# Towards resilient adaptive socio-technical systems

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### ABSTRACT
Today's socio-technical systems (STSs) are more open to the environment than before. As the environment changes more often and rapidly, so do STSs. The nature of work has changed as technology has become more widespread but also increasingly sophisticated and connected. Adaptive socio-technical systems provide a systemic approach to describe this changing world. These systems are needed to deal with the constant flux in systems and organizations that is partly due to disruptive technologies. We describe why we need adaptive STSs, noting the potential downside to adaptation. Organizations can remain resilient by using sensitization and constructive engagement to exploit the opportunities provided by adaptive STSs. We are currently defining a set of characteristics to define adaptive STSs with a view to identifying ways to make systems and organization more adaptive, and being able to track this process.

### Author Keywords
Socio-technical systems; resilience; disruptive technologies; open systems

### ACM Classification Keywords
H.1.2 User/Machine Systems

### INTRODUCTION
People have employed technology to help them perform work for thousands of years. Initially the technology was very simple, but since the industrial revolution it has become increasingly sophisticated. In addition the technology has become more widespread, with computer-based, and computer controlled systems (and systems of systems) now being widely deployed in many domains. As these systems continue to increase in scale and complexity, it is becoming clearer that there is a pressing need for new approaches to describe and inform system development.

The notion of socio technical systems (STSs) was developed by researchers at what is now called the Tavistock Institute to describe how work is carried out. The term emphasizes the importance of the interdependencies and interactions between the social and technical elements of the systems which can lead to emergent behaviors.

Before STSs, engineers focused on the technical aspects, ignoring the people costs, and simply designed whatever the organization needed without changing the structure of jobs [19]. STSs involve a complex interaction between people, technology and the environment in which the systems are deployed—both the physical environment, and the regulatory environment of standard operating procedures, rules, laws and so on. The Tavistock Institute was conducting research for the mining industry in the post-war era, focusing on long wall coal mining in particular. They discovered that the first step of mechanization of long wall mining led to one-man-one-task roles with low job satisfaction. It was necessary to find a way to recover the group cohesion and self-regulation that had existed before the mechanization took place.

The idea behind the socio-technical systems concept was to help to design work through autonomous groups which would participate in decisions concerning their work arrangements to increase quality of work while also improving technical performance [20]. These systems were fairly localized and more or less standalone. The focus was on the internal structure and the technological component was one of the boundary conditions between a company and its external environment. The technological component belonged to the company and was therefore excluded from the use of others (environment) [19]. The behavior of the STS was influenced by the external environment only to a minimal extent (e.g. introduction of faster machines). The structure of work, however, remained unaltered. The basic process of mining coal did not change with the introduction of the new more technologically advanced equipment.

Networking technologies and distributed systems which first emerged in the 1970s have further changed the nature of work. Systems in different locations could now be connected and share data, and be remotely controlled. The operators' role changed from one of hands on control to one of monitoring and supervisory control. The concept of Open STSs was developed which took account of how STSs could now operate with each other and with the environment [1].

STS started to alter their behavior and react to changes that were happening in their well-defined external environment. The interdependent parts of STSs started to adapt to and pursue goals in the external environment [1]. The way that connections to the external environment could happen, however, was controlled and could be constrained by the design of the STS. In other words, there were protocols for how STSs connected with their external environment, and these protocols had to be followed to allow for the interchange of information with that environment to take place in a legitimate and structured manner.

The advent of the Internet and the continued growth in availability of new, cheap and free technologies (e.g. cloud computing and smartphones) has changed the work landscape still further. As people start to bring their own devices to work, for example, it becomes clear that there are at least some aspects of work that are not adequately captured by the notion of open socio-technical systems.

In parallel with the changes in technology, there have also been changes in the way we think about the safety of technology and how we deal with risks. The concept of resilience has recently emerged to deal with these changes. In the next section of the paper we describe how the concept of resilience was developed as a way of addressing some of the issues introduced by the changes in technology. We then go on to introduce the concept of adaptive STSs which we believe can be used to describe the world as it is now and will be in the future. We go on to show how resilience can be maintained in adaptive STSs as the new technologies become increasingly accepted and adopted. We close by considering where further work is needed to demonstrate the utility of the concept of adaptive STSs.

## FROM STRUCTURAL TO SYSTEMIC APPROACHES

In the first half of the 20$^{th}$ century, and even up until the 1970s, most of the technology that was introduced into the workplace was largely mechanical. These systems were directly controlled by the operators (pulling levers, rotating wheels and so on) and any safety concerns were considered to be structural issues. The methods that were used to analyze safety issues, such as fault trees, consequently focused on the structural aspects of the system.

In the latter part of the century, and the early part of the 21$^{st}$ century, most of the technology that was introduced was computer based, and there was a shift towards centralized control (operating several chemical plants from one control room, for example). The occurrence of high profile accidents, such as the nuclear event at Three Mile Island [15], brought about a change in the perception of safety as it was realized that human factors and organizational issues had to be taken into consideration. New methods, such as Reason's Swiss Cheese Model [16] and the Cognitive Reliability and Error Analysis Method [9] emerged to take account of these changes in perspective.

Within the last decade, bigger and more complex systems (and systems of systems) have been developed, which are not only computer-based, but also sometimes computer-controlled. Many organizations are now reliant on these systems to operate and survive. Issues like safety are now perceived as systemic and once again, new methods have been developed that take a more systemic view of the world [7, 12]. These methods build on Normal Accident Theory (NAT) [15] and High Reliability Organisations (HRO) [17]. NAT, focuses on technical system focusing on the dimensions of interactions (which range from linear to complex) and coupling (which range from loose to tight). In general, linear interactions and loosely coupled systems are regarded as safer and more reliable. Perrow notes, however, that as we develop more and more complex systems, which have a higher number of complex interactions, and tightly coupled functions, we will inevitably end up with more accidents (hence the title of his book, *Normal Accidents*) [15]. On the other hand, there are many examples of organizations that have relatively high numbers of complex interactions, and tightly coupled functions, yet have lower than expected numbers of accidents. These so called HROs achieve higher levels of reliability by working at it everyday: it becomes an inherent part of everybody's job, and is embedded into the organizational culture.

The systemic view builds on the advantages of NAT and HRO theory. Dependability—an emergent system property—describes the ability of a system to avoid failures that are more frequent or more severe, and outage durations that are longer than is acceptable to the system's users [14]. More recently, the notion of resilience has been developed to take into account the fact that these systems are now operating in an environment that is constantly changing as organizations react to both internal and external events. Resilience can be defined as the maintenance of dependability in changing conditions. Although the concept emerged from work on safety-critical systems, it can be applied to other systems organizations, and even national infrastructure. There are two key aspects to resilience: changes (in people, technology, and environment) [6, 18] and persistence (resilience has to be actively maintained over time). The changes can be characterized according to their nature, their prospect, and their time frame [11].

Resilience has to be actively maintained over time by reacting to change (through feedback loops) as well as anticipating change (through feedforward loops) [10]. It is important to consider resilience as something that a system *does* rather than something that a system *has*. Resilience therefore requires a careful balancing of scarce resources (people, technology, and environment), particularly if some of these resources will be expended on anticipating future changes, rather than dealing with the current state of the system or organization. It is also important to note that people play a vital role in maintaining resilience, mainly because of their flexibility and adaptability, properties that are often lacking in technological systems [11].

## ADAPTIVE SOCIO-TECHNICAL SYSTEMS AND RESILIENCE

STS approaches have evolved as the nature of systems has changed from being largely mechanical to being computer-based and computer-controlled. The changes to STSs have made it more difficult to identify precisely where the boundaries of the STS lie. Open STSs, as characterized by Badham, Clegg and Wall [1], for example, can connect to the environment in fairly well defined and tightly controlled ways. This characterization includes human factors and organizational aspects at a broader level than the original definition of STSs, thereby reflecting developments in computer networking technologies, for example.

We use the notion of *adaptive* socio-technical systems as a way of dealing with systemic issues in large scale, complex systems. We believe that adaptability is needed to deal with the constant flux in systems and organizations that is partly due to disruptive technologies. The ways that STSs interact with their global environment cannot be completely defined when the STS is being developed, and are often less well controlled after the STS is deployed [5]. Reactive adaptations are used to deal with failures and degradations in performance, [4], but we also allow adaptations to be made for anticipative, and positive reasons.

Adaptive STSs have the intrinsic ability to locally adapt—from both a structural and a behavioral perspective—to deal with contingencies arising from changes in the environment. Local adaptations may adversely affect the wider STS, however, unless care is exercised to make sure that these adaptations are coherent and consistent with entire organization before the effects ripple out. As STSs have become increasingly large and complex it has become correspondingly difficult to be able to reliably predict all the outcomes of a particular task or process [8]

Users have always utilized workarounds to overcome what are usually technological shortcomings, so they can perform their tasks. Nowadays they may utilize disruptive technologies as part of these workaround, which can lead to these technologies being dynamically incorporated into the STS structure. In these cases, the initial adaptation process starts bottom up. Once the use of the new technology reaches the point, where it is deemed to be acceptable, coherent and consistent with the wider organization, the adaptation process can be rolled out in a top down manner, by the IT department, for example.

Users contribute to the resilience of systems. The adaptability and flexibility of human behavior allow users to bridge the gaps and make the system fit for purpose where the technology is too brittle. As systems get bigger and more complex, however, users are moving from manual workarounds to using technologies to help them bridge the gaps. This introduces trade-offs, however, between whether the users or the technology are determining the direction of the workaround. In other words, does the user decide on the workaround and choose a technology to help them carry it out, or do they choose the technology and adapt the workaround to fit with that particular technology. Either way, users now have the power to quickly, easily and often cheaply deploy new technologies from outside of the traditional company structure in which the IT department would dictate which technologies were permissible.

If we take the example where a user makes use of cloud computing we can see that the organization ends up being dependent on the cloud provider. Cloud provision is still a relatively new area, however, and it is not possible to predict with 100% certainty that the chosen cloud provider will still exist in one, two, or five years' time. The organization has effectively ceded some control to the cloud provider, which introduces a new element of uncertainty and risk. The resilience of the organization can be maintained to deal with these challenges, as long as any adaptations (such as a user employing cloud computing as a workaround) are performed appropriately [11].

In order to ensure that the adaptations are appropriate, the techniques of sensitization and constructive engagement can be used [2]. Users need to be sensitized to the potential impact of making adaptations involving disruptive technologies, for example. This will make them more aware of the potential effects (both good and bad). By constructively engaging in discussions with the users too, the company IT department can help the users make informed decisions about important issues including: which of the available technologies to use; and how to ensure that any adverse effects are locally contained. The constructive engagement, in particular, would be a two way process, with the users providing the IT department with feedback on the adaptations and the technologies that they used. This information could then be used to guide decisions about propagating the adaptations more widely.

If adaptation is done in an ad hoc, unprincipled way by the users, processes and tasks may become opaque, unmeasurable and incomparable. At the moment, many companies forbid the use of disruptive technologies because they have not worked out a way to integrate them with their existing structures. An adaptive STS approach would allow these technologies to be deployed in a more careful and controlled way, similar to empirical studies. In this way it should be possible to locally contain any adverse effects of using disruptive technology, whilst at the same time providing a way to measure the potential benefits, and consider issues of generalization if the adaptation was rolled out to other parts of the STS. Following this approach should allow us to maintain the resilience of the STS, and to learn lessons about the nature and effects of adaptations on resilience.

## SUMMARY AND FUTURE WORK

Developments in technology and how it is used continue to happen in ways that can be difficult to predict and at an increasing pace. Cheap (and free) technologies are now widely available, and people are increasingly using and depending on the so-called Big Five challenges: cloud computing; big data; consumerization; mobile; and social media. We know that these technologies can yield benefits, but we also know that they can cause problems if they are used in an ad hoc or unprincipled way (e.g. see [3]). In other words, these technologies can lead to a reduction in the resilience of systems and organizations. These technologies are here to stay, however, so we need to find a way to reap their benefits while avoiding (or at least limiting) their adverse effects.

As we have built bigger and more sophisticated systems, the methods used to analyze these systems have changed. It is now clear that as we continue to build systems (and systems of systems) of increasingly large scale and ever greater complexity, we need methods that adopt a systemic viewpoint to analyze and build these systems. We believe that adaptive STSs have a role to play here. The notion of adaptive STSs also shows that there is still a need for sociotechnical systems theory in the 21st century [5].

Systems are now so tightly woven into organizations that they have become highly dependent on technology. Any system outages can often give rise to major financial losses, as well as damaging the organization's reputation (possibly beyond repair). It is therefore increasingly important to make sure that systems (and organizations) are resilient.

Finding a way to incorporate disruptive technologies into an organization without compromising the organization's resilience is a major challenge. The adaptive STS framework offers a way forward. The people in the system have a critical role, with the IT department sensitizing the users at the sharp end of the system to the pros and cons of disruptive technologies within their organization. The IT department and the users also need to partake in constructive engagement to make sure that both are aware of ongoing efforts to utilize disruptive technologies.

One of our aims is to identify a set of characteristics for adaptive STSs, similar to those for open STSs [1]. We can already see, for example, that adaptive STSs react to change in ways that are structural *and* behavioral. We also hope to be able to identify ways of making systems and organization more adaptive, and being able to measure this.

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