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An Analysis of Processes, Risks, and Best Practices for Use in Developing Systems Engineering Process Simulators

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Abstract

Systems engineering simulation models provide a valuable means to understand and learn important concepts related to systems engineering. Simulators can be used for education and as decision support systems in order to evaluate the dynamic consequences of various courses of action. This paper examines existing research mined from literature related to systems and software engineering processes, risks, and best practices. It seeks to guide the definition of priorities for systems engineering process simulator development. The paper identifies an initial set of research opportunities for the development of systems engineering process simulators.

Keywords: Systems Engineering Simulator; Process; Risk; Best Practices; Systems Engineering Process Simulation

1. Introduction and Motivation

The demand for systems engineers [1] and the expected shortage of engineering professionals attributed to workforce retirement drives a desire to accelerate the development of senior systems engineers [2]. Systems engineers require "systems thinking" skills that enable the engineering of complex systems. Davidz and Nightingale [2] identify experiential learning or learning based on experience as an important way to develop these systems thinking skills in engineers.

A case has been made that using systems engineering process simulation can enable experiential learning of systems thinking skills related to systems engineering projects [3,4]. Understanding the dynamics of a system promotes "systems thinking". System dynamics was developed by Jay Forrester [5] and is a well-established modeling methodology. System dynamics allows an understanding of the

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complicated relationships between various socio-technical factors and includes principles of feedback control.

The increasing system technical complexity in systems leads to greater management complexity. Stupples [6] discusses that systems projects can be as “complex as the engineering solution with behavior that is extremely dynamic in nature”. Projects can have a significant quantity of dynamic and interacting factors. The uncertainty associated to these factors compounds the complexity. Systems engineering process decisions impact important project success indicators related to cost, schedule performance, quality, and risk. Therefore, systems engineers need to understand the impact of the decisions related to their projects. This knowledge can be used to assess the impact of their decisions as well as to improve these decisions.

Simulation allows a user to view a system’s dynamics over time without having to build, interrupt or affect it. Simulation can be used for education and decision support to evaluate dynamic consequences of various courses of action. Systems engineering process simulators can be used to explore various aspects of systems engineering including processes, risks, and other important concerns. Ferreira [3,4] discusses more details on the benefits of developing systems engineering process simulators.

While simulation is used for supporting product development, very little research has been performed that considers the use of simulation to support systems engineering related project and process education and decision support. This paper focuses on research that can guide the definition of priorities and identifies a set of research opportunities for systems engineering process simulators.

2. Systems Engineering & Software Process Simulation Research

The growth in the amount of software used in complex systems drives an increasing synergy between systems and software engineering. While there are differences in the disciplines, similar processes are shared between both disciplines which makes it imperative to apply research from software engineering for the benefit of systems engineering process simulation.

With this in mind, the authors performed an extensive literature review of both systems and software engineering process simulation. Over 400 works were found in the literature related to both systems engineering and software engineering process simulation. The literature encompasses journal and conference papers, dissertations, theses, books, and book chapters. The vast majority of the literature that was mined focuses on and discusses software engineering process simulation. Only approximately 6% of the mined literature currently discusses and makes a contribution specifically to systems engineering process simulation. These results are in the form of simulation models, causal models, frameworks, and related items.

The literature review results were analyzed to identify existing research contributions related to processes and risks. In order to be considered, the literature had to discuss systems or software process simulation and provide a related contribution such as a causal model, simulator, or other items that furthered existing research. In addition, a separate literature search was performed to identify best practices related to systems engineering given the close relationship of best practices to processes.

This section of the paper will present a limited subset of the preliminary results as examples of what was found in the literature review. In particular, this section also focuses on the identification of research opportunities based on both an analysis of what does exist in the mined literature as well as what does not exist and could be considered as potential prospects for further research.

2.1. Processes

A process is defined as a "set of interrelated or interacting activities which transforms inputs into outputs" [7]. Multiple systems engineering processes are used throughout a system's lifecycle. The researchers evaluated the results of simulation research associated with processes. The results were

categorized by processes or process groups. Categories include requirements engineering, design, implementation, integration, verification, planning, assessment and control, resource management, and quality management. An example of one of the sets of processes, requirements engineering, is selected to illustrate a portion of the results of the literature review. The term "requirements engineering" is associated with both systems and software engineering. Major activities involved in requirements engineering include requirements elicitation, requirements analysis and negotiation, requirements validation, and requirements management [8]. The simulation literature with research contributions focused on requirements engineering includes 17 articles. 3 of the 17 articles are papers that progressed from conference papers to journal articles, leaving 14 articles [9-22].

While the simulation research contributions associated with this process were primarily addressing software engineering, other processes researched did have some limited systems engineering references. However, the existing software engineering literature does have the vast majority of existing references. The analysis of the process focused simulator research leads to a number of research opportunities.

Research Opportunity 1: **Assess the software engineering process simulation research for its applicability to systems engineering.** As discussed previously, there is an overlap between systems and software engineering processes. Much literature exists that focuses on various aspects of software process simulation modeling, including particular processes. The reuse of existing software engineering simulation model efforts, including existing patterns, can benefit systems engineering simulation research. However, caution must also be exercised to recognize the differences in the disciplines when migrating existing software process simulation research and applying it to systems engineering.

Research Opportunity 2: **Simulate processes and aspects of processes that may only exist within systems or systems of systems engineering (e.g. capability engineering).** Simulation opportunities exist in recognizing the unique aspects of systems engineering and in better understanding and analyzing these. Applying a systems thinking perspective, including gaining an understanding of the particular socio-technical system dynamics related to systems engineering, can only benefit the discipline. It is expected that additional factors and factor relationships exist beyond those recognized by software engineering.

Research Opportunity 3: Evaluate the use of simulation during systems engineering cost estimation exercises. Systems engineering cost estimation could benefit by the use of simulation in considering the important system dynamics related to processes, risks, and other considerations. Models can be developed to yield stochastic results related to cost and schedule. An estimator can perform sensitivity analysis using a systems engineering process simulator.

2.2. Risks

The researchers evaluated the results of simulation research specifically associated with risks in both systems and software engineering. Risks identified in the simulation research include requirements volatility, excessive schedule pressure, instability and lack of continuity in project staffing, lack of staff commitment (low morale), lack of senior manager commitment, inaccurate cost estimation, cost & schedule overruns, low productivity, low quality, excessive paperwork, long review/approval cycles, variability in development process, incapable acquisition management, lack of process discipline, and lack of acquirer's technical knowledge.

An example of a risk, excessive schedule pressure, was selected to illustrate a portion of the risk related results of the literature review. Even though most of the research results were extracted from software engineering, excessive schedule pressure is a risk that also applies to systems engineering projects. The simulation literature with research contributions related to excessive schedule pressure includes 18 articles. 2 of the 18 articles are papers that progressed from conference papers to journal articles, leaving 16 articles [23-38].

An analysis of the risk focused simulator literature leads to the following research opportunities:

Research Opportunity 4: Assess software engineering risk simulation research for applicability to systems engineering. Many software engineering risks have been simulated. Depending on the type of risk, it may be possible to reuse the factors and factor relationships for systems engineering simulation.

Research Opportunity 5: Evaluate systems engineering and systems of systems engineering risks to determine the priorities for simulation. The criticality and priority of software engineering risks may not match those for systems engineering. There will most likely be additional risks for systems engineering that may not be present for software engineering. There may also be differences in risks at the level of systems of systems engineering.

Research Opportunity 6: Use simulation of systems engineering and systems of systems engineering risks to further understand, analyze, and identify improvement opportunities. Simulation of systems engineering related risks can provide a means to better understand the factors and relationship between factors associated with a risk. A more comprehensive understanding of a risk can allow individuals to assess when a higher potential for a risk may exist and possible opportunities for changes that may reduce the severity of the impacts of a risk.

2.3. Best Practices

No literature was found that indicates that systems engineering best practices have been simulated. Given this, an additional literature search was performed to identify systems engineering best practices. Limited results were found for systems engineering best practices [39-41].

The following are a set of research opportunities related to best practices:

Research Opportunity 7: Identify systems engineering best practices using analytical and statistical methods. It is important to distinguish a "best practice" from a "good practice". Bardach [42] discusses "the extensive and careful research to document a claim of "best" will almost never have been done". The limited results for best practices may perhaps be due to the lack of rigorous empirical analysis as well as the ability to benchmark practices across organizations. Guidelines for qualifying best practices for systems engineering may be helpful. Empirical research methods can be used to characterize a potential best practice relative to other practices that may be used on a project.

Research Opportunity 8: Develop simulation models that illustrate best practices. Given the availability of best practices for systems engineering, models can be developed that show the differences between best practices and other available practices relative to their impact on cost, schedule, quality, and other parameters.

3. Summary

This paper discusses an effort that surveys existing research related to systems and software engineering process simulation and characterizes research contributions related to processes and risks. The research analysis related to processes and risks in software engineering was performed to determine the opportunities that exist to leverage this work for the development of systems engineering process simulators. In addition, a literature search was also performed to identify systems engineering best practices since these are typically related to processes. A number of research opportunities for the development of systems engineering research simulators were identified as a result of analysis of the findings related to processes, risks, and best practices.

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