recent contribution by Yasar (2005).

Table 8 contains an RTCM application: two SCM methods – capacity rationing (CR) and capacity extending (CE) – and two DCM methods – demand bumping (DB) and demand recapturing (DR) – are combined to deal with the customized management of, as illustrations, either a goods problem concerned with the rationing of equipment to produce classes of goods or a services problem concerned with the rationing of nursing staff to co-deliver classes of services. More importantly, in a 2-class customized management of the {CR, CE, DB, DR} problem and employing an incremental analysis or greedy algorithm solution approach, it can be shown that:

Table 6 Complex service systems: healthcare system considerations

System Stages	Healthcare System Considerations	Critical Methods	
		Integrative	Adaptive
1. Purpose	Stakeholders; Triaging; Business Model	✓	✓
2. Boundary	Spatial; Temporal; Interdependent	✓	✓
3. Design	Robust; Efficient; Effective	✓	✓
4. Development	Models; Scalability; Sustainability	✓	✓
5. Deployment	Risk; Uncertainty; Unintended Consequences	✓	✓
6. Operation	Flexible; Safe; Secure	✓	✓
7. Life Cycle	Predictable; Controllable; Evolutionary	✓	✓

Table 7 Complex service systems: supply integration and demand adaptation research

Supply Integration	Demand Adaptation	
	Fixed	Flexible
Fixed	**Unable To Manage** Price Established (At Point Where Fixed Demand Matches Fixed Supply)	**Demand Chain Management (DCM)** Product Revenue Management Dynamic Pricing Target Marketing Expectation Management Auctions
Flexible	**Supply Chain Management (SCM)** Inventory Control Production Scheduling Distribution Planning Capacity Revenue Management Reverse Auctions	**Real-Time Customized Management (RTCM)** Customized Bundling Customized Revenue Management Customized Pricing Customized Modularization Customized Co-Production Systems

Table 8 Examples of real-time customized management of supply and demand chains

Real-Time Customized Management Methods	Goods Example	Services Example
	Rationing of equipment to produce classes of products	Rationing of nursing staff to co-deliver classes of services
Supply Chain Management • Capacity Rationing (CR) • Capacity Extending (CE)	• CR of equipment • CE of equipment (e.g., outsourcing, overtime)	• CR of nurses • CE of nurses (e.g., outsourcing, overtime)
Demand Chain Management • Demand Bumping (DB) • Demand Recapturing (DR)	• DB of customer orders • DR of customer orders	• DB of nursing services • DR of nursing services

- the profit from simultaneously applying {CR, DB} $\geqslant$ the profit from sequentially applying {CR, DB};
- the more customized management methods employed, the more robust or stable the profit;

- the smaller the initial capacity, the more profit is impacted by the customized management methods;
- the profit from applying {CR, CE, DB, DR} ⩾ the profit from applying {CR, CE, DB} ⩾ the profit from applying {CR, CE} or the profit from applying {CR, DB} ⩾ the profit from applying {CR} ⩾ the profit from applying {first come, first served}; and
- the {CR} application is equivalent to a single period {newsvendor} problem.

Extending the 2-class to an *n*-class customized management of the {CR, CE, DB, DR} problem and employing a greedy algorithm and simulated approximation solution approach, it can be shown that:

- the same findings and insights can be obtained as in the case of the 2-class problem;
- the profit from an *n*-class problem ⩾ the profit from an (n−1)-class problem; and
- the greater the n value, the more robust or stable the profit.

Additionally, extending the *n*-class customized to a real-time customized management of the {CR, CE, DB, DR} problem and employing an adaptive, non-parametric regression of successive differences (in incoming data) solution approach, it can be shown that:

- the same findings and insights can be obtained as in the case of the *n*-class customized management problem;
- the profit from real-time customized management ⩾ the profit from just customized management; and
- the fewer the number of customized management methods employed, the greater is the sensitivity of profit to real-time solutions.

In sum, it has been shown that the real-time, simultaneous application of customized management methods to both the supply and demand chains yields significant system efficiency, if not effectiveness. However, solving these real-time problems require solution approaches that transcend the steady-state approaches that are currently available.

Returning to Table 7, it should be emphasized that it is in the RTCM or fourth quadrant of the exhibit that both system integration (as reflected in the SCM methods) and system adaptation (as reflected in the DCM methods) are combined and dealt with simultaneously. Thus, a combined integration and adaptation research effort is synonymous to a real-time customized management (RTCM) activity, which can only occur when both demand and supply are flexible and thereby allowing for real-time mass customization. This fourth quadrant also highlights the complexity involved in designing a service system that is at once both integrated and adaptive. Clearly, healthcare is an example of such a complex system. Finally, it should be noted that electronic data processing underpins nearly all aspects of integration and adaptation, especially in regard to healthcare (Meyer 2008).

6. Concluding Insights

A number of insights can be ascertained from an integrated and adaptive view of healthcare services. First, as noted earlier, electronic-based medical records constitute the glue that should keep the healthcare system integrated and adaptive. Unfortunately, most medical records – including patient data, drug prescriptions, laboratory diagnostics, clinician reports, and body scans – are still in manual folders and, as a consequence, difficult to access, fuse and analyze. More recently, Microsoft and Google, respectively, launched HealthVault and Health for consumers to store and manage their personal medical data online, and Wal-Mart is allowing its intranet to serve as a repository for the health histories of its more than one million staff members. While patients have a legal right to obtain their medical records from doctors, hospitals, and testing laboratories, it is indeed a tedious and overwhelming process due to the fact that the records are not in electronic form. Nevertheless, sharing such electronic records with new medical providers and third-party services should make it easier to cut waste, eliminate red tape, coordinate care, spot adverse drug interactions, reduce repeat or ineffective tests, allow for medication reminders, and track vital signs. Indeed, as part of the 2009 economic stimulus package, the U.S. is mounting a massive effort to modernize healthcare by making all health records standardized and electronic within five years, a monumental task given that only about 17% of the 800,000 clinicians employ computerized records. Moreover, personal data residing on Microsoft, Google or Wal-Mart server grids or clouds do raise significant privacy concerns. At present, the Health Insurance Portability and Accountability Act (HIPAA) only requires doctors, hospitals and third-party payers to not release information without a patient’s consent. Of course, HIPAA’s requirements could be broadened and new rules could be enacted that give consumers stronger protection and legal recourse if their records are leaked or improperly shared for other than its intended purpose.

Second, as real-time healthcare decisions must be made in an accelerated and co-produced manner, the human service provider (e.g., clinician) will increasingly become a bottleneck; he/she must be supported by a smart robot or software agent. For example, the clinician could use a smart alter ego or agent – sometimes called a virtual personal assistant – which could analyze, and perhaps fuse, all the existing and incoming e-mails, phone calls, Web pages, x-rays, drug prescriptions, and medical examinations, and assigns every item a priority based on the clinician's preferences and observed behaviors. It should be able to perform an analysis of a message text, judge the sender-recipient relationships by examining an organizational chart and recall the urgency of the recipient’s responses to previous messages from the same sender. To this, it might add information gathered by watching the clinician via a video camera or by scrutinizing his/her calendar. Most probably, such a smart agent would be based on a Bayesian statistical model – capable of evaluating hundreds of user-related factors linked by probabilities, causes and effects in a vast web of contingent outcomes – which can infer the likelihood that a given decision on the software's part would lead to the clinician's desired outcome. The ultimate goal is to judge when the clinician can safely be interrupted, with what kind of message, and via which device. In time, smart agents representing both providers and consumers will become the service co-producers; they will employ decision informatics techniques and cloud computing to accomplish their tasks. It should be noted that smart agents may never be appropriate for certain situations, especially, as examples, where a nuanced patient behavior is critical or when a catastrophic surgical consequence is on the balance. Obviously, these situations require direct patient-clinician interaction or co-production, perhaps assisted by smart agents – with access to databases and algorithms that are a part of cloud computing – which can help in the identification of alternative diagnoses and treatments.

Third, perhaps the best example of an integrated and adaptive service system is the evolving Web 2.0. It is user-built, user-centered and user-run. In other words, it is a social network for integration – including collaboration and communication – of activities (e.g., eBay, Amazon.com, Wikipedia, Twitter, MySpace, Friendster, LinkedIn, Plaxo, etc.), entertainment (e.g., Facebook, Ning, Bebo, Second Life, World of Warcraft, etc.), searches (e.g., Google, Yahoo, MSN.com, etc.), and knowledge computation (e.g., Wolfram Alpha). Unfortunately, the integrated web, while being a somewhat successful e-commerce platform, is unable to interpret, manipulate or make sense of its content. On the other hand and with the encoding of web pages in a semantic web format, the evolving web will be able to allow for the above mentioned smart or decision informatics supported agents to undertake semantic analysis of user intent and web content, to understand and filter their meaning, and to adaptively respond in light of user needs. The Semantic Web, then, could be an ideal complex service system where integration and adaptation will constitute the basis for its functionality. However, several obstacles must be overcome before reaching full functionality. For example, semantic standards or ontologies – such as the Web Ontology Language (OWL) – must be established so as to maintain compatible and interoperable formats; at present, health care and financial services companies are each developing their own ontology. Indeed, a healthcare system of systems (SoS) also needs a common ontology to allow for new system components to be appropriately integrated into the SoS without a major effort, so as to achieve higher capabilities and performance than would be possible with the component systems as stand-alone systems. Of course, the healthcare ontology must be transdisciplinary – beyond a single disciplinary – in scope; with such an ontology, healthcare may indeed exist as a social network of patients, clinicians, insurers and other related providers.

Fourth, as a critical aspect of complexity, modern systems of systems are also becoming increasingly more human-centered, if not human-focused; thus, products and services are becoming more personalized or customized. Certainly, services co-production implies the existence of a human customer, if not a human service provider. The implication is profound: a multidisciplinary approach must be employed for, say, healthcare – it must also include techniques from the social sciences (i.e., sociology, psychology, and philosophy) and management (i.e., organization, economics and finance). As a consequence, researchers must expand their systems (i.e., holistic-oriented), man (i.e., decision-oriented) and cybernetic (i.e., adaptive-oriented) methods to include and be integrated with those techniques that are beyond science and engineering. For example, higher patient satisfaction can be achieved not only by improving service quality but also by lowering patient expectation. In essence, as stated by Hipel et al. (2007), systems, man and cybernetics is an integrative, adaptive and multidisciplinary approach to creative problem solving; it takes into account stakeholders' value systems and satisfies important societal, environmental, economic and other requirements in order to enhance the decision making process when designing, implementing, operating and maintaining a system or system of systems to meet societal needs in a fair, ethical and sustainable manner throughout the system's life cycle. Interestingly, an adaptive, human-centered (i.e., human-to-human) system that functions in real-time is the Twitter social network, based on easy-to-use, 140-character bursts of constant chatter which can inform and engage a participant with an intensity that cannot be replicated offline.

Fifth, perhaps the most critical U.S. healthcare issue is, as alluded to earlier, the universal access of patients to healthcare. Payers – particularly private insurances – have nearly eliminated access of at-risk individuals to healthcare providers, by not allowing them to enroll in their insurance programs. (At the extreme, only the very healthy and relatively young individuals are able to purchase a private insurance plan.) Thus, a huge access problem is created for the uninsured, which solution is to go to the emergency room, at a time where severity of illness is already advanced and costly and where treatment must be provided at no cost. A vicious subsidization cycle ensues whereby individual insurance premiums sky-rocket, mainly to pay for the care of individuals who are at-risk and unable to get insurance or who cannot afford the insurance premium. Indeed, by employing the technobiology approach of systems engineering to remedy the U.S. healthcare is what is required in order to equilibrate the insurance imbalance and to make it an efficient and effective system. In this regard, payment for care should be more weighted to output or value provided than to input or activity undertaken (Porter & Teisberg 2006). Additionally, such manufacturing techniques as cross-training and multi-use of facilities can enhance both efficiency and effectiveness. Furthermore, contrary to a widely-held belief, waste is not a necessary by-product of excellence. All of these issues must be taken into consideration as the U.S. Congress seeks to reform healthcare; it must integrate public plans (e.g., Medicare and Medicaid) with a plethora of private plans (that are neither affordable nor portable) in order to achieve healthcare coverage for all its residents.

Sixth, a final insight concerns the customization or personalization of medical treatments through advances in genetics, proteomics and metabolomics. Most common illnesses will eventually be preventable; the challenge is to know which prevention effort will be most effective for a given individual. Employing markers of risk (e.g., gene variants, blood levels of a protein moiety, etc.) may allow for the targeting or personalization of preventive measures in a highly cost-effective way. In this manner, humans can be sheltered from chronic illnesses and pandemics, and remain fully functional until an advanced age (say, 100), beyond which survival is genetically limited. Thus, healthcare is indeed a service, one that can be personalized and that can enhance the quality – and length – of an individual's life.

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