Service Science: At the Intersection of Management, Social, & Engineering Sciences

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ABSTRACT

Services industries comprise about 75% of the economy of developed nations. To design and operate services systems for today and tomorrow, we need to educate a new type of engineer who focuses not on manufacturing but on services. Such an engineer must be able to integrate 3 sciences - management, social and engineering – into her analysis of service systems. Within the context of a new research center at MIT – CESF (Center for Engineering Systems Fundamentals) – we discuss how newly emerging service systems require such a 3-way integrated analysis. We deliberately select some non-standard services, as many business services such as supply chains have been studied extensively.

INTRODUCTION

Services industries comprise over 75 percent of the U.S. economy and the great majority of the 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. Analysis of problems of services industries requires more than efficient moving of widgets from point A to point B. The human element is almost always present in the analysis. Narrow, purely technocratic solutions are not adequate for service systems, as perspectives and tools from multiple disciplines are required.

A small group of us at MIT are trying to wrestle with multi discipline based analysis of services systems while retaining scientific 'rigor.' We are doing this at the new Center for Engineering Systems Fundamentals (CESF), established in 2005. CESF is to advance 'fundamentals' of this new field called *Engineering Systems*. 'Engineering' in this phrase could be viewed as an adjective or a verb. Our research and teaching tend to be at the intersection of a Venn diagram whose overlapping circles represent ***traditional engineering science***[1]***, management science and social science.*** In our view, services system design and operation require attention to all three sciences. Other papers in this special issue of the *IBM Systems Journal* reinforce this perspective.

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[1] Truly transformative in nature, engineering science is a fundamental approach first brought to undergraduate engineering education by MIT in the 1960's.

Application of engineering principals to services is not new. But the explicit incorporation of management and social science 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 (Erlang 1909, 1917). The telephone switch allowed any caller to phone any other person having a telephone on the network. This was quite different from the original telephone invention – two telephones and one wire connecting the two calling parties[2]! 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 in frustration would hang up and become discouraged due to inability to connect on calls in a timely manner. Callers' behavior here is largely psychological, and excess queue delays and/or denial of service would create a negative psychological response that the telephone company would experience in lost customers and lost revenue. Today the psychology of queueing is just about as important as the physics of queueing (Larson 1989). And the management decision regarding the capacity of queues remains important in nearly all applications of queueing analysis. Queues appear in many perhaps most service systems, and their integrated analysis remains a top priority today.

National defense represents a critical component of government-provided services. Frederick W. Lanchester in 1915 created a simple mathematical model of warfare that demonstrated linear and quadratic relationships between size of opposing armies and outcomes on the battlefield (Lanchester 1915). 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 the analysis. Again like Erlang, Lanchester's simple analysis has led to scores of enhancements and refinements over ensuing decades – including explicit consideration of management ("command") and social science issues.

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* (B. R. Guile and J. B. Quinn 1988). For additional recent discussions focused on the need to create a 'services science,' a special issue of *Communications of the ACM* was devoted to this topic (Volume 49, No. 7, July 2006). In that issue, see in particular the paper by H. Chesbrough and J. Spohrer, "A research manifesto for services science," pp. 35-40. So, we see that momentum has been building for at least a century for engineers to become more involved with analysis of services systems. The broadening of that analysis is our concern today.

[2] One could argue that the invention of the centralized telephone switch heralded the start of the first technology-enabled social network.

We now briefly review several of the services sector research initiatives started by CESF in its first two years. Much is work in progress, as the center and its research projects are all new. A continuing theme is the need to work at the intersection of a Venn diagram whose three circles are respectively 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 Venn diagram components – engineering, management and social sciences – is important in undertaking the research.

CESF RESEARCH INITIATIVES IN SERVICES

Demand Management for Critical Infrastructures

We start with 'rush hours' in infrastructure systems. Infrastructure systems are connected networks delivering services and/or products from point to point along the network. They include transportation networks, telecommunication networks, and utilities. Each is a fixed capacity system having marked time-of-day and day-of-week demand patterns. Usually, the statistics of demand, including hourly patterns, are well known and often correlated with outside factors such as weather (short term) and the general economy (longer term).

An infrastructure system is difficult and expensive to design and construct. Once built, it can have a mean lifetime ranging from 20 years (telecommunications) to over 100 years (water). 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. One attempts to do this by 'managing demands' for service away from peak periods, in essence by 'shaving the peaks' and 'filling in the valleys' of demand. That is the focus of this research.

Some current examples include time-of-day congestion pricing for vehicles to go into city centers in Singapore and London; for-profit 'toll-ways' adjacent to freeways (Larson and Sasanuma 2007); 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 the year; auction type bidding for some infrastructure services, with higher prices paid for congestion periods. In our congestion pricing research in cities, we have found queueing theory (started by Erlang) to be essential for understanding the phenomenon of car drivers "cruising" to find relatively inexpensive on-street parking. And our queueing 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 framing of the topic, **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 above.

Traditional engineering can be found everywhere in the design and operation of critical networked infrastructure. Where is the social science? It is in understanding the cost/benefit relationships that would make users willing to defer services consumption at times of peak demands. These are often life style issues – when to travel or when to do the laundry. Where is the management? It 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[3].

Proposing New Products. E-Electricity Management
The ideas of this paper can be used to create new products and services, all with the three-part Venn diagram in mind. Here we present ideas for one such new product, in the area of electricity demand management.

We propose a system for automated graceful shedding and/or delay of discretionary electricity usage in the home, business or other location. The system may use Bluetooth, the Internet, wi-fi, RFID, and other new communication technologies, in conjunction with a home computer or special control box, to turn OFF or delay turning ON one of more addressable electrical 'appliances'. In USER CONTROL mode, such a system would reduce user costs when the electricity provider institutes time-of-day or dynamic state-of-the-system pricing. One wants to shave the peaks and fill in the valleys of electricity demands. A 2nd usage – PROVIDER CONTROL MODE -- would be for graceful degradation of service in those cases in which the electricity provider would usually implement blackouts or brownouts. With the proposed system, everyone would 'hurt a little' instead of a few (those being shut down 100%) being hurt a lot. This system is Step 1 in creation of a home- or business-based lifestyle energy optimizing system.

This 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. It is the least efficient electricity generation plants that are turned on last, and they are most costly to operate. And they tend to be polluters. Those who use electricity in peak periods should have to pay top dollar. Those who defer until off-peak times should pay less. It is the law of supply and demand, and consumers can have 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 off or defer turning ON such appliances when the current 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 to wash dishes or clothes. But there are many others. The device we have in mind may in fact be a piece of 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 about $100 and in a world in which there is time-of-day or dynamic pricing of electricity, the purchaser of the proposed system may save on his or her electricity bill the

[3] These ideas are expanded in a CESF White Paper, ***The 3 R's of Critical Energy Networks: Reliability, Robustness and Resiliency*** **(** to MIT Energy Research Council, 10/30/05).

purchase price or more just in the 1st year of usage. The utility providing the electricity may want to subsidize its purchase, perhaps even install it free, due to the fact that 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 USA. We might expect several millions of these devices to be sold and installed in Year 1 of production[4].

The proposed e-Electricity Management System is a product for both consumer and provider, providing a win-win situation. Within lifestyle preferences and constraints, the consumer can manage her/his use of electricity to minimize cost within an environment that charges higher prices for electricity during higher demand periods. We are bringing the science of revenue management, invented by the airlines in the 1980's as a response to airline deregulation, to electricity usage – also in part due to deregulation and in part due to high prices of energy. Airlines price seats higher during higher demand periods, and the consumer with lifestyle options can select off-peak flights to save money. In our future world of electricity, the utilities and other providers will charge more for electricity during peak periods, and the consumer again with lifestyle flexibility has the option to purchase certain amounts of electricity at off-peak hours. This helps everyone – the consumer who saves money, the utility that does not need to expand capacity (billions of dollars), and the public that sees less air pollution from old plants. From the electricity-provider's point of view, brownout and blackout situations can now be approached by using the new product in PROVIDER CONTROL MODE, shutting down fractions of electricity usage for many instead of unfairly shutting down 100% for some customers and leaving the remainder untouched.

Prior art is best represented by Constantopoulos, *et al* (1991) and Black (2005). The Constantopoulos, *et al* paper utilized *stochastic dynamic programming* to adjust space conditioning temperature settings in response to spot prices of electricity. Dynamic programming is an optimization technique originally put forth by Richard Bellman in the 1950's as a rigorous formalism for framing, formulating and executing decisions sequentially in an evolving uncertain (probabilistic) environment (Bellman, 1957). 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 envisaged 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

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[4] For external confirmation of market need, see United States Government Accountability Office, "Consumers Could Benefit from Demand-Response Programs, but Challenges Remain," August, 2004. http://www.gao.gov/new.items/d04844.pdf

occupants of the home or business and manage energy usage internally within the structure in a way statistically compatible with lifestyles.

Example 1: With room-based or floor-based thermostats, the system can automatically adjust downward or upwards the temperature in a room or floor in anticipation of people's regular movements and needs for that space, adjusted in real time by knowledge of each person's current location (via RFID or similar device on each person).

Example 2: 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 maintaining only one set of 'entertainment appliances' ON at any given time. From a marketing point of view, this is not only a 'Smart House,' it is a 'Cool House'!

Voting in U.S. Presidential Elections

Perhaps unusual among services systems, voting systems in democracies are services systems, very important systems indeed. Voters go to voting facilities and – if all voting machines are busy when they arrive -- may have to stand in queue and wait their turn to vote. In the USA these queueing times in Presidential Elections range from zero minutes to over 8 hours! There are no accepted standards. There are many who argue that *potential* voters were discouraged from voting in both the 2000 and 2004 Presidential Elections due to long lines, caused by too few voting machines and support personnel in certain voting places (Belenky and Larson, 2006). As there are no "exit polls" of queue-discouraged voters to raise the red flag, we have the possibility of *stealth disenfranchisement*.

Some administrators of voting systems have blamed voters for slowness of the lines, perhaps citing English as a second language, unfamiliarity with new voting machines, complex ballots, etc. No doubt voters have responsibilities in casting votes, but no more than customers of any service system. Imagine a retail store, serving customers poorly and then blaming the customers for the bad service! Voters don't create ballots, acquire voting machines, and operate poll stations. The total voting system is like a symphony orchestra: each musician may play perfectly, but without a good conductor the musicians together will produce only noise. Voting machines, software, and ballots might each be excellent, but without a professional systems design, the 'voting system' will offer only discordancy.

Blame not ballots, machines or voters. There is a systems problem with voting. Systems designers should compete offering total voting systems, utilizing the analysis tools of service science. They can bring harmony to design and function, leading the way to virtuoso quality for arguably the most important service offered to our citizens: the act of voting.

Traditional engineering here is in 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’) across voting precincts. Social science is in the psychology of queues: what makes potential voters balk at joining long lines or renege (i.e., leave the queue) in slow moving lines? Is it life style constraints, impatience, frustration at queue wait disparity? Management becomes involved with the supervision of implementing a voting machine deployment system and in responding to unanticipated long queues during Election Day.

Social Distancing in an Influenza Pandemic

Health care services comprise over 15% of the US GDP, making health care the largest single services system in the US. 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 1918-1919 ‘Spanish Flu’. That influenza pandemic killed more Americans in one year than all the wars of the 20th 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, often examining social distancing historically used in 1918, and later in 2003 to combat the SARS epidemic.

We view this as a topic of extreme national and international importance, as hundreds of millions of lives could be at stake – depending on how we individually and collectively respond to a pandemic should one occur.

Traditional engineering here is really engineering science, using operations research and related fields to create ever more accurate and insightful mathematical models of flu progression under alternative assumptions. Management is extremely complex, as if one imagines 100 “Hurricane Katrina’s” occurring simultaneously across the country. Each town and city will be responsible for its local public response as will individuals, families and businesses. Laterally aligning the objectives of all stakeholders will be difficult but important. Psychology is one branch of social sciences that will be key: under what circumstances will families decide to withdraw from 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 in the Midst of a Pandemic. Should the H5N1 virus mutate to become efficiently transmitted from human to human, or should another highly virulent flu virus emerge with these properties, there will likely be no flu vaccine available for at least six months. Anti-viral medicines are only marginally effective. Even after six months, only a miniscule fraction of the planet’s six billion inhabitants will have access to the vaccine, due to finite production and distribution capabilities. We might say that we will be “naked against the flu’’ for at least six months and perhaps longer. During that time, the flu might have run its course around the world. Hospitals, made leaner during the past 20 years, have very little surge capacity to deal with hundreds of thousands, perhaps millions of cases. So, what are our 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 becoming infected with the flu. Social distancing has roots over centuries, often as a type of group evolutionary survival mechanism. In rural India in the 19th and early 20th Centuries, subsistence farm families who lived closely together in villages but who worked separate land plots outside of the villages, left the villages and lived separately on their land whenever they heard from a trusted messenger that 'a plague' was 'in the vicinity.' They returned to their village homes once the signal was given that the risk of plague had subsided, the duration of the distancing typically being about two weeks[5]. While this policy seemed to work well for rural subsistence farmers, we may well ask, "What is the analogue to the movement to the land in our highly-networked interconnected Western style of life?" We are not self sufficient and we 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? (Larson, 2007) We do not know the answer to this question, but research directed at the question is vitally important.

Some recent results are promising. The population of Hong Kong in 2003, 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% during this period of tightest controls. (Lo, *et al*, 2005) 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 created by a single infected person in a population of 100% susceptible individuals. While we have difficulties with the way this is commonly used in practice, there is value in considering typical values cited for R_0. For pandemic influenza, the usual value found in published papers is between 2.0 and 2.5. While any value greater than 1.0 assures a near-term exponential increase in the numbers infected, the fact that R_0 is not larger than about 2.5 implies that we need only reduce its value by 50 to 70% in order to change exponential increase to exponential decay and 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

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[5] 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, state of Gujarat, India. Once as a boy he had to leave the village with his family to avoid 'the plague.' Our hypothesis is that the terminology 'the plague' related to several different serious and sometimes fatal diseases and did not precisely refer to any specific plague such as the bubonic plague.

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%, one is a long way toward reducing R_0 to below-pandemic levels. And 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 where social science meets 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 amongst different social activity level groups within one community (Larson, 2007) and now spatially across communities as well (Nigmatulina and Larson, 2007). An illustrative finding is depicted 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 ever more stringent social distancing measures. (Details are in Nigmatulina and Larson, 2007.). 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 half that many in the fifth and last.

We voice 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 with the huge number of cases. With WWI on going, 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 and, eventually, a panic that had hospitals guarded by armed police to reduce the chance of doctors and nurses being 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, 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 we – the engineers, physical scientists, social scientists and physicians – educate the public about our findings to replace tendencies towards panic with the confidence of control.

Hurricane Preparedness & Response

Disaster preparedness and response requires the design of service systems to confront likely disasters, be they acts of nature, industrial accidents or terrorist attacks. Some of these are now called High Consequence, Low Probability (HCLP) 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 decision questions such as when to mobilize response personnel, to pre-position supplies and equipment, and eventually to evacuate residents. Again facing a time-sequenced optimization problem under uncertainty, the analytical framework we are employing is stochastic dynamic programming. Here the stage, a decision point, is the time that meteorologists – with satellite, radar and airplane data – update the depiction of the hurricane. The update gives a new state vector: location of the eye, hurricane intensity and size, and 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 our best estimate of the probability of its occurring. Within a dynamic programming framework, complex problems tackled in this manner often suffer from the "curse of dimensionality," meaning that the number of possible future trajectories that one has to consider explodes exponentially, making exact analysis exceedingly difficult. The hurricane problem falls into this category.

Engineering science is again operations research, married to 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), then 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, then 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 (Metzger and Larson, 2007). Social science often provides equation-based relationships that are just as critical as Newtonian physics. Management 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 2nd largest services sector in the USA, comprising about 10% of the GDP. Needless to say, education is important in all parts of the world.

MIT LINC is the Learning International Networks Consortium. http://linc.mit.edu LINC, a volunteer effort housed in CESF, is a quasi-professional society of leaders world-wide who believe in the following transformative nature of technology as it pertains to education: ***With today's computer & telecommunications technologies, every young person can have a quality education regardless of his or her place of birth.*** Until recently, the assets of a country lay buried underground, such as oil, gas, gold, silver and diamonds. Today, the key assets of a country lie ***'buried between the ears of its citizens!'*** Investing in the mind – that is the key to a better tomorrow for all.

LINC is concerned with design and implementation of technology-enabled education systems in developing regions of the world. This might be *the* exemplary messy and complex Engineering Systems problem!

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. My personal belief is that 'education' be at or near the top of the ranking. Internet-related technologies can deliver world-class teaching opportunities to students who otherwise would have no access to such excellence. And the marginal cost per additional student is very low. What needs to be placed into the 'delivery system' is superlative on-site teachers working with the students, to act as mentors, coaches and inspirational figures. The photo in Figure 2 shows four young women who are middle school students in an unheated classroom in a farming village in central China, studying a multi-media biology lesson delivered by satellite. This is the same lesson 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, to answer questions about the lesson, and to build from what they learned from the computer-based exercise. Systems such as these in China, Mexico and other emerging regions are educating 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 (Larson, Murray, 2007).

All three parts of the Venn diagram are vital to understanding and improving education in the emerging world. Engineering sciences involve distributed learning ICT technologies & operations research for system design. Social sciences here include economics, history, and country culture especially related to learning and the effectiveness of alternative pedagogical models. Management relates to the supervision of the entire educational system.

REFLECTIONS.

Engineering Systems is different from Systems Engineering because the former explores complex systems using the three components of the Venn diagram intersection: traditional engineering, management and social sciences. 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 science and/or the management component may be problematic and interesting research, we must also recall that Engineering Systems ***is*** engineering. So, of the three components, engineering must be the dominant paradigm in the sense that ultimately we want to design and create a system. We want to build and operate something, in the finest tradition of engineering. We will be *engineering* systems. We include social sciences and management in order to design, build and operate 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 design and operation of complex systems.

We may also call our approach part of the emerging field of "Services Science, Management and Engineering (SSME)." INFORMS, the Institute for Operations Research and the Management Sciences, and the largest Operations Research professional society in the world, has recently approved the establishment of a new special interest group within INFORMS: "Services Science". This is a good step "back to the future," as Operations Research when born in the 1940's tackled complex services systems problems with multi-disciplinary teams involving physicists, mathematicians, engineers, social scientists and management leaders (Morse, 1946).

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References

Alex Belenky, and Richard C. Larson, *To Queue or Not To Queue? In a U.S. Presidential Election, that should NOT be a question!,* June 2006 *OR/MS Today* (http://www.lionhrtpub.com/orms/orms-6-06/frqueues.html)

Bellman, Richard E. *Dynamic Programming*. Dover, NY. 1957.

Black, Jason W., *Integrating Demand into the Electricity System: Technical, Economic and Regulatory Frameworks for Responsive/Adaptive Load*. MIT Ph.D. Thesis, 2005.

Black, Jason W. and Richard C. Larson, *Strategies to Overcome Network Congestion in Infrastructure Systems,* MIT EDS Working Paper, October 2006. http://esd.mit.edu/WPS/esd-wp-2006-22.pdf Revised version to appear in the *Journal of Industrial and Systems Engineering*.

Constantopoulos, P., F. Schweppe, and R. C. Larson, "ESTIA: A Real-Time Computer Control Scheme for Space Conditioning Usage Under Spot Electricity Pricing." *Computers and Operations Research,* 18(8): 751-765,1991.

Erlang, A. K., "The Theory of Probabilities and Telephone Conversations", Nyt Tidsskrift for Matematik B, vol 20, 1909.

Erlang, A. K., “Solution of some Problems in the Theory of Probabilities of Significance in Automatic Telephone Exchanges", Elektrotkeknikeren, vol 13, 1917.

Guile, B. R., and J. B. Quinn, eds., *Managing Innovation: Cases from the Services Industry*, Washington, D.C.: National Academy Press, 1988.

Lanchester, F. W., “Aircraft in Warfare: The Dawn of the Fourth Arm — No. V, the Principle of Concentration,” *Engineering*, Vol 98, 422-423. 1914.

Larson, R. C., "Perspectives on Queues: Social Justice and The Psychology of Queueing." *Operations Research* 35(6): 895-905, November-December, 1987.

Larson, R. C., "Operations Research and the Services Industries." An invited book chapter in *Managing Innovation: Cases From the Services Industries*, B. R. Guiles and J. B. Quinn (eds.). Washington, D.C.: National Academy Press, pp. 115-143, 1988.

Larson, Richard C., “Simple Models of Influenza Progression within a Heterogeneous Population,” *Operations Research*, Vol. 55, No. 3, pp. 399-412, 2007a.

Larson, R. C., “Holistic Trinity of Services Sciences: Management, Social, & Engineering Sciences.” IBM Palisades Conference. In Hefley, W. and Murphy, W. (in press). *Service Science, Management, and Engineering (SSME): Education for the 21st Century*. New York: Springer Science+Business Media, LLC. 2007b.

Larson, R. C. and M. E. Murray, “Distance Learning as a Tool for Poverty Reduction and Economic Development: A Focus on China and Mexico,” to appear, *Journal of Science Education and Technology*.

Larson, Richard C. and Kats Sasanuma, *Congestion Pricing: A Parking Queue Model*, Working Paper, MIT, August, 2007. Submitted to the journal, *Transport Policy*.

Lo, Janice Y.C., Thomas H.F. Tsang, Yiu-Hong Leung, Eugene Y.H. Yeung, Thomson Wu. And Wilina W. L. Lim, Respiratory Infections during SARS Outbreak, Hong Kong, 2003. *Emerging Infectious Diseases*, Vol. 11, No. 111, Nov. 2005. pp. 1738-1741.

Metzger, Michael and Richard C. Larson. *False Alarms: Their Significance and Relation to the Boy Who Cries Wolf Effect,* Working Paper, MIT. April, 2007.

Morse, Philip M., *Of Men and Machines*. *MIT Technology Review* 49 1, 1946. pp. 29-31.

Nigmatulina, Karima and Richard C. Larson. *The Impact of Government and Socially Imposed Interventions on the Spread of Influenza***,** Working Paper, MIT, Sept., 2007.

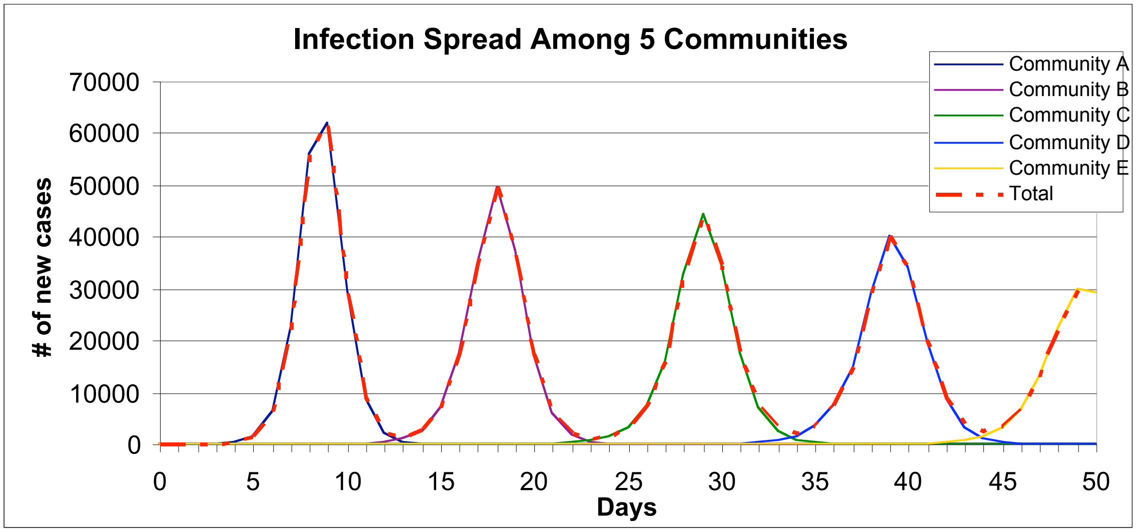

Figure 1: The spread of infection amongst a linked chain of five communities where each community implements an intermediate level social distancing strategies based on the experiences of the previous communities.

Figure 2. Middle School Students in an Unheated Classroom in a Farming Village in Ningxia Autonomous Region, PRC, Studying a Multi-Media Biology Lesson Delivered by Satellite (Late October, 2004).

Research Topic Area	Engineering	Management	Social Sciences
Critical Energy Infrastructures	Electrical & Systems Engineering	Planning large capital investment projects; maintaining systems	Understanding cost/benefit relationships for users in order to shave peak demands
Election Queues	Operations Research of Queueing Physics	Managing the pre-election day deployment and real time re-deployment of resources	Understanding voters' choices to balk or renege from voting lines
Flu 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 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 & 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

Table 1. CESF Research Initiatives: Components of Engineering, Management & Social Sciences