

Holistic Trinity of Services Sciences: Management, Social, & Engineering Sciences

Richard C. Larson

Massachusetts Institute of Technology

Cambridge, Massachusetts 02139

<rclarson@mit.edu>

617 253 3604

SUMMARY

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 services systems. Within the context of a new research center at MIT – CESF (Center for Engineering Systems Fundamentals) – we show how newly emerging services systems require such a 3-way holistic analysis. We deliberately select some non-standard services, as many business services such as supply chains have been studied extensively.

INTRODUCTION

CESF was created on September 1, 2005, by then-Director of MIT's Engineering Systems Division (ESD), Prof. Dan Hastings. ESD is a crosscutting new entity in the School of Engineering that includes faculty from all 7 departments in the school as well as faculty from the Sloan School of Management and the School of Humanities, Arts and Social Sciences. ESD focuses on complex 'messy' systems involving people and technology. Our research and teaching are at the intersection of a 'Venn diagram' whose overlapping circles represent traditional engineering, management and social sciences.

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 preference is to consider both interpretations simultaneously.

Services system design and operation require attention to all three circles of the Venn diagram. Narrow, purely technocratic solutions are not adequate for services systems. Since we are applying the full range of scientific methods to the analysis and synthesis of services systems, we choose to label as *science* not only *social science* but also *management science* and *engineering science*. Truly transformative in nature, engineering science is a

fundamental approach first brought to undergraduate engineering education by MIT in the 1960's.

Among ESD faculty members there has been an active discussion as to whether Fundamentals for Engineering Systems could be derived in a context-free environment or as a result of generalizing results discovered doing contextually motivated research. CESF has been emphasizing research on real systems, with the hypothesis that generalized Fundamentals may be extracted from contextually motivated results. This has been the dominant history of fundamentals discovery in related fields such as Operations Research and Optimal Control.

We now briefly review several of the services sector research initiatives started by CESF in its first year. A continuing theme is the need to work at the intersection of an ESD 'Venn diagram' whose three circles are respectively labeled engineering, management and social sciences.

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 of 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; 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.

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.

About the holistic trinity: 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 times¹.

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 places². As there are no “exit polls” of queue-

discouraged voters to raise the red flag, we have the possibility of a *stealth disenfranchisement*.

About the holistic trinity: 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.

About the holistic trinity: 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 unusual 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?

¹ 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).

² *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>)

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. One analytical framework we are employing is *stochastic dynamic programming*.

About the holistic trinity: 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. 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.

Water Systems

Water distribution systems for drinking, irrigation and cleaning are services systems. CESF hopes to bring together a multi-disciplinary team to examine water systems within an international perspective.

We plan to embark on a major, multi-year research effort that examines water systems in all-important aspects, with special emphasis on applications in Asian countries. Our interests are water distribution systems... in poor rural regions without modern support networks, use of water in the design and operations of homes and other buildings, and more... rural Asia is a special focus of this work.

Our work must be contextualized within constraints and traditions of Asian culture. Asian countries have well-developed traditional cultures that are, for various reasons, not always compatible with 21st century Western approaches to decision-making. The institutional issues are tied up with the local culture, and westerners often have relatively little credibility in this area. Naïve application of western 'scientific methods' can backfire...³

About the holistic trinity: Traditional civil and environmental engineering are everywhere in design and operation of water distribution systems. The social science lies in understanding how water and its use are embedded in local culture, traditions and history of the country or region being studied. Management again is in the planning and execution of large capital investment projects and in operating the created systems.

MIT LINC Teaching Initiative in the Middle East

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! As an example of LINC's activities, LINC has submitted a proposal to USAID: ***Blended Learning for High School Math Classes: A Partnership Between MIT and Arab Universities to Foster Creative Critical Thinking in High School Math Classes.*** The extended abstract starts with this overview:

³ ***Water: East Meets West,*** *The Need for Appropriate Technologies and Systems*, 3/19/06, a joint effort: CESF & the Department of Civil & Environmental Engineering. At the time of this writing, this CESF White Paper is under review by a committee creating the Singapore Research Initiative.

Our focus will be on high school teachers of mathematics, with the idea of inspiring high school students to study math-oriented careers in engineering and science. ... we propose to create a set of short 'Learning Modules,' offered by volunteer professors from MIT and from participating ... universities in the Middle East. Each learning module will be available either on line ... or on CD, DVD or videotape. Each will be configured to be compatible with any given curriculum as an interesting, informative and insightful addition to the usual mathematics program. A learning module might ... be a short video lecture followed in class by some exercise, building from the usual curriculum content plus the new 'challenge content' of the module. The usual in-class teacher would ... direct the in-class activity. This type of learning is an example of 'Blended Learning,' a new and growing pedagogical model in which the content expert enlightens the class with ... new ideas and mind-extending challenges, and the class with its regular teacher follows up, climbing new exciting learning heights. ...

About the holistic trinity: All three parts of the ESD 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.

SUMMARY TABLE

A summary of 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 that research.

SUMMARY 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 difficult 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.

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
Water Systems	Traditional Civil Engineering plus Operations Research	Planning large capital investment projects; maintaining systems	Understanding people's culture in their need for and use of water
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