
Editorial: 21st century research and application challenges for the emerging system of systems engineering field

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This special issue of the journal stems from work generated during a conference on next generation infrastructure challenges in research and applications for the 21st century. The special issue emphasis is focused on a system of systems engineering (SoSE) perspective. The special issue invites an opportunity to take stock of the current state of the SoSE field and reflect on the future challenges that must be confronted if the field is to remain relevant and evolve. This assemblage of papers provides a reference point to amplify some perspectives and challenges for the future development of the SoSE field.

The SoSE problem domain of the 21st century is characterised by a confluence of several factors that have eluded more traditional forms of technology centric approaches to resolve. We are realising that increasing complexity and compounding contextual factors (e.g., politics and power) are beyond the singular reach of technology to adequately address. We are rapidly being forced to reconsider a technologic centric paradigm necessary to address this new domain. This new domain, and the challenge for the SoSE field, is characterised by:

- 1 the dominant and escalating role of information as the currency of systems and reliance of information intensive systems and technologies as integral to system-based solutions
- 2 diverse stakeholders with potentially divergent, or incompatible, worldviews and interpretative schemas
- 3 increasing intrusion of politics and power into traditionally technically dominated decisions spaces
- 4 growing pressures on availability, distribution, and shifts in scarce resources
- 5 instabilities in problem domains, resulting in constantly shifting requirements and expectations for solution development

- 6 increasing speed of technological advancement that outpaces the capabilities, and potential compatibility, of existing infrastructures to support
- 7 pressure for systems to rapidly and robustly compensate for emergence, shifts in operating assumptions, and discontinuous domain knowledge
- 8 surrender of long term perspectives to deal with immediate concerns – rendering traditional forms of planning geared to long time horizons virtually innocuous
- 9 problem domains that display increasing ambiguity, emergence, and uncertainty that challenge traditional approaches rooted in clarity, stability, and certainty.

At first glance this domain is somewhat unsettling. However, as gloomy as this domain appears, although SoSE does not offer complete resolution, it does provide a more sophisticated understanding and developing capabilities to more successfully deal with the domain. The topics and papers provided in this journal all respond to some aspect(s) of this domain. Therefore, this is an ideal opportunity to reflect and offer a perspective on the young and maturing SoSE field and the challenges this field faces for the future.

To frame the development of the SoSE field to deal with the 21st century problem domain, four reflective themes are offered. Our first theme suggests that the evolution of the SoSE field and the inherent ambiguities in the evolving identity of the field is natural and should not be unnecessarily forced. Second, the emerging multidisciplinary nature of the SoSE field is enabling as well as constraining to both the pace and trajectory of field development. Third, the maturation of the SoSE field must balance the tension between purposeful development and development by unstructured self-organisation. Fourth, the SoSE field development will be accelerated and more sustainable by focusing beyond the narrow development of application and tools to include advancement and grounding in philosophical, theoretical, and methodological foundations. The degree to which the researchers and practitioners deal with these reflective themes will be instrumental in how the SoSE field either matures or simply devolves into a passing and unsustainable fad.

As a consequence of being in the early stages of development, the *SoSE field is naturally struggling to find an identity*. This identity must distinguish the SoSE field from other related fields (e.g., systems engineering) while simultaneously serving to discover the essence of the field. For example, there are those who would support the claim that SoSE is really nothing new and is not distinct from systems engineering. In effect, this claim suggests that SoSE is simply an extrapolation of systems engineering. As such, the models, tools, standards, and processes that have served the systems engineering field effectively for decades should simply be extrapolated to the SoSE problem domain. In contrast, another view suggests that SoSE is a field that is significantly new and different from existing related fields. This view considers SoSE to be addressing a different problem domain marked with ambiguity, emergence, and uncertainty beyond the capabilities of traditionally rooted fields (e.g., systems engineering) to address. This view supports the claim that existing fields, focused primarily on the technical aspects of complex problems, are insufficient. Further, that the technical aspects of a problem domain may need to be subordinated to the human, social, managerial, organisational, political, and policy dimensions. Therefore, technology may be relegated to a background role as other dimensions are placed in the foreground of the problem domain. A third view suggests that SoSE is a subset of systems engineering, focused on the achievement of ‘technical’ interoperability of multiple technical systems. The emphasis of this

perspective is to focus the SoSE field solely on the technical aspects of the problem domain. The non-technical aspects of the problem domain are relegated to the background, if considered at all. Arguments can and have been made in support of each of the three SoSE viewpoints presented.

Each of the presented perspectives of SoSE is correct. Each of these perspectives is also incorrect. Correctness or incorrectness is a function of the particular vantage point from which the perspective is taken. Each perspective has an underlying logic and rationale that support its propositions. However, the existence and propagation of these disparate perspectives mark the immaturity of the field and the lack of a coherent identity. A coherent identity is essential to provide a grounding of the field and distinguish its essence in relationship to other fields. Therefore, an unambiguous identity serves to focus the field and more easily establish what is included as well as what is excluded. The struggle of the SoSE field to find an identity is necessary and should not be taken as a flaw, but rather embraced as a necessary evolutionary process as the field matures. The objective of seeking a more unified perspective of the field is not to have a singular voice devoid of intellectual conflict, especially in the early development of the field. Narrowing of perspectives too early is likely to shut out potentially fruitful dialogues, explorations, and challenges. However, allowing the field to meander for too long, without a glimmer of integration or consistent identity, will most certainly ensure unproductive fragmentation, invite a premature demise, and facilitate an early exit from relevance. The SoSE field has been in existence long enough to begin to congeal around central tenets of an identity, yet appears to be lagging in this respect.

A second point of reflection for the developing SoSE field is the *emerging multidisciplinary nature of the field as well as the problems addressed by SoSE*. The multidisciplinary nature of SoSE is both constraining and enabling for field development. The very notion of multidisciplinary implies a wide boundary for application of the field. This suggests that the development of field artifacts (e.g., methodologies, tools, methods, processes) must have applicability across multiple ‘application’ fields such as healthcare, energy, education, and transportation. Each of these application fields have their history and traditions for approaches that have served them. The injection of a ‘new’ multidisciplinary approach to dealing with problematic issues in the specific application field, likely accustomed to particular ‘favoured’ approaches and paradigms, might easily be met with skepticism. Therefore, SoSE field maturity is constrained by the wide range of multidisciplinary application. In contrast, the multidisciplinary focus of SoSE is also enabling for development of the field. Multidisciplinary emphasis supports development of an identity that distinguishes the field against those that are more singularly focused on specific fields or aspects within fields (e.g., technology integration). The applicability of SoSE as a multidiscipline is a strength that can distinguish SoSE. By addressing application specific problems from the multidisciplinary SoSE perspective, new insights might accrue. These insights might hasten the acceptability of SoSE and accelerate development and acceptance of the field as truly multidisciplinary.

The third point of reflection for development of the SoSE field is the *limited degree to which the field is purposefully developing*. It might be argued that purposeful development is difficult at best and impossible at worst for an emerging field. Purposeful development invokes concepts of thoughtful and organised advancement of the field. In established disciplines there is a governing function that provides direction, oversight, and accountability for evolving the discipline. This purposeful development is a major distinction between a field and a field that has evolved into a more formal discipline.

Unfortunately, in an emerging field such as SoSE, this governance is lacking. SoSE has no structured development, no governing body, and no recognised development authority. On the contrary, the SoSE field has largely been evolving in a self-organising ad hoc fashion. Except for some fragmented efforts (e.g., *International Journal of System of Systems Engineering*, National Centers for System of Systems Engineering) directed to consolidation of work and purposeful development of the field, there is a lack of concerted effort to organise the emergent field. This is not a critique of the field, but simply an observation that maturation of the SoSE field is impeded by lack of orchestrated purposeful development. This lack of purposeful development represents a major obstacle in the orderly evolution of SoSE from an emerging field to a more stable multidiscipline.

The fourth point of reflection for the SoSE field is the *limited holistic development that balances both application (e.g., tools, methods, techniques) and conceptual (e.g., philosophy, theory, methodology) emphases*. If SoSE field development is to be dominated by a wholly application orientation, the field maturation will certainly suffer as a result. Application dominated development is narrow and will ensure that the field reaches limited maturity. In addition to application, a field must embrace more wide ranging developmental thrusts. For example, development of philosophical, theoretical, conceptual, and methodological foundations are essential to provide an appropriate grounding for the emerging field. This is not to say that the SoSE field cannot develop without this wider consideration. However, without a more holistic basis for development, the conceptual foundations will not be in place to provide stability that balance can support. Unfortunately, the preponderance of effort in development of the SoSE field appears to be focused on the application side of development. If this trajectory continues unchecked, it is likely that the SoSE field will be slowed and certainly not reach its full potential.

The papers in the journal issue represents a cross-section of the present state of the SoSE field that can collectively amplify many of the themes presented in this editorial. The Neaga and Gheorghe paper on ‘A ‘system-of-systems’ standardised architectural approach driven by cloud computing paradigm’ is operating at the most foundational levels of SoSE, attempting to suggest a new paradigm for architecture, based in cloud computing. Of interest is the challenge to existing paradigms, while still drawing reference back to several of the accepted standards for systems and software engineering. This illustrates the need to develop and embrace new paradigms, but also to acknowledge and bring forward applicable standards and practices that are appropriate to the SoSE problem domain. In ‘An approach to regional planning in India’, King, Rathi and Sudhira recognise a problem that requires a multidisciplinary response that crosses economic, social, and environmental aspects of planning. They provide an approach that embraces emergence and offers a multidisciplinary method to deal with planning dilemmas in the SoSE problem domain. Interestingly, in their paper ‘Considering emergency and disaster management systems from a software architecture perspective’, Mukherjee and Asundi acknowledge and develop arguments that recognise the qualitative (non-technical) aspects of dealing with information and communication technologies for emergency and disaster management software systems. Thus, they support a more holistic and multidiscipline perspective to a complex problem. In developing the role of tools to assist decision makers in planning for emergencies, Narang, Hoysala, Arlekar, Chadgar and Asundi’s paper ‘Developing GIS tools for planning, mitigation and preparedness for large scale emergencies and disasters’ suggest the multidisciplinary importance of other

supporting fields, and the tools they can bring, such as modelling and simulation. In the paper 'Evaluating infrastructure resource allocation in support of regional stability', authors Teague, Warner and Brown explore stability from a systems approach developed from an agent-based modelling perspective. They project stability from a multidisciplinary viewpoint, including a wide range of perspectives such as governance, security, and development in support of more informed decisions. Vaidyanathan and King continue the multidisciplinary theme with their paper 'Institutional analysis of urban transportation in Bangalore'. In this paper, the authors focus on transportation planning, the methods used for that planning, and the multiple agencies that must be integrated to achieve planning. This certainly embraces the more holistic emphasis of SoSE, resisting the technology centric solution emphasis. In dealing with uncertainties of a future for electric vehicles, authors Taneja, Bijloo, Ruitenbergh and van Schuylenburg examine the use of simulation as a method to better understand complex interrelationships and their impacts in different future-based scenarios. As such, game-based simulations are suggested as an approach to overcome complexities in future market model development. In a paper also focused on the utility of simulation-based gaming to understand the dynamics and interactions for emerging markets, 'The E-CITY 2020 game: the use of simulation games can accelerate market model design for the electric vehicle charging infrastructure', authors Helmer, Noom, and Warnier suggest the use of simulation-based games to better understand and deal with uncertainties associated with future scenarios.

The articles in this journal have certainly demonstrated their relationship and contributions to the SoSE field themes of being multidisciplinary and taking a holistic perspective, although there is an emphasis on the use of 'tools'. However, the articles also suggest the continuing lack of cogent identity and the apparent absence of purposeful evolution for the field. There is much to be done in the development of the SoSE field, but the potential of this emerging field to address many of the most vexing problems of the 21st century justifies the continuing journey.

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