Service science: At the intersection of management, social, and engineering sciences

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Service industries comprise roughly 75 percent of the gross domestic product of developed nations. To design and operate service systems for today and tomorrow, a new type of engineer must be educated, one who focuses on services rather than manufacturing. Such an engineer must be able to integrate three sciences—management, social, and engineering science—in the analysis of service systems. Within the context of the Center for Engineering Systems Fundamentals, a research center at the Massachusetts Institute of Technology, we discuss how newly emerging service systems require such a three-way integrated analysis. We deliberately select some nonstandard services, because many business services, such as supply chains, have been studied extensively.

INTRODUCTION

Service industries comprise more than 75 percent of the U.S. economy and the great majority of the gross domestic product (GDP) of virtually all developed nations. Services cover a very broad and diverse range of activities, including health care, education, transportation and logistics, utilities, financial services, government services, including national defense, entertainment, and more. The analysis of the problems of services industries requires more than the efficient solution of purely technical challenges. The human element is almost always present in the analysis. Narrow, purely technocratic solutions are not adequate for service systems; perspectives and tools from multiple disciplines are required.

A small group of researchers at the Massachusetts Institute of Technology (MIT) are trying to address the challenges of multidisciplinary analysis of service systems while retaining scientific rigor. This is being done at the Center for Engineering Systems Fundamentals (CESF), established in 2005. CESF is dedicated to advancing the fundamentals of the new field called *engineering systems*. In this phrase, *engineering* can be viewed as an adjective or a verb. Our research and teaching tend to be at the intersection of traditional engineering science, management science, and social science. In our view, service system design and operation require attention to all three of these sciences. Other papers in this special issue of the *IBM Systems Journal* reinforce this perspective.

The application of engineering principles to services is not new. The explicit incorporation of management and social sciences into the analysis does appear to be new. For example, the Danish telephone engineer A. K. Erlang invented the mathematical theory of queues in the period 1909–1917. Erlang and his superiors wanted to know the performance characteristics of a new invention—the centralized telephone switch or "automatic telephone exchange"—as a function of its capacity to hold calls.[1,2] The telephone switch allowed any caller to phone any other person on the network having a telephone. This was quite different from the original telephone invention, which had only two telephones connected by a single wire. One could argue that the invention of the centralized telephone switch heralded the start of the first technology-enabled social network.

Implicitly, Erlang brought management and social science into his analysis. If the switch had too much capacity, no one would ever be denied service but the Copenhagen Telephone Company would be spending more on capital investment than necessary, a poor management decision. If the switch had too little capacity, callers would hang up in frustration and become discouraged because of their inability to place calls in a timely manner. Callers' behavior here is largely based on their psychology, and excess queue delays or denial of service would create a negative psychological response that the telephone company would experience as lost customers and lost revenue. Today, the psychology of queuing is almost as important as the physics of queuing,[3] and management decisions regarding the capacity of queues remain important in nearly all applications of queuing analysis. Queues appear in many (if not most) service systems, and their integrated analysis remains a top priority today.

National defense represents a critical component of government-provided services. In 1915, Frederick W. Lanchester created a simple mathematical model of warfare that demonstrated linear and quadratic relationships between size of opposing armies and outcomes on the battlefield.[4] While the analysis was simple, it was revolutionary, as it provided the first serious engineering analysis of warfare. Like Erlang in the same period, Lanchester implicitly, rather than explicitly, incorporated management and social science issues into his analysis. Similarly, Lanchester's simple analysis has led to scores of enhancements and refinements over the ensuing decades, including the explicit consideration of management ("command") and social science issues.

Momentum has been building for at least a century for engineers to become more involved with analysis of service systems. The broadening of that analysis is our concern today. The National Academy of Engineering, in 1988, demonstrated its desire for engineers to devote more effort to services with release of its book, *Managing Innovation: Cases from the Services Industry*.[5] Additional recent discussions devoted to this topic[6] and in particular the paper by Chesbrough and Spohrer[7] have focused on the need to create a *service science*.

In the following, we briefly review several of the services-sector research initiatives started by CESF in its first two years. Much of the work described is in progress, as the center and its research projects are all new. A continuing theme guiding this work is the need to work at the intersection of engineering, management, and social sciences. As a guide to the reader, the major research initiatives of CESF are shown in ***Table 1***, with examples of how each of the components must be considered in undertaking the research.

CESF RESEARCH INITIATIVES IN SERVICES

In the following, we describe six ongoing projects at CESF and indicate the role of engineering, management, and the social sciences in their analysis.

Demand management for critical infrastructures

Infrastructure systems are connected networks delivering services or products from point to point along the network. They include transportation networks, telecommunication networks, and utilities. These are fixed-capacity systems having marked time-of-day and day-of-week demand patterns. Usually, the statistics of demand, including hourly use patterns, are well known and often correlated with outside factors such as weather (a

Table 1 CESF research initiatives: Components of engineering, management, and social sciences

Research Topic Area	Engineering Science	Management Science	Social Sciences
Demand management for critical infrastructures	Electrical and systems engineering	Planning large capital investment projects; maintaining systems	Understanding cost-benefit relationships for users in order to shave peak demands
Voting systems	Operations research of queuing	Managing the pre-election day deployment and real-time re-deployment of resources	Understanding voters' decision to abandon voting lines
Social distancing in influenza pandemic	Modeling the physics of disease progression	Planning responses of government, businesses, and families	Understanding and managing human behavior in the presence of a pandemic
Hurricane preparedness and response	Modeling the physics of hurricane progression	Managing evacuations and related responses	Understanding people's propensity to follow evacuation orders
e-learning in developing countries	Computer science, electrical engineering, and operations research	Managing the deployment of technology and human assets and maintaining the system	Understanding learners' responses to pedagogy by culture, gender, age, and related measures

short-term factor) and the general economy (a longer-term factor).

An infrastructure system is difficult and expensive to design and construct. Once built, it can have a mean lifetime ranging from 20 years (as in telecommunications) to more than 100 years (as in water systems). As populations grow and the economy improves, increasingly large demands are being placed on infrastructure systems. Eventually, they must be upgraded with additional capacity. However, if capacity upgrades can be delayed, huge cost savings are possible. This can be attempted by managing demand for service away from peak periods, in essence reducing the magnitude of the minima and maxima of the demand graph. This demand management is the focus of one CESF research initiative.

Some current examples include time-of-day congestion pricing for vehicles to enter city centers in Singapore and London; for-profit "tollways" adjacent to freeways;[8] time-of-day pricing for electricity; time-of-day pricing for long-distance telephone calls; use of revenue management in airlines to balance travel demands over the course of a week and over a year; and auction-type bidding for some infrastructure services, with higher prices paid for congestion periods. In our congestion-pricing research for cities, we have found queuing theory (started by Erlang) to be essential for understanding the phenomenon of car drivers "cruising" to find relatively inexpensive on-street parking. Our queuing model, believed to be new, contains psychological and economic parameters indicating how long drivers will cruise before settling for more-expensive off-street parking.

The research aims to create a uniform conceptual framing of the topic, called "strategies to overcome network congestion in infrastructure systems." We seek to identify new, exciting, and previously unexplored strategies that show promise for one or more of the types of infrastructure systems mentioned earlier.

Traditional engineering can be found everywhere in the design and operation of critical networked infrastructure. The social science component is in understanding the cost-benefit relationships that would make users willing to defer service consumption at times of peak demand. These are often lifestyle issues—for example, when it is best to travel or to do the laundry. The management component is in the planning and managing of large-infrastructure capital investment projects and in the management of dynamic pricing and related strategies for shaving peak demands and deferring them to off-peak times. These ideas are expanded in Reference 9.

E-electricity management

The ideas presented in this paper can be used to create new products and services, all with the three-science intersection in mind. Here we present one such new product, an example of demand management for critical infrastructures, in the area of electricity demand management.

We propose a system for automated graceful reduction and delay of discretionary electricity usage in homes, businesses, and other locations. The system may use Bluetooth**, the Internet, Wi-Fi (wireless network access), RFID (radio-frequency identification), and other new communication technologies, in conjunction with a home computer or special control box, to turn off or delay turning on one or more addressable electrical appliances. In "user control" mode, such a system would reduce user costs if the electricity provider institutes time-of-day or dynamic state-of-the-system pricing. The goal is to moderate the maxima and minima of electricity demand. A second usage, "provider control mode," would enable graceful degradation of service for those cases in which the electricity provider would usually implement blackouts or brownouts. With the proposed system, all users would experience a slight inconvenience, rather than a few users (those being shut down entirely) being extremely inconvenienced. This system is seen as the first step in the creation of a home- or business-based lifestyle energy-optimizing system.

The proposed new product envisages a world in the not-too-distant future in which electricity is priced more in line with the marginal cost of its production and delivery. Currently, the least-efficient electricity generation plants are activated last, are the most costly to operate, and tend to be polluters. Those who use electricity in peak periods should have to pay a premium. Those who defer usage until off-peak times should pay less. This is a simple application of the law of supply and demand and gives consumers some control over their own demand profiles. We imagine a device (in the home or business) that can communicate with electrical appliances (we use the word *appliance* with broad meaning) to turn them off or defer turning them on when the quoted price of electricity is too high. These appliances can be turned on later, when the cost is lower.

An exemplary application is the electric water heater and its use for washing dishes or clothes. The device we have in mind may in fact be software for one's Internet-connected home computer together with several electrical devices attached to addressable appliances. If such a device can be placed on the market for roughly $100 and there is time-of-day or dynamic pricing of electricity, the purchaser of the proposed system may save on his or her electricity bill to the extent that the device may pay for itself in the first year of usage. The utility providing the electricity could subsidize its purchase, or perhaps even install it at no charge, since the utility can use the device in provider control mode to gracefully shed a percentage of load during summer blackout or brownout conditions, thus saving some customers from total shutdown. The market for this device is equal to the number of homes and businesses in the United States. We might expect several millions of these devices to be sold and installed in the first year of production. For external confirmation of the market need for these devices, see Reference 10.

The proposed e-electricity management system is a product for both consumer and provider, providing benefits to both. Within lifestyle preferences and constraints, consumers can manage their use of electricity to minimize cost. Thus, this system brings the science of revenue management, invented by the airlines in the 1980s as a response to airline deregulation, to electricity usage, responding, again, to deregulation and in this case to high energy prices. Airlines price seats higher during higher-demand periods, and the consumer can select off-peak flights to save money. Giving the consumer the option to purchase certain amounts of electricity at off-peak hours benefits the consumer, who saves money; the utility, which does not need to expand capacity (at the cost of billions of dollars) and can exploit the provider control mode; and the environment, through a reduction in air pollution from old electricity-generation plants.

Previous research in this area is best represented by References 11 and 12. Constantopoulos et al.[11] discuss use of stochastic dynamic programming to adjust space conditioning temperature settings in response to immediate-delivery prices of electricity. Dynamic programming is an optimization technique originally put forth by Richard Bellman in the 1950s as a rigorous formalism for framing, formulating and executing decisions sequentially in an evolving uncertain (probabilistic) environment.[13] The recursive equations developed and used are frequently called “Bellman equations.” These equations have three components: state variables, stage variables, and physics transition equations depicting evolution of the system from stage to stage. The work of Constantopoulos et al. represents what might become a subroutine or procedure in our envisaged home- or business-based energy control system.

The final product to be offered to the public would be a “lifestyle energy optimizing system” in which the e-electricity management system would be an important component. The lifestyle energy optimizing system would also include data-mining and algorithmic software that would monitor the energy-related lifestyles of the occupants of the home or business and manage energy usage internally within the structure in a way that is statistically compatible with the occupants’ lifestyles.

For example, with room-based or floor-based thermostats, the system can automatically adjust the temperature in a room or floor in anticipation of people’s regular movements and needs for that space, adjusted in real time by the system’s knowledge of each person’s current location (detected by use of an RFID or similar device on each person).

In another example, as an RFID-tracked occupant moves from one room to the next, the TV or stereo can be turned off in the vacated room and, if preferences suggest it, turned on in the new room occupied. One’s entertainment environment can efficiently track a person around a house, while ensuring that only one set of entertainment appliances is on at any given time.

Voting in U.S. presidential elections

Voting systems in democracies are very important service systems. Voters at voting facilities may have to stand in queue and wait for their turn to vote. In the U.S., these queuing times in presidential elections range from zero minutes to more than eight hours. There are no accepted standards for these queuing times. It has been suggested that potential voters were discouraged from voting in both the 2000 and 2004 presidential elections due to long lines that were caused by too few voting machines and support personnel in certain voting places.[14] Because there are no exit polls of queue-discouraged voters, there may be an undocumented phenomenon of voter disenfranchisement. Some administrators of voting systems have blamed voters for slowness of the lines, citing such contributing factors as unfamiliarity with English, the new voting machines, or complex ballots. No doubt voters have responsibilities in casting votes, but no more so than customers of any service system. A retail store would be unjustified in serving customers poorly and then blaming the customers for the bad service. Voters do not create ballots, acquire voting machines, and operate poll stations. The total voting system must be coordinated; voting machines, software, and ballots might each be excellent, but without a professional systems design, the system will not function well. Systems designers must compete and offer total voting systems, utilizing the analysis tools of service science. They can bring harmony to design and function, leading the way to high quality for what is, arguably, the most important service offered to our citizens.

In this research, traditional engineering involves the industrial engineering or operations research of the physics of queues. There is a need to create a deployment algorithm to distribute voting machines (“queue servers”) throughout voting precincts. Social science is involved in the psychology of queuing: what makes potential voters balk at joining long lines or abandon slow-moving lines? Is it lifestyle constraints, impatience, or frustration at the disparity in queue waiting times? Management science is involved with the supervision of implementing a voting machine deployment system and in responding to unanticipated long queues on election day.

Social distancing in an influenza pandemic

Health-care services comprise more than 15 percent of the United States GDP, making health care the largest single service system in the country. A major threat to human health today is the possible emergence of a deadly influenza virus that could be efficiently transmitted from human to human, as was the virus responsible for the Spanish flu of 1918–1919. That influenza pandemic killed more Americans in one year than all the wars of the twentieth century combined.

CESF has arranged a team to examine preparedness and response to a potential influenza pandemic. Our focus is on *social distancing* as a control strategy for containing the spread of the influenza virus. Our students and faculty have drafted preliminary research papers on this topic, examining the use of social distancing historically in 1918, and in 2003 to combat the SARS (severe acute respiratory syndrome) epidemic. We view this as a topic of extreme national and international importance because hundreds of millions of lives could depend on how we individually and collectively respond to a pandemic, should one occur.

Traditional engineering in this context involves using operations research and related fields to create increasingly accurate and insightful mathematical models of flu progression under various assumptions. Management science addresses the extremely complex challenge of handling a health crisis of enormous magnitude. Each town and city will be responsible for its local public response, as will individuals, families, and businesses. Aligning the objectives of all stakeholders will be difficult but important. Psychology is one branch of the social sciences that will be critical: under what circumstances will families decide to withdraw from their usual social interactions in an attempt to isolate themselves from the virus? How do we collectively avoid panic responses to the threat of the illness and the shortage of supplies that may be created by supply-chain breakdowns?

Decisions during a pandemic

Should the avian influenza H5N1 virus mutate to become efficiently transmitted from human to human, or should another highly virulent flu virus emerge with similar properties, there will likely be no flu vaccine available for at least six months, and antiviral medicines are only marginally effective. Even after six months, only a minuscule fraction of the six billion inhabitants of the planet will have access to the vaccine, because of finite production and distribution capabilities. We may be nearly defenseless against this disease for six months and perhaps longer. During that time, the disease might have run its course around the world. Hospitals, made leaner during the past 20 years, have very little excess capacity to deal with hundreds of thousands, perhaps millions, of cases. Given this scenario, what are the control variables in such a complex and life-threatening system?

Research suggests that careful social distancing with hygienic steps can reduce the chance of any one person's becoming infected with the flu. Social distancing is centuries old, having often been used as a type of group evolutionary survival mechanism. In rural India in the nineteenth and early twentieth centuries, subsistence farm families frequently lived closely together in villages but worked separate land plots outside the villages. Whenever they heard from a trusted messenger that a plague was in the vicinity, they left the villages and lived separately on their land. They would return to their village homes once the signal was given that the risk of plague had subsided. The duration of the distancing was typically about two weeks. This policy of Indian farm families was presented to the author by Dr. Nitin Patel, whose father reported that tradition to him. Dr. Patel's father was born in 1909 and lived in the rural village of Karamsad, in the state of Gujarat, India. Our hypothesis is that the terminology *plague* in this context related to several different serious and sometimes fatal diseases and did not precisely refer to any specific plague (e.g., the bubonic plague).

While this policy seemed to work well for rural subsistence farmers, we may well ask, "What is the analog to the movement to the land in our highly networked, interconnected, Western style of life?" We are not self-sufficient and rely on others to provide virtually all essential services and products for living. Given all the interconnected networks upon which we rely, is social distancing itself, in the simple ways in which we can do it, sufficient to control the evolution and penetration of a flu pandemic?[15] We do not know the answer to this question, but research directed at the question is vitally important.

Some recent results are promising. In 2003, the population of Hong Kong, in fighting SARS, implemented a number of aggressive steps in social distancing and hygienic behavioral changes. Not only was SARS eradicated, but seasonal respiratory infections including seasonal flu, as measured in laboratory specimens, dropped by 90 percent during the period of tightest controls.[16] This is strong, if statistically uncontrolled, evidence that social distancing accompanied by behavioral changes such as frequent hand washing, wearing face masks, and self-isolation, can reduce the chance of becoming infected by a respiratory virus.

Most published mathematical models of pandemic flu progression contain a parameter called R_0, the generation-to-generation "flu multiplier." Technically, R_0 is the mean number of new infections

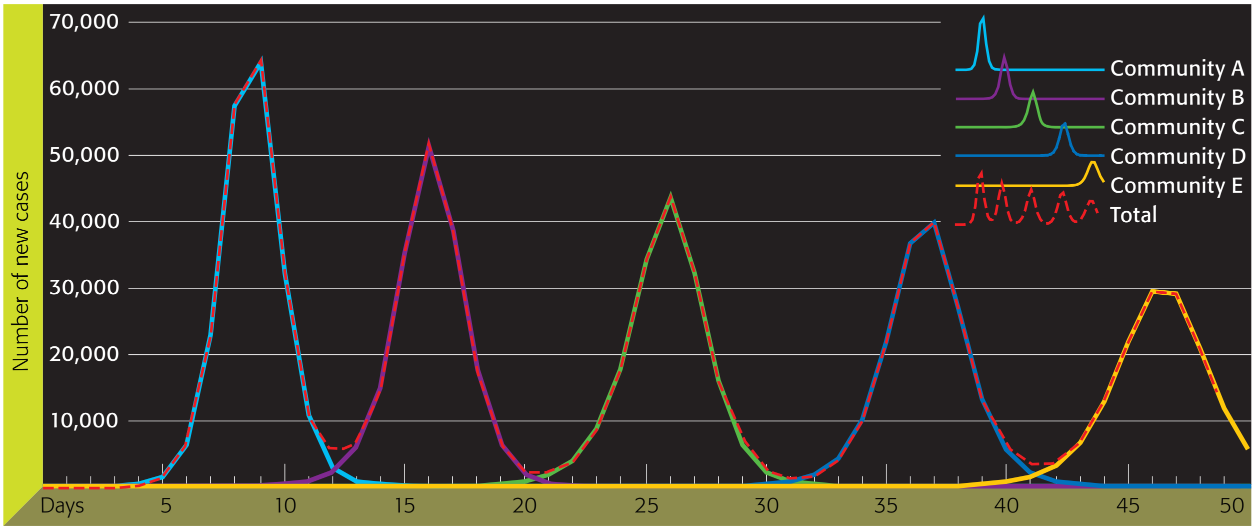

Figure 1
The spread of infection in a linked chain of five communities

created by a single infected person in a population of 100-percent-susceptible individuals. While we question the way this is commonly used in practice, there is value in considering typical values cited for R_0. For pandemic influenza, the typical value is between 2.0 and 2.5. While any value greater than 1.0 assures a near-term exponential increase in the number of those infected, the fact that R_0 is not larger than approximately 2.5 implies that we need only reduce its value by 50 to 70 percent in order to change exponential increase to exponential decay and cause the eradication of the disease.

In our models to date, R_0 is found to depend critically on the product of two quantities: (1) the probability of infection given face-to-face contact with an infected and infectious individual; and (2) the frequency of such contacts. Thus, rather than a fixed input parameter to a model, R_0 is controllable to a large extent. If one can reduce the frequency of human contacts by 50 to 70 percent, one is well on the way toward reducing R_0 to below-pandemic levels. Social science data suggest that a minority of the population is responsible for the great majority of human daily contacts. This is a prime example of the intersection of social science and engineering science in the modeling and control of disease progression.

We have developed a series of difference equation models that depict the evolution of the flu through a population, at first only among different social-activity-level groups within one community,[17] and then spatially across communities as well.[18] An illustrative finding is represented in ***Figure 1***, where we show the evolution of the flu through five serially linked communities as the virus spreads from one community eastward to its adjacent neighbor. Here we assume that each newly affected community has learned from observing its neighbors to the west, so that each newly infected community implements increasingly stringent social distancing measures. (Details are in Reference 18.) Note that as this occurs, the incidence of infection decreases, from a total of over 60,000 new cases per day in the first community to less than one-half that many in the fifth community.

We have one final concern about pandemics. In Philadelphia during late October of 1918, at the height of the pandemic, panic was a common response of the population. Loved ones were dying in their beds at home, with no medical attention given to them by doctors or nurses, many of whom themselves had fallen ill to the disease and others who were simply exhausted and overwhelmed by the huge number of cases. With World War I in progress, governments were not forthright about any topic that might demoralize the population. Ironically, their lack of honesty and transparency regarding the flu (which the local Philadelphia government officials often minimized as simple seasonal influenza) caused vast demoralization. This led to a panic during which hospitals were guarded by armed police to reduce the chance that doctors and nurses would be kidnapped by desperate relatives of sick and dying loved ones. If holistic research on behavioral changes in the face of the flu suggests strongly that risk of infection can be dramatically reduced, then panic may be replaced with confident feelings of control. This seemed to be the situation in Hong Kong in 2003, where there was a sense of shared community control in the face of SARS. If mathematical models and additional empirical research suggest that a similar approach may be successful against pandemic influenza, then it is critical that engineers, physical scientists, social scientists, and physicians educate the public about their findings to replace tendencies towards panic with the confidence of control.

Hurricane preparedness and response

Disaster preparedness and response requires the design of service systems to confront a variety of incidents, including acts of nature, industrial accidents, and terrorist attacks. Some of these are now called *high consequence, low probability* events.

We are developing a planning model to formulate rational policies for preparedness and response to hurricanes. Given a hurricane off the coast with a certain location, intensity, and movement vector, we are examining important decisions such as when to mobilize response personnel, when to pre-position supplies and equipment, and when to evacuate residents. Facing a time-sequenced optimization problem under uncertainty, the analytical framework we are employing is stochastic dynamic programming. In this context, the decision point is the time that meteorologists (using satellite, radar, and airplane data) update the depiction of the hurricane. The update yields a new state vector: the location of the eye, the intensity and size of the hurricane, and its velocity. These updates occur every several hours when the hurricane is far offshore, but become more frequent as the hurricane approaches landfall.

In considering decisions that might be made at each state update, one has to work through various future scenarios with regard to where the hurricane will make landfall (if indeed it does reach land), and its size and intensity at that time. The number of future scenarios is very large, and each has to be weighted with the current best estimate of the probability of its occurrence. Within a dynamic programming framework, complex problems tackled in this manner often suffer from the "curse of dimensionality," that is, that the number of possible future trajectories that one must consider explodes exponentially, making exact analysis exceedingly difficult. The hurricane problem falls into this category.

Engineering science is involved in this project in operations research, linked with meteorology to develop the probabilistic inclinations of the approaching hurricane. A social science component involves a local population's propensity to evacuate, given an evacuation order. There is a "boy who cried wolf" syndrome here: if a recent hurricane evacuation order elsewhere proved to be unnecessary (in retrospect), the people currently threatened are less prone to follow a new evacuation order. If, on the other hand, as with Hurricane Katrina, an order is given and people do not evacuate and as a result there are numerous deaths, the currently threatened population is more likely to follow an evacuation order. This latter propensity was shown in Houston, Texas, with Hurricane Rita, when the entire city was eager to evacuate. These tendencies can be quantified and incorporated into the model.[19] Social science often provides equation-based relationships that are just as critical as Newtonian physics. Management of the crisis requires the proper execution of recommendations from the model, tempered with all-important human discretion.

MIT LINC e-learning

Provision of education to a populace is a service. Education is the second-largest services sector in the United States, comprising about 10 percent of the GDP. Needless to say, education is important in all parts of the world.

LINC is the Learning International Networks Consortium of MIT, a volunteer effort housed in CESF.[20] LINC is a quasi-professional society of leaders worldwide who believe in the transformative nature of technology as it pertains to education. Given today's computer and telecommunications technologies, the LINC philosophy states that every young person can have a quality education regardless of his or her place of birth. Investing in the mind is the key to a better tomorrow for all, and LINC is concerned with the design and implementation of technology-enabled education systems in developing regions of the world.

At some time in the next 50 to 100 years historians will rank order the domains of societal activity positively affected in transformative ways by the Internet. We believe that education will be at or near the top of this ranking. Internet-related technologies can deliver world-class teaching to students who otherwise would have no access to such excellence. The marginal cost per additional student is very low. The input to the delivery system is very-high-quality on-site teachers working with the students, to act as mentors, coaches, and inspirational figures.

The photograph in *Figure 2* shows middle school students in an unheated classroom in a farming village in central China studying a multimedia biology lesson delivered by satellite. This is the same lesson which has been studied by similar-age students in more affluent parts of the country, such as Beijing and Shanghai. No longer is home location or distance from large population centers an impediment to learning. The students shown also had a well-trained in-class teacher to encourage them, answer questions about the lesson, and build on what they learned from the computer-based exercise. Systems such as these in China, Mexico, and other emerging regions are educating the children of peasant farmers and other poor families to join the information-rich and technologically advanced economies that so many of us take for granted.[21]

All three parts of the three-science intersection are vital to understanding and improving education in the emerging world. Engineering sciences involve distributed-learning information and communications technologies and operations research for system design. Social science in this context involves economics, history, and country culture, especially as they relate to learning and the effectiveness of alternative pedagogical models. Management is necessary for the supervision of the entire educational system.

REFLECTIONS

Engineering systems is different from systems engineering because the former explores complex systems using the components of the three-science intersection, while systems engineering does not. Each of the research initiatives described here involves all three components. The social sciences component is sometimes the most difficult from a research perspective. While the social sciences or the management component may be problematic and interesting research, we must also recall that engineering systems is engineering. Of the three components, engineering must be the dominant paradigm in the sense that ultimately the goal is to design and create a system. We want to build and operate something, in the finest tradition of engineering. We will be engineering systems, and we include social sciences and management to design, build, and operate these systems intelligently, with full awareness of all essential aspects of the problem. Our students must become expert in the integrated analysis of systems, incorporating social, management, and engineering science. If we are successful, engineering systems may indeed become a transformative multidiscipline for approaching the design and operation of complex systems.

Our approach may be considered part of the emerging field of service science, management, and engineering (SSME). INFORMS, the Institute for

Figure 2
Middle school students in a farming village in the Ningxia autonomous region, People's Republic of China

Operations Research and the Management Sciences, which is the largest professional society for operations research in the world, has recently approved the establishment of a new service science special interest group. This is a good step forward as well as a throwback to operations research as it was when it was born in the 1940s, tackling complex services systems problems with multidisciplinary teams involving physicists, mathematicians, engineers, social scientists, and management leaders.[22]

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