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Invited Commentary

The Future of Sociotechnical

Systems Theory and Practice:
The Challenges for Information System Design

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When you analyze the design of a battleship, you discover the design of the organization that built it. To design the battleship of the future, we must design the organization that designs and builds it. (A physicist in the US Navy - 30 years ago)
In a world that requires agility, it seems to me that that quality is only available in human beings actively collaborating and creating novel interpretations of challenges and opportunities.

THE COMPLEXITY OF PRODUCTIVE ORGANIZATIONS – ST SYSTEMS

Sociotechnical Systems (STS) practitioners and researchers have always hoped that their discipline would achieve "whole system design," that is, that our models, analyses, and design principles are sufficient to design a complete functioning productive organization. That is the implication of Enid Mumford's insistence that an "open systems perspective" is required if the potential benefits of STS methods are to be realized. We cannot draw a simple boundary around the organization. The open systems perspective emerged from General System theory (von Bertalanffy, 1968) which evolved from Schrödinger's boundary spanning book *What is Life*? (Shrodinger, 1944) Where he considered that the growth of a complete human being from a single cell violated the laws of physics. He coined the term "negative entropy" referring to the need of living organisms to import order to maintain themselves in the face of pressures of entropy. His formulation of negative entropy is identical to Shannon's formula for information (Shannon & Weaver, 1959). The roots of STS are embedded in a framework that sought to bridge between physics, biology, information, and organization, a radical multi-disciplinarity. The future of STS will require an extension and integration of an even wider set of disciplines as a resulted of the growing complexity and tight coupling or organizations and their networks.

Historically, STS dealt with design challenges by calling for "joint optimization" or concurrent design of technical systems and the organizations that would operate them. That was quite a leap 50 years ago even if it involved but two core disciplines. It was the key to STS success and limitations. Success came from linking team design to technical system problems and challenges. The limitation, academically, was that STS could not find a home in any discipline since it required cross-disciplinary collaboration. The challenges of whole systems design have only increased.

No single discipline can achieve practical competence in "whole systems design" if we include in such design work organizations, technical systems, information systems, managerial structures, and the economics of the organization let alone incorporating ecological, environmental, and societal obligations. We cannot specify the boundaries of whole systems design without excluding many of these areas.

The original linking of social and technical systems was a remarkable, but simplistic, breakthrough in organizational thought. What about engineering, economics, accounting, information, environmental systems? What about partitioning "social" into psychology, sociology, and the various organizational sciences? We can try to integrate these areas by simplifying their issues with respect to whole organization design. That was much simpler when most work was physical. Given automation and the capital intensity of productive organizations, the roles of employees are to monitor, control, and maintain technical systems. Problem solving has become the value-adding function of employees; machines do the rest. The content of problems and challenges is likely to cross disciplinary boundaries.

Lawrence Miller has called for STES, Sociotechnical Economic Systems. That is certainly justified (Miller, 2013). The original Durham coal mine experiment involved changing the economic relationship of the miners to the British Coal Board. Instead of working for wages, they acted as a subcontracting team paid for the amount of coal they produced. What does "Economic" mean? Not managerial accounting which creates most of the "economic" reality in organizational data. Managerial accounting principles are hierarchical rather than systemic. The sum of the costs of all of the parts is supposed to add up to the costs of the whole. The cost of each part is independent of the cost of other parts. Theory of Constraints (Smith, 2000) looks at costs systemically. It views a plant as an economic market with internal opportunity costs. The cost of particular parts is the opportunity cost of not making other parts. Under such a model, any machine or technical system with excess capacity has a marginal cost of zero. On the other hand, the value of an hour's capacity in the governing constraint, bottleneck, is equivalent to an hour of the whole plant. The opportunity cost of that hour is that great. These are two radically different methods of presenting "economic reality." Which is "true?" Which should guide our design decisions? What does the "E" in STES refer to?

This is a real problem. Boeing uses fully loaded management accounting to establish costs. Given very high overhead rates, it is next to impossible to determine costs. As an accounting executive explained, "*Overhead is like peanut butter. It is spread thickly and you cannot see anything through it.*" A Boeing director of finance said, and I am quoting precisely, "*We have a divine intervention cost accounting system. Only God knows where these numbers are coming from*." All of this transfer costing information is carefully and consistently logged and documented in an information system that creates the economic "reality" of their operations.

General Electric resolves similar problems with an economic approach. The electric motor divisions have to operate as competitive suppliers. The customer divisions can choose to buy anywhere. The supplying divisions compete for non GE customers. The cost management "reality" is a set of competitive market prices that are the transfer costs between divisions. This "reality" is documented as sales between divisions. Of course, that is not the model within the plants. At least, market pricing operates between plants.

Technology presents an equally problematic challenge to STS design. We tend to simplify the challenges of technology and technical systems when we reduce them into necessary tasks and problems to be controlled rather than investigating the complexities of such systems. Technology is the body of knowledge that informs technical systems design. We operate technical systems to achieve particular ends. Technologies are inherently incomplete resulting in technical systems complexities and failures. Complexity can be measured as the number of potential paths to failure. Nuclear power plants (NPP) are among the most complex systems ever built. Our modern supply chains are far less complex. Both NPP and supply chains are subject to failure. Fortunately, failures in supply chains are not catastrophic.

Dr. Nathan Sui, of the Nuclear Regulatory Commission, a physicist and statistician, has called for an "*Ethos* of searching for failure" as an organizing principle in NPP. NPP have, literally, hundreds of millions of paths to failure. Such complexity is beyond the cognitive capacity of any known organization. "*Ethos"* is explicitly an appeal to organization designers. How can we design an organization with the capacity to search for failures? That is the only path to push back the walls of uncertainty in NPP. It is recognized that we cannot depend on our present understandings of NPP. Therefore, they are built with triple containment systems to avoid the catastrophic consequences of failure. They are "high consequence systems," a euphemism that is a reference to nuclear weapons. How do we design organizations for such operational complexity?

The BP Transocean drilling rig catastrophe presented similar complexities and uncertainties. Three large firms, each remotely managed, plus a variety of subcontracting firms all presumably collaborating on a giant drilling rig grappling with an unknown set of events 5000 meters distant under water and ground. That failure cost lives and vast ecological damage.

We all believe that such failures can be prevented if we had better organization designs. Certainly, we should be able to make NPP safer with better organization. I witnessed exactly that perception at an American Nuclear Society meeting. We can discover the fallacy of such thinking if we go all the way back to the roots of systems theory. Schrödinger coined the term negative entropy to signal that living systems appeared to violate one of the most fundamental laws of physics, the Second Law of Thermodynamics which states that all energy transactions MUST increase entropy or disorder. All of our technical systems must break down.

Complex technical system failures can be the result of physical laws independent of human organizations and error.

We should never confound failure with human error. And, we must understand technical systems if we are to grapple with their failure modes. We should assume-that all of our networked, complex supply chain, economic organizations will exhibit similar modes of failure although, hopefully, with far milder consequences.

I suggest that we consider ST Information Systems, STIS. We cannot subsume IS under the rubric of "technology" even if that is how the public labels them. Information Systems are not *technologies.* They certainly are not Social Systems. They are a different kind of system. Such distinctions, invisible in common language, are important from an organizational design point of view. They are relevant to the challenge of whole organization design.

SYSTEMS

Enid Mumford said:

Any organization subsists from moment to moment as an emergent property of interactions among the people who are its members, creating systems that are not just open but dynamic. (Mumford, 2006)

Her construct of an organizational system has several boundaries. People are part of the system when they are in the organization and not when they are at home. The organization has a time boundary; it ceases to exist after hours. There are no economic or technical elements. Mumford's *Point of View* (PoV) is as a social psychologist. We recognize her construct as valid, useful, and incomplete.

A system is a *Point of View.* The planets orbiting the sun are not a system. Rather, Newton's formulation of gravitational force allows us to understand them as a system. Newton simplified his system by ignoring the gravitational interactions between planets. All systems are simplifications that reflect the choice of PoV. Our theories, models, and systems all simplify in order to allow us to focus on particular *relevant* questions; they are "lenses" that increase the resolution of some phenomena at the cost of blurring other phenomena. No one can escape that cost. Feyerabend (1968) noted that the relationship between theory and data is incestuous. Theory defines what relevant data are and that data, in turn, validates the theory. In a world of complex networked tightly connected economic organizations operating exceedingly complex tightly coupled technical systems, no single systems model can encompass all of the critical questions. The world was much simpler a century ago.

We can classify the various disciplines that are cogent to the design and operation of productive economic organizations. Of course, our list is a simplification. An organization is a collection of individuals and, therefore, social psychology is relevant to understanding their motivations, cognitive processes, and modes of interactions. The Myers-Briggs exemplifies this PoV. An economic organization is a set of interacting work roles within a social structure governed by a culture, rules, and coordinating mechanisms. Mintzberg's *Structure in Fives* represents the organization theory discipline. Each of these PoVs focuses on different important relevant questions. One does not replace the other.

What is technology? Technology is a body of knowledge about the cause and effect relationships of human work. It is not about nature. It is about all of the artifacts that we invent and deploy to meet our needs. Man, alone of all animals, is capable of purposeful non-organic evolution; he makes tools (Drucker, 1959). Stone tools were formed into spear points and arrow heads increasing the range of effective hunting. We do not have wings so we build aircraft. Technology is about artifacts that we create in order to take advantage of the laws of nature. All technologies are governed by the laws of nature which limit what we can do. Technical systems, then, incorporate challenges that derive from nature, the environment, and the limitations of our artifacts. For example, all technical systems must, eventually, break down. A measure of the complexity of a technical system is the number of potential paths to failure. Our technical systems pose a rich variety of design issues for economic organizations.

What are information systems? They are certainly artifacts of human invention. However, they are not governed by the laws of nature. If the speed of our chips did not increase beyond present capacities, our information systems would still operate quite effectively. The questions we would address to analyze technical systems are not relevant to IS.

Logic governs IS and computing systems. We know from the work of Kurt Gödel (Nagel & Newman, 1986; Casti & DePauli, 2000) that a system as complex as ordinary arithmetic cannot be perfect and complete. In other words, at the level of pure logic, without hardware or software or the realities of economic organizations, a system cannot be perfected. The limitations of IS are inherent in the models that are represented by software. Therefore, the set of questions that we would raise with respect to IS are very different from those directed at technical systems and social systems. For example, IS are problematic even when they work as designed. We will consider the organization design issues presented by IS after we have modeled an approach to whole organization design.

To design the battleship of the future, we must design the organization that designs and builds it.

The above insight by a US Navy physicist identifies the challenge of whole organization design. It is not simply a process. It requires a "design organization" and, if agility and adaptive capacity are understood as critical capabilities that design organization will have an ongoing existence in operating organizations. In traditional STS terms, design and redesign are continuing processes.

THE DESIGN TABLE

Metaphorically, let us label that organization the "Design Table." Who is at the table? What do they bring to the table? Multiple disciplines must be engaged at the Design Table (DT) along with operators whose work is becoming increasingly professional in content. Each will bring to the table the uncertainties and challenges that emerge at the boundaries of their discipline. The DT is the locus of deliberations whose purpose is to adapt the organization to emergent challenges. While no one discipline can claim enough breadth to achieve whole organization design, the DT can bring together enough competence to design and implement evolving, agile, and adaptive organizations.

The model for the DT may be based on the work of C. West Churchman who wrote *The Design of Inquiring Systems* (Churchman, 1971). He raised the practical question: *How will we determine if there is life on Mars?* It was assumed by the designers of the first *Viking Lander* that the associated computing system could determine whether or not there was life on Mars. More generally, Churchman asks, "How does science determine the truth content of an assertion?" Historically, there were several competing approaches. John Locke was an empiricist claiming that all truth was to be discovered in data. Leibniz was suspicious of data and its necessary errors and argued that truth was to be found in our models and theories. Statistics is such a modeling offering a way of interpreting data. Kant said that theory and data are complementary. Hegel argued that truth was to be discovered in conflict offering his *dialectic.* In principle, for every set of data at least two theses can be ventured, each in opposition to the other, and both supported by the data. (I have always found at least three.) In other words, truth will be discovered in the conflicting assumptions that underpin our models and theories (Berniker & McNabb, 2006). Finally, there is Singer; Churchman is a Singerian. Singer argues quite effectively that at the boundaries of each discipline are challenges that require additional disciplines. As science progresses, problems are pushed out to the boundaries of each science and those challenges will require sweeping in many other sciences. Science will become increasingly eclectic. Our DT must be eclectic and incorporate the diverse perspectives that are cogent to the challenges faced by the organization. ST??? Systems may include quite a long list.

The DT is a collaborative forum where each participant brings those challenges faced by their approach. For example, engineers must apply safety factors to cover design uncertainties. Many uncertainties will be operational. One common approach is to make the operating system "idiot proof." Lock down everything so that the unreliable operators will not cause problems. Limit what those operators need to know. At the edge, do we trust the pilot of the commercial aircraft or the computer system running the avionics? There was an incident in Europe of an Airbus landing in a driving rain and hydroplaning. When the pilot tried to set the brakes, the computer, sensing a lack of traction, would not permit that action. In a Boeing, the pilot could override the computer; in the Airbus, he could not (Leveson, 1995). Dr. Sui's call for an "ethos of searching for failure" directs us to exactly the opposite approach. The engineers are to bring their uncertainties to the DT offering an opportunity for learning, for exploration, and for careful observation. Nuclear Power Plants (NPP) should be organized to systematically push back the walls of uncertainty. That is the opportunity offered by the multi-disciplinary DT (Berniker, 2013). Similar arguments can be advanced for economic, financial, environmental, and societal concerns. Concurrently maintaining these concerns and considering their challenges is the path to more effective designs.

Operators will participate in the DT in their role as professionals. We are not used to seeing operations as a professional role. STS roots in coal mines and factories would not suggest the professionalization of work roles. Organization designers can ask a simple question to make the professionalization of work very evident. *What is the capital cost of a job?* Twenty-five years ago, I asked that question of a very large telecommunications firm. An executive quickly made the calculation, total assists divided by total employment and was shocked to find that the average capital cost of jobs in his firm was $500,000. Plants are being proposed in my area with a capital cost of over $10M per job. In 1978, Shell built a plant in Sarnia, Ontario at a cost of $2.75M per job. Assume, conservatively, a capital cost of $2M per job and compute its annual cost. Assume 10% ROI and a 10 year depreciation period. The job has an annual cost of $400,000 before the power is turned on. Nor does that include the value of the hourly throughput in such huge facilities.

At these investment levels, we can automate just about everything we can specify clearly. What is left? Problem solving, maintenance, control, monitoring, and recovery operations. The result is an inversion. Organizations are efficient and produce value when people are not "working." They are not producing value when workers are busy trying to recover operations. The cognitive content of work is increasing; the physical demands are disappearing into machines. Lou Davis recognized this multi-disciplinarity when he design paper mill teams to include maintenance mechanics and maintenance teams to include operators. In NPP, the most important resource in discovering failures are trained experienced operators. With respect to the creation and organization of technical knowledge, operators should be seen as professionals.

The Design Table is not the same as a team. It is likely to have temporary members and even virtual members depending on the issues addressed. Given environmental concerns, some participants may not be members of the primary organization. Given networked organizations, we may see parallel members from similar disciplines. Considering each discipline as a "silo," the effective functioning of the DT will be problematic. Participants will have to recognize the limits of their approaches, models, and information. They will have to share authority. Their particular organizations will have to allow them to share authority and accept challenges to their models. This is new territory for organization designers. If our goal is "whole systems design," we are elevating STS towards Socio, Psychological, Technical, Economic, Informational, and Environmental Systems Design. Each of these categories may be expanded to relevant subcategories. Nor can we expect the temporary, time limited, task of organization design to reduce these stresses. The DT will have an ongoing function in the organization.

THREE LEVELS

When we create the DT and "design the organization that will design the organization," we will not abdicate the need to design the operating organization. Rather, we will create the model for three kinds of functioning teams in complex organizations. The DT includes operators, as we have noted. The Operating Teams will be a subset of the DT. There may be several of them in networked organizations or in very complex systems. An oil drilling rig in the North Sea would require quite a few teams operating a multitude of technical systems. Each of these teams will be engaged in the knowledge creation and the management of uncertainties. They will report to an ongoing DT that integrates operational knowledge for the entire rig. In the event of *potential* high consequence failures, a higher level Recovery Team would be activated. This team can draw on resources from beyond the organizational or networked organizational boundaries. *Potential* is emphasized because in the majority of cases, such failures will be avoided, controlled or mitigated. The Reliability Team will gain mastery from such events.

The Design Table, the Operating Teams, and the Recovery Team will involve the same people in different roles. They would all operate on the drilling rig. There is no shift to remote management. A three level architecture would create a shared organizational framework with intimate knowledge of their technical systems, their irregularities and uncertainties, and the history of its maintenance. It would be the most qualified group to deal with potential high consequence failures. The multi-disciplinary DT would be the learning process that creates the competence of both operating teams and the proposed Recovery Team.

The creation of an effective DT is more than a communication issue. There is a need for cross disciplinary learning, sharing of authority, and a focus on failure. Assume, for the moment, that dialectical relationships exist between the many models and disciplines. Methods that seek consensus may smooth away the very problematic issues that need to be the focus of the DT. Pava (1986) suggested deliberation models for nonlinear knowledge work. I believe that organization designers will have much to learn if DTs are to be successful.

REFLECTION

If what we mean by a *system* is a Point of View (PoV) that gains us a coherent view of the functioning of productive organizations, then organizations are NOT systems. We do not have a comprehensive or encompassing systems view. Rather, we require a mélange of PoV's to encompass the complexities of productive organizations. That is the meaning of ST…..S. A comprehensive understanding of a whole organization escapes us. Nor can the collection of PoV's signaled by social, technical, economic, financial, and information "systems" as necessary for the Design Table achieve "whole system" design. The complexity of modern human organizations is greater than what our various PoV's can encompass. "Whole system design" is more a hope than a practice.

That should not signal paralysis. We have been, nevertheless, very effective in inventing and reinventing organization designs. There has been rich progress over the last century. STS has been remarkably successful and the notion of work teams has become ubiquitous. Why? How?

Organization design, as Peter Drucker pointed out a half century ago, is a technology, not a science. The test of technologies is not truth or understanding; it is that they work. Humanity has been using fire to change our habitat and gain sustenance for two million years before we understood what it was. Fire has always been associated with religion as if it were some kind of magic. Lavoisier discovered oxygen and hydrogen in 1778 after James Watt had improved upon the steam engine in 1775. The technologies utilizing fire were highly advanced before we understood what fire was.

Therefore, we should understand whole organization design as a developing technology and an evolving art form rather than invoking incomplete and often incommensurate "whole systems" methodologies. The point of the DT is that we all have much to learn from each other. Nor can we foresee a time when that will not be the case.

DIGITAL INFORMATION SYSTEM CHALLENGES

Given the above, it is necessary to clearly define what I mean by "information systems." For the purposes of this discussion, let us label, not define, *Digital Information Systems* (DIS) as a set of technical systems that manipulate digitized information in computers and provide such information for use by the members of organizations. I am purposefully drawing a boundary between people and digitized information.

The first implication of the above discussion is that no DIS can be created that will encompass all of the workings of a complex work organization since no single PoV can comprehend all those workings. Every DIS must be a simplification. The second implication is that several DIS may be necessary working in parallel. People may have to interpret the outputs of those DISs as a basis for action.

Practitioners and academics may simplify the above implication by assuming that the client PoV is the controlling and relevant PoV when designing an organizational DIS. That is the basis of most DIS architectures. If such systems are implemented, they lead to the kinds of failures evident in the Volkswagen debacle and the BP Deepwater Horizon catastrophe. Large scale ERP systems, for all of their data, are necessarily simplifications of the complex organizations that utilize them. That must be the case if only because ERP systems require far greater consistency than adaptive operating organizations.

Moreover, even if we could conceive of coherent enterprise wide DIS, we would come up against the limitations of logic. Kurt Gödel demonstrated that a system as simple as ordinary arithmetic cannot be perfect and complete. Absent hardware, software, or any organizational or economic reality, the limits of logic will bring about situations where assertions will be concurrently both true and false. Our models are necessarily incomplete. Computing power does not overcome the limitations of logic.

There are many ways to define and distinguish between data, knowledge, and information. Before digital computing, one classification was that *data* was the result of observations and recordings, i.e.

empirical. The interpretation of such data was based on models and theories applied by humans to develop meaning from that data or what we call *information*. *Knowledge,* then, was the integration of information into larger schemes as a basis for human action. Human cognitive processes are central to the above sequence.

The above view has become somewhat obsolete as a result of DIS. Enterprise wide systems collect particular data, model it in prescribed ways, and assign the meanings that are to be assumed when determining actions. Such systems impose meanings on the organization, limit alternative understandings and produce the "governing" reality available to organization members. This should not be surprising. They are optimized for hierarchical control which is confounded with efficiency. Assigning meaning and effective action are increasingly the province of remote managements. One result is to curtail the adaptive capacities of organizations.

Over the years, STS theory and practice has evolved in many directions resulting in effective organization designs in a wide variety of organizations. STS now represents a variety of approaches. A new set of challenges arises from the impacts of the internet and social networking on organizations. We are moving from the one-to-many society rooted in the printing press to the many-to-many society enabled by the internet. There is the story about IBM before the modern internet. A small group in one location became very interested in some very innovative software. Higher executive levels nixed the project but the group continued to develop it. The members of the group were dispersed to multiple locations. IBM's internal "internet' system was open enough to permit the group to continue their work. The story suggests that their project was one of those "skunk works" efforts that "saved" the company.

The internet and, now, social networking, have enabled powerful self-organizing capacities that are producing knowledge of considerable value without hierarchical controls or any of the elements of classic economic organizations. Witness Linux, Apache, NASA clickworkers, Wikipedia and the many forms of peer production discussed by Benklar (2006) in his "Wealth of Networks." Social networking has demonstrated the human capacity for effective self-organizing in the pursuit of shared goals. None of these efforts required either STS principles or DIS design.

There is an article in yesterday's paper that suggests an empirical test of two notions of organization. "Musk tube travel idea drives rival companies" by Paresh Dave (2015) Los Angeles Times. One firm is using a conventional organization to develop high speed tube transport. The other is using a radical crowd sourcing approach. Most of its workers will be working part time. The conventional firm believes in "full time" co-located talent. The other says it needs "the best minds on the planet' and expects to draw them as part timers working in companies across the planet. It will depend on the self-organizing capabilities of part time workers. They are the direct result of the many-to-many universe created by the internet and ubiquitous telecommunications. We cannot ignore that emerging world and the potential impact on work organizations.

In a world that requires agility, it seems to me that that quality is only available in human beings actively collaborating and creating novel interpretations of challenges and opportunities. That collaboration will be based on the self-organizing capacities of groups. It is unlikely to emerge in hierarchical organizations that attend more to financial community demands than their own members.

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