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ON INTEGRATION AND ADAPTATION IN COMPLEX SERVICE SYSTEMS

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Abstract

The services sector employs a large and growing proportion of workers in the industrialized nations, and it is increasingly dependent on information and communication technologies. While the interdependences, similarities and complementarities of manufacturing and services are significant, there are considerable differences between goods and services, including 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). In general, services can be considered to be knowledge-intensive agents or components which work together as providers and consumers to create or co-produce value. Like manufacturing systems, an efficient service system must be an integrated system of systems, leading to greater connectivity and interdependence. Integration must occur over the physical, temporal, organizational and functional dimensions, and must include methods concerned with the component, the management, and the system. Moreover, an effective service system must also be an adaptable system, leading to greater value and responsiveness. Adaptation must occur over the dimensions of monitoring, feedback, cybernetics and learning, and must include methods concerned with space, time, and system. In sum, service systems are indeed complex, especially due to the uncertainties associated with the human-centered aspects of such systems. Moreover, the system complexities can only be dealt with methods that enhance system integration and adaptation. The paper concludes with several insights, including a plea to shift the current misplaced focus on developing a science or discipline for services to further developing a systems engineering approach to services, an approach based on the integration and adaptation of a host of sciences or disciplines (e.g., physics, mathematics, statistics, psychology, sociology, etc.). In fact, what is required is a services-related transdisciplinary – beyond a single disciplinary – ontology or taxonomy as a basis for disciplinary integration and adaptation.

Keywords: Services, service system, system components, system integration, system adaptation, system of systems, decision informatics, real-time decision making

1. On Services

Before viewing a service system as an integrated system in Section 2, an adaptive system in Section 3, and a complex system in Section 4, it is helpful to define services – and their uniqueness, especially in contrast to goods – in this beginning section. Some concluding insights are provided in Section 5. 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.

In order to provide a context for considering services, it is instructive to review the critical stages in a nation's economic evolution. As summarized in Table 1, there have been three stages. The first – mechanical – stage focuses on agriculture and mining (i.e., living off of the land, air and sea); it seeks to enhance farming productivity, employs mechanical tools that have product life cycles on the order of decades, depends mostly on muscle power, embraces a living standard concerned with subsistence, and is limited in its scope of economic influence – primarily impacting the family or immediate locale. The second – electrical – stage focuses on manufacturing and construction (i.e., creating and producing goods and structures); it seeks to enhance factory productivity, employs electromechanical machines that have product life cycles on the order of years, depends on both muscle and brain power, embraces a living standard concerned with the quality of goods, and is broader in its scope of economic influence – impacting the region or nation. The third – information – stage focuses on services (i.e., creating and delivering added value that is essentially intangible); it seeks to enhance information (i.e., processed data) productivity, employs information (including communications) technologies that have service life cycles on the order of months, depends mostly on brain power, embraces a living standard concerned with the quality of life, and is global in its scope of economic influence. More recently, the words "experience economy" (e.g., tourism, Starbuck coffees, space station visits, etc.) have been employed to underscore the quality of life focus of this third stage in a nation's economic evolution.

In general, every nation has gone or will go through these three stages of economic evolution: today, the underdeveloped nations are still at the mechanical stage; most of the developed nations are at the electrical stage; while the economically advanced nations are at the service stage. Interestingly, the U.S. has seen the onset of each new stage every 100 years or so: in the late 1700s for the mechanical stage, in the late 1800s for the electrical stage, and in the late 1900s for the information stage. On the other hand, while some countries – like China – have been slow in moving from the mechanical to the electrical stage, they have since been moving

Table 1 Stages in a nation's economic evolution

Characteristics	Mechanical	Electrical	Information
Economic Focus	Agriculture; Mining	Manufacturing; Construction	Services
Underlying Technology	Mechanical	Electromechanical	Information/Communication
Productivity Focus	Farming	Factory	Knowledge
Human Power	Muscle	Muscle/Brain	Brain
Living Standard	Subsistence	Quality of Goods	Quality of Life
Impact Scope	Family	Nation	World
U. S. Onset	Late 1700s	Late 1800s	Late 1900s

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

Table 3 Reported jobs by graduating students

ECONOMIC SECTOR	CLASS OF 1984-1985	CLASS OF 2004-2005
Services	29%	69%
Manufacturing	71	29
Agriculture	0	0
Construction	0	2
Mining	0	0
TOTAL	100	100

Source: *Career Development Center*, Rensselaer Polytechnic Institute

toward the information stage at an incredible speed, perhaps because of the accelerated pace of change in computer technology.

As detailed in Tien and 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 industrialized 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. Alternatively, one could look at the distribution of employers for graduates from such technological universities as Rensselaer Polytechnic Institute (with which the author was previously affiliated); not surprisingly, as indicated in Table 3, there has been a complete flip of employment statistics within the past twenty years – from 71 percent being hired into manufacturing jobs in 1984-1985 to 69 percent entering the services sector in 2004-2005. Moreover, the figures are even more pronounced among graduates from broad-based, liberal arts universities; for example, over 95 percent of the University of Miami (with which the author is currently affiliated) graduates are hired into the services sector.

Clearly, the manufacturing sector provides critical goods (e.g., autos, aircrafts, satellites, computers, etc.) that enable the delivery of effective and high-quality services; equally clear, the services sector provides critical services (e.g., financial, transportation, design, supply chain, etc.) that enable the production, distribution and consumption of efficient and high-quality goods. Moreover, such traditional manufacturing powerhouses as GE and IBM have become more vertically integrated and are now earning an increasingly larger share of their income and profit through their services – including maintenance – operation. For example, in 2006, IBM's pre-tax income was \$13.3 billion (based on a total revenue stream of \$91.4 billion) and it was divided into three parts: 23 percent from systems and technology, 40 percent from software (which can considered to be a service activity), and 37 percent from global services. Thus, IBM earned 23 and 77 percent of its net revenues from goods and services, respectively; as a result, IBM no longer considers itself a computer hardware company – instead, it offers itself as a globally integrated innovation partner, one which is able to integrate expertise across industries, business processes and technologies.

Yet, as Tien and Berg (2006) augur, university 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. As a consequence, 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).

The following subsections consider, respectively, the emergence of electronic services, the relationship of services to manufacturing, and the movement toward mass customization of both goods and services.

1.1 Emerging Electronic Services

Prospectively, it is perhaps more appropriate to focus on emerging electronic-services. E-services are, of course, totally dependent on information technology; they include, as examples, financial services, banking, airline reservation systems, and consumer goods marketing. As discussed by Tien and Berg (2003) and detailed in Table 4, 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.

Table 4 Comparison of traditional and electronic services

	SERVICE ENTERPRISES	
ISSUE	TRADITIONAL	ELECTRONIC
Co-Production Medium	Physical	Electronic
Labor Requirement	High	Low
Wage Level	Low	High
Self-Service Requirement	Low	High
Transaction Speed Requirement	Low	High
Computation Requirement	Medium	High
Data Sources	Multiple Homogeneous	Multiple Non-Homogeneous
Driver	Data-Driven	Information-Driven
Data Availability/Accuracy	Poor	Rich
Information Availability/Accuracy	Poor	Poor
Economic Consideration	Economies of Scale	Economies of Expertise
Service Objective	Standardized	Personalized
Service Focus	Mass Production	Mass Customization
Decision Time Frame	Predetermined	Real-Time

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.

1.2 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 and 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 the production/delivery stage, 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 5, 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 5, services can be considered to be "chipper", while manufactured goods are a "pitirur".

Another critical difference between manufacturing and services concerns their intellectual property (Tien and Berg 2006). More specifically and in contrast to manufactured goods, services are based on intellectual property that is rarely protected by any patents belonging to the service provider. Usually the service provider uses technologies or goods that belong to outside suppliers (who protect their intellectual property by patents). However, the use of the intellectual property, either by product purchase or by license, is available non-exclusively to all competing service providers. Examples abound: the airline industry uses jet airplanes, which technology is protected by patents owned by the aircraft manufacturers and other suppliers; Wal-Mart, as part of its vaunted supply chain leadership, relies on point-of-sales cash registers developed and sold by IBM, which holds the intellectual property for those devices; and Citibank, the leader in employing the automated teller machine (ATM) innovation, does not hold the ATM-related patents – Diebold does.

Table 5 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*

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 lecturer should get better over time, especially if the same lecture is repeated.

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 (e.g., health care, education, etc.). However, with new multimedia and broadband technologies, some hospitals are personalizing their treatment of patients, including the sharing of electronic records with their patients, and some institutions are offering entire degree programs online with just-in-time learning capabilities (Tien 2000).

1.3 Toward 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).

Extending the three economic stages in Table 1, Exhibit 6 predicts – in italics – a fourth stage in a nation's economic evolution; that is, as information, communication and decision technologies become better, faster and cheaper, many goods and services will be partially mass customized beginning in the early 2000s and mass customized in real-time beginning in the mid 2000s. Three additional points should be made concerning Exhibit 6. First, 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. Second, when mass customization occurs, it is difficult to say whether a service or a good is being delivered; that is, a uniquely fitted jacket

Table 6 Towards lower case customization

U.S. Onset Period	Goods		Services	
	Types	Customization Level	Type	Customization Level
Late 1700s	Minimal	Customized	Minimal	Customized
Late 1800s	Few	Mass Produced	Few	Standardized
Late 1900s	Many	Partially Customized	Many	Partially Customized
Early 2000s	*Many*	*Partially Mass Customized*	*Many*	*Partially Mass Customized*
Mid 2000s	*Infinite*	*Real-Time Mass Customized*	*Infinite*	*Real-Time Mass Customized*

can be considered to be a co-produced service/good or "servgood". Third, the implication of real-time mass customization 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.

Increasingly, customers want more than just traditional or electronic services; as indicated earlier, they are seeking experiences (Pine and Gilmore 1999) that they can customize to their liking. Customers walk around with their iPods, drink their coffee at Starbucks while listening to and downloading music, dine at such theme restaurants as the Hard Rock Cafe or Planet Hollywood, shop at such experiential destinations as Universal CityWalk in Los Angeles or Beursplien in Rotterdam, lose themselves in such virtual worlds as Second Life or World of Warcraft, and vacation at such theme parks as Disney World or the Dubai Ski Dome, all venues which stage a feast of engaging sensations that are provided by an integrated set of services and goods. There is, nevertheless, a distinction between services and experiences; a service includes a set of intangible activities carried out for the customer, whereas an experience engages the customer in a personal, memorable and holistic manner, one that tries to engage all of the customer's senses. Obviously, experiences have always been at the heart of entertainment, from plays and concerts to movies and television shows; however, the number of entertainment options has exploded with digitization and the Internet. Today, there is a vast array of new experiences, including interactive games, World Wide Web sites, motion-based simulators, 3D movies and virtual realities. Interestingly, one may well ask if experiences will accelerate the commoditization of services, just as services – especially electronic services – have accelerated the commoditization of goods?

2. On Integration

A service system is actually an integration or combination of three essential elements – people, processes and products. Moreover, integration can occur over the physical, temporal, organizational and functional dimensions, and can include methods concerned with the component, the management, and the system.

2.1 Integration Elements

People, processes and products are the essential elements of an integrated service system. In particular, people can be grouped into those demanding services (i.e., customers, users, consumers, buyers, organizations, etc.) and those supplying the services (i.e., suppliers, providers, 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 element or component 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. People-oriented, decision-focused methods are considered in Section 3.

The U. S. health care 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 a non-system. As a consequence, a coordinated and integrated health care system must be created, 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 health care in terms of access and use of validated information.

Processes which underpin system integration include standards, procedures, 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., 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. The tags are being placed on pallets or individual items passing through the supply chain. In essence, RFLID serves to make the supply chains more visible in real-time, and as the price of tags decreases, RFLID will become ever more popular and critical to the efficient functioning of any supply chain, including the distribution and shipping of goods.

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 1, 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. From a business perspective, there are, of course, three reasons to act – to create a new service, to solve a particular problem, or to compete in a specific area. Thus, one can create a new service by combining skiing and surfing (i.e., snowboarding); one can solve the consumer problem by establishing Big Box stores (i.e., Costco) or shopping malls (i.e., Mall of America); or one can compete by feature and price differentiation (i.e., cell phone plans).

2.2 Integration Dimensions

As detailed in Table 7, 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 (e.g., closed, open, hybrid), constructed (e.g., goods, structure, systems) or virtual (e.g., service, simulated, e-commerce) environment. An urban center's infrastructures (e.g., emergency services, travel 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,

Table 7 System integration: dimensions

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

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. Recent technological advancements on imbuing infrastructures with "intelligence" make it increasingly feasible to address the safety and security issues, 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 (e.g., analytical, procedural, political), tactical (e.g., simulation, distribution, allocation), and operational (e.g., 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 and Cahn (1981) postulated and validated, "satisfaction is a function of expectation," service performance or satisfaction can be enhanced through the effective "management" of expectation.

Organizational integration can be defined by the degree of systems co-management of resources (e.g., people, processes, products), economics (e.g., supply, demand, revenue), and management (e.g., 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 and Berg 2006), resulting in a "servgood".

Functional integration can be defined by the degree of systems co-functioning in regard to input (e.g., location, allocation, re-allocation), process (e.g., informatics, feedback, control), and output (e.g., 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 manufactured goods are primarily a result of an efficient supply chain, while services are primarily a result of an effective demand chain.

2.3 Integration Methods

As summarized in Exhibit 8, service system integration methods span the component, the management, and the system, so as to achieve primarily system efficiency and secondarily system effectiveness. The component integration methods include design (e.g., computer-aided, creative, responsive), interface (e.g., standardization, cognition), and interdependency (e.g., integrity, reliability). Design, or creative problem solving, constitutes the philosophical foundation upon which all engineering disciplines can flourish and mature. The design process permits humans to employ the imaginative or "right brain" component of their intelligence in concert with their analytical or "left brain" capabilities to creatively solve, often in an iterative manner, tough problems, ranging from designing intelligent transportation systems to developing effective government policies. The information technology revolution has permitted the analysis part of design to be largely replaced by computers. For example, a human can tentatively imagine the main features of an advanced transportation vehicle having certain capabilities for satisfying transportation objectives; these features can then be rigorously analyzed and viewed graphically using a Computer Aided Design (CAD)/Computer Aided Manufacturing (CAM) program. Based on this analytical and visual feedback, the vehicle can be redesigned and analyzed again in an iterative manner until a satisfactory design is achieved which meets specified performance (e.g., human interface, environmental, fuel efficiency) criteria.

The management integration methods include issues of philosophy (e.g., just-in-time, just-in-case), operation (e.g., scalability, sustainability), and collaboration (e.g., co-production, co-functioning). As an example, Xu et al. (2008) show how an integrated approach for agricultural ecosystem management is critical to its sustainability. Collaboration – especially inter-company collaboration – is perhaps the most surprising integration method. After all, patents were established to protect intellectual property, long enough for the inventors to recoup a good return on their creative investment. However, since services are, by necessity, co-created or co-produced, collaboration is essential. Indeed, as noted by Palmisano (2004), the innovation challenges are too complex; they require collaboration across disciplines, specialties, organizations and cultures. Additionally, the easy access to information through search

Table 8 System integration: methods

Integration Concern	Methods	Objectives	
		Efficient	Effective
Component	Design: Computer-Aided; Creative; Responsive	✓	✓
	Interface: Standardization; Cognition	✓	✓
	Interdependency: Integrity; Reliability	✓	✓
Management	Philosophy: Just-in-Time; Just-in-Case	✓	✓
	Operation: Scalability; Sustainability	✓	✓
	Collaboration: Co-Production; Co-Functioning	✓	✓
System	Foci: Goals, Objectives	✓	✓
	Models: Simulation; Optimization	✓	✓
	Entities: Connectivity; System of Systems	✓	✓

engines (e.g., Google, AOL, Yahoo, Microsoft Network, etc.), the proliferation of collaborative software (e.g., Microsoft Office Live Meeting, MySpace), and the open source software movement (e.g., Linux, Open Invention Network) have all combined to facilitate collaboration. Govindarajan and Trimble (2005) recommend that past assumptions, mindsets, and biases must be forgotten (especially in regard to collaboration), and Sanford and Taylor (2005) further underscore this point by suggesting that companies must "let go to grow". A critical by-product of collaboration is, of course, standardization. Standards establish clear boundaries of function and operation, eliminate data interface problems, define interchangeable components and platforms, and assure a high level of performance. In turn, a cornerstone of standardization has been the ubiquitous bar code – called the Universal Product Code (UPC) – that has been uniquely associated with almost every good or service. The UPC is making way for the Electronic Product Code (EPC) which, as noted earlier, is stored in a radio frequency location and identification (RFLID) tag or computer chip with a transmitter.

The system integration methods include its foci (e.g., goals, objectives), models (e.g., simulation, optimization), and entities (e.g., connectivity, system of systems). The connectivity of system entities refers to the progressive linking and testing of system components to merge their functional and technical characteristics into a comprehensive, interoperable system of systems (SoS). For example, in a fully integrated SoS, each system can communicate and interact with the entire SoS, without any compatibility issues. For this purpose, an SoS needs a common language, without which the SoS components cannot be fully functional in the sense that new system components cannot be appropriately integrated into the SoS without a major effort. The concept of an SoS arises from the need to more effectively and efficiently implement and analyze large, complex, and heterogeneous systems working in a cooperative and interdependent manner. The driving force behind the desire to view these systems as an SoS is to achieve higher capabilities and performance than would be possible with the components as stand-alone systems.

Sadly, however, the same advances that have enhanced interconnectedness have created new vulnerabilities, especially related to equipment failure, human error, weather and other natural disasters, and physical and cyber attacks. Thus, electronic viruses, biological agents and other toxic materials can turn a nation's "lifelines" into "deathlines" (Beroggi and Wallace 1995), in that they can be used to facilitate the spread of these materials – whether by accident or by willful act. Even the Internet – with over a billion users – has become a terrorist tool; jihad websites are recruiting members, soliciting funds, and promoting violence (e.g., by showing the beheading of hostages). Thus, the tools or technologies that underpin a modern society can likewise serve as weapons for undermining, if not destroying, society. Biological, chemical and nuclear advances can be employed as weapons of mass destruction; the highly effective Internet can be a medium for cyber viruses, hackers and spammers; and airplanes can be employed as missiles against people, infrastructures and commerce.

3. On Adaptation

Because a service system is, by definition, a co-producing system, it must be adaptive. Adaption is a uniquely human characteristic, based on a combination of three essential elements –decision making, decision informatics, and human interface. Moreover, adaptation can occur over the monitoring, feedback, cybernetic and learning dimensions, and can include methods concerned with space, time and system.

3.1 Adaptation Elements

Decision making, decision informatics, and human interface are essential elements of an adaptive service system. 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 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 in a knowledge economy. In a continuum of data, information,

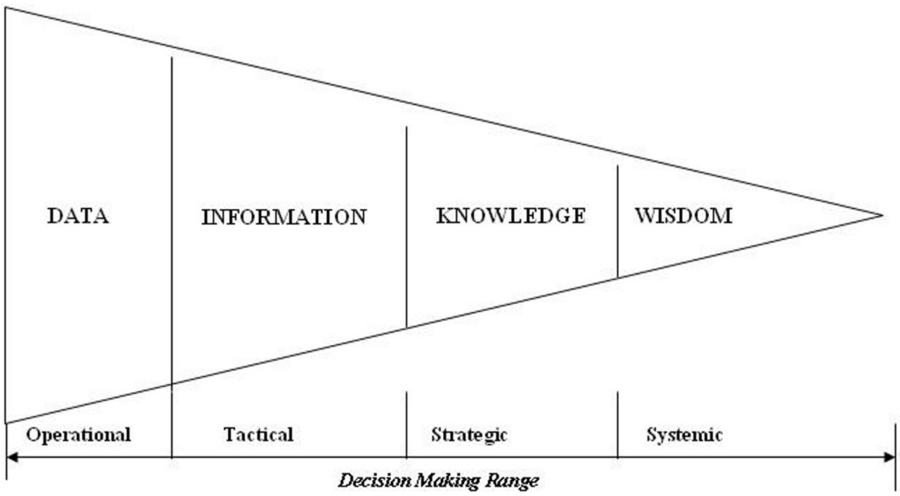

Figure 1 System adaptation: decision making framework

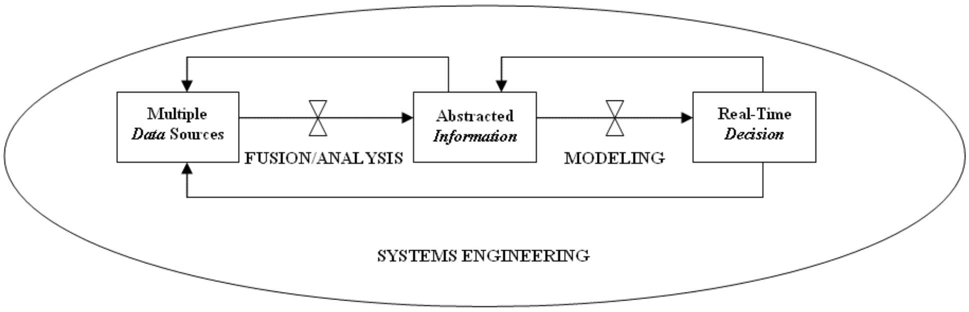

Figure 2 System adaptation: lower case decision informatics paradigm

knowledge, and wisdom, the U. S. – as well as other advanced economies – is, at best, at the beginning of a data rich, information poor (DRIP) conundrum, as identified in Section 1.

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. 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. 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 includes the information-based modeling and analysis of alternative decision scenarios; they include operations research, decision science, computer science and industrial engineering. 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. Thus, non steady-state and 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 alluded to in Figure 2 concern the integration of people, processes, and products from a systems perspective; they include electrical engineering, human-machine systems, systems performance and systems 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.

A final point about Figure 2: the depicted decision informatics paradigm is, as a framework, generic and applicable to most, if not all, decision problems. In fact, since any data analysis or modeling effort should only be undertaken in support of some kind of a decision (including the design of a good or a service), all analyses and modeling activities should be able to be viewed within the decision informatics framework. Thus, the framework can be very appropriately applied to critical issues in regard to a particular service, good, or infrastructure system. The decision informatics approach is needed not only to develop new innovations in services (especially e-services and/or experiences) but also, if appropriate, to be packaged within a software algorithm that can serve to automate – and thereby enhance the productivity of – the developed innovation. Additionally, the adaptive nature of decision informatics is very much akin to the evidence-based – or, more appropriately, risk-based – medical protocols that are becoming increasingly employed in health care. Actually, the paradigm is likewise applicable to any design problem, inasmuch as the essence of design is about making decisions concerning alternative scenarios or designs. (Not surprisingly, innovation is sometimes characterized as "design thinking".) In short, decision informatics represents a decision-driven, information-based, real-time, continuously-adaptive, customer- centric and computationally-intensive approach to intelligent decision making by humans and/or software agents.

In regard to the three levels of decision making, strategic decisions are usually distinguished from tactical and operational decisions by the organizational and financial impact of the decisions (i.e., the impact of a strategic decision being significantly greater than those at the tactical and operational levels); by the 'clock speed' (i.e., major strategic decisions usually do not arise as often as tactical and operational decisions and the amount of time available for strategic decision making is usually greater than that for tactical and operational decision making, sometimes significantly so); and by the complexity or scope of the decisions (i.e., strategic decisions – in contrast to tactical and operational decisions – must also take into consideration political, legal, social and ethical issues). At all three levels of decision making, it is not only about making the right decisions; it is also about making timely –

and therefore adaptive – decisions. This is especially true at the operational level, where humans must react in seconds and software programs must react in milliseconds. Thus, real-time, information-based decision making – which Tien (2003) calls decision informatics – is needed for enhancing the production and delivery of services, especially emerging e-services. Appropriate decision making techniques developed in systems engineering and operations research can be effectively utilized. More specifically, systems engineering focuses on all levels of decision making; on unstructured and complex problems; on qualitative and quantitative data; on soft and hard systems; on the integration of technical, institutional, cultural, financial and other inputs; on multiple conflicting objectives; and, quite appropriately, on a system of systems perspective. As one progresses from the operational to the strategic level of decision making, one tends to employ more societal system models and fewer physical system models.

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, emergency responders 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 an individual's tasks, goals, and interests. 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.

3.2 Adaptation Dimensions

As detailed in Table 9, service system adaptation can occur over the monitoring, feedback, cybernetics and learning dimensions. Monitoring adaptation can be defined by the degree of sensed actions in regard to data collection (e.g., sensors, agents, swarms), data analysis (e.g., structuring, processing, mining), and information abstraction (e.g., derivations,

Table 9 System adaptation: dimensions

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

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 tsunamis, for example, seismographs, deep ocean detection devices with buoy transmitters, and/or tide gauges can all sense a potential tsunami. 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. Nevertheless, through the careful analysis or mining of the data, Davenport and Harris (2007) describe how high-performing companies are developing their competitive strategies around data-driven insights based on sophisticated statistical analysis and predictive modeling. Companies as diverse as Capital One, Procter & Gamble, the Boston Red Sox, Best Buy and Amazon.com have made better decisions by identifying profitable customers, accelerating innovation, optimizing supply chains and pricing, and discovering new measures of performance. 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 information that could serve as input to operational decision support models and/or provide the basis for making informed decisions. Second, as also shown 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 (e.g., pre-structured, pre-planned), procedural (e.g., policies, standard operating procedures), and algorithmic (e.g., 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. As another example, Larson (2005) identifies a range of decision models for response planning. Indeed, response is about allocating or reallocating resources, which is the essence of operations research – a science that helped the U.S. minimize shipping losses during World War II, brought efficiencies in production, and developed optimal scheduling of personnel. Another set of critical emergency response models includes those that can simulate, as examples, the impact of an airliner hitting a chemical plant, the dispersion of radioactive material following the explosion of a dirty bomb, and the spread of illness due to a contaminated water supply.

Cybernetics 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). 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 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 a SoS assumes that it can be characterized by a set of interconnected systems or agents with a common goal. Classical techniques of control design, 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 to and among the SoS sub-systems.

Finally, learning adaptation can be defined by the degree of unstructured actions based on cognition (e.g., recognition-based, behavioral), evidence (e.g., information-based, genetic), and improvisation (e.g., 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 appropriately 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 and Wallace 2004).

3.3 Adaptation Methods

As summarized in Table 10, service system adaptation methods span space, time, and system, so as to achieve primarily system effectiveness and secondarily system efficiency. Space adaptation methods include people (e.g., providers, consumers), processes (e.g., procedural, algorithmic), and products (e.g.,

Table 10 System adaptation: methods

Integration Concern	Methods	Objectives	
		Efficient	Effective
Space	People: Providers; Consumers	✓	✓
	Processes: Procedural; Algorithmic	✓	✓
	Products: Physical; Virtual	✓	✓
Time	Culture: Attitudes; Behaviors; Expectations	✓	✓
	Technologies: Autonomous; Service-Oriented Architecture	✓	✓
	Actions: Informed; Improvised	✓	✓
System	Operation: Bayesian Networks; Social Networks	✓	✓
	Customization: Partial; Mass; Real-Time	✓	✓
	Evolution: Perturbation; Innovation	✓	✓

physical, virtual). At all levels of decision making, there are a spectrum of possible models that can be utilized, ranging from those that can be regarded as supporting war games to those with avatars and virtual environments. The World Wide Web will soon be part of a World Wide Simulation where an immersive, three dimensional environment may well combine elements of such virtual worlds as Second Life with such mapping tools as Google Earth. Moreover, sight and sound will be complemented with virtual-touch technology or haptics, which can give users the sensation that they are feeling solid objects through tactile interfaces and physical resistance.

Tien and Berg (2003) also call for viewing services as spatial systems that require integration and adaptation with other systems and processes; in fact, they make a case for further developing a branch of systems engineering called "service systems engineering". In this manner, they demonstrate how the traditional systems approach to analysis, control and optimization can be applied to a service system of systems that are each within the province of a distinct service provider. They underscore this special focus not only because of the size and importance of the services sector but also because of the unique opportunities that systems engineering can exploit in the design and joint production and delivery of services. In particular, a number of service systems engineering methods are identified to enhance the design and production/delivery of services, especially taking advantage of the unique features that characterize services – namely, services, especially emerging electronic-services, are decision-driven, information-based, customer-centric, computationally-intensive, and productivity-focused.

Time adaptation methods include culture (e.g., attitudes, behaviors, expectations), technologies (e.g., autonomous, service-oriented architecture), and actions (e.g., informed, improvised). Autonomous control of a system assumes that it can be characterized by a set of 'intelligent entities' that can be implicitly or autonomously controlled. Although the concept of autonomous or intelligent control was first introduced three decades ago by Gupta et al. (1977), the control community has only recently paid substantial attention to such an approach, especially in regard to a variety of industrial applications (e.g., cameras, dishwashers, automobiles, etc.). Most of these applications are due to Zadeh (1996) and involve fuzzy logic, neural networks, evolutionary algorithms, and soft computing; the strength of these methods is in its ability to cope with imprecision, uncertainties and partial truth. Moreover, the methods can be used to process information, adapt to changing environmental conditions, and learn from the environment; thus, they are adaptive and, to a large extent, responsive to a data stream of real-time input. However, additional research is required before autonomous control can make full use of a continuous data stream, including taking into consideration the possible future state of a system of systems.

Another critical e-service technology is the Global Positioning System (GPS); it is bringing significant productivity improvements to the world's transportation and emergency service (i.e., police, ambulance and fire) agencies, as well as to other dispatch-oriented industries (e.g., taxicab companies, delivery services, and maintenance services). Yet another technology is the ubiquitous Internet, the world's data superhighway in which businesses can interact with their far-flung offices, or with other businesses; customers can buy goods and services; and individuals can exchange e-mails or surf for information. Despite the "dot-com bubble" burst in the early 2000s, the Internet is flourishing and e-services or e-commerce is continuing to grow, especially as Web 2.0 becomes a reality.

System adaptation methods include operation (e.g., Bayesian networks, social networks), customization (e.g., partial, mass, real-time), and evolution (e.g., perturbation, innovation).

System adaptation is being enhanced by new wireless telecommunication advances; they will soon make mobile devices a multi-purpose services instrument, with more memory and better screens and where traditional voice and data (i.e., Internet and email) services will converge with digital music, video clips, video conferencing, satellite radio, location tracking, traffic reporting, and other personal needs (e.g., credit checks, online education, etc.). All of these technological innovations – which are based on real-time computing – have ushered in a range of real-time or on-demand enterprises, which claim that critical business information is always up-to-date and available and that decisions can be promptly made; that is, the detection of an event, the reporting of that event, and the response decision can all occur within a very short time frame or near real-time. Clearly, as examples, the slow and inadequate responses to recent urban disruptions (e.g., 2001 9/11 tragedy, 2002 SARS – Severe Acute Respiratory Syndrome – epidemic, 2004 South Asia Tsunami, and 2005 Hurricane Katrina) demonstrate that although real-time actions are desirable, they are not yet a pervasive reality. On the other hand, Amazon.com does employ real-time information technology and automated decision making to suggest alternative reading material for its customers. Thus, real-time decision making is not only about real-time computing but also about developing the tools or algorithms that can adaptively support real-time actions and activities.

4. On Complexities

Service systems are indeed complex,

requiring both integrative and adaptive approaches to handle their complexity – which is considered in this section in terms of its architectural considerations (Tien 2008, Jain et al. 2008), its range of examples, and its research potential.

4.1 Architectural Considerations

There are a number of ways of identifying the complexity of a system, especially a service system. Table 11 lists seven system stages that render a service system complex, and that require integrative and adaptive methods to mitigate, if not handle, their 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, failures, crashes, 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.).

Table 11 Complex service systems: architectural considerations

System Stages	Service System Considerations	Critical Methods	
		Integrative	Adaptive
1. Purpose	Stakeholders; Objectives; 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 12 Complex service systems: integration/adaptation examples

Integration Dimensions	Example Contexts	Adaptation Dimensions			
		Monitoring	Feedback	Cybernetics	Learning
Physical	Electric Power	System Spikes	Network Redundancy	Spot Market	Soft Degradation
Temporal	Urban Disruption	Tactical Prediction/Prevention	Strategic Preparation	Tactical Recovery	Operational Detection/ Response
Organiza-tional	Cyber Space	Bloomberg Financial	Google	Commodity Futures	World of Warcraft
Functional	Health Care	Medical Triaging	Referrals	Specialties	Emergency Care

Table 13 Complex service systems: integration/adaptation research

SUPPLY	DEMAND	
	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

4.2 Integration/Adaptation Examples

Given the four system integration dimensions (i.e., physical, temporal, organizational, and functional) and the four system adaptation dimensions (i.e., monitoring, feedback, cybernetics, and learning), Table 12 identifies 16 service system examples; actually, there are four sets of four sub-examples, each set being within an example context (i.e., electric power, urban disruption, cyber space, and health care).

In regard to the urban disruption set of examples, Tien (2005) demonstrates why adaptive decision making is critical when confronting such disruptions. While terrorist acts are the most insidious and onerous of all urban disruptions, it is obvious that there are many similarities in the way one should deal with these willful acts and those caused by natural and accidental incidents that have also resulted in adverse and severe consequences. However, there is one major and critical difference between terrorist acts and the other types of disruptions: the terrorist acts are willful – and therefore also adaptive. One must counter these acts with the same, if not more sophisticated, willful, adaptive and informed approach. The right decisions must be made at the right time and for the right reason, including those concerned with the strategic preparation for a major disruption, the tactical prediction of such a disruption, the strategic prevention or mitigation of the disruption, the operational detection of the disruption, the operational response to the disruption, and the tactical recovery steps that are necessary to adequately, if not fully, recuperate from the disruption. As a consequence, one must trade off or balance between productivity and security; between just-in-time interdependencies and just-in-case inventories; and between high-probability, low-risk life-as-usual situations and low-probability, high-risk catastrophes.

4.3 Integration/Adaptation Research

Although only depicting a simple two-by-two, supply versus demand, matrix (Tien et al. 2004), Table 13 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 thereby allowing for real-time mass customization).

Table 13 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) – he combines two SCM methods (i.e., capacity rationing and capacity extending) and two DCM methods (i.e., demand bumping and demand recapturing) to deal with the real-time customized management of, as examples, either a goods problem concerned with the rationing of equipment to produce classes of goods or a services problem concerned with the rationing of consultants to co-produce classes of services. More importantly, it is shown that the combined, simultaneous real-time management of the two SCM and the two DCM yields a significantly more profitable outcome than the tandem application of these two sets of methods. Moreover, the real-time management approach required a more sophisticated solution approach than the traditional steady state approach.

It is in this fourth, RTCM quadrant of Table 13 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/adaptation research is synonymous to real-time customized management (RTCM, which can 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. Indeed, health care is an example of such a complex system.

5. On Insights

A number of insights can be ascertained from an integrated and adaptive view of services. First, it is obvious that systems – especially service systems – are becoming increasingly more complex; indeed, each system can be regarded as a system of systems, together with all the attendant life-cycle design, human interface, and system integration and adaptation issues. For example, central to the mission of transforming the current U. S. army into a leaner, more technologically advanced fighting force is a vast computerized network – called the Future Combat Systems (FCS) – that would link humans (i.e., soldiers, commanders, etc.) to a panoply of sensors, satellites, robots, drones, and armored vehicles. Initiated in 2002, FCS has a projected price tag of $230 billion through 2030; it would require the writing of over 60 million lines of computer code, the most ever for any system. The Boeing Company and its main subcontractor, Science Applications International Corporation (SAIC), are managing this very complex effort which, if successful, could change the nature of warfare and lift the proverbial fog of war from the battlefield. The decision informatics paradigm (Tien, 2003) must, of course, be at the heart of any FCS that requires adaptive, real-time decision making.

Second, as real-time decisions must be made in an accelerated and co-produced manner, the human service provider will increasingly become a bottleneck; he/she must make way for a smart robot or software agent. For example, everyone could use a smart alter ego or agent which could analyze, and perhaps fuse, all the existing and incoming e-mails, phone calls, Web pages, news clips, and stock quotes, and assigns every item a priority based on the individual'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 user 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 user's desired outcome. The ultimate goal is to judge when the user can safely be interrupted, with what kind of message, and via which device. Perhaps the same agent could serve as a travel assistant by searching the Internet and gathering all the relevant information about airline schedules and hotel prices, and, with the user's consent, returning with the electronic tickets and reservations. In time, smart agents representing both providers and consumers will be the service co-producers; they will employ decision informatics techniques to accomplish their tasks.

Third, perhaps the best example of an integrated and adaptive complex 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.), and searches (e.g., Google, Yahoo, MSN.com, etc.). 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 (DI) 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, will 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. Also, while AdWords and AdSense have helped to attract online advertising dollars to search sites, most social networking sites – where millions of "eye balls" or users congregate and interact – do not have a viable business model. Indeed in November 2007, when Facebook tried to get between its users with its Beacon program (which tracked Facebook users' purchases and displayed them to their friends), protests of privacy violations were lodged and the program had to be severely scaled back (Urstadt 2008). Furthermore, as has been indicated many times, customization – which is a form of adaptation – has benefited greatly from advances in computation; however, customizing or targeting at the individual level does raise issues of privacy and confidentiality. In this regard, it is critical that every user of any online – or offline – site must be offered the choice of "opting out", whereby their personal data, activities or actions could not be used for any other purpose than its intended purpose.

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 – it must also include techniques from the social sciences (i.e., sociology, psychology, and philosophy) and management (i.e., organization, economics and entrepreneurship). 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 customer satisfaction can be achieved not only by improving service quality but also by lowering customer 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, which takes into account stakeholders' value systems and satisfies important societal, environmental, economic and other criteria 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.

Fifth and finally, although some companies (e.g., IBM) are focused on developing a science for services, it should be noted that services – like manufacturing, agriculture, construction, or mining – is an economic sector or application domain, not a basic discipline. Thus, services are not akin to a computer, which computational underpinning can be subjected to a scientific or disciplinary approach. On the other hand, like manufacturing and the other application domains, services can be subjected to a systems engineering approach – which, in turn, implies an integration and adaptation of a host of scientific disciplines (e.g., physics, mathematics, statistics, behavioral science, social science, etc.). Indeed, what is required is a services-related transdisciplinary – beyond a single disciplinary – ontology or taxonomy as a basis for disciplinary integration and adaptation.

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