AC 2012-4002: APPLICATION OF CASE STUDIES TO ENGINEERING MANAGEMENT AND SYSTEMS ENGINEERING EDUCATION

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Application of Case Studies to Engineering Management and Systems Engineering Education

Abstract

As engineering system complexity has increased over the years, numerous complex systems projects have failed due to the lack of an appropriate systemic perspective. Since the solution to this challenge is itself a complex system, educating and training our current and future technical leaders on these challenges, and providing suggested changes in their mind sets, is imperative. As an educational tool, case studies can be a platform through which the analysis, knowledge application, and drawing of conclusions can occur to facilitate coping with the most complex systems. Case study learning has proven successful in the training of business leaders with real life examples of the strategies and tactics used by leading businesses to succeed globally. A valuable characteristic of case studies is that they support a holistic understanding and interpretation of the systems of action or interrelated activities engaged in by the participants. However, case studies are not as broadly used in engineering management and systems engineering education. This paper describes the importance of case studies to engineering management and systems engineering education, discusses frameworks for their implementation, and presents a case study template that can be used as a guideline in engineering education.

Introduction

Engineering has long been regarded as a set of technical processes, based upon the application of practical methods and scientific knowledge, which is used by some people (e.g., engineers) in attempting to solve a broad class of problems intended to improve the lives of human beings. As technology, our capabilities, and human-made constructions have evolved, further advances have become increasingly more complicated to where many of our intentions have far outrun the availability of tools for accomplishing the goals. Although the word “complexity” is often used to describe this state of affairs, we feel that a fundamental (paradigm) shift in our mindset is required to grasp the true nature of the issue, namely that people need to be considered part of any engineered system, and that we are far beyond the machine (or even information) age; we are now more strongly influenced by global concerns and social networking. Accordingly, we must embrace the technical influences of political, operational, economic as well as technological aspects. Beyond these factors, we must delve into psychology and even philosophy[1] if we are to have much hope in achieving accelerated progress in the engineering of systemic solutions. However, beyond emphasizing the crucial direct influences of people in systems engineering and management, we must still be mindful of endemic effects that may be only indirectly related to or even independent of human behavior. Complex systems do not necessarily respond to reductionist approaches or follow predictable paths such as occur in many engineering and science projects, especially when dealing with systems over which there is little or no control, e.g., as in the “war on terror” since 9/11.

As has been demonstrated throughout history, younger generations have opened the doors to many cultural and technological paradigm shifts. In recent years, this demographic has been much more attuned to some of the key traits of complex human systems, e.g., sharing information, collaborating, and self-organizing. Whether this perspective will be sustained into adulthood and be more conducive in solving humanity's major problems compared to previous generations remains to be seen. Therefore, we have an obligation to educate and train our current and future technical leaders to sustain these traits to better address not only our traditional technological problems but also to recognize and contribute to solving our world's more complex problems. We need to make a concerted effort to create appropriate learning conditions and facilitate their further development along these lines. Unfortunately, most schooling methods in the United States (U.S.) are more linear in their philosophies and approaches (based in part on the success of the U.S. space program, perhaps) where students come to believe that every question has a known answer. We need to find methods that enhance their learning by allowing them to ask and contemplate questions for which there may not be answers or when answers are not constrained by cultural, political or dogmatic solutions. We should nurture and instil a profound understanding of complexity into our children's minds so they can better deal with improving the quality of human life and the sustainability of the planet.

Useful Notions to Keep in Mind

A key notion in addressing complex projects is not being held strictly to the paradigm established by the Project Management Body of Knowledge[2] in managing their nine knowledge areas of integration, scope, time, cost, risk, quality, human resources, communications, and procurement. Again, it is important to recognise that the Project Management Institute's reductionist techniques which were applied with notable success in going to the moon and subsequent space exploration projects, for example, have limitations when applied to many current earth-bound problems. Complexity is more profound in human-made crises such as religious-extremist terrorism, the enduring Middle Eastern disputes, world financial melt-downs, global-warming-induced climate changes, unbounded material growth, and overpopulation.

One continually questions whether these vast problems can be usefully addressed. Worriers about these crises are clearly crying out for solutions. But it is abundantly clear that such problems cannot be solved by the traditional methods applied to normal projects. Traditionally, project sponsors and customers have attempted to package projects into controllable, confining spaces to obtain clear scopes, well-defined requirements, and bounded costs and schedules, all of which reduces the opportunities for evolutionary change and truly effective solutions. When engineers attempt to solve such problems with reductionist techniques they and their customers, sponsors, and especially the system users and/or operators, are usually disappointed.

Instead, concepts of systems thinking are central to successfully addressing such complex projects as those noted above. This has strong implications for the future direction of engineering education. The following notes briefly describe a number of systems thinking techniques[3] which contribute to the proper definition of project stakeholders, their objectives, underlying assumptions, and possible methods for solving these "wicked" problems.[4]

> **Strategic Assumptions Surface Testing** recognises the benefits of various stances of a range of participative, adversarial, integrative, and managerial-minded stakeholders, and locates them on a certainty/importance scale.
>
> **Soft Systems Methodology** is a most powerful technique for solving wicked problems especially using rich pictures developed from many conceptual models of the real world, and

enhancing these by using additional perspectives (or modalities)[5] including faith, love, justice, social intercourse, feeling, and sensory perception. These are especially relevant in cross-cultural and/or international conflicts, for example.

Critical Systems Heuristics relates to the partial pre-suppositions that underpin system judgments. This methodology provides Ulrich's twelve boundary questions that affect project scope,[6] and focuses on who is marginalized and suggests techniques that allow these groups to be heard. Emotive forces in groups are recognized.

Post-modern Systems Thinking recognizes conflict between groups and critically questions 1) power relations; 2) the role of language; 3) the extent to which people are self-determining; and 4) the roles of signs and images, and provides a technique for first and second phase deliberation, debate, and decision.

Total Systems Intervention asserts that the traditional approach has been to focus on the functional whereas we need Linstone's approach[7] of focusing on technical, organizational, and procedural aspects, which act as filters through which systems are viewed.

Such techniques as those named above will significantly broaden the education of engineers and make them much better grounded and equipped to help solve complex problems.

However, abstract theory is fine and a critical part of everyone's on-going life-long education about why the world works the way it does. Indeed, that's the main purpose of science, the illumination and dispelling of mysteries and the deepening of our understanding of natural and human made phenomena. But story-telling is a powerful activity that creates awareness and motivation, and there is no substitute for practical examples showing what really works well. This is why we advocate good case studies in systems engineering (SE), particularly in the less familiar categories of System of Systems (SoS), enterprises, and complex systems. Case studies have been and are being used effectively for many years in educational fields such as social studies, psychology, medicine and health care, and business, but have found limited application in the engineering field. It is our contention that in a growing era of complex systems, where our solutions to problems are more systemic and less linear—and often quite nonlinear—case studies can have a stable home in engineering education.

Examples of How Case Studies Can Benefit Engineering Management Education

A simple Google search yields sources to numerous examples of case studies already utilized in engineering education. For example, MIT's Engineering Systems Division is on the forefront of educating graduate students in complex and enterprise systems engineering. Many of their case studies efforts are publically available.[8] In addition, MIT's System Design and Management (SDM) master's degree program produces case studies.[9] Similarly, doing a Google search for case studies in engineering management yields another publically available resource.[10] The Stevens Institute of Technology hosts a plethora of case studies and related material.[11] There is more on engineering case studies at the University of Vermont,[12] the University of Virginia,[13] and the University of Texas.[14] The University of Southern California's (USC's) Viterbi School of Engineering offers courses in case studies.[15] There is less available on case studies (it seems) at the University of Illinois.[16] It is left to the reader to explore any of these sources for case studies of interest or for additional references on how to conduct a case study. As a reference we also recommend is a classic book by Yin on preparing case studies.[17] Another case studies effort worth noting, by the IEEE SoS Technical Committee, is underway for the Trans-Atlantic Research and Education Agenda in Systems of Systems (T-AREA-SoS) project.[18]

Time and space limitations preclude any further detailed discussion supporting the importance of case studies in engineering and engineering management. However, the considerable evidence that the above mentioned universities are employing case studies so prevalently in engineering and engineering management speaks for itself. Further, the authors are working on a new book entitled *Case Studies in System of Systems, Enterprises, and Complex Systems Engineering,* to be published in 2013 by Taylor & Francis/CRC Press. We expect this book to complement what is already being done in engineering management case studies with a greater thrust toward complex systems engineering.

Now we suggest and elaborate on what we consider the main sections of and a proposed outline for a case study of complex systems.

Relationships Among Main Sections of Case Study

Referring to Figure 1, we assert that the main case study sections, each marked by an integer, within the same colored node are relatively tightly coupled, and that any two sections that are part of different nodes are loosely coupled. The following remarks explain these sections.

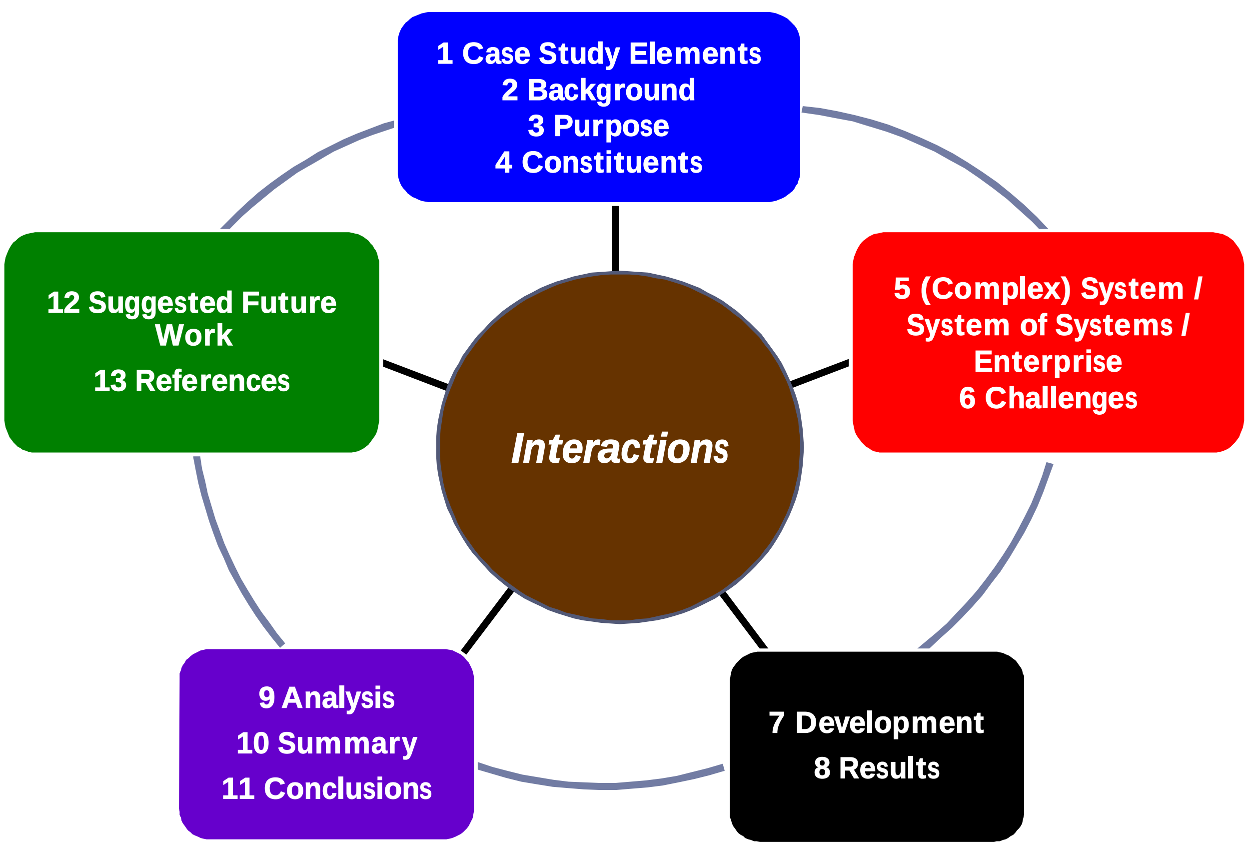

Figure 1. Relationships Among Case Study Sections

The **blue** node contains the basic facts associated with the case study. The **red** node contains further detail about the subject system, emphasizing the level(s) of difficulty. The black node contains the heart of the case study, focusing on the elements of Development and Results. The **purple** node contains elements about what it all means. The **green** node contains suggestions as to where to go next.

We emphasize that Figure 1 represents a nonlinear process characteristic of complex systems with feedback and interactions among the various aspects of the case study. As one progresses in trying things and seeing what happens, often with considerable delay in the observable feedback, there may be changes of direction, emphasis, expectation, and strategy. Although the outline and the "wheel" of Figure 1 (read in a logical clockwise and numerical order fashion)suggests a linear progression, that is not intended because a linear mindset is rarely effective with Complex Systems Engineering (CSE). Refer to Appendix A for some system related definitions.

The principal objective of each case study section of Figure 1 is presented in Table 1. Again, it does not matter much in which order these objectives are obtained. Their collective impact is what is important. However, for the purposes of easing the formidable problem of comparing multiple case studies, it would help if each case study of a given set followed the same outline.

Table 1. Principal Objectives of Case Study Sections

Index	Main Section of Case Study	This Section's Principal Case Study Objective	Color*
1	**Case Study Elements**	Provide enough concise information to enable a researcher/practitioner or general reader to decide whether this case study is of particular interest.	**Blue**
2	**Background**	Further define the case study, especially for those that are not yet sure if it is relevant to their interests.	**Blue**
3	**Purpose**	Capture the impetus behind and specific reasons for the case study, and show some of the passion that drove or is driving this transformation.	**Blue**
4	**Constituents**	Characterize people and institutions interacting in the case study, and illuminate their motivations, e.g., what incentives drove or drive them?	**Blue**
5	**(Complex) System / System of Systems / Enterprise**	Provide a clear and complete but focused description of the subject complex system, system of systems, or enterprise.	**Red**
6	**Challenges**	Highlight the principal aspirations and difficulties.	**Red**
7	**Development**	Show just how transformational change can occur.	**Black**
8	**Results**	Answer the "So what?" questions.	**Black**
9	**Analysis**	Provide suggestions to others in how to interpret results of their system transformation and what it all means.	**Violet**
10	**Summary**	Complement mainly the Case Study Elements, Background, and Purpose sections, especially for those that only want to skim the case study and not delve into the details.	**Violet**
11	**Conclusions**	Whet a reader's appetite to revisit the case study body for more detail.	**Violet**
12	**Suggestions for Future Work**	Motivate additional effort to further understand complex systems and advance complex systems engineering.	**Green**
13	**References**	Lend credibility to the case study and highlight relevant literature from related bodies of knowledge.	**Green**

*Refer to the color of the nodes of Figure 1.

Case Study Outline

A suggested outline to follow in preparing a case study is provided in Appendix B. Each main section (whose sub-title is indicated by the index integers [for short-hand reference] and in **bold**-faced type) of this outline is explained in detail as follows. Relatively minor sections and additional optional aspects (that can be pursued by the author(s) are indicated in brackets […]) of the outline are not given integer indices.

Case Study Elements

This first section is intended to be a "bulletized" executive summary that can be: 1) used for sorting among all case studies; and 2) scanned quickly to understand the nature of the case study. The Fundamental Essence and Topical Relevance, respectively, should briefly indicate: 3) what the case study is about; and 4) why it matters. What Domain(s) is represented by the case study, or to what Domain(s) does it apply? Sample Domain(s) are Academia, Commerce, Government, Industry, and Other, the latter requiring specification. The Country of Focus and the Interested Constituency, respectively, i.e., the: 5) country (or countries) most involved; and 6) stakeholders who cared or cares the most need to be indicated. The Primary Insights or main "takeaways" should be summarized.

We have included Key Words, an Abstract, and an optional Glossary. Consistent with current conference paper practice, we suggest Key Words (or short phrases) be listed alphabetically and separated by commas. The Abstract should be informative but concise, perhaps no more than about 200 words. A Glossary may be worthwhile to define acronyms or abbreviations, especially if they are many; again these terms should be alphabetized.

Background

This section is intended to provide further information beyond that of the Case Study Elements section. An executive summary (textual as opposed to bulletized) style should still be utilized. Explain the Context, i.e., how this case study arose or arises, and why. What theoretical knowledge or Pertaining Theories were applied? What were or are the Guiding Principles, i.e., the main principles, precepts and/or tenets of the case study? Characterize the case study in terms of Type of System, its Maturity (as to legacy, upgrade or new system), the system Environment, and the Engineering Activities involved. Compare and contrast the before and after nature of the System Description.

Terms likely to be unfamiliar to most readers should be defined. Any important research results employed should be at least mentioned explicitly. In addition, an overview of the supporting literature may be provided. Another useful augmentation, though optional, would be any notable Existing Practices, including extant methods, available tools, and/or proven processes, to be recommended. Before and After System Descriptions should include High-Level Diagrams and possibly representative Performance Graphs as options.

Purpose

Describe what is behind the system transformation documented in this case study. Provide a brief History of the system, what prompted the attention to its creation or improvement and how it evolved. This would include the Then Current Situation, an initial view of the system's Known Problem(s), its Mission and Desired or Expected Capabilities, and the need and reason for the system's Transformation. The Mission and Desired or Expected Capabilities might include, as options, the associated Vision, Goals, and Objectives.

Constituents

Who was or is involved in the system transformation? Identify the relevant organizations, principal players, as appropriate, and their objectives and roles. Here is a good place for telling interesting stories about project/program activities, especially concerning the principals of the action, without divulging sensitive and/or personal information, of course.

(Complex) System/System of Systems/Enterprise

Describe each of the following aspects of the subject of the case study in sufficient detail. What was or is its Environment, i.e., in what was or is it embedded, what were or are its external factors, and what (e.g., funding, changing "requirements", new capabilities, etc.) flowed or flows back and forth between it and its environment? How big was or is its Scope (purview, span of control or influence) noting the influence on Boundaries below? What was or is its architectural Structure (sub-entities and their interrelationships, perhaps characterized by the functions of network nodes and links)? How were or are its Boundaries defined, noting the implications on Scope above? Amplify its most significant Internal Relationships, noting the dependence on Structure above. What were or are the most influential External Factors coming from the Environment above? Surely there were or are Constraints from the Environment that limited its Scope, Boundaries, Structure, Internal Relationships, and potential capabilities and/or operations. What were or are some of them? Add any Other Descriptors which may not be well covered by the above aspects.

Challenges

What were or are the greatest hopes or worries people, particularly the main proponents and stakeholders, had or have about the entity's transformation, i.e., what kept people awake at night? Make a distinction between the challenges that were Anticipated from others that were Actual, with special emphasis on those that were unexpected.

Development

How was or is the entity's transformation accomplished? Conventional SE methods may apply here to some extent but presumably several non-traditional processes were invented, tried, or adopted, as well. With an eye toward SE innovation from which others may benefit, emphasize the degree to which non-conventional approaches were successful and why.

This is an area that should be expanded upon greatly. For example, there are various generally relevant traditional categories, e.g., Program Management (primarily Planning), (narrow-sense, traditional, or conventional Systems Engineering, as opposed to CSE), and Change Management.

Under Planning, there are many possible nuances, and those that are the most relevant in the case study should be given some prominence. For example, one must plan for Contingencies and how information will be management, especially regarding the Sharing of Information and Information Security. Attention must be allocated to an overall guiding Strategy and the expenditure of Resources, to include classically, Staffing, particularly contributing Roles, and the Budget which often is revised based upon continually incremental funding. Compared to conventional SE, in CSE one should strive to move more toward rewarding results as opposed to paying up-front for perceived promises.[19] Of course, every program needs a planned Schedule, although unanticipated events can and usually do disrupt planned schedules, necessitating continual managerial flexibility in creating updated schedules. Paraphrasing General Dwight D. Eisenhower's famous statement, all plans are (essentially) worthless in combat but (continuous) planning is invaluable. It is also good practice to involve Users/Operators up-front and throughout the development process, primarily to gain their input and insights and to minimize surprises when testing and fielding the system being developed. Clearly, both developers and Users/Operators can benefit from these interactions. An optional feature for the case study is the listing and explanation of any significant processes that were instantiated.

Good traditional SE includes the construction of a guiding system Architecture that does not change very much or often compared to the system under development. If the architecture is too unstable in this sense it cannot be a good one! Alternatives Analysis is a critical aspect of SE. This involves several System Approaches with their Descriptions, the Technology contemplated and selected for each, and optionally, the levels of Technology Readiness. It is important, especially in CSE to carry at least two alternatives well into the development process to mitigate risk and protect against unexpected events. Opportunity as well as Risk Management is paramount in CSE because one is likely to go off-track frequently due to unforeseen events or influences from the system environment, necessitating adaptation in the form of revising requirements and re-scoping the job. Arguably, the biggest risk in SoS, enterprise, or CSE is not pursuing opportunities, at least until it becomes clear that such an opportunity leads to a significant new risk, in which case something else should be tried. This is made more difficult to the extent that there are delays in observing the effects of heuristic decision-making.

Once the Selected Approach(es) to pursue are decided, the development continues in earnest with detailed Design(s). The more favored designs are also implemented, at least partially. To the extent possible the sub-systems of these implementations should be integrated "vertically" as part of the same system. In addition, at least the "hooks" for integrating these sub-systems "horizontally" with other systems with which the subject system will be interoperating should be included. Testing should begin as soon as possible on both types of Integration so that the inevitable errors in design or unanticipated consequences can be fixed or mitigated with lesser impacts on cost, schedule, and performance, compared to what would happen if these flaws were left undiscovered and unattended until later in the development. In parallel, plans for Fielding the system or upgrade should proceed with the hope of minimizing "glitches" or further delays in achieving smooth operation once the system is made available to users. A formal mechanism for gathering and acting on feedback from the field operations is critical for ensuring user acceptance. Optional aspects would include a description of system Sustainment and its eventual Retirement.

The Development is likely to be more successful if Change Management is taken seriously, i.e., how was it instituted (implemented and integrated) into the development? Greater complexities increase the likelihood of unforeseen events perturbing development. Thus, whether a formal contingency procedure was established in advance is of interest in the case study. Optionally, Change Management Philosophy, Policy, and/or Operations could be discussed. The system's environmental effects of Politics, Operations, Economics, and Technologies on Change Management should be considered.

Results

So what happened from all this effort? Describe what emerged (particularly the unexpected results) from the above Development including the major improvements, added capabilities, user or operator satisfactions, set-backs, shortfalls, and unintended consequences.

The case study should describe the system Transformation Accomplished in terms of the system's Functions, Services, and Other Assets or Capabilities. The Final System Description should include a High-Level Diagram and possibly (as an option) Performance Graphs.

Analysis

This section should contain a summary of the technical assessments performed as part of the transformation effort. More importantly, the "Why?" questions should be answered, e.g., what were the root causes of the results from an analytical point of view? If it was or is not possible to readily determine the causes precisely, do a credible job of explaining the primary set of conditions responsible.

Analytical Findings include principal Activities (i.e., the key tasks and their interactions), Time Frame/Line aspects including the Sequence of Events (an option), Significant Delays Incurred and Why, and Methods Employed (and their efficacies).

Lessons Learned, a very important topic in case studies, should include answers to the questions How Were Biggest Challenges Met?, What Worked and Why?, What Did Not Work and Why?, What Should Have Been Done Differently?, and To What Extent Were Lessons Applied to Subsequent Programs/Projects? What changes in policies or procedures were or are being implemented so that these lessons are really learned and not forgotten?

Capturing Best Practices for the benefit of others would also be helpful. Addressing how practical this case study might become for Replication Prospects, including Necessary Conditions and Proposed Action Steps should be of interest.

Summary

Provide a concise overview of the problem, its proposed solution, the transformational approach and the results, all with the benefit of hindsight. This might include (as an option) and Epilogue describing any significant events that might have happened after the designated endpoint of the case study.

Conclusions

List the most important ideas that the reader should take away from this case study. This could be modeled after an elevator speech where one must convey the essence of the topic in a very short time.

Suggested Future Work

There undoubtedly are several unanswered questions that arose or arise during the entity's transformation. These questions can be shaped into suggestions for future work in the form of research, experimental practices or processes, postulated precepts or principles, lessons to be learned and exercised, etc. Endeavor to stimulate further progress in this or transformations by preparing some compelling reasons to continue improvements.

This should include Further Questions for Discussion and suggestions for Additional Research. These are intended primarily for educational and academic purposes. Such Questions could enliven SE classroom discussions, for instance. Those interested in adding the SE body of knowledge might be stimulated by future research topics.

References

It is always useful to at least some readers to provide outstanding references (and/or a bibliography) that completely cite and fully document previous work upon which the present work depended or depends upon. These references should help justify the present transformation by explaining or supporting assumptions or statements made in the case study. They should also be rich in offering additional background detail.

The case study citations might include both primary and secondary References. The standard professional Institute of Electrical and Electronics Engineers (IEEE) format should be utilized.

End Notes

Footnotes can be used in the case study but if there are many of these side-comments, collecting them at the end of the case study in the form of End Notes might be more convenient for the readers.

Appendices and an Index are optional.

Conclusion

We strongly believe in the power of case studies for furthering the good and more effective practices of SE within the ever increasing complexity of the problem spaces facing humanity and the global community. For example, if we do not advance our practice of SE in helping to conserve our Earth's resources, the unsustainability of unlimited material growth and overpopulation will eventually drag us all down to much lower standards of living.[20] We must greatly advance our understanding of complex systems and our application of CSE principles to the world's problems. Clearly, this pursuit of this goal will be accelerated if we concentrate on educating and motivating emerging technical leaders and those already recently in or entering the engineering profession about modern SE, i.e., CSE. This education can also extend into trans-disciplinary fields of philosophy, psychology, sociology, economics, politics, organizational change management, and chaordic[21] leadership, for example.

Bibliography

1. Boardman, John, and Brian Sauser, *Systems Thinking—Coping with 21st Century Problems*, CRC Press, Boca Raton, FL, 2008.
2. *A Guide to the Project Management Body of Knowledge: (Pmbok Guide)*, 4th Edition, Project Management Institute, 31 December 2008, http://www.pmi.org/PMBOK-Guide-and-Standards/Standards-Library-of-PMI-Global-Standards.aspx.
3. Michael C. Jackson, *Systems Thinking: Creative Holism for Managers*, New York: Wiley, November 2003, ISBN: 978-0-470-84522-6.
4. "Wicked problem," Wikipedia, The Free Encyclopedia, 2011, http://en.wikipedia.org/wiki/Wicked_problem.
5. Birgitta Bergvall-Kåreborn, "Enriching the model-building phase of soft systems methodology," *Systems Research and Behaviorial Science*, Volume 19, Issue 1, January/February 2002, pp. 27–48, Article first published online: 12 December 2001, DOI: 10.1002/sres.416. Wiley On-Line Library, http://onlinelibrary.wiley.com/doi/10.1002/sres.v19:1/issuetoc.
6. Werner, Ulrich "A brief introduction to critical systems heuristics (CSH)," Web site of the ECOSENSUS project, Open University, Milton Keynes, U.K., 14 October 2005, http://www.ecosensus.info/about/index.html, Also available from the author's home page at http://geocities.com/csh_home/csh.html.
7. Harold A. Linstone, *Decision Making for Technology Executives: Using Multiple Perspectives to Improve Performance*, Boston and London: Artech House Publishers, 1999.
8. The Massachusetts Institute of Technology (http://esd.mit.edu/); also, refer to SEAri (http://seari.mit.edu/)and LAI (http://seari.mit.edu/): http://search.mit.edu/search?q=case+studies&btnG=go&site=mit&client=mit&proxystylesheet=mit&output=xml_no_dtd&as_dt=i&as_sitesearch=esd.mit.edu&ie=UTF-8&ip=127.0.0.1&access=p&sort=date:D:L:d1&entqr=3&entsp=0&oe=UTF-8&ud=1&is_secure=.
9. The Massachusetts Institute of Technology (http://sdm.mit.edu/): http://search.mit.edu/search?site=sdm&client=mit&proxystylesheet=mit&output=xml_no_dtd&as_dt=i&q=case+studies.
10. Engineering Management Case Studies: http://www.bing.com/search?q=case+studies+in+engineering+management&qs=n&form=QBRE&pq=case+studies+in+engineering+management&sc=0-26&sp=-1&sk=.
11. The Stevens Institute of Technology (http://www.stevens.edu/): http://www.stevens.edu/sit/search.cfm?cx=001246728825567149980%3Amlcoplzz4w4&cof=FORID%3A11&q=case+studies&sa.x=14&sa.y=13.
12. The University of Vermont: http://www.uvm.edu/search/?q=case%20studies.
13. The University of Virginia: http://www.google.com/cse?it+is+a+tool+under+custom+searches=this+custom+google+search+engine++was+set+up+by+Rich+Gregory&cx=001051378019901782744%3Aaryse_cxxlw&ie=UTF-8&q=engineering+case+studies&submit1.x=28&submit1.y=5#gsc.tab=0&gsc.q=engineering%20case%20studies&gsc.page=10.
14. The University of Texas: http://www.engr.utexas.edu/search?option=com_googlesearch_cse&n=30&cx=010165778158772724462%3A83i3acrhdki&cof=FORID%3A11&ie=ISO-8859-1&q=engineering+case+studies&hl=en&sa=.

15. The University of Southern California: http://search.usc.edu/?cx=017196764489587948961%3A0uzwqg1rcr4&ie=utf8&oe=utf8&q=engineering+case+studies.
16. The University of Illinois: http://engineering.illinois.edu/search/node/engineering%20case%20studies.
17. Robert K. Yin, *Case Study Research—Design and Methods*, Third Edition, Applied Social Research Methods Series, Volume 5, Thousand Oaks, CA: Sage Publications, 2003.
18. IEEE SoS Technical Committee (Roadmapping Exercise), T-AREA-SoS project, point of contact: S. A. Henson@lboro.ac.uk.
19. White, B. E., "Complex Adaptive Systems Engineering (CASE)," IEEE Aerospace and Electronic *Systems Magazine*, Vol. 25, No. 12, December 2010, 16-22, ISSN 0885-8985; White, B. E., "Complex Adaptive Systems Engineering, (CASE)." 3rd Annual IEEE International Systems Conference. Vancouver, Canada. 23-26 March 2009.
20. Meadows, Donella H., *Thinking in Systems—A Primer*. Edited by Diana Wright, Sustainability Institute. Chelsea Green Publishing, White River Junction, VT, 2008.
21. "Chaordic," Wikipedia, The Free Encyclopedia, 8 December 2011, http://en.wikipedia.org/wiki/Chaordic.
22. White, B. E., "Engineering Lexicon," Complex and Enterprise Systems Engineering Book Series, Taylor & Francis Group, 2007, http://www.enterprise-systems-engineering.com/lexicon.htm.
23. White, B. E., "On Principles of Complex Systems Engineering—Complex Systems Made Simple Tutorial," INCOSE Symposium, Denver, CO, 20-23 June 2011.

Appendix A

Definitions

So what do we mean by system, system of systems (SoS), enterprises, and complex systems? Readers should understand that these definitions[22] are not meant to be sacrosanct; however, they were constructed with three basic goals in mind: 1) relative brevity; 2) essential essence; and 3) non-violation of other definitions from respected sources.

System An interacting mix of elements forming an intended whole that is greater than the sum of its parts.

System of Systems (SoS) A collection of systems that functions to achieve a purpose not generally achievable by the individual systems acting independently.

Enterprise A complex system in a shared human endeavor that can exhibit relatively stable equilibriums or behaviors (homeostasis) among many interdependent component systems.

Complex System An open system with continually cooperating and competing elements.

It may be helpful to think of a system, a SoS, an enterprise, and a complex system in terms of the Venn diagram of Figure A1.

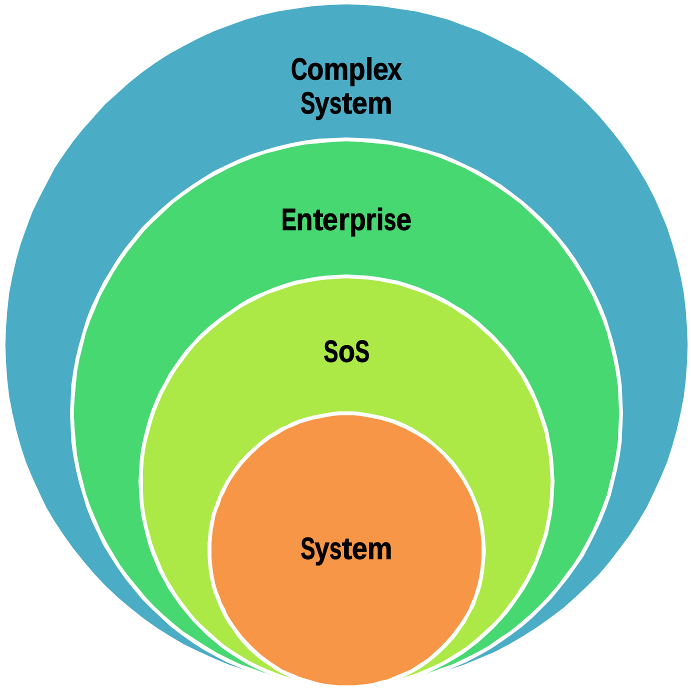

Figure A1. Venn Relationships Among System Types[23]

Appendix B

(Complex) System/System of Systems/Enterprise Case Study Outline

[optional items are indicated in brackets]

1. Case Study Elements (bulletized, for sorting purposes)

- Fundamental Essence (briefly, what's this about?)
- Topical Relevance (briefly, why does this matter?)
- Domain(s) (choose one)
  - Academia
  - Commerce
  - Government
  - Industry
  - Other (specify)
- Country of Focus (country most involved)
- Interested Constituency (who cared or cares?)
- Primary Insights (takeaways)

Key Words (alphabetized, separated by commas)

Abstract (no more than 200 words)

[Glossary (abbreviations and acronyms, alphabetized)]

2. Background

- Context (how did this arise, and why?)

Relevant Definitions (define unfamiliar terms)
Pertaining Theories (theoretical knowledge applied)
[Literature Overview]
Research Nuggets (past and present)
[Existing Practices (extant methods, available tools, and/or proven processes]
Guiding Principles (applicable principles, precepts, and/or tenets)
Characterizations
Type of System (refer to Fig. A1 of Appendix A)
System Maturity (legacy, upgrade, or new)
Environment
Systems Engineering Activities (before and after)
"As Is" System Description (before)
High-Level Diagram
[Performance Graphs]
"To Be" System Description (after)
High-Level Diagram
[Performance Graphs]

3. Purpose

History (describe previous situation and evolution)
Then Current Situation
Known Problem(s)
Mission and Desired or Expected Capabilities
[Vision
Goals
Objectives]
Transformation Needed and Why

4. Constituents (their identification, objectives, and status)

Sponsor
Customer
Other Stakeholders

5. (Complex) System/System of Systems/Enterprise (refer to Appendix A for some definitions) (describe each of the following items in sufficient detail)

Environment
Scope
Structure
Boundaries
Internal Relationships
External Factors
Constraints
Other Descriptors

6. Challenges (what kept people awake at night?)

- Anticipated
- Actual

7. Development (emphasize <u>non</u>-conventional aspects)

- Program Management
  - Planning
    - Contingencies
    - Information Management
      - Sharing
      - Security
    - Strategy
    - Resources
      - Staffing
        - Roles
      - Budget
    - Schedule
    - User/Operator Involvement
    - [Processes Instantiated]
- Systems Engineering (in narrow sense)
  - Architecture
  - Alternatives Analysis
    - System Approaches
      - Description
      - Technology
        - [Technology Readiness]
        - Technologies Selected
  - Opportunity and Risk Management
  - Selected Approach
    - Design
    - Implementation
    - Integration
    - Testing
    - Fielding
    - [Sustainment]
    - [Retirement]
- Change Management (how implemented and integrated?)
  - [Philosophy]
  - [Policy]
  - Politics
  - [Organization]

- Operations
- Economics
- Technologies

8. Results

- Transformation Accomplished
  - Functions
  - Services
  - Other Assets or Capabilities
- Final System Description
  - High-Level Diagram
  - [Performance Graphs]

9. Analysis

- Analytical Findings
  - Activities (key tasks and their interactions)
  - Time Frame/Line
    - [Sequence of Events]
    - Significant Delays Incurred and Why
  - Methods Employed (and their efficacies)
- Lessons Learned
  - How Were Biggest Challenges Met?
  - What Worked and Why?
  - What Did <u>Not</u> Work and Why?
  - What Should Have Been Done Differently?
  - To What Extent Were Lessons Applied to Subsequent Programs/Projects?
- Best Practices (what would be recommended to others?)
- Replication Prospects (how practical might this case study become?)
  - Necessary Conditions
  - Proposed Action Steps

10. Summary (provide concise overview of what happened after the fact)

[Epilogue] [what significant events have occurred since?]

11. Conclusions (construct an elevator speech)

12. Suggested Future Work

- Further Questions for Discussion
- Additional Research

[End Notes]

13. References ([primary and secondary] using IEEE format)

[Appendices]

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