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Extending systems ergonomics thinking to accommodate the socio-technical issues of Systems of Systems

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ABSTRACT

Socio-technical issues for Systems of Systems (SoS) differ in several ways from those for systems, mainly because the individual systems that are components of the SoS are usually owned by different organisations, each responsible for the optimisation and operation of its own system. Consequently, management of the SoS is about negotiation and management of the interfaces. Because of issues of Intellectual Property Rights (IPRs), commercial confidence, and the like, there is seldom sufficient, timely information in circulation about the SoS. Surprises are endemic to SoS, and resilience is a fundamental requirement. This paper outlines the different characteristics of SoS compared to ordinary systems, discusses many of the socio-technical issues involved, and then outlines a generic approach to these issues, treating the SoS as a 'wicked problem'. Endemic to this is the need for governance, which is discussed briefly. This is followed by a description of the evident gaps in knowledge about the functioning of SoS, and a listing of tool classes, the development of which would enable progress to be made more effectively. Finally, the paper discusses how the SoS approach might be the best way to entrain ICT to address global drivers, thus pointing to the importance of the SoS approach.

1. Introduction to, and characterisation of, Systems of Systems

The ergonomics profession is fairly well-equipped to deal with the socio-technical issues of systems, as the papers in this Special Issue attest. However, when one moves up to the next level of complexity, where systems themselves become bound into Systems of Systems (SoS), more issues emerge that require consideration, and which affect both the application of systems ergonomics thinking at the lower level of systems and at the SoS level. This paper discusses these extra issues, and ways in which they may be addressed.

By definition, SoS are much larger than the systems of which they are composed, and in many cases will be in existence for much longer than these component systems. They are often fundamental to the fabric of society and the functionality of the nation-state; examples are the government of the state itself; defence, law and order, and the continuous provision of energy, clean water, health & social security, and transport.

The aim of this paper is to highlight particular Human and Organisational issues that pertain to the design and operation of an SoS and to outline new approaches, methods and tools that need to be developed to address these issues. We begin by setting the context to provide a framework for the discussion which follows.

Section 1 introduces some of the established ways of characterising SoS, and outlines some of the differences compared to Systems Engineering. Section 2 discusses a number of the socio-technical issues arising from these differences; section 3 outlines how complexity within an SoS renders nugatory the standard, reductionist approach to solving systems issues. Section 4 then addresses the problem of delivering resilience in a SoS, making use of the 'wicked problem' approach, and section 5 discusses the technical and engineering governance of SoS, without which the 'wicked problem' approach is unlikely ever to succeed, and finally section 6 outlines a role for the SoS approach in addressing global drivers, as a way of showing its importance. However, on the basis of what goes up also comes down, the paper ends by considering some of the lingering drawbacks of this approach.

1.1. What is an SoS?

There are many definitions of System(s) of Systems, some of which are dependent on the particularity of an application area.

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Jamshidi (2009) has reviewed more than seven definitions of SoS and, although none are accepted universally by the community, the following has received substantial support and is adopted for the purpose of this paper:

> *"A SoS is an integration of a finite number of constituent systems which are independent and operable, and which are networked together for a period of time to achieve a certain higher goal"* (Jamshidi, 2009)

Firstly, it should be noted that according to this definition, formation of a SoS is not necessarily a permanent phenomenon, but rather a matter of necessity for integrating and networking systems in an organized way for specific goals such as robustness, cost, efficiency, etc.

Secondly, there are overlaps with the concepts of Systems, and of Complex Adaptive Systems. Indeed, the SoS approach, as currently understood and discussed, can be seen as an organizational version of the latter, and therefore as a class of system. However, the characteristic of managerial independence for the constituent systems and the implications that flow from this justify a separate classification for SoS, as discussed later.

As an example, consider a hospital, funded by the state, and serving a local community. In essence, this is a patient-processing system where initial triage defines the path each patient will take through the specialities, services and functions that are resident within the hospital, such as an ambulance service, X-ray, neurosurgery, paediatrics, maternity, physiotherapy, ward management, nutrition, patient records, waste management, portering, maintenance and many more.

Functionally, each of these services can be considered to be a system; for each there is a group of people supported by technology, intercommunicating and interoperating to reach a given goal, and, from a control perspective, able to do this independently of other systems. In practice, as opposed to just a control perspective, each of these will rely on the infrastructural systems such as water, power and so on in order to perform, and, on the basis of the flow of patients and information among the constituent systems, each will fulfil its goals. Fig. 1 illustrates the generic interfaces that such systems will require in order to participate long-term in a SoS.

The inter-relationship among these systems is highlighted when the phenomenon of 'bed-blocking' occurs, as discussed cogently by (Williams, 2010), where wards become full (for example because of a local epidemic or serious industrial accident). Because in the UK the hospital is legally obliged to accept patients, new ones are allocated to other wards. When these in turn become full, patients may be shifted on again; the problem becomes significant when patient records on occasion are not able to keep up with this, and a patient may become temporarily 'lost' in the system of systems that comprises the hospital, with a hunt going on to find the patient and restore the patient's treatment path through the designated services.

1.2. Characterisation of system of systems

A widely-adopted characterization (Maier, 1998) is given below:

- The elements of the system are themselves sufficiently complex to be considered systems
- Operating together the systems produce functions and fulfil purposes not produced or fulfilled by the elements alone
- The elements possess operational independence. Each element fulfils useful purposes whether or not connected to the assemblage. If disconnected the element can continue to fulfil useful purposes
- The elements possess managerial independence. Each element is managed, at least in part, for its own purposes rather than the purposes of the collective.

As Maier points out, the implications of these characteristics are:

- The development of stable intermediate forms over time for the SoS. Since the constituent systems have managerial independence, they may evolve in their own ways. For the SoS to remain fully functional it may be necessary to identify intermediate forms that enable this evolutionary process to occur without compromising the whole SoS
- There is a need for policy triage for the whole SoS; in other words, to know what can be fixed and what can't. Standards and agreed functional protocols are a means of ensuring a degree of constancy and stability in the SoS.
- Because of the endemic characteristic of managerial independence of the constituent systems, the main sources of leverage

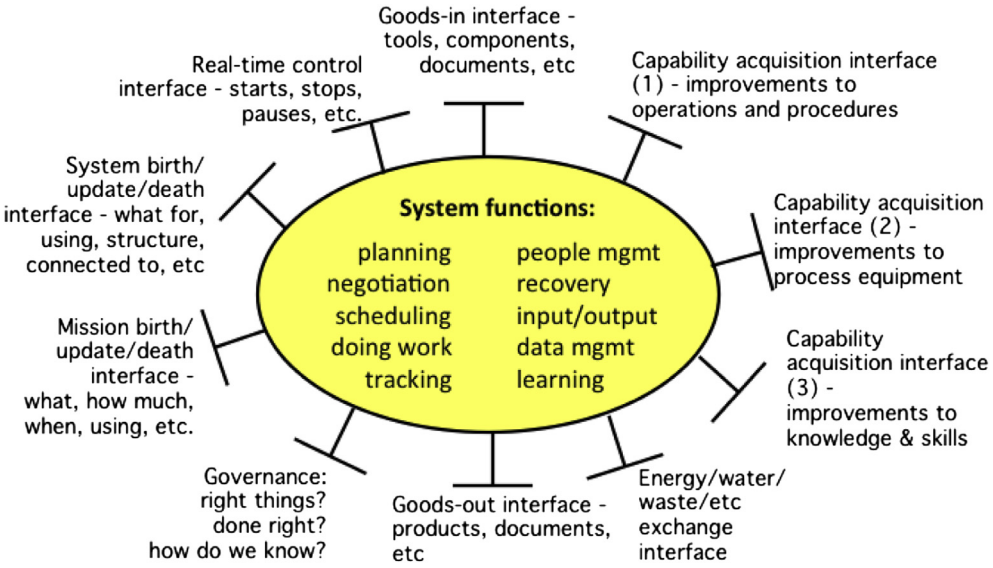

Fig. 1. Representation of generic boundary interfaces for systems. At right are system improvement interfaces; the rest are concerned with system operation within its environment. In a system of systems, all of these interfaces will be active to ensure its long-term operation.