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Promoting Systems Thinking Through Alignment of Culture and Process: Initial Results

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Abstract

Standardized processes are used to address three contemporary issues in engineering: increasing system complexity, increasing average age within the engineering community, and longer development cycles that result in fewer experiential learning opportunities for young engineers.

Heidi Davidz (Davidz 2006), in her doctoral research identified enablers and barriers to systems thinking among engineers. Because most engineering work is completed in teams, this research seeks to build upon Davidz's research and identify enablers and barriers to systems thinking within teams and organizations of engineers. The authors have termed this *collaborative systems thinking* and have chosen to focus this research study on the role of standardized processes in promoting collaborative systems thinking.

Despite anecdotal evidence suggesting standardized processes obscure big picture thinking in favor of facilitating distributed work, initial results from secondary case study analysis suggest the tools and artifacts of standardized processes can enable collaborative systems thinking. These results, along with background information and proposed research methods are presented in this paper.

Introduction

As stated earlier, this research is motivated in part by the rising average age of engineers in the United States. In a recent report by the National Academies, it is estimated that more than 60% of scientists and engineers in the United States are over the age of 45. In no field is the contrast as stark as within the aerospace field. The current average age of an engineer at NASA is 49 (Lemos 2006). The problem is further aggravated by longer development cycles that results in fewer and fewer opportunities for experiential learning.

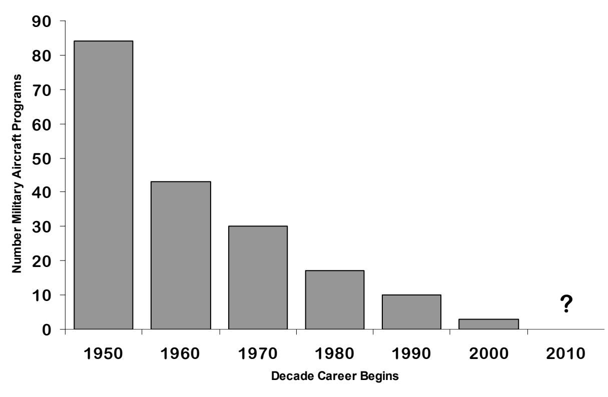

Figure 1. Number of Military Aircraft Program Starts During a 40 Year Career Based on Decade of Career Start. [Adopted from Figure 1.4, page 21 (Murman, et. al. 2002)]

Figure 1 shows the number of military aircraft programs expected in a forty year career based on the decade in which the career starts. The drop off is striking. Engineers graduating today can expect no more than three programs during their careers, in comparison to nearly 80 programs for those engineers graduating in the 1950's.

Conversations with industry executives indicate they are aware of the demographics and experience a quandary. They are looking to standardized processes as both a way to codify best practices, but also as an experience leveler for new hires. While not a formal knowledge transfer mechanism, executives hope standardized processes will reduce knowledge loss as experienced engineers retire en masse.

One of the identified strengths of experienced engineers is systems thinking: the ability to see the big picture. Systems architects, program leads, and managers rely on this ability to balance program requirements, resources, and constraints, and for making effective decisions. The question this research seeks to address is how standardized processes and the associated tools and artifacts affect the development of systems thinking within teams of engineers and the organizations within which these teams reside.

Background

The three key constructs of this research are standardized process, culture, and systems thinking. The primary research goal is to determine the interrelationships of these constructs in the hopes of identifying enablers and barriers to collaborative systems thinking. This section explores each construct in greater detail.

Standardized Process. Process is a logical sequence of tasks performed to achieve an objective, a way of decomposing a large task into smaller subtasks. Process defines what is to be done without specifying how (Martin 1997). Standardized processes are therefore agreed upon ways of decomposing large tasks such as engineering design and development. Standardized processes offer an opportunity to codify best practices and facilitate effective coordination among individuals and groups while reducing ambiguity and unpredictability (Schein 2004). Figures 2 and 3 illustrate this point. Figure 2 shows a typical enterprise representation, showing the structure of an enterprise as a set of stakeholders that together form the enterprise.

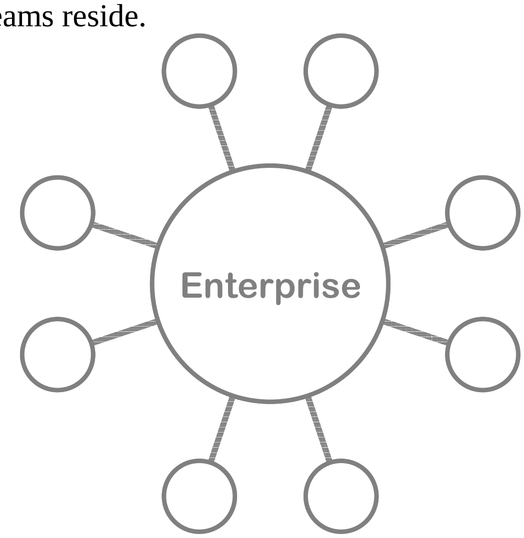

Figure 2. Typical Model of Enterprise.

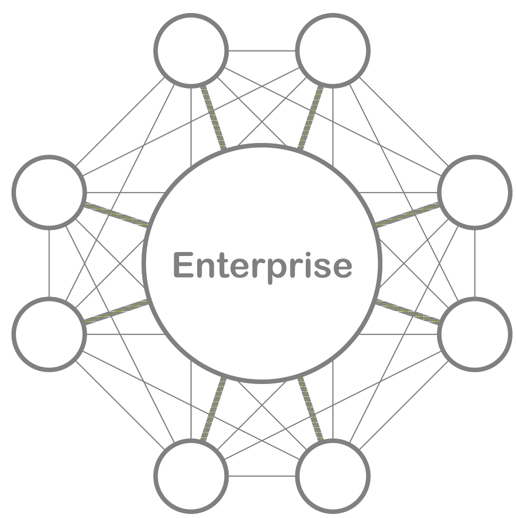

Figure 3. Standardized Processes Provide Links Between Nodes in Enterprise Model

Figure 3 illustrates how process provides context and specifies the interrelationships of these parts. While just a simple graphical representation, Figures 2 and 3 show how standardized process provide structure beyond that found in an organizational chart. Process specifies information flows.

Processes can take many forms: unarticulated norms of behavior, standardized ways of doing things, or sets of common assumptions (Malone 2004). This research is focusing on standardized processes in part because of the increased emphasis on capability maturity models (e.g. Software Engineering Institute's Capability Maturity Model Integration (CMMI®)) as a model to evaluate and improve standardized processes.

Benefits of standardized process include the promotion of consistent design execution, providing engineers with a context for their work, and acting as an experience leveler for engineers lacking design experience. Formed either at the group or organizational levels, standardized processes provide a common language and framework for design. Within the Toyota Production System, rigid process specifications are seen as supporting flexibility and creativity (Spear and Bowen 1996). Within the scientific method of Toyota's process improvement, rigid specifications allow for easy measurement of the benefits of incremental process improvement. The failure to specify standard processes is a systemic inefficiency. In the absence of standard process, new members to an organizations or team must relearn what does or does not work, thus duplicating efforts.

However, standardized processes are not sufficient to ensure success as typified by the failure of many organizations to achieve success through copying Toyota's well documented processes. These failures point to the importance of organizational culture as a compliment to processes. Other detractors of standardized processes include the charge that the rigid nature of standardized processes reduces an organization's ability to quickly adapt to a changing environment (Malone 2004). Processes may also extend beyond "what" to do instead specifying "how" work is to be done—confusing the abstract entity of process with the execution of the process by an individual or team (Pajerek 2000). Continuing, (Pajerek 2000) says process advocates who claim teams can achieve high levels of effectiveness by copying the behaviors (and therefore processes) of successful teams are confusing correlation and causation. Going one step further, (Dougherty 1990) claims a reliance of established procedures, whether internally developed of not, impedes the effective communication of information in a manner that fosters true understanding. Dougherty's results reinforce that process only encodes one component of success. Culture and leadership encode the other components and link culture and process together.

Organizations adopt process through a combination of organically grown procedures and by adopting others' best practices. Capability maturity models, such as CMMI®, recognize the need to tailor processes. However, there is still much room for clarification on the correct level of tailoring, how to consider an organization's culture, and how the process interacts with said culture and what the correct level of process standardization is.

The paradox of standards is finding a balance between specifying sufficient detail to help everyone move in the same direction while being broad enough to allow collaboration and establish connections between diverse activities (Malone 2004). These implications limit the ability to engineer and optimize processes in the same manner as systems engineering is used to design and optimize systems (Pajerek 2000). As such, process needs context. Organizational culture is an essential part of this context as well as an additional way to look at process and drive process improvement.

Culture. Culture is defined as a "dynamic phenomenon and a set of structures, routines, and norms that guide and constrain behavior" (Schein 2004). Artifacts, espoused beliefs and basic underlying assumption form an organization's culture (Schein 2004). Culture provides structure, encapsulating the unarticulated norms of behaviours that exist as underlying assumptions in an organization or team and are themselves processes. By forming a set of shared assumptions and accepted behaviors, cultural norms likely support collaborative systems thinking. This explains, in part, why teams with stable membership histories work so well together. Many effective team norms do not evolve naturally within group settings and must be consciously created and introduced (Hackman 2002), further substantiating the link between culture and process.

Figure 4 and 5 show two proposed interactions between an organization's culture and its standardized processes. When an organization's basic underlying assumptions are in harmony with its standardized processes, culture and process interact in a reinforcing loop. Changes to standardized process impact culture and changes in culture impact, or update the standardized process.

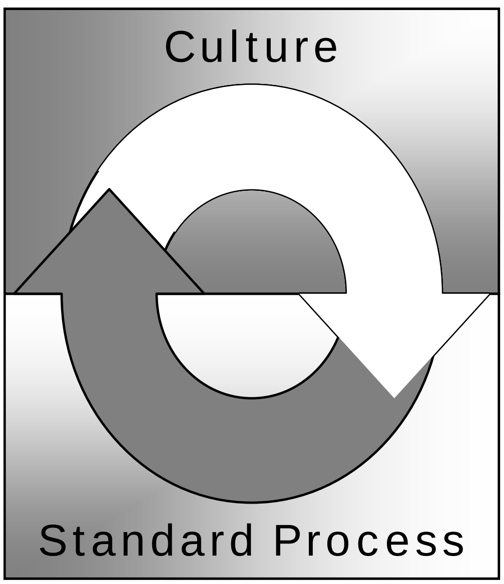

Figure 4. Synergistic Relationship Between Standardized Process and Culture.

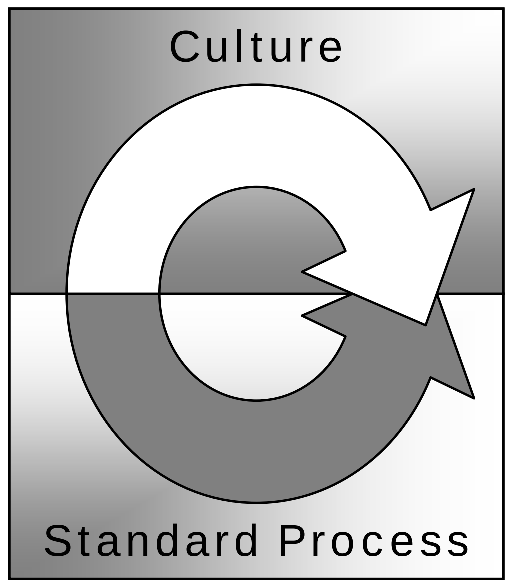

Figure 5. Inhibiting Relationship Between Standardized Process and Culture.

Standardized processes operate at all levels of culture. Organizational charts, job titles, and integrated product team (IPT) assignments are all tangible artifacts. The processes these teams follow are at the level of espoused beliefs. While not explicitly part of culture, the social network through which processes are executed is also relevant to the interaction of culture and process.

While such a reinforcing cycle is likely to support collaborative systems thinking and effective organizations, it is only a necessary condition. One can easily imagine an organization whose processes and culture are aligned, but are moving the organization in the wrong direction.

Figure 5 represents a misalignment between culture and process, representing process usage as being resisted in some organizations.

The recognition of the link between culture and process is powerful. A culture is desired where systems thinking is promoted. However, as identified by (Davidz 2006) one of the barriers is the subjective definition of systems engineering. In addition, current organizational cultures reward depth of knowledge, not breadth or integration capabilities.

Processes are more easily changed than culture. By explicitly considering the interaction of culture and process, cultural and social network analysis frameworks can be used to bring new insights into the benefits and drawbacks of standardized processes. Standardized processes are inherently a mechanism to affect cultural change (Allee 2003). Cultural resistance to change may impact the effectiveness of standardized processes. Acknowledging these links will allow for more effective process interventions.

Systems Thinking. Much research on systems thinking at the team and organizational levels has come out of systems dynamics research from the likes of Russell Ackoff and Peter Senge.

Ackoff defines systems thinking as "holistic versus reductionistic thinking, synthetic versus analytic" (Ackoff 2004). He continues by saying that reductionistic and analytic thinking see the whole as the sum of the parts where as holistic and synthetic thinking begin with the whole out of which the parts are derived (Ackoff 2004). Senge's definition of systems thinking is a set of tools and accumulated knowledge that allow individuals to see patterns more clearly and to affect these patterns (Senge, 2006). Coming from systems dynamics backgrounds, both of these definitions, while aimed at teams and organizations, are not specifically tailored for engineering situations.

In the book *The Dance of Change*, (Roberts and Kleiner 1999) propose five types of systems thinking: open, social, systems dynamics, process, and living. Open systems thinking concentrates on flows and constraints. Social systems thinking views relationships as its fundamental unit. Systems dynamic thinking concentrates on causal loops. Process systems thinking is concerned with how information flows. Living systems thinking is based on viewing interactions.

These five distinct, but related takes on systems thinking illustrate the difference between a pure systems dynamics view of systems thinking, and an engineering view. Engineering systems thinking must certainly include the principles in Ackoff's and Senge's definitions. In engineering design, constraints and interactions are most important as emphasized by Davidz's own definition of system thinking as the "analysis, synthesis, and understanding of interconnections, interactions, and interdependencies that are technical, social, temporal, and multi-level" (Davidz 2006). At the team and organization levels, relationships and information flows become equally important. At the team level the challenge is not just technical, but rather the completion of a technical task within a social context.

Within a team or organization there may be individual systems thinkers. However, the team as a whole may also possess systems thinking traits; that is the team may be capable of collaborative systems thinking. Shared mental models are one mechanism that might explain collaborative systems thinking.

Everyone has mental models of how the world works. Mental models affect how individuals interact with and make decisions about their environment (Newman, 1999). Mental models, much like engineering models, are simplifications of reality based on truths, part-truths, and missing or implied information. Documented standardized processes form the basis for mental models of the development process. Because mental models influence the ways in which individuals interact with their environments, an accurate mental model of the development process is necessary to facilitate efficient and effective decision making. Mental models of the development process might serve as enablers of collaborative systems thinking. Likewise, standardized processes flow diagrams may be an artifact that facilitate in the creation of accurate mental models.

Construct Interactions. Not only has past research richly defined the constructs of interest, there is also unstructured evidence showing construct interaction. Engineering is a sociotechnical activity requiring many people to interact. If each individual has a slightly different mental model of the development process, unarticulated assumptions may cloud their collective ability to execute the process. There is a concept of a shared mental model, a shared view of reality that is built up within a group over time. Shared mental models may explain why stable groups work more efficiently together. Mental models are intriguing because these models get at the way work is actually executed. Formal and informal design reviews may be another way to not only promote mental models of the design process but to provide organizational context for those models. Reviews, by emphasizing requirements and surfacing assumptions may help to form shared mental models, thus facilitating systems thinking. However, the reviews themselves are specified by standardized process, showing one way in which standardized process may support collaborative systems thinking.

Design is a dynamic process and sometimes the problems encountered are a result of static views rather than process thinking. (Senge, 2006) Process thinking and the sharing of mental models are likely enablers of higher level systems thinking. However, the process by which teams develop shared mental models is unclear. Perhaps standardized processes form a set of shared assumptions and facilitate in the formation of shared mental models.

Research Design

Exploratory Research. The proposed research is an exploratory study of the ways in which standardized processes facilitate or hinder collaborative systems thinking. The inductive methods of exploratory research are a suitable choice as insufficient data and theory exist to form an initial hypothesis.

Grounded theory research, an exploratory research method, starts with an interesting question or area of inquiry and ends with a set of hypotheses that form the basis for new theory (Glaser and Strauss 1967). Grounded theory research is characterized by concurrent and systematic data collection, analysis, and theory development (Glaser and Strauss 1967, Strauss and Corbin 1998).

Secondary case study analysis and pilot interviews will be used to identify areas for future inquiry. A set of case studies will then be used to populate the data set. Case studies are well suited for exploratory research because cases are a flexible and effective means to gather many types of information (Yin 2003). In addition, case studies are helpful in establishing external validity of the data collected as well as increasing the generality of findings (Yin 2003).

Secondary Case Study Analysis. Identified case studies on aerospace and automotive topics will be used to identify linkages between systems thinking and standardized processes. These linkages will be used to propose interactions between the three constructs: standardized process, culture, and systems thinking. Information gathered will direct future questioning and lines of inquiry.

Pilot Interviews. After identifying potential links between the three key constructs, pilot interviews will be used to validate these linkages and gather initial data. Pilot interviewees will also be asked to help identify potential case studies of interest. Questions will focus both on linkages between constructs as well on definitions of constructs.

Case Studies. As stated above, this research will consist of several case studies. As a general rule of thumb between six and ten cases are necessary to ensure sufficient coverage for the exploratory research. Companies in the aerospace sector will be preferentially selected due to the first author's aerospace background and association with the Lean Aerospace Initiative (LAI). LAI is a research consortium headquartered at the Massachusetts Institute of Technology's Department of Aeronautics and Astronautics.

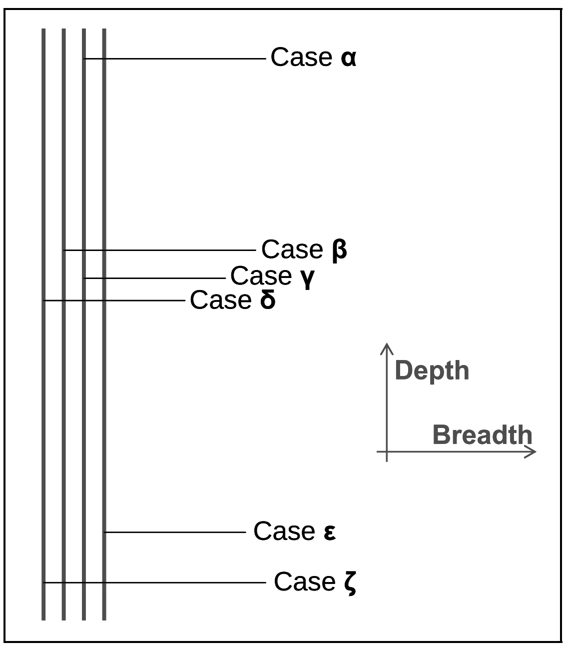

Figure 6. One In-Depth Case Study Will Be Supplemented With Several Smaller Case Studies to Provide Breadth of Research.

Figure 6 shows the proposed case study structure. One in-depth case study will be supplemented with several smaller case studies to increase the generality of results. The in-depth case study is at this time already selected and follows an organization as it updates its standardized process set, allowing for time series data collection. Additional cases will be selected from organizations with varying levels of process maturity and will be identified through pilot interviews. Within each organization, one or more project teams will be followed as the primary unit of analysis.

Within each case study interviews, surveys, and primary process documentation will be used as data sources. By combining data from multiple sources, a richer picture will emerge of how the engineering process is specified and applied. Contradictions between specification and application will likely be barriers to higher level systems thinking. Areas of alignment will likely be enablers.

Surveys instrument will be used as a tool to define the structural aspects of an organization. Primarily social network data will be gathered with the survey, indicating how work is actually executed. Examples of social network data include patterns of interaction (exchange analysis), clustering, and differences between an organizations' formal structure and underlying social structure (Allee 2003). Additional questions will gage team stability, team identity, and patterns of process use within teams.

Interviews and focus groups will be used to capture more open-ended data relating to process usage, culture, and group interactions. The focus group may include a group activity to allow for observation of group dynamics and culture.

Results

Over a dozen targeted case studies were read seeking information on links between standardized process and collaborative systems thinking. As stated earlier, most of the existing literature on organizational systems thinking takes a decidedly managerial tone. However, by targeting engineering case studies, evidence was found to support a link between standard process usage and systems thinking.

Anecdotal evidence shows resistance to standardized processes in engineering in some organizations. Those opposing standardization cite issues of inflexibility, and impeded creativity as their reasons for concern. Schedule and budgetary concerns are also popular reasons for opposing standardized processes. While some processes have been designed in ways that conflict with human nature, (Pajerek 2000) is quick to point out evidence does exist for the benefits of process improvements.

The case study analysis concentrates on LAI sponsored case studies (because of the authors' affiliations) but also because the LAI case studies referenced process usage in an engineering context with the unit of analysis being the enterprise, or organization. Lean thinking, a concept analogous to systems thinking, is also prevalent in the cases reviewed. Crossing functional and organizational boundaries are traits of lean thinking that compliment collaborative systems thinking.

Secondary case study analysis found evidence that process tools such as value stream mapping, process or change roadmaps, and walk-throughs support forming mental models of both the organization and the products or services it produces, thus enabling collaborative systems thinking. This is in contrast to research by (Dougherty 1990) showing standardized processes as stifling creativity and obscuring the whole. A case study of Rockwell Collins cited the danger of over alignment, in which group think would occur, but cited strong leadership commitment as a key to ensuring proper levels of alignment that facilitated work without impinging creativity (Roth 2006). Thus leadership is a key component in fostering collaborative systems thinking, as supported by (Senge, 2006) in his book *The Fifth Discipline*.

It also appears that just as many subsystems are systems in their own right, so too can systems thinking be applied at several levels. In a case following C-130 depot maintenance, a switch from crew-based maintenance to flow-based maintenance showed this dichotomy (Dickmann 2005). In crew-based maintenance, a crew followed one aircraft through depot maintenance. With this procedure, the crew developed a keen understanding of the aircraft as a system and was able to effectively execute repairs. However, the depot as a system suffered. By switching to a flow-based maintenance system, depot performance improved, but at the cost of the maintainers interacting with the aircraft as a system. The success of the switch was dependent of providing the workers a sense of progress and system at the depot level (Dickmann 2005). The ability to apply systems thinking to different levels might be a barrier to collaborative systems thinking unless the system (or organization) level of import is effectively communicated.

A common theme across cases was the role of leadership. Leadership came in the form of long-term commitment (Roth 2006) and the effective use of tools to communicate vision (Roth 2006). In the C-130 case, leadership was necessary to commit to the changes while workers developed a "depot as system" mindset. The need for leadership commitment is well explained by Vic Leo's analogy between organizational learning and annealing. Annealing is the time a metal or glass takes to slowly adjust and crystallize. In an organization this is mirrored by the time needed to let newly learned concepts take root and produce benefits (Roth, 2003). Leadership showed up again as necessary in both forming effective teams (Klein 1994) and keeping an active mental model for accurate decision making (Roth 2006).

Processes foster the ability of teams and team members to communicate. The more stable a team's membership is, the more effective the development cycle (Klein, 1994). The role of stability in team effectiveness points to the interaction of culture and standardized processes. As stated earlier, alignment between culture and standardized processes is likely an enabler, but not a guarantee of collaborative systems thinking. This is because culture and process must evolve with each other.

These themes support the existence of interactions between process, culture and systems thinking warranting further research.

Conclusion

As of this paper's publication, pilot interviews are underway and the key case study has been selected. Building on research exploring the enablers and barriers to systems thinking at the individual level, this paper provides an overview of the motivation for studying the role of standardized processes as enablers or barriers to systems thinking at the team and organizational levels. The research design outlined is an exploratory, case-study based plan using interviews and surveys to gather data. Outputs of this research will include an operational definition of collaborative systems thinking and identify ways in which standardized processes enable or inhibit collaborative systems thinking. The intention is to develop a set of heuristics that help teams and organizations better design and implement standardized processes so as to promote collaborative systems thinking. Initial results show links between system thinking concepts and standardized process usage do exist. These links, however, have not been explicitly studied to date, motivating the more rigorous approach of this doctoral research study.

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