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Come back sociotechnical systems theory, all is forgiven...

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Abstract

Why, despite all the effort and expense, do engineering systems sometimes show an abject lack of resilience, with the smallest of human failures being the difference between normality and a calamitous disaster? Why do people take our impeccable logic and rationality, then proceed to bend and hack our technically optimised systems to suit their own seemingly irrational needs and preferences? If they didn't we would surely have more robust systems? For a while, an approach called Sociotechnical Systems Theory provided a radical solution to this problem, and it did so by employing open-systems principles to make people and technology jointly optimised. This paper revisits a concept which used to be as popular as today's process improvement techniques, like six sigma and total quality management, had astounding success, but then fell out of favour and is now largely forgotten. Given the challenges now confronting Civil Engineering this paper allows us to wonder if it could be time to say "come back sociotechnical systems theory, all is forgiven".

An engineers' paradise

To quote American novelist Kurt Vonnegut's character in the dystopian book *Player Piano*, "if it weren't for the people, the god-damn people [...] always getting tangled up in the machinery. If it weren't for them, the world would be an engineer's paradise." (1952 p. 332). So true. If people made the kind of rational choices tacitly designed into our civil engineering endeavours then a fair slice of humanity's grand challenges would probably disappear. Then again, what sort of world would it be if everything really did conform to the cool hard logic of engineering? Would it be the world from whence the opening quote comes, a dystopian world dominated by a super computer and run completely by machines? This seems unlikely. Come to think of it, is civil engineering really only about cool hard deterministic logic? This Journal has been arguing something different for more than 30 years. So maybe it's not the engineering (the 'technical') versus the people (the 'socio'), but the way they are combined which gives us true resilience. If that is the case we can go further than normal in this paper. Rather than spell out in ever increasing detail the 'problem' we can instead present a 'solution'. A message of hope from sixty years previous and an obscure topic called Sociotechnical Systems Theory (STS). Here we have – or at least 'had' - the application of open systems principles to the design of organisations. It showed us how to harness the edge-of-chaos phenomena that emerge when humans and engineering worked together. We don't hear much about it these days (and we will look at why) but for a while there it was the darling of the operations improvement field. Something as fashionable as lean thinking and Six Sigma are today in the professional Civil Engineering discipline. Sociotechnical Systems Theory was not a mere academic curiosity, it was a business reality, and a successful one at that. Several large firms embraced the principles to give rise to organisations that were highly adaptable, flexible, responsive, above all resilient. To quote Vonnegut once more, if the job of the civil engineer is to "open new doors at the head of the procession of civilisation" (p. 128) then it might be time to say 'come back sociotechnical systems theory, all is forgiven...'

Socio and technical

The phrase 'sociotechnical' is something of a buzzword in some circles. Is it 'sociotechnical' (all one word) or 'socio-technical' (with a hyphen). Is it Sociotechnical Theory, Sociotechnical System or Sociotechnical Systems Theory? All of these terms, hyphens or otherwise, appear quite frequently in the civil engineering literature (no less than 41 times in this Journal alone) but what does it really mean? Sociotechnical clearly refers to the interrelatedness of 'social' and 'technical' but Sociotechnical 'Theory' proper is founded on two explicit principles. One is that the interaction of social and technical factors creates the conditions for successful (or unsuccessful) system performance. These interactions are comprised partly of linear cause and effect relationships, the relationships Civil Engineers try and design, and partly from non-linear, complex, even unpredictable relationships, which are those that bounce back out of the ether to delay projects, cause additional expense, and generally scare us with how brittle our systems really are. If we assume that 'all' engineered systems involve humans at some point in their lifecycle (after all, humans commission, design, construct, use, maintain and dispose of systems) then it follows that 'all' civil engineering systems are sociotechnical systems at one level or another. The consequence of mixing 'socio' with 'technical' is that the socio does not necessarily behave like the technical, after all, people are not machines. More depressingly perhaps, with growing complexity and interdependence even the 'technical' can start to exhibit non-linear behaviour. Inevitably, both types of interaction occur when sociotechnical systems are put to work. The corollary of this, and the second of the two main principles, is that optimisation of either socio, or far more commonly the technical, tends to increase not only the quantity of unpredictable, 'un-designed', non-linear relationships, but those relationships that are actually harmful to the system's performance. Sociotechnical 'Theory', therefore, is all about 'joint optimisation'.

The irrationality of rationality

“Formal organisation design, or deliberate as opposed to informal or evolved organisation design, is part of the evolution of both Western and Eastern civilisations” (Davis, 1977, p. 261). Civil Engineering, in the broad sense, is an organisation. The dictionary definition of ‘organisation’ invokes terms like ‘give orderly structure to; initiate or make arrangements for; enlist person or group’ (Allen, 1984) and so on. Organisation is a major factor in Civil Engineering’s ability to “direct the great sources of power in nature for the use and convenience of man” (Tredgold, 1828). The key issue is that in virtually all developed civilisations the recent history of organisational design is wedded to a shared ‘industrial age’ mindset (Beringer, 1986). Indeed, out of all fields it is Civil Engineering which has shown the world that this mindset works.

Or does it? Even at the peak of industrial progress there were many who were exercised not by the apparent mastery of human endeavour, but instead, the various maladies that accompanied the modern industrial age. Organisational theorist Elton Mayo (1949) for one wrote that, “to the artist’s eye, something was decidedly askew in Victorian progress; and that something continues to this day.” (p. 4). These industrial-age systems were occasionally injurious to human well-being. Although technically effective they are often criticised for being ‘dehumanising’ (Ritzer, 1993). In extreme cases they can even become unwittingly ‘anti-human’, and perhaps we see that in some of the grand challenges around resilience and sustainability.

Formal rationality is a prominent part of the ‘implicit theory’ that has guided modern organisational design since the industrial revolution. A formally rational organisation is labelled, in the scientific rather than pejorative sense, a bureaucracy. We can imagine a ‘version’ of Civil Engineering fitting into this characterisation quite well. Remember, we are using the term ‘organisation’ in the

broadest sense here, and rationalising organisations exhibit a tendency towards hierarchies, reductionism and the maximisation of the following (Ritzer, 1993, pp 20-21):

1. Efficiency: A rational organisation is “...the most efficient structure for handling large numbers of tasks...no other structure could handle the massive quantity of work as efficiently”
2. Predictability: “Outsiders who receive the services the bureaucracies dispense know with a high degree of confidence what they will receive and when they will receive it”
3. Quantification: “The performance of the incumbents of positions within the bureaucracies is reduced to a series of quantifiable tasks...handling less than that number is unsatisfactory; handling more is viewed as excellence”
4. Control: “...the bureaucracy itself may be seen as one huge nonhuman technology. Its nearly automatic functioning may be seen as an effort to replace human judgement with the dictates of rules, regulations and structures”.

Let us indulge this thought experiment a little more. Does Civil Engineering rest on “tried and true assumptions: that the whole will be equal to the sum of the parts; that the outputs will be proportionate to the inputs; that the results will be the same from one application to the next; and most fundamentally, that there is a repeatable, predictable chain of causes and effects”? (Smith, 2006, p. 40). Or what about, “when all the incumbents have, in order, handled the required task, the goal is attained. Furthermore, in handling the task in this way, the bureaucracy has utilized what its past history has shown to be the optimum means to the desired end”? (Ritzer, 1993, p.20). Some of this certainly sounds familiar. It describes a version of Civil Engineering organised (tacitly or otherwise) along bureaucratic lines. It describes a way of imposing control-theoretic behaviour on a

large scale, and in so doing, trying to make inputs, processes, outputs, even humans sometimes, behave deterministically. Here we have a clear case of technical rather than 'joint' optimisation, and it creates some fundamental problems for resilience. This is because "rational systems, contrary to their promise, often end up being quite inefficient" (p.122).

Ritzer (1993) goes on to explain: "Instead of remaining efficient, bureaucracies can degenerate into inefficiency as a result of 'red tape' and the other pathologies we usually associate with them. Bureaucracies often become unpredictable as [role incumbents] grow unclear about what they are supposed to do and clients do not get the services they expect. The emphasis on quantification often leads to large amounts of poor-quality work...All in all, what were designed to be highly rational operations often end up growing quite irrational" (Ritzer, 1993, p.22). The challenges of resilience force us to confront the fact that in extreme cases Civil Engineering interventions can inadvertently create inefficiency (instead of efficiency), unpredictability (instead of predictability), incalculability (instead of calculability) and complete loss of control (Ritzer, 1993; Trist & Bamforth, 1951). These are the antithetical problems, ironies and productivity paradoxes that now require systems thinking to be taken seriously. Enter Sociotechnical Systems Theory.

Sociotechnical theory

What have a social psychologist and a coal mining graduate student got to do with Civil Engineering? In a seminal paper Eric Trist (the psychologist) and Ken Bamforth (the ex-coal miner student) derived three core principles that later went on to directly inspire the creation of new and jointly optimised organisations, often on a large scale. This first study, published in the journal Human Relations in 1951, was entitled: "Some social and psychological consequences of the longwall method of coal getting". It was motivated by new ways of organising the coal mining task using the principles of

mass production and large scale machinery. These 'factory principles' replaced the perceived inefficiencies of small teams of miners using basic tools. It should have worked but "faced with low productivity despite improved equipment, and with drift from the pits despite both higher wages and better amenities [...] a point seems to have been reached where the [coal] industry is in a mood to question a method it has taken for granted" (Trist & Bamforth, 1951, p. 5). Organisational theory seems like a long way from the concerns of Civil Engineering systems, but it is conceptually important. The authors referred to "interactive technological and sociological patterns" (p. 5), which in turn quickly evolved to become the term 'sociotechnical'. The three core principles were as follows:

Responsible Autonomy

Sociotechnical theory was pioneering for its focus on the group as the primary unit of analysis. Writing about their coal mining case-study, Trist and Bamforth say that "under these conditions there is no possibility of continuous supervision, in the factory sense, from any individual external to the primary work group" (Trist & Bamforth, 1951, p. 7). Hard physical constraints prevented the task from being carried out 'rationally', so instead of a larger 'whole of shift' based organisation accountable to intermediate layers of management, the previous non-mechanised method embodied internal supervision and leadership at the level of the 'group' resulting in so-called 'responsible autonomy' (Trist & Bamforth, 1951, p.6). This is important from a resilience point of view because as Carvalho (2006) explains: operators use this proximity and group membership "...to produce continuous, redundant and recursive interactions to successfully construct and maintain individual and mutual awareness..." (p. 51).

Adaptability

As Trist and Bamforth put it, “though his equipment was simple, his tasks were multiple”, the miner “...had craft pride and artisan independence” (1951, p. 6). The ‘hand-got method’ of coal mining was an example of a simple organisation (and equipment) that required people to do complex tasks. The mechanised longwall method, on the other hand, is an example of a complex organisation (and technological infrastructure) that only permits humans in the system to do simple tasks. Job simplification has long been associated with lower moral and diminished job satisfaction (e.g. Hackman & Oldman, 1980; Arnold, Cooper & Robertson, 1995). In the pre-mechanised situation a type of ‘human redundancy’ was created (e.g. Clarke, 2005) in which “groups of this kind were free to set their own targets, so that aspiration levels with respect to production could be adjusted to the age and stamina of the individuals concerned” (Trist & Bamforth, 1951, p. 7). In other words, outcomes or ‘effects’ were more important than activities or the precise means by which those effects were achieved. Trist & Bamforth (1951) go on to note that “a very large variety of unfavourable and changing environmental conditions is encountered at the coal-face, many of which are impossible to predict. Others, though predictable, are impossible to alter.” (p.20). The mechanised longwall method is clearly inspired by the appealing industrial age, rational principles of ‘factory production’ wherein “a comparatively high degree of control can be exercised over the complex and moving ‘figure’ of a production sequence, since it is possible to maintain the ‘ground’ in a comparatively passive and constant state” (Trist & Bamforth, 1951, p. 20). In many contexts, coal mining and Civil Engineering systems among them, there is little in the way of opportunity for maintaining the ‘ground’ in such a state, thus limiting “the applicability [...] of methods derived from the factory” (Trist & Bamforth, 1951, p. 20). In a more literal sense this has been a perennial challenge in Civil Engineering, with a long standing tension between site construction and pre-fabrication.

Meaningfulness of Tasks

Sociotechnical theory is as concerned with the experience of humans in systems as it is with the system's ultimate performance. Indeed, it sees the two as one. Trist and Bamforth (1951) go into detail as to how this was realised in their mining example. They identify the previous hand-got method as having "the advantage of placing responsibility for the complete coal-getting task squarely on the shoulders of a single, small, face-to-face group which experiences the entire cycle of operations within the compass of its membership." Furthermore, "for each participant the task has total significance and dynamic closure" (Trist & Bamforth, 1951, p. 6). As one of Vonnegut's characters says, "the main business of humanity is to do a good job of being human beings [...] not to serve as appendages to machines, institutions, and systems." (1952, p. 315). What we had here was a 'meaningful task'.

Let us zoom out of the obscure coal mining antecedents of Sociotechnical Systems Theory and consider its major influence. Trist and Bamforth's pioneering work was less to do with the specific example of coal mining and much more to do with changing a prevailing viewpoint. From seeing problems in purely engineering or human resource terms to instead relating "...the social and technological systems together" (Trist, 1978, p. 43). This is the root of Sociotechnical Systems Theory, and in the world of Civil Engineering a similar shift is (arguably) far from complete. As Paul Jowitt notes, "The role of the civil engineer was absolutely central to the rational phase. Civil engineers will be even more central to the systems/holistic phase, but they will need to adapt" (2004, p. 82).

Sociotechnical systems

Following the pioneering work of Trist and Bamforth in 1951 the field of STS developed significantly. In part this was due to the theoretical developments originating from the Tavistock Institute, the leading exponents of Sociotechnical Systems Theory, but more from the dramatic improvements in system performance and resilience achieved when the principles were put into practice. One of the earliest accounts of a comprehensive organisational re-design according to sociotechnical principles is reported by Rice (1958) in textile mills in Ahmedabad, India. Again, the subject of the case-study is much less important than the underlying concepts. The re-designed organisation foregrounded the role of teams, promoted responsible autonomy, adaptability and meaningful tasks. Here, as elsewhere, the “reorganization was reflected in a significant and sustained improvement in mean percentage efficiency and a decrease in mean percentage damage [to goods]...the improvements were consistently maintained throughout a long period of follow up” (Trist, 1978, p. 53). No doubt encouraged by a growing body of similar findings, sociotechnical systems theory, for a time at least, experienced the same kind of commercial uptake currently enjoyed by operations improvement processes familiar in the world of Civil Engineering today, such as lean production, six sigma, decision support, expert systems, removal of non-value adding processes, change management and so on.

The most famous example of sociotechnical design is undoubtedly that undertaken at Volvo’s Kalmar and Uddevalla car plants (e.g. Hammerstrom & Lansbury, 1991; Knights & McCabe, 2000; Sandberg, 1995). What singles these two examples out is that while many practical examples of Sociotechnical Systems Theory are criticised for their limited degree of ‘technological’ change (choosing to focus instead on the altogether less expensive aspects of ‘socio’ and ‘organisational’ change; Pasmore et al 1982) the Volvo case study embraced the principles based on a clean slate approach. The defining feature of the Kalmar car plant’s design was a shift from a rationalistic style

of hierarchical organisation to one based on smaller groups. In Volvo's case the change was radical. The production line, the mainstay of automobile manufacture since the days of Henry Ford, disappeared. It was replaced by autonomous groupwork undertaken by well qualified personnel, "advanced automation in the handling of production material; co-determination in planning and minimum of levels in the organisation" (Sandberg, 1995, p. 147). Obviously, individual groups still needed to be related to the wider system, which in turn required someone to work at the system boundaries to "perceive what is needed of him and to take appropriate measures" (Teram, 1991, p. 53). The new organisation shifted the primary task of managers away from processes of internal regulation to instead being more outwardly focused (Trist, 1978). A roving post called a "lagombud" (or 'group ombudsman') related teams to "other groups and to the product shop manager" (Sandberg, 1995, p. 148). This is an important conceptual difference. Managers became a form of executive, coordinating function, 'designing behaviours' rather than arduously 'scripting tasks' (e.g. Reynolds, 1987). As a result, from a resilience point of view, "the learning in this work organisation is impressive. Being engaged in all aspects of work makes the production comprehensible and the employees become, as part of their job, involved in the customer's demands and in striving after constant improvement. Work intensity is high" (Sandberg, 1995, p. 148). Critically, "whereas the former organisation had been maintained in a steady state only by the constant and arduous efforts of management, the new one proved to be inherently stable and self-correcting" (p. 53).



“In Kalmar we want to create a manufacturing facility which, without any sacrifice in efficiency, or profitability, will give employees the opportunity to work in groups, communicate freely with each other, to shift between jobs...

...facilitated a production system in which man controls the machine and not vice versa...

...no longer necessary to feel bound to the traditionally symmetric form of a building. This has made it possible to subdivide the work among twenty five teams. The plant is, so to speak, ‘multi-cornered’. Each team has its own small workshop...

...no matter what system the team chooses the personal working cycle is about twenty five minutes...

...to give variation to their work the teams let the various tasks rotate amongst them according to a system they themselves decide...

...another important feature is the buffer system arranged between the respective team zones...makes the individual team more independent of the overall flow of operations. It also means the team can vary its rate of production during the day...

...each team is responsible for the quality and follow up of its own work. Responsibility has thus been decentralized and re-delegated extensively...

...cars manufactured in a good working atmosphere by skilled people who have a say in their own working situation end up by being good cars.”

Produced by AB VOLVO Communications (1973)



This classic case study of organisational re-design has powerful and appealing analogues with what we want to achieve with resilient systems. In engineering systems we too want the human and technical elements to be able to maintain a steady state despite a wide range of external disturbances; we too want different sub-systems to be better related to each other; we too want to move away from ‘over designing’ behaviours; we too want work intensity to be high; above all, we too want our engineering systems to be inherently stable and self-correcting. We can see rendered in this classic study, then, some key attributes made explicit in the later work of Davis (1977) and shown in Table 1. They illustrate what a resilient, jointly optimised Sociotechnical System at any scale, and in any domain, should ‘look like’, indeed, how Civil Engineering systems could be

evaluated for 'joint optimisation' right now. The only modification being that the word 'organisation' is replaced with 'civil engineering system':

Table 1 - Attributes of resilient jointly optimised sociotechnical systems (from Davis, 1977, p. 265-266)

		Yes/No?
Systemic	"...all aspects of [the civil engineering system] functioning are interrelated".	
Open System	"...continuous adaptation to requirements flowing from environments".	
Joint Optimization	The principle that socio and technical elements of a [civil engineering] system should be jointly considered and maximised.	
Organisational Uniqueness	"...Structure of the [civil engineering system]...suits the specific individual [system's] situation" (relates back to adaptation above).	
Organisational Philosophy	The design of structures and roles is "congruent with agreed values" (In other words, not a 'bolt-on' solution but pervasive and ubiquitous).	
Quality of Working Life	"...integrity, values, and needs of individual members are reflected in the roles, structure, operations, and rewards of the [civil engineering system]." The intrinsic nature of work is enhanced (e.g. Hackman & Oldman, 1980).	
Comprehensive Roles for Individuals or Groups	The content of work and the people used to carry it out (and their organisation into teams or groups) should reflect the principles of 'meaningful' and 'whole tasks'.	
Self-Maintaining Social Systems	"...social systems are such that organisational units can carry on without external coercion...i.e. they are to become self-regulating".	
Flat Structure	An attribute of a Sociotechnical System (one that is jointly optimised) is that there are "fewer organisational layers or levels".	
Participation	"...democratization of the [civil engineering system]" with individuals able to contribute to problem solving and governance.	

Minimal Differentials	Status	“any differences which are unrelated to role and organisational needs” are to be avoided	
Make Large Small		“Organisational and physical structures provide both smaller, more intimate organisational boundaries and a feeling of a smaller physical environment for individuals or groups”.	
Organisational Process	Design	“...components of the [civil engineering system] evolve in a participative, iterative manner, only partially determined by advance planning”.	
Minimal Specification	Critical	“...designers specify (design or select) the crucial relationships, functions, and controls, leaving to role-holders the evolutionary development of the remainder”.	

Sociotechnical Systems Theory really was the leader in operations improvement, and it went far beyond a coal mining proof of concept and a large scale implementation in a Swedish car plant. The core principles of responsible autonomy, adaptability and meaningful tasks were taken up by a large number of organisations. Indeed, there are enough examples (over 200) to warrant meta analyses of Sociotechnical Systems Theory’s wider impact (e.g. Cummings, Molloy and Glen, 1977; Pasmore et al., 1982; Beekun, 1989). Between them, these studies provide a substantial overview of STS’s thirty eight years’ worth of ascendancy. The results are quite staggering:

Table 2 – The use and effectiveness of common sociotechnical measures (Source: Pasmore et al., 1982).

Sociotechnical feature	Percentage of studies using the feature (N=134)	Percentage of studies reporting success in terms of attitudes (Socio)	Percentage of studies reporting success in terms of Productivity (Technical)
Autonomous work groups	53%	100%	89%
Skill development	40%	94%	91%
Action group	22%	93%	100%

Reward system	21%	95%	95%
Self inspection	16%	100%	90%
Technological change	16%	92%	60%
Team approach	16%	100%	80%
Facilitative leadership	14%	100%	100%
Operators perform maintenance	12%	100%	88%
Minimum critical specification	9%	100%	100%
Feedback on performance	9%	100%	100%
Customer interface	9%	100%	100%
Self-supply	8%	100%	80%
Managerial information for operators	7%	100%	67%
Selection of peers	6%	100%	100%
Status equalization	4%	100%	100%
Pay for learning	4%	100%	100%
Peer review	3%	100%	100%
% studies successful		94%	87%

To say they “support most of the claims that [sociotechnical] researchers have been making for three decades concerning the beneficial nature of this organizational redesign strategy” (Beekun, 1989, p. 893) is something of an understatement. So why don’t we see more Sociotechnical Systems Theory? Where did it go?

Gone but not forgotten...

In November 1992 Volvo closed down its innovative plant in Kalmar. The reasons were not due to an inherent failure of the sociotechnical paradigm as such, rather it was more to do with a resurgence of 'neo-rationalism' inspired by the manufacturing excellence then evident in Japan and the highly (formally) rational methods and practices used to achieve it (Dankbaar, 1993). This shift coincides with the so-called 'information revolution' and the increasingly inventive ways in which computing and networked technology could be deployed to make complex organisations and shifting contexts behave rationally in the face of complexity. There is no doubt the subsequent character of sociotechnical research has been affected. For Volvo, sociotechnical systems theory has given way to lean production which has a rather different value base and assumptions about human workers (Niepce & Molleman, 1998). The days of ambitious large scale implementations of sociotechnical principles have largely given way to work of a smaller and more self-effacing theoretical nature. Hirschhorn, Noble and Rankin (2001) are right to complain that sociotechnical approaches are, as we have seen, too often rooted in notions of mass production and labour use and are not always well attuned to the contemporary concerns of industry (see also Pava, 1986). "As a consequence of the dominant emphasis of the traditional [sociotechnical] model on the micro level of organizational design, its relevance for modern open system organisation theory is diminishing." (Heller, 1997, p. 606). As such, to quote yet another of Vonnegut's characters, "people are finding that, because of the way the machines are changing the world, more and more of their old values don't apply any more. People have no choice but to become second-rate machines themselves, or wards of the machines." (1952, p. 356). This is a shame, because what we have in Sociotechnical Systems Theory is a powerful demonstration of how to harness the emergent edge-of-chaos properties of humans, jointly optimised with engineering, which could offer a radical new approach to resilience. After all, out of all the components in engineering systems which one is best able to withstand minor disturbances and agile enough to respond to major incidents? Which component is best able to cope with complexity, ambiguity and variability? The human of course.

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