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RESEARCH NOTE

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The theoretical foundation(s) for Systems Engineering?

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Abstract

I present a short argument for the enlargement of the theoretical foundations of Systems Engineering beyond Systems Science/General Systems Theory.

KEYWORDS

foundations, methodology, practice, Systems Engineering, Systems Science, theory

In his recent address, the President of the International Society for the Systems Sciences raises some important observations about the state of Systems Engineering and need for theoretical foundations (Rousseau, 2019). The description of problems in this industry is frank and to be welcomed (Rousseau, 2019; section 2). Whereas his address also concerned the general (fragmented) state of Systems Science, its relationship to Complexity Theory, and the requirements for General Systems Theory to act as a foundation for Systems Engineering and Systems Practice generally, my response concentrates specifically on its relevance to the foundations of Systems Engineering. It is pertinent to position both in the context of the relationship that exists between the International Society for the Systems Sciences and the Systems Science Working Group of the International Council on Systems Engineering, which was formalized by the Relationship Agreement that was signed between the two organizations in 2011 and as emerged from a joint meeting that was held in January 2011 (International Society for the Systems Sciences & International Council on Systems Engineering, 2011; Lawson, 2011; Martin, 2011). This agreement has been periodically reviewed as a Memorandum of Understanding (International Society for the Systems Sciences & International Council on Systems Engineering, 2017).

This most recent statement of the relationship sets out that its principles are (a) to jointly further practices in Systems Sciences and Systems Engineering, (b) to state that International Council on Systems Engineering members are interested in gaining foundational knowledge in Systems Science concepts that are relevant to Systems Engineering practice, (c) to express that International Society for the Systems Sciences members are interested in seeing systems theories applied in practice, and (d) to define how the relationship should be coordinated. Therefore, with regard to the Memorandum of Understanding, the president's address is well aligned. The relationship provides an excellent opportunity for good science to take place as it addresses the necessary praxis that occurs at the intersection between the empirical and the theoretical. A succinct diagrammatic summary of this praxis can be found in Singer et al. (2012).

The realm of Systems Engineering is ever expanding, as a systemic sensibility percolates across engineering practice, and Systems Engineering itself produces distinctive new branches of knowledge such as Model Based Systems Engineering and System of Systems Engineering. However, is Systems Science and General Systems Theory[1] the only route to take in order to provide theoretical foundations for Systems Engineering? At face value, Systems Science would appear to be an obvious way forward. However, the key knowledge assets suggested by Rousseau (2019, table 3) seem disjoint from the phenomena of the introduction to his paper.

[1] As General Systems Theory* (Rousseau, 2019; section 4).

I suggest there is another place to look for Systems Engineering foundations. Almost 50 years ago, Peter Checkland joined the Management School at Lancaster University, signing up to the agenda set by Gwilym Jenkins to apply Systems Engineering principles to complex problems of management (Checkland, 2000, 2012). These came off rather badly in the encounter, but the ensuing action research programme over many years and many hundreds of engagements led to the emergence and development of Soft Systems Methodology (Checkland, 1981; Wilson, 1984).

Soft Systems Methodology was taken up by systems groups, albeit outside of engineering, and eventually became part of a wider endeavour in Management Science more generally known as Soft Operational Research (Soft OR) and Problem Structuring Methods (PSMs). However, in the 30 years since the publication of "Rational analysis for a problematic world: Problem structuring methods for complexity, uncertainty and conflict" (Rosenhead, 1989), which first brought together Soft Systems Methodology, Strategic Choice Approach, and Strategic Options Development and Analysis under the PSM label, this knowledge has remained largely confined to the discipline of Management Science, the pages of a few journals,[2] and essentially disconnected from its engineering roots,[3] and even those of General Systems Theory (Checkland, 2000, p. S11). It is perhaps time that this rich—and growing (Lowe & Yearworth, 2019)—repository of theoretical, methodological and practical knowledge found its way back to Systems Engineering. There is enough material here to establish a useful research agenda to test these contributions in a modern Systems Engineering context thus taking the Lancaster Group's original agenda in the reverse direction.

However, although Soft OR/PSMs can be seen to be broadly systems-based in approach and therefore highly relevant to Systems Engineering, it is also worthwhile to ask the question what else should Systems Engineers know about that is relevant to developing foundational knowledge? Clearly Systemic Intervention (Midgley, 2000) and Critical Systems Thinking (Jackson, 2001, 2019) are highly relevant. Jackson (2019) looks at the strengths and weaknesses of 10 systems methodologies (including Systems Engineering) and organizes them according to whether they emphazise technical, process, structural, organizational, people/social, or coercive complexity. The argument is that "wicked problems" (Rittel & Webber, 1973) typically involve all these forms of complexity, and so, an enhanced Systems Engineering needs access to a range of methodologies and the ability to use them in combination. However, I believe it is also incumbent on Systems Engineering to look to the wider social sciences for foundational knowledge.

In my own teaching of postgraduate engineers at the University of Bristol, I used a critical reading exercise on a research methods course to introduce material from a broad range of social science. One of my favourite papers to set was Diane Vaughan's account of the National Aeronautics and Space Administration during the Columbia accident investigation published in the American Journal of Sociology (Vaughan, 2006). Written in a lively first-person rhetorical style, she presents an engaging ethnography of her experience and its relation to her earlier work during the Challenger accident investigation (Vaughan, 1996). The reaction of the engineering students was interesting. Predominately this was an initial claim that the work was "unscientific" because of the ethnographic method and writing in the first person. However, and this was truly interesting, Vaughan's notion of the normalization of deviance resonated with the students. It was a concept that, no matter how it was derived, was believable and, crucially, they could see how it might apply in other engineering organizations especially where safety was of paramount concern.

It is not too difficult to see that once the language of social science and variety of essentially qualitative research methods is mastered, there is a rich source of knowledge available and relevant to Systems Engineering. The opportunity is vast, and here, I can only point to a few examples, in addition to Vaughan, that I have found useful and relevant to the phenomena that Rousseau (2019) touches on in his paper—large infrastructure project failures (Flyvbjerg, 1998; Flyvbjerg, Garbuio, & Lovallo, 2009), strategic misrepresentation (Kutsch, Maylor, Weyer, & Lupson, 2011), strategic ambiguity (Denis, Dompierre, Langley, & Rouleau, 2011), and paradox (Poole & van de Ven, 1989; Schad & Bansal, 2018). This literature bears little relationship with Systems Science and General Systems Theory but nonetheless is likely to be highly relevant to Systems Engineering practice.

Perhaps Systems Science needs Systems Engineering more than Systems Engineering needs Systems Science and General Systems Theory? I suggest that Systems Science/General Systems Theory is just one of a number

[2]Notably Systems Research & Behavioral Science, European Journal of Operational Research, Journal of the Operational Research Society, Group Decision and Negotiation, and Omega—The International Journal of Management Science.

[3]Although attempts have been made in the Faculty of Engineering at the University of Bristol to reconnect them through research methods teaching to postgraduate engineers on the Engineering Doctorate in Systems programme that ran from 2009 to 2018 (Yearworth, 2011; Yearworth, 2016; Yearworth et al., 2015; Yearworth & Edwards, 2014; Yearworth, Edwards, Davis, Burger, & Terry, 2013; Yearworth, Edwards, & Rosenberg, 2011; Yearworth & White, 2015).

of foundations and that Systems Engineering needs to embrace a much broader research agenda. In my capacity as Systems Field Editor/Systems Engineering for Systems Research and Behavioral Science, I would like to encourage submissions to this journal that make theoretical, methodological, and practice-based contributions to this debate. I would also like to see the debate spread into the pages of Systems Engineering and other related systems-oriented journals in engineering. The specific case of reconnecting Soft Systems Methodology to engineering practice (generally) via Soft OR/PSMs is my own area of work. The reason for advocating this reconnection is the recognition of the *messiness* of the real-world that engineers face and frequently stated as the characteristics of wicked problems enumerated by Rittel and Webber (1973). This recognition then sets up the need for approaches such as PSMs that enable Systems Engineering practitioners to deal with problem situations involving many interested parties with different perspectives (worldviews), problem situations that are not well defined, where there is difficulty agreeing objectives and success requires creating agreement among parties involved, and that there may be many uncertainties and lack of reliable data (Mingers, 2011). However, in addition to this, I firmly believe that future development of Systems Engineering foundations need to draw from the wider social sciences, not just Soft OR/PSMs.

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