An Inter-disciplinary approach to the planning, sustainment and resilience of socio-technical Systems

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Abstract

This paper reports a first step towards developing an open-ended way of expanding and growing an integrated approach to describing and analyzing socio-technical Systems. The nature of this research is interdisciplinary as it spans the fields of enterprise architecture, systems engineering, sociology, communications and culture studies. The work is aimed at supporting all stakeholders who need a wider context for understanding the structure and behavior of socio-technical Systems including planners, designers, constructors and implementers, oversight managers, analysts, and potentially, users. This initial work explores an ontological approach to integrating the modeling technique results from System Dynamics and an expanded Enterprise Architecture with concepts from sociocultural factors to get this wider view of socio-technical Systems and to both lower risks posed by sociocultural factors in development and operation and support better forensic analysis in cases of failure.

A semantic ontology can provide a basis both for tracing the entities and relationships in the socio-technical System across the terminology of multiple viewpoints and modeling techniques and allows consistent naming. This approach has been used in some Enterprise Architecture techniques. Our work is motivated by recent large and expensive product or project failures where the underlying causes of failure included sociocultural issues that were not considered in early failure investigations or were not given appropriate consideration during development or operation. Sociocultural issues may lie latent in socio-technical Systems, only to surface after a lengthy period, when accumulated risks driven by cultural issues reach a critical point where they affect the behavior of the socio-technical System adversely. This adversity may appear as technical failure or as unwanted, unplanned, or unexpected human behavior. Observing the effects of sociocultural factors and modeling them alongside technology models, we believe is a step in addressing these long-term effects earlier in the design cycle. We believe this approach provides a way to model underlying, long-term effects using techniques and tools we already have. This paper presents our initial investigation into developing this kind of semantic ontology.

Introduction

The term socio-technical System was coined by Eric Trist, Ken Bamforth and Fred Emery in the World War II era, based on their work with workers in English coal mines at the Tavistock Institute in London. Socio-technical Systems pertain to theory regarding the social aspects of people and society and technical aspects of organizational structure and processes. Here, technical does not necessarily imply material technology. The focus is on procedures and related knowledge, i.e., it refers to the ancient Greek term techne. "Technical" is a term used to refer to structure and a broader sense of technicalities. Socio-technical refers to the interrelatedness of social and technical aspects of an organization or the society as a whole. [HATCH 2013]

Socio-technical refers to the combination of social and technical factors in a System or organization. It recognizes that technology is not developed or used in isolation from its social context, but rather is shaped by and influences the social dynamics and interactions within a given environment. A socio-technical System approach emphasizes the interdependence and mutual influence of social and technical aspects in the design, implementation, and use of technology. It recognizes that the success and effectiveness of a technological system depend not only on the technical features but also on the social, cultural, organizational, and human factors involved. This approach aims to create a balance between the needs and capabilities of both the technology and the people using it, leading to more efficient and effective systems.

In contrast, sociocultural refers to the combination of social and cultural factors that shape and influence individuals and societies. It refers to the way people's behaviors, beliefs, norms, values, and practices are influenced by their social interactions and the cultural environment they are a part of. Sociocultural factors can include elements such as language, religion, education, social institutions, traditions, customs, and social and organizational/enterprise norms. These factors play a significant role in shaping individuals' identities, attitudes, and behaviors, as well as the overall dynamics of a society.

The dual nature of socio-technical Systems that are comprised of a technical component as well as a sociological component begs an interdisciplinary approach to their construction, operation, sustainment and ultimate demise. In the area of information technology, the science of systems engineering is used to design as many aspects of the socio-technical System as the designers can foresee. But during actual deployment and operation of these systems failures occur that were often a result of the sociological factors that surrounded the operations of the system working in conjunction with the technical inner workings of the system.   Failure in a socio-technical system can be defined as a lack of success or the inability to meet an expectation. Socio-technical Systems are complex Systems made up of interdependent social and technical aspects, such as people and technologies. Failure in these Systems can be pervasive and is often part of their normal functioning. However, failures can be viewed differently depending on the context and stakeholders involved. For example, organizational change programs can fail if they focus too much on one aspect of the System, such as technology and don't consider the complex interdependencies between the social and the technical aspects.

The authors are intrigued by the body of literature in sociology, communications and culture studies. We are exploring the extension of architecture and dynamic models and techniques to encompass concepts of human behaviors both in the planning stage of a socio-technical System as well as during the operations of the System. We are also intrigued by the potential use of similar techniques to analyze socio-technical System failure.

The goal of our work is to develop an open-ended way of expanding and growing an integrated approach to describing and analyzing socio-technical Systems. There currently exist multiple ways of describing and analyzing socio-technical Systems. These approaches are focused on different types of problem areas and solution approaches, such as System Dynamics (SD) and Enterprise Architecture (EA). [SD 01, SD02, RAO 2019] We start with an investigation of how the approaches of System Dynamics and Enterprise Architecture, together with concepts from sociocultural factors, can be integrated to get a wider view of socio-technical Systems to both lower risk in development and better forensic analysis in cases of failure. This paper is focused on our current findings in ways of integrating SD and EA approaches with an aim to improve design and analysis of socio-technical Systems.

Our approach is to use methods and techniques from Architecture Frameworks, used in EA, to enable the integration of various modeling techniques found in System Dynamics and Enterprise Architecture. Basically, we want to enable the ability to add or expand viewpoints (i.e., collections of models that provide information of interest to specific groups of stakeholders) by including models from the disparate existing approaches in SD and EA. To do this, we need to provide an underlying common and expandable terminology to allow models from disparate approaches to be relatable. We propose using an ontological approach to allow standardization of the terminology across these disparate existing approaches. This approach would provide a way of relating the elements of various modeling techniques to create integration between the models across viewpoints and models and allow an extended, overall analysis of socio-technical Systems. Our investigation is focused on potential applicability of semantic integration between ontologies from different domains of discourse (in this work, the domains of architecture definition, social and cultural modeling, and System Dynamics modeling) to develop a unified technique that brings the benefits of multiple modeling techniques to analyze facets of the same underlying problem. This paper is only the first step in a process: seeing if a common language (i.e., an ontology) can be successfully developed to link and integrate EA and SD models.

Our motivation for this work is based on our study of some recent failures in socio-technical Systems that might have been avoided if SD and EA approaches had been used in tandem and the results from each could be easily related or integrated.[1]

One example is the $1B failure of the Expeditionary Combat Support System (ECSS). This project was an attempt to introduce a single software system for logistics processing across the entire United States Air Force. The U.S. government investigation of this failure identified the impact of user (cultural) resistance to new logistics software and processes as one of the key causes of the failure. One underlying cause of the user resistance was that there were no project leaders who were in the chain of command of all the commands impacted (basically all). Thus, there was no project leader who had the authority to order the use of the new system. The project organization violated the military sociocultural factor of the military chain of command and control. [SENAT 2014]. Another underlying cause was the lack of understanding of how current processes worked before attempting a revolutionary transformation in the way people work ignoring best practices for business process re-engineering. [HAMM 1993]

Another example is the fatal failure of the Boeing 737 MAX airplane in two avoidable crashes. In this case, one of the elements of the failure was the impact of changing Boeing Company executive management value priorities at Boeing (after the merger with McDonnell-Douglas). Executive management at the highest level changed the top priority of Boeing to profit rather than engineering

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[1] Our interest in the research presented in this paper was stimulated by findings from several investigations [CTI 2020] that indicated that underlying causes of failure had origins in socio-cultural factors long before the failure events occurred. The systems engineering and modeling that were restricted to the operational and technology aspects of the system, though exhaustive, could not uncover problems that were created due to management hubris and deep cultural divisions between the financial objectives of the program and the need for quality and safety in critical systems. Our attempt is to expand the scope of analysis a priori to incorporate socio-cultural factors and model the static and dynamic effect on the socio-technical system.

quality and safety as was previously done. [KACI 9-2019, TALT 2024, TERL 1-2024, SAPO 2023, ABUL 2024] The US House of Representatives investigation identified changes in Boeing Commercial Airplane (BCA) division project management interaction with engineers and the U.S. Federal Aviation Administration (FAA) as an underlying cause in the increase in risk of the 737 MAX failure. Increasing profit pushed cost cutting measures such as rigid adherence for project cost and schedule, loss of senior engineers, and cutting back on labor intensive processes such as quality assurance and configuration control. In the balance between safety and reduced cost for many technical decisions, management took the cost saving measure, compromising safety risks. So, while technical issues were the immediate cause of the MAX crashes, an underlying cause was the sociocultural factor of changes in the prioritization of the company's espoused values. [ROBI 2021]

The failures in both these examples could have been better predicted or understood by examining a combination of models from SD (Causal Loop) and EA (organizational structure and resource-needs models with sociocultural factors added) integrated with a common vocabulary.

The paper is organized into the following sections: a brief review of SD, EA, and sociocultural factors; integration of SD and extended EA with sociocultural factors; potential advantages of the integrated approach of unified planning and simulation; and summary and future research areas. A set of definitions for the terminology used is included in an Appendix.

Brief Review of EA, SD and Sociocultural Factors as Related to Socio-Technological Systems

This section provides a brief review of examples of relevant sociocultural factors and key aspects of SD and EA, including how these two disciplines can use these sociocultural factors.

Sociocultural Factors

Sociocultural factors help us understand the modulating effects of human agency over established or implicit command and control channels (i.e., the planned or expected rules of organizational behavior). Sociocultural factors that are relevant to understanding the social side of socio-technical Systems are described in the writings of a variety of social scientists. Examples include the writings of Schein [SCHEIN 2017], Hofstede [HOF 2017], and Menzefricke [MENZ 2021] to name a few.

Schein introduced the notions of *espoused values* and *intrinsic assumptions* of organizations. *Espoused values* include an organization's or enterprise's explicitly stated strategies, goals, and philosophies: what members feel are the justifications and rationalizations of what they do. These espoused values may not align with what is observed behavior in the organization or enterprise, that is, the *intrinsic assumptions* that are the unconscious, taken-for-granted beliefs of the members of the organization: "the way we do things around here."

Hofstede developed a cultural dimensions model which includes an Uncertainty Avoidance Index (UAI) that measures how different cultures interpret the future, the unknown, and unpredictability. His writings address ways of measuring risk tolerance in organizations or projects and organizational risk avoidance. Hofstede includes discussions of *power differences* in interactions between individuals, roles, and organizational units. Hofstede talks about high power distance and low power distance. An example of high-power distance is accepting hierarchy as a status quo rather than challenging it. The caste system in India and the glass ceiling phenomenon for women and minorities in the U.S. were both examples of high-power distance between pre-existing culture top-of-the-hierarchy individuals and lower-in-the-hierarchy individuals. Menzefricke also provides measures of *risk tolerance* of organizational units (formal or informal) and *uncertainty* of project or product characteristics such as safety, user acceptance, or marketability.

These sociocultural factors can be seen in action in many organizations. For example, when the technical parts of a socio-technical System are designed, the designers assume a particular set of sociocultural factors will be in play when the technical system is in each phase of its lifecycle. (These are the Design Assumptions and Factors which may be a combination of organizational espoused values and intrinsic assumptions.) When the technical system is developed, the designers assume that the system will be developed following a specific process that has a known set of activities, each of which has a set of required inputs and outputs and is performed by personnel from an identified organizational group or set of organizational roles requiring a specific set of knowledge, skills, and experience. In addition, each activity is assumed to be performed in a way consistent with a set of rules or controls such as management oversight and required exit/completion criteria. Similarly, when the technical system is in operation, the designers assume that the users will have a certain common understanding of how to use the system in the performance of their jobs. However, these design assumptions and factors may not hold true on every project or for every user.

Power distance causes organizations to allow deviations from established process. In some organizations with high power distance, management has the power to order the skipping of critical process steps or to disregard engineering identified risks in order to meet management schedule and cost goals. These actions may result in unexpected behaviors or outright failures of the technical system. The Challenger disaster is an example of management disregard for engineering warnings about the risks of launching during adverse weather conditions. [PCSSCA 1986]

Low power distance promotes affordances. In technical system operation in organizations with low power distance, users will stretch a system's functionality beyond its designed capabilities and limits and find unplanned ways to use the system or disregard for rules/policy by adding their own applications to employer provided cell phones and computers against company rules. This sort of behavior often leads to company security breaches and other unwanted outcomes. Another common phenomenon is the use of any currently unused defined system storage space, such as unused elements in a database, for their private work notes or other information. (Example: Garbage accumulates in vacant lots.) This behavior creates difficulties and extra work for the Data Base Administrators during database consistency checks and when the previously unused elements are needed to hold legitimate data from new or updated applications.

It might seem difficult to get information on some of these sociocultural factors, but there is a great deal that can be discovered through open sources such as organizational websites, government required reports for organizations whose stock is publicly traded (such as the Security and Exchange Commission Form 10-K in the United States), industry publications (such as Aviation Week), other news and opinion magazines, and newspapers. Espoused values are usually published by most large corporations on their websites. Intrinsic assumptions can be divined from other sources such as financial reports, industry publications, and newspaper reports including interviews with employees and whistle blowers. Local newspapers are a good source for information relating to corporate culture for organizations that have high importance in a specific area. For example, The Seattle Times reports extensively on the Boeing Company and has a full-time reporter for aerospace news because of the long-term importance of Boeing in the local economy.

Common Features of SD and EA

SD and EA have common roots in problem definition and Systems Thinking. While different types of modeling are used, both approaches start with identifying the problem that needs to be considered and what types of results are desired. Without this focus, any results are usually useless. Both disciplines rely on Systems Thinking. Systems Thinking views the world according to activities, processes, events, people (roles), functional organizations, patterns, structures, and their interrelationships. The defining characteristic of a System is that it cannot be understood as a function of its isolated components. That is, the real emphasis of these approaches is to see how all the parts of the System integrate to form a whole. The System parts are not primary; the focus is the relationship between and among the parts. In fact, what SD considers as a socio-technical System, EA considers as an enterprise. These two disciplines take two different views of the same thing, and these dual views are what makes it important to be able to integrate their results.

Both System Dynamics and Enterprise Architecture use models that are representations of real-world objects and concepts to enable analysis and fitness for some design or analysis purpose. A modeling technique, to be applicable widely for a class of real-world problems, uses abstractions or classifications of real-world objects. In SD, all variables of interest are abstracted in the modeling technique such as stores and rates. In EA, for example, all specific activities are abstracted as ACTIVITY, all performers of such activities are abstracted as PERFORMERS, etc. The process of modeling is to associate real-world objects to modeling abstractions to perform analysis – qualitative or quantitative. Our focus in this paper is to relate the modeling abstractions that we call the ontology of the modeling techniques.

Both SD and EA approaches need to be cognizant of sociocultural factors and incorporate these factors. [BERN 2015] For example, organizational tribal (subculture) factors modulate the formal organization structure by introducing informal backchannels of communication and control behavior. [WILC 2004, LOGAN 2008] Power distance factors between formal or informal organizations/roles can also introduce communications and control distortion. Thus, EA organizational and communications-needs models must include organizational tribes (also termed subcultures) to provide a fully useful model, even though these subcultures may be difficult to identify from outside the organization. These organizational tribes have dynamics that are emergent in nature. These groups may have constantly evolving alliances, associations, and affinities driven by organizational politics and pragmatics or external events outside the organization. The tribes may employ constantly changing tactics procedures to achieve their internal goals. Organizational tribes may develop unforeseen group behaviors resulting from Black Swan events such as COVID or 9/11. Organizational tribes may adjust their internal structures driven by evolving professional Communities of Practice or Communities of Interest.

In SD models, the measures of sociocultural factors are often used as variables. These variables are usually qualitative in nature as opposed to quantitative. These sociocultural factors may be difficult to measure except on some subjective numerical scale (i.e., 1 to 5 or 1 to 10) in much the same way patient pain is measured in medicine and risk is measured in risk matrices.

In Enterprise Architecture, sociocultural factors can appear as architecture elements, and their measures can appear as attributes of architecture elements or as attributes of relationships between architecture elements. *Risk* is a sociocultural factor that can be an architecture element and is measured in terms of group perception of uncertainty management. *Uncertainty avoidance* describes a culture or society's tolerance of unpredictable and unstructured situations. This level of tolerance informs social norms, business practices, and human behavior. Risk of an activity producing a desired outcome, risk of the occurrence of a critical event, risk of a performer performing an activity successfully, are all examples of associating a risk attribute with an architecture element or relationship.

System Dynamics: Relevant Features

System Dynamics (SD) was developed to support exploration of System problems through simulation (either mental or computer assisted) at multiple lifecycle phases such as design, development, operation, and evolution. SD provides a set of techniques to model and analyze the dynamic behavior of Systems over longer periods of time. These techniques include Causal Loop and Stock and Flow models. System Dynamics is well suited for analysis based on use cases or scenarios and deals specifically with quantitative and qualitative terms for simulation and observation of their variations in dynamic behavior.

SD is very flexible in terms of the types of problems and domains to which it can be applied. We are focusing on the domain of socio-technical Systems. Causal loop modeling supports simulations that test outcomes based on changing starting values of variables that can be either quantitative or qualitative in nature. These variables can be the values of sociocultural factors when they are relevant to the problem being considered. This flexibility is needed because sociocultural factors can intrinsically modulate peoples' behaviors as well as the activities they perform. Simulation supports the identification of potentially emergent behavior. SD modeling of feedback loops helps identifying potential long-term impacts of various types of changes, both internal and external, on socio-technical Systems.

While the SD approach emphasizes a focus on a System as a whole, it suggests that models be started on one aspect of the problem and expanded to include additional aspects of the problem until the necessary view of the whole System is included. However, there is no specific guidance or direct mechanisms to ensure that work by different groups focused on different specific problems of the same socio-technical System can be integrated or use a common vocabulary or naming strategy.

The only ontology currently available for SD models is based on the elements of the modeling techniques themselves and is domain independent. Thus, the ontology elements just refer to the boxes and arrows used in the models and not to the semantic nature of the System elements from the domain being represented using the boxes or arrows.

While, SD does not directly address planning or strategy for the System under investigation, the results of the simulations can and should impact planning and strategy decisions being made for socio-technical Systems.

Enterprise Architecture: Relevant Features

An enterprise architecture is a description or representation of the structure and behavior of an enterprise. The discipline of EA was developed to support planning for enterprise transformation and evolution and looks at this transformation in time phased snapshots. An Enterprise Architecture starts with an As-Is architecture description and follows with potentially multiple To-Be architecture descriptions, each focused on a particular time frame in the transformation process.

An enterprise architecture makes explicit the elements of an enterprise that contribute to fulfilling the mission and purpose for which the enterprise exists. A goal of EA is to support alignment of organizational strategy, organization structure, process, and supporting Information Technology (IT). This alignment includes the integration and interoperability of processes and technical systems. Usually, a specific enterprise architecture follows the standards and structure provided by an Architecture Framework. When we discuss the features of EA in this paper, we will be using the structure and standards of the United States Department of Defense Architecture Framework (DoDAF) [DODAF 2.02, RAO 2019, RAO 2011], but readers will not need to have any detailed knowledge of the DoDAF. There are other EA Frameworks such as The Open Group Architecture Framework (TOGAF). [OPEN 1]

The DoDAF divides the architecture description into collections of models or viewpoints, each targeted to a particular set of stakeholders such as managers, planners, operation personnel, and IT staff. The models in these viewpoints are integrated using the DoDAF ontology both within each viewpoint and across the viewpoints. The ontology describes the types of architecture elements a DoDAF EA may contain and the relationships between these elements. [DoDCIO 1] In addition to the viewpoints and the ontology, the DoDAF requires a Dictionary for each architecture description. This Dictionary provides the details of each architecture element in that specific description in a manner that is consistent and singular for the collection of models developed to represent that architecture description for analysis.

The DoDAF is an open-ended standard that allows extensions with inclusion of additional models or viewpoints but requires these models to be integrated with the standard set of models; that is, the new or extended models or viewpoints need to have relationships to architectural elements in the standard set of models. DoDAF models accommodate tailoring; models can be extended or simplified to fit the purpose of the modeling effort. Additional documentation is required to describe the questions the architecture should answer and the set of models that will be included in an architecture description and any tailoring that will be used. However, the DoDAF standard set of models has limited support for simulation and limited ways to identify potential emergent behavior. The current standard does not include specific mention of sociocultural factors but these can easily be added through tailoring.

In this paper we will be focusing on the ontology rather than the models that use the vocabulary of the ontology.

Table 1 summarizes the similarities and differences between the techniques of System Dynamics and Enterprise Architecture from the point of view in this paper.

Table 1: Summary of System Dynamics and Enterprise Architecture Features

Aspect	System Dynamics	Enterprise Architecture
Purpose	• Analysis of dynamic behavior of S(s)ystems through modeling and simulation	• Planning the transformation of Systems/Enterprises • Alignment of Business and Technology • Ensuring system integration and interoperability
Focus	• Modeling specific System problems • Scaling up to multiple projects and related cross-functional analysis	• Family of systems/systems of systems • A common architecture language for communication among planners, designers, and developers of different component systems from different sources
Modeling Techniques	• Stock-Flow Diagrams • Causal Loop Diagrams • Includes mathematical analysis and graphic representations of simulation results	• Structural architecture representations • Behavioral architecture representations • Allows tailoring for sociocultural factors
Primary Ontological Concepts	• Flow Rates, Stocks, • Sources and Sinks • Variables (including sociocultural factors) • Flows • Causal Relationships • Feedback Loops	• DoDAF Ontology Architecture Elements (see Figure 2)

Integration of System Dynamics and Enterprise Architecture

Models used in SD and EA are symbolic representations of real-world or abstract objects and more broadly, concepts that describe objects of a specific domain and their relationships to each other. These models are useful for sharing common representations and understanding across multiple audiences, performing simulations, and developing designs and analyses.

Figure 1 depicts the relationships between EA, SD, Systems Thinking, Systems Engineering, and the addition of sociocultural factors that affect the behavior of people and organizations due to individual agency. Today, these are viewed as different but complementary disciplines with variations in terminology, definitions and modeling techniques all purporting to help the task of Systems Engineering in build quality Systems.

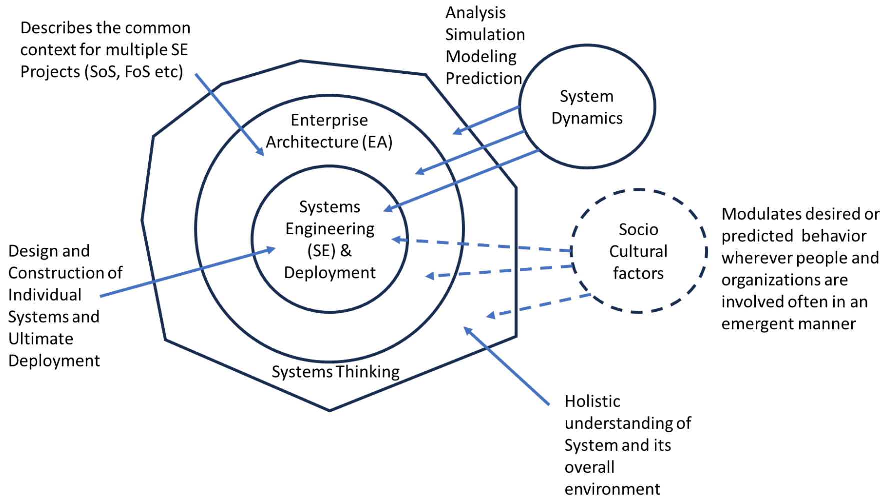

Figure 1 Showing relationships between EA, SE, SD and Systems Thinking in the context of Socio-Technical Systems

If EA and SD techniques are being used together to design and analyze socio-technical Systems (or enterprises) then the relationships between EA and SD ontology elements must be understood so that the relationships of elements from different models and simulations can be identified, and the elements consistently named. That is, the different models should integrate in the sense that they provide different views of the same reality, and the related elements can be identified and traced across models by their names (or by their aliases as noted in a Dictionary).

However, when both SD and EA techniques are being used, care must be taken to ensure that the SD models and EA models are at similar levels of abstraction. That is, there must be a documented relationship among models so that the reality represented in a SD model can be related to the reality represented in some EA model and vice versa. For example, SD diagrams may be used to simulate behavior in systems that are contained within larger scope process/system elements in the enterprise architecture. In this case, the SD diagram element names may not appear in the EA diagrams and the relationship of the diagrams (in terms of information sources) may only be noted in the Dictionary. Some information from the SD simulation studies may be captured as sub-elements in an EA diagram such as required bounds on flow rates in resource (i.e., information or materiel) exchanges in an EA operational resource flow matrix. For example, while planning a deployment of military personnel from the US to a theater area abroad, the flow rate of the transportation mechanisms from the various bases to the destination may be the subject of a SD exercise. The DoDAF EA model that represents the flows of personnel through the transportation network is an operational resource flow matrix.

First, we introduce the current DoDAF ontology and discuss how sociocultural factors can be accommodated in that ontology. Then we discuss adding SD modeling concepts to the DoDAF ontology.

The DoDAF Ontology

We start with the DoDAF ontology because it is semantically based, and the EA discipline has evolved by integrating disparate modeling techniques used in systems engineering to represent a shared reality that is hidden by different terminologies for each type of model.

The existing high level DoDAF ontology[2] is usually presented in the graphic diagram shown in figure 2. This figure shows the key ontological entities that form the foundation for the DoDAF and are the abstract types of elements used to build DoDAF compliant models. All the relationships indicated in the figure are unidirectional. This ontology was developed for the military domain and is based on a minimal set of concepts common across the U.S. military. The elements of the DoDAF ontology that we will reference, are defined in Table 2 of this paper. However, the DoDAF allows the *tailoring* of its basic representation models to include new entity types and new entity attributes as well as new relationships and relationship attributes. This flexibility was included to deal with additional concepts specific to individual military services and missions, but it makes the ontology open to expansion to address needed concepts and relationships for general socio-technical Systems. These new entities, relationships, and attributes are added to specific EA descriptions by providing definitions and relationships in the Dictionary of each EA description.

The DoDAF high level ontology does not include any the attributes, i.e., the properties of entities or relationships. The DoDAF ontology also implies that all entities can have subtypes, they can be associated with different parts in different states, and that they can be structurally composed of one or more parts. In addition, anything can have associated measures. This is important, as measures are the staples for Systems Dynamic models. The effect of one measure on another is the subject of analysis using SD models and simulations.

[2] In the figure, the flags represent various nations that have endorsed and adopted the same framework ontology based on the IDEAS foundation ontology.

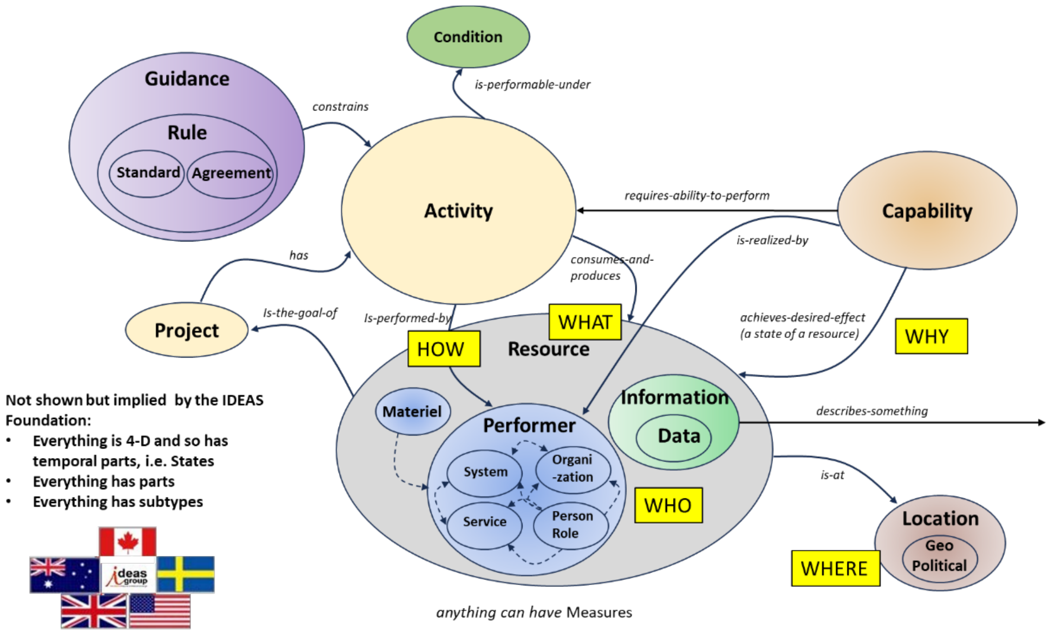

Figure 2 DoDAF High-level Ontology

Table 2: Definitions of Selected DoDAF Ontology Entities

Element Name	Element Definition
Activity	Work, not specific to a single organization, system, or individual/role that transforms inputs (Resources) into outputs (Resources) or changes their state.
Resources	Data, Information, Performers, Materiel, or Personnel Types that are produced or consumed • Materiel: Equipment, apparatus or supplies that are of interest, without distinction as to its application for administrative or operational work purposes. • Information: • Data: • Performer: Any entity – human, automated, or any aggregation of human and/or automated – that performs and activity and provides a capability ○ Organization ○ System ○ Person Type/Role ○ Service
Capability	The ability to achieve a Desired Effect under specified (performance) standards and conditions through a combination of ways and means (activities and resources) to perform a set of activities.
Location	A point or extent in space that may be referred to physically or logically. Examples of location are geo-political locations, installations, facilities and virtual locations.

We are including more attributes or parts of both entities and relationships in our discussions below to make our ideas about the expansions needed for the DoDAF ontology clear. These expansions include sociocultural factors and dynamic concepts from SD. As it stands, the DoDAF ontology covers the concepts for the static models that are used in the DoDAF and make up the majority of the models used in the DoDAF, but it may not cover all the dynamic concepts in the more dynamic models of the DoDAF such as the State Transition Description (a finite state model) and the Event-Trace Description (Unified Modeling Language (UML) Sequence Diagram style model [DODAF 2.02] that both require some notion of *event* or *triggering event*.

We first examine how the DoDAF ontology can be expanded to handle sociocultural factors and then look at adding the concepts from SD models.

Integrating Sociocultural Factors into an Expanded DoDAF Ontology

Sociocultural factors are primarily related to individual roles and sometimes organizations as performers and as personnel resources with respect to the activities that they perform. Sociocultural factors are at the root of emergence and hence the cause of unpredictability in socio-technical Systems.

Sociocultural factors need be added to the specific EA descriptions that require them. Examples of adding a sociocultural factor is provided below and illustrates how this can be done with or without needing to expand the ontology. The addition of additional types of sociocultural factors in DoDAF EA descriptions has been discussed in more detail in [REEDY 2021].

Sociocultural factors can appear in at least three different ways in EA descriptions: as new entities, as parts of entities (i.e., as attributes), or as parts of relationships (i.e., as attributes). The last two ways do not require expansion of the existing ontology (because it is a high-level ontology and does not contain all the parts/attributes of entities and relationships). New entities may require new types of relationships, but these don't always require expansion of the high-level ontology as the ontology generalizes multiple relationships as a simple association between two entities.

Each sociocultural factor that needs to be included in an EA description must be examined to see which of these three approaches is applicable. The DoDAF allows customization to include sociocultural factors but provides no specific guidance on how to do this. The two examples below show how two sociocultural factors could be included in an expanded ontology.

Example 1: Adding an additional sociocultural factor to the DoDAF ontology: *organizational tribe/subculture*.

The original definition of the ontology entity organization is defined as "a specific real-world assemblage of people and other resources organized for an ongoing purpose." [DODAF 2.02] This definition is frequently interpreted as a formal organization or suborganization within the larger organization/enterprise being described by an enterprise architecture. The easiest way to incorporate organizational tribes/subcultures into the ontology is to expand the definition of the ontological entity organization to include informal internal groups or overlapping external groups (such as unions) that don't usually appear on an organizational chart. Organizational tribes may extend across formal organizational boundaries. An organizational tribe entity should be able to appear anywhere an organization entity can appear in models. In models, an organizational tribe entity requires two new relationship types that connect an organizational tribe to another organizational tribe or organization: contains-members-from and has-alliance-with. (These relationships will not appear on the ontology graphic because relationships at this level do not appear on that graphic.)

Example 2: Adding sociocultural factors as attributes or parts of ontology entities: *risk tolerance/uncertainty avoidance* as parts of organization entities or person role entities.

Risk tolerance is defined as the level of risk an entity is willing to assume in order to achieve a potential desired result or the level of risk or the degree of uncertainty that is acceptable to an organization. [NIST CSRC] *Risk tolerance* and *uncertainty avoidance* directly deal with decisions undertaken by formal organizations, tribal entities or persons performing a role in an activity, for example, in types of models where these decisions are involved with uncertainty due to risk. Modeling risk tolerance as an attribute may require assigning a scale such as 1 to 10 for high-risk avoidance as a 10 and low or no risk avoidance as a 1. Specific organizations may be assigned a value for risk tolerance based on their activities or mission. Regulatory organizations might to have a value closer to a 10 as would financial organizations; sales and marketing organizations or weapons carrying person roles may have values closer to 1. This type of addition does not involve expanding the ontology since it is an attribute.

Integrating SD Concepts into an Expanded DoDAF Ontology

SD uses two major modeling techniques, Stock and Flow diagrams (SFD) and Causal Loop diagrams (CLD), along with a variety of general graphing of simulation results over time. In general, the integration of SD model concepts with EA entity concepts and relationships identified in the DoDAF ontology involves tracing the SD model concept to the DoDAF ontology entity that it describes. That is, by tracing a simulation concept to the entity the simulation concept represents a property of or that it describes, we can integrate the simulation concept into the ontology. The integration of the concepts of the two major models are addressed separately below.

SD Stock and Flow Diagram Integration into an Expanded DoDAF Ontology

SD Stock and Flow diagrams (SFD) are focused on behavior and support for simulations, while the DoDAF Operational Resource Flow Description and Operational Resource Flow Matrix models are focused on structural requirements. These DoDAF models document the exchanges of various types of resources between two performers at the two end points of the exchange. This is a static representation that is unable to tell the story of waxing and waning throughput and other variations in the resource flows. This story is suited to a dynamic simulation of the exchange using the SD Stock and Flow modeling techniques. The SFD allows users to study the impact of various *flow* rates on *stock* (i.e., resource) accumulations while the DoDAF diagrams document the need for resource flows between performers (human or otherwise) of specific activities at specific locations and the details of the requirements for these flows, potentially including what flow timing and rate may be required or desired.

The SFD *stock* represents the amount of a specific resource in a specific system location at any instant in time. That is, *stock* represents a *measure* of a RESOURCE in DoDAF terms. The *stock* can represent the resource state of a single system or the abstraction of joint resource state of multiple systems in a module and the location may be abstract rather than a specific physical location. Each *stock* has a type, which correspond to any of the Resource elements identified in the DoDAF ontology (Materiel, Performer, Information/Data). In addition, each *stock* has an implicit associated *location* part that aligns with the Location entity in the DoDAF ontology as well as an implicit associated measure type that is the unit of measure for the resource in the *stock*. This part/attribute aligns with the measure type in the DoDAF ontology. Either of the location part/attribute or measure type (i.e., measure unit) part/attribute may or may not be included in the SFD itself. To support simulation, each *stock* in a SFD may have an associated initial value measure as a part/attribute**.**

The SFD *flow* concept represents the rate at which a *stock* is changing at a particular instant. *Flows* directly affect the *stocks* they flow into or out of. Each *flow* has a flow rate or function as a part/attribute. In DoDAF models, a *flow* would be considered a relationship between *stocks*, but in SFD *flows* are treated as separate concepts although they are always associated with *stocks*. That is, each *stock* has a relationship to at least one source/input *flow* and each *flow* has a relationship as a source to at least one *stock*. Each *stock* has a relationship to at least one sink/output *flow* and each *flow* has a relationship as a sink to at least one *stock*. (There are the obvious exceptions for external stocks or flows.) Note that each *flow* must be related to *stocks* of the same type (or subtype) of RESOURCE. The difference between the way these concepts are handled in DoDAF models and SFD do not seem critical at the ontological level, so no additions to the DoDAF ontology are needed to handle SFDs.

SD Causal Loop Diagram Integration into an Expanded DoDAF Ontology

SD Causal Loop diagrams (CLD) are also focused on behavior and simulation. Causal loop diagrams are a technique to depict the effect of one variable on another using causal relationship arrows that depict whether the causal effect is to increase the amount of the impacted variable or to decrease it. A causal loop diagram has to be matched with a more quantitative Stock Flow Diagram to specifically quantify the effects that the causal loop diagram illustrates qualitatively. Causal loop diagrams identify feedback loops that are constantly increasing a set of variables (reinforcing loops) or constantly decreasing a specific set of variables (balancing loops)

There are three major concepts in CLD that need to be examined for their relationship to the existing DoDAF ontology: *variable*, *causal relationship*, and *feedback loop*.

Like a SFD stock, a CLD *variable* is an element whose value is a measure and can vary over time. Each *variable* has an implicit part/attribute that is the unit of measure for the value of the *variable*. Since a CLD *variable* is something that has a value that is a measure, a *variable* could be the part/attribute of any architectural element identified in the DoDAF ontology. The challenge is that in some CLDs *variables* may represent attributes of CLD elements that are not currently included in DoDAF models and do not map to types in the ontology. An example is a *variable* that deals with financial concepts such as revenue, cost, and profit or *variables* that deal with sociocultural concepts such as Power Difference. The existence of these types of *variables* in simulations that address socio-technical Systems indicates there are architectural elements and/or parts/attributes that are currently missing from DoDAF models and may need to be added to the ontology.

Sociocultural factors can easily be tailored into DoDAF models as additional parts/attributes since these concepts are associated with Organizations and human Performers and their relationships as discussed above. For example, increasing power distance as an attribute of an organization such as the US Federal Aviation Administration with respect to Boeing may have the result of decreasing manufacturing defects as a consequence of fear of upsetting a powerful entity – something that can be simulated with these variables.

While some financial entity concepts can appear in DoDAF EAs, concepts from many financial models are currently missing from the DoDAF because budgeting and financial processes in the military are controlled by their own preexisting complex regulatory processes that are unique to U.S. military and governmental organizations. For use in non-governmental enterprises, the DoDAF may need to be expanded with a Financial Viewpoint and possibly a Culture Viewpoint.

Two CLD *variables* can be related with a directed *causal relationship*. This relationship indicates that a change in the value/measure of the first *variable* impacts the value/measure of the second *variable*. For example, an increase in the value of the first *variable* causes an increase in the value/measure of the second *variable*. In a CLD diagram, a positive or increasing *causal relationship* is usually depicted as an arrow from the first *variable* toward the second *variable* with a plus sign over the head of the arrow. Similarly, a negative or decreasing *causal relationship* is usually depicted as an arrow from the first *variable* toward the second *variable* with a minus sign over the head of the arrow. A CLD *causal relationship* may also have a part/attribute that is a mathematical function that provides a formal quantitative description of the relationship between the measure values of the two *variables* it connects.

In the DoDAF ontology, a CLD *variable* is a measure entity. The DoDAF ontology documentation states that a measure entity has a measure type (i.e., a part/attribute that is the unit of the measure value). Thus, fitting the CLD *causal relationship* into an expanded DoDAF ontology requires adding an additional relationship type to the ontology: A *causal relationship* type is a relationship that relates the value of the measure of one entity to the value of the measure of another entity. Note that the *causal relationship* can be between two measures (of different measure types) of the same entity.

A closed, one-way, pair-wise sequence of CLD *variables* connected by *causal relationships* forms a *feedback loop*. A *variable* may be part of multiple *feedback loops* in the same CLD. In a CLD, each *feedback loop* should have a unique label or name. The form of these labels may be different depending on the style of the diagram but should indicate whether the *feedback loop* is a *balancing* loop or a *reinforcing* loop. A *balancing feedback loop* contains *decreasing causal relationships*. A *reinforcing feedback loop* consists of a loop with only *increasing causal relationships*.

To fit the concept of *feedback loop* into an expanded DoDAF ontology, the ontology needs a new entity type (*feedback loop*) that has a name and a loop type as parts/attributes. The DoDAF ontology says that everything has parts, so a new *is-part-of* relationship that connects entities of type measure to entities of the type *feedback loop* is available. Entities of type measure may have multiple *is-part-of* relationships to distinct feedback loops. (The whole part nature of a feedback loop is the existence of component causal arrows that make up the loop.)

To summarize, the expanded ontology includes:

- A new relationship type *has-causal-relationship* that relates two measure entities (that represent CLD variables)
- A new entity of type *feedback loop,* where *feedback loops* have names and loop types (balancing or reinforcing)
- A new *is-a-part-of* relationship that relates a measure to a feedback loop that the measure is part of

Figure 3 illustrates these new parts of the expanded ontology.

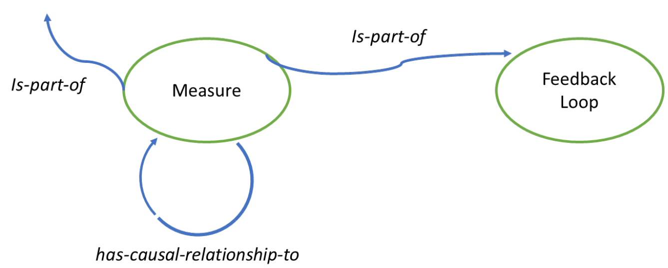

Figure 3 New Parts of the Expanded Ontology

The ontology fragment in figure 3 should be included in the graphic of the Expanded DoDAF ontology in figure 2 as an extension of the “is-part-of” arrow where the “anything can have Measures” notation is.

Summary of Integration Section

In this section we have described how the ontological aspects of the DoDAF (DoDAF ontology entities and relationships) can be integrated with the ontological concepts of System Dynamics models (Causal Loop Diagrams and Stock and Flow Diagrams) for the socio-technical Systems domain and how some samples of sociocultural factors (such as Risk Tolerance/Uncertainty Avoidance and Power Distance) can be introduced into the combined semantic ontology of the SD and EA disciplines. The methods of aligning the ontologies from these disciplines relied on the expansion of the DoDAF entities, the addition of attributes to existing entities as well as the addition of new relationships to express a semantic dependency between existing or augmented entities.

Potential Advantages of an Integrated Approach that Combines EA, SD and Sociocultural Factor Techniques

EA and SD techniques and approaches have been used independently to design and analyze socio-technical Systems. SD is focused on dynamic behavior while EA is mostly focused on structure, though EA does model behavior in the limited form of planned operational activities or planned system activities. Using EA and SD together to get a better understanding of socio-technical Systems makes sense: EA can provide a structured, larger context for SD analysis while SD can provide dynamic models that add longer term behavior analysis to EA. EA provides a contextual canvas for the judicious selection of problems based on use cases and scenarios for SD modeling. Without the larger canvas of architecture, the selection of systems modeling scenarios run the risk of missing critical aspects of the System. The EA provides a fertile ground to examine multiple scenarios before selecting a set of representative ones to model in detail.

EA provides a canvas for consistently naming data elements that cross project and organizational boundaries of SD modelers. Our approach of mapping the elements of SD models (sources, sinks, variables and rates) to EA ontological entities provides support for using EA and SD techniques in tandem by providing a method of consistent naming elements across the models from both disciplines. Large organizations such as the US Department of Defense have tackled the problem of consistently naming data element standardization by using constructs from the underlying ontology such as an enterprise data model. [DCMA 2022] This consistent naming of elements can provide easy communications across different modeling groups with different viewpoints looking at the same socio-technical System and provide an easier way to share results from their efforts. The EA (in particular, an enterprise information model) provides the commonly accepted noun phrases to name the data elements that are the variables of SD analysis.

Unifying Planning and Simulation for Transformation

Our work is aimed at looking at socio-technical Systems in the large, to improve design and analysis of these Systems. The objectives for EA are to provide a high-level architecture for specific Systems for decision makers, sponsors and key stakeholders of the system, while also providing a common architecture for developing system of systems and family of systems that collaborate, cooperate and interoperate with each other. EA was developed to support long term, multi-year transformational planning for socio-technical Systems. For example, the DoDAF was developed to address the design of complex System of Systems, Family of Systems and large weapons systems that represent very complex socio-technical Systems that marry warfighters with advanced technology-based weapons.

A major part of this planning process is to develop an As-Is description of the System as the starting point, and design a sequence of phased transformations, each phase of which describes a stable state of the System that is closer to the most current set of organizational/enterprise goals and objectives. As the beginning of each phase, the EA is only detailed enough for management to identify the projects needed to make the current version of the System match the version of the System described in the next transformation phase.

One of the tasks in designing a set of transformation phases is to decide the priority and order of the changes that need to be made. Often, there are multiple ways the transformation steps can be made. The ability to use SD simulation techniques in tandem with the phased architecture description, can be used to support the observation of effects and outcomes of each planned phase of the System's transformation. This testing can help with comparing alternative phasing of the transformation, in identifying emergent behaviors over time, and identifying risks of failures. For example, when transformation phasing is initially developed, the designers need to make assumptions about the state of various variables such as management support, schedules, funding, availability of resources, and System users' acceptance of change.

The use of SD modeling can be used to evaluate the impact of these assumptions on the potential for success and to identify risk. The results of this type of testing can be used to identify a sequence of transformations that has better potential for success with less risk. This type of testing can also identify the values of certain variables that need to be monitored during a transition phase because they indicate the risk of failure of some kind is becoming too high and that risk remediation and replanning are needed.

Specific Advantages to SD Efforts

Current interests in the SD community are focused on adding multiple perspectives to SD models to incorporate aspects of social, ethical and environmental factors, as an example. In such an environment, more than one model may be required to analyze, explain and present outcomes and effects to a diverse group of stakeholders who are likely affected by the results of the analysis and the presentation of the results. If a set of *multiple* SD simulation efforts for the same socio-technical System is planned, then adding some EA modeling of the System enterprise to the effort will add consistent, structural, large context information to ensure that all the simulations reflect the same reality. The larger context will help define what elements of the System are the subjects of each SD modeling effort, how each of these efforts relate to each other in terms of the larger System, and how the modeled problems may impact each other. EA serves to make multiple System Dynamics models of the same problem set coherent. The EA provides the context to normalize the concepts that are at the root of the variables.

Using the extended ontology mapping of SD modeling elements to EA modeling elements supports the consistent naming of model elements across multiple SD simulation efforts as illustrated in figure 4. This consistent naming of SD variables supports the tracking of variables across multiple simulations and seeing how many variables related to the same structural entity appear across multiple simulation efforts. This information may help identify critical entities in the socio-technical System/Enterprise.

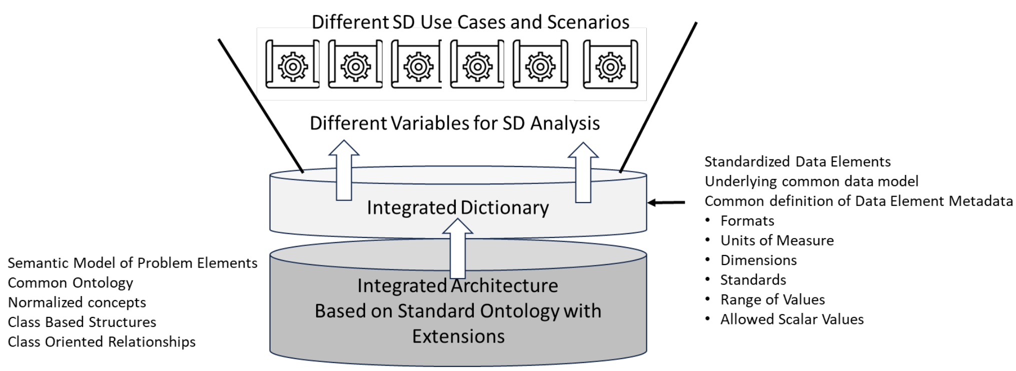

Figure 4 Unifying Multiple SD Simulation Efforts

Specific Advantages to EA Efforts

Adding SD modeling to EA efforts could identify what, where, or how sociocultural factors might impact the long-term success or risk of failure of various transformational phases of the effort. Failures in EA efforts are frequently caused by sociocultural factors. For example, large and expensive governmental projects have failed at least partly due to lack of user acceptance of transformational changes to the way they performed their work. [SENAT 2014] Investigations into some of these failures have identified issues such as inadequate user training, failure to track user reaction to the user training that was provided, lack of appropriate management involvement or agreement in the changes, or lack of consideration of the impact the changes made on the users' other required activities. In some cases, the changes made the users' work more difficult instead of easier. All these types of issues involve sociocultural factors that were not included in the EA modeling and might be difficult to capture in the usual type of EA modeling. Adding SD modeling could also help in identifying potential risks in the next planned transformation phase and how changes in the current transformation phase might impact the planned changes in the next phase.

Synergy: Incorporation of Emergence in Planning Models

The use of both SD and EA techniques together could improve risk identification and risk management especially in the case of unanticipated risks of an emergent nature. Simulations (mental or computer supported) can explore potential impacts due to various types of emergent behavior such as change in management culture due to mergers and acquisitions or changes in worker behavior driven by the rapid evolution of technology. Right now, the rapid expansion of AI technology is driving massive change in what is possible in the workplace and will bring changes in regulations and laws, all of which is bringing unplanned changes in enterprises and socio-technical Systems.

In addition to improving risk management, the use of both SD and EA techniques together could identify elements, such as sociocultural factors, that were missing in either EA models or in SD models so that these elements can be added into other models where they were missing, thus strengthening the accuracy of the overall set of models and their results.

Forensic Analysis of Socio-technical Systems

Forensic analysis of project and product failures in socio-technical Systems is important for extracting lessons learned and identifying causal factors that may need more attention in the planning and analysis of similar projects and products. Using EA and SD together could support a more holistic forensic analysis of failed socio-technical Systems. As Heidegger states only when a hammer is broken is there an incentive to look at the inner structure of the hammer. When the hammer is unbroken, its utility serves to mask the need to understand the inner workings. Similarly in a socio-technical System, a major failure or catastrophe provides the impetus to analyze the causes for that failure. Analyzing a socio-technical System failure involves looking at potential failure modes in the social aspects as well as the technical aspects of the System and exposing possible causes.

Often, once the socio-technical System is deployed, external factors start to change both the technical and social aspects of the system. These external factors arise from emergent phenomena that could neither be anticipated nor planned for. These emergent factors sometimes are the cause for the failure of the socio-technical System. Analysis of a socio-technical System's failure yields clues to deficiencies in the initial technical design of the system, mistaken design assumptions that were not borne out during the operation of the system, or emergent factors that may or may not have been predictable, and that may or may not have resulted from continuous patching and refactoring of the system over time.

In the event of serious product or project failures, a combination of EA and SD could be used to investigate, document, and understand the causes of the failure. Current forms of investigatory reports usually discuss results textually and focus on the short-term causes or the technical causes of the failure. There is no modeling involved and no graphics, such as SD Causal Loop Diagrams, to explain the cause-and-effect issues and summarize the overall text. (Pictures speak louder than words.) Current reports do not always explain underlying causes especially when these underlying causes include sociocultural factors that have evolved over many years. EA and SD modeling can be used to document these underlying causes and trace these causes to recent failures.

For example, Boeing's recent string of failures, starting with the two fatal crashes of the 737 MAX 8 in 2018 and 2019 and followed by groundings, continuing serious delays in deliveries of airplanes and costly rework driven by poor quality assurance, lawsuits with Boeing's airline customers and passengers, and potential loss of business plus the most recent problem of having a "door plug" pop out of the side of a 737 MAX 9 after takeoff have caused discussion about how Boeing's old reputation for excellence in engineering and safety is being destroyed. [CTI 2020, GATES 1-2024, ROSEN 2024, GATES 1-2024, KOEN 2-2024, GATES 2-2024]. After the MAX crashes, there was at least one opinion published that pointed to changes in Boeing's executive management priority with their espoused values as an underlying cause of the crashes. That is, there was a change from safety and engineering quality as top priority to profit as the top priority. Recent opinion pieces in The Seattle Times, The Wall Street Journal, The New York Times, and Aviation Week have all pointed to a change in Boeing executive management's *culture* after the merger of Boeing and McDonnell-Douglas in 1997 as the underlying source of the current problems. [KACI 9-2019, TALT 2024, TERL 1-2024, SAPO 2023, ABUL 2024] However, in these textual discussions it is difficult to identify the long-term chains of cause and effect. Some modeling could make these chains of cause and effect clearer and strengthen these arguments.

We are exploring an empirical model for the hierarchy of perceived causes of socio-technical System failure based on the patterns of initial finger pointing turning into deeper cultural causes on further analysis [ROBI 11-2021, GATES 8-2022, KOEN 3-2022]. The empirical model is based on the 5 Why approach to determining the root causes for failure [OHNO 1988] by iteratively asking the "WHY" question. In the specific case of Boeing: the first inclination was to blame the pilots, followed by faulty maintenance, followed by determining that an undocumented, piece of software was pushing the plane down against the pilot's efforts to climb, followed by the decision not to document or re-certify the plane dues to a cost implication, followed by the recognition that such cost decisions were endemic to the culture of the company with more failures ready to occur.

Figure 5 illustrates our initial starting point for a hierarchy of failure causes in the top to bottom order that they are usually found.

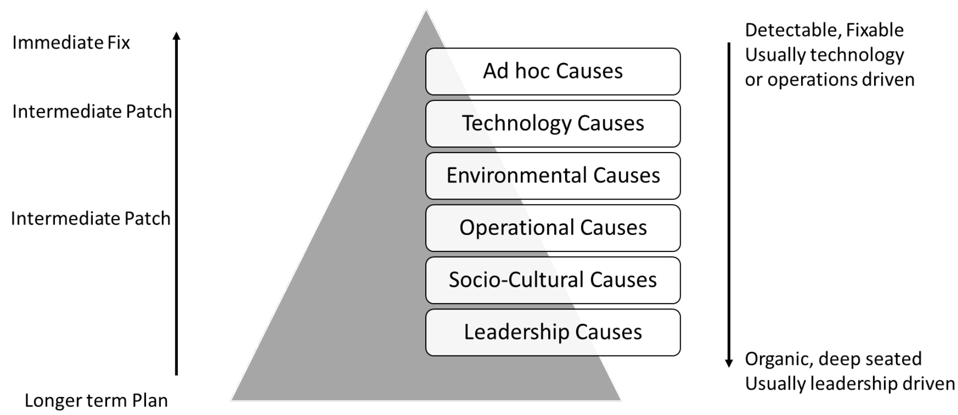

Figure 5 Failure Cause Hierarchy

Summary and Future Research Goals/Areas

Summary of approach and findings

We set out to investigate an open-ended way of expanding and growing an integrated approach to describing and analyzing socio-technical Systems. As a first step, we started with an investigation of how the approaches of System Dynamics and Enterprise Architecture can be integrated to get a wider view of socio-technical Systems.

We started with an ontological approach to allow normalization of the terminology for groups of analysts across the enterprise. This approach provides a way of relating the elements of various modeling techniques from SD and EA to create integration between the models across viewpoints and models and allow an extended, overall analysis of socio-technical Systems. The benefit of this approach is the ability to use SD and EA techniques in tandem while enabling mapping the modeling elements of EA and SD to each other. Consistent naming of model elements creates a way to integrate findings from both techniques.

Future research work areas

There are several areas that need further work. First, we need to finish the expansion of the DoDAF ontology and test it by developing one or more large case studies. The textual investigation reports and other material on the Boeing MAX product failures and the ECSS project failure provide plenty of information for two such case studies. In addition, there are at least two new potential new viewpoints that can be added to EA together with the additional ontology entity types and relationships that these viewpoints need. These two viewpoints are: a Finance Viewpoint to include standard commercial financial models and a potential Culture Viewpoint to further help integrate sociocultural factors into EA. This work would include integration of new models into existing model sets, potentially expanding the ontology further, and developing example models to illustrate the use of the new viewpoints and their synergy with SD techniques. The Financial viewpoint serves the analysis of financial factors that affect and modulate the structure and behavior of the enterprise. The Cultural Viewpoint would serve the analysis of social scientists looking at the effect of culture on structure and behavior.

While we have used the DoDAF as an example ontology standard there are other EA frameworks such as The Open Group Architecture Framework (TOGAF) that are not ontology based, but rather based on a collection of models that have overlapping ontology concepts; cases where two different types of models call the same concept different names. [OPEN 1] The integration that comes from a unified ontology, within the DoDAF stems from a very simple abstract foundation ontology that abstracts all underlying objects as a few top-level objects. We have yet to study the application of some of the techniques described in this paper to other EA frameworks than the DoDAF.

Appendix: Terminology and Acronyms

This section provides short definitions for some of the terminology and acronyms used in this paper. Since some of the definitions are related, the definitions are listed in three categories: Sociocultural factors, enterprise architecture, and System Dynamics.

Terminology

Socio-technical System: Socio-technical Systems are comprised of a technical component as well as a sociological component. This dual nature of begs an interdisciplinary approach to their construction, operation, sustainment, and ultimate demise. In the area of information technology, the science of systems engineering is used to design as many aspects of the socio-technical System as the designers can foresee. But during actual operation and deployment of these systems, failures occur that are often a result of the sociocultural factors that surrounded the operations of the System working in conjunction with the technical inner workings of the system.

Systems Thinking: The uniqueness of Systems thinking entails a differentiation from traditional analysis that separates individual pieces of what is being studied. Instead, Systems thinking focuses on how the things interact with the other constituents of the System. The System is a set of elements that interact to produce behavior. Systems thinking involves expanding views to consider larger numbers of interactions as an issue is studied. The defining characteristic of a System is that it cannot be understood as a function of its isolated components.

system: A technology-based collection of components that is designed and engineered based on a set of requirements or assumptions about the way it will be used and the context in which it will be used.

System Dynamics (SD): System Dynamics provides a set of techniques to model and analyze the dynamic behavior of Systems over time. These techniques include Causal Loop and Stock and Flow models.

Culture: Culture is manifested as written and unwritten rules of behavior. These rules constrain behavior, and cultural rules can modulate behavior to conform with cultural norms. In the absence of cultural constraints, behavior is determined by the other factors that also constrain such as policy, regulations, law, and guidance.

Sociocultural Factors: Sociocultural factors affect the social side of socio-technical Systems, that is, the human behaviors that surround the design, construction, operation, and sustainment of technology systems and can modulate the outcome of operating the technology system for better or for worse. Note that we are talking about the practice and concepts of Sociology, i.e., sociocultural factors, and not the discipline. (Anthropology and Sociology are dealt with together.)

Organizational Tribes: Organizational tribes (also known as workplace tribes or subcultures) are informal groups or subcultures that form within an organization outside the formal organizational structures. Tribalism modulates formal organizational structures by adding informal connections between organizations and roles.

Context Difference: Context Difference is the awareness of the scope of the context between two collaborating performers. Context awareness is dependent on factors such as experience, skill, observation powers, sensitivity to emotional climate etc. Context difference applies to relationships and not to individual performers. High context (need for less info) and Low context (needs for more info); High (need for high involvement) and low interest (low need for involvement).

Risk Management/Risk Tolerance/Uncertainty Avoidance: The purpose of risk management is to identify potential problems before they occur so that risk-handling activities may be planned and invoked as needed across the life of the product or project to mitigate adverse impacts on achieving objectives. In simple terms, risk management is the continuing process to identify, analyze, evaluate, and treat loss exposures and monitor risk control and financial resources to mitigate the adverse effects of loss.

Power Distance: Power is manifested as a power difference or distance between two collaborating performers, or two communicating parties. That is, Power difference/distance is a characteristic of a relationship between individuals or organizational units/tribes. Power differences can modulate communication content at the source itself despite any additional noise introduced by the type of communication. Power difference, not absolute power matters. Difference may be based on legitimacy (i.e., direct reporting or chain of command) or by force of personality or informal leadership.

Enterprise: An enterprise is an undertaking that is beset with risk and uncertainty. Enterprises can be simple or complicated and complicated or complex. An enterprise can be a project, a business unit, a governmental agency or a military unit, for example. An enterprise is not necessarily a single organization but can span multiple organizations that collaborate to achieve a common mission. Note that an enterprise is usually a socio-technical System and usually not a technological system alone.

Ontology: An ontology is a mechanism for formally representing knowledge about a domain. An ontology specifies the concepts that describe the domain and relationships among those concepts. That is, an ontology provides a vocabulary of terms that describe the aspects of a domain. One of the primary purposes of ontologies is knowledge sharing and reuse. An ontology can therefore be seen as a formal vocabulary that becomes the basis of a common understanding and sharing of knowledge about a domain or across related domains.

Enterprise Architecture: An enterprise architecture is a description or representation of the structure and behavior of an enterprise. An architecture makes explicit the elements of an enterprise that contribute to fulfilling the mission and purpose for which the enterprise

exists. Usually, a specific enterprise architecture follows the standards and structure provided by an architecture framework.

Architecture Framework: An architecture framework provides standards and structures to conceptually organize, divide up, and represent the vast scope of architecture elements and relationships that comprise the enterprise architecture description. An architecture framework typically subdivides the architecture elements by viewpoints of different stakeholders based on the correlation between a particular element and its visibility to the stakeholder. Not all elements are relevant, of interest, or visible to all stakeholders. The examples we use in this paper reference the Department of Defense Architecture Framework (DoDAF) but detailed knowledge of this framework is not necessary to understand this paper.

Acronyms

BCA: Boeing Commercial Airplane

CLD: System Dynamics Causal Loop Diagram FAA: US Federal Aviation Administration

DoD: US Department of Defense

DoDAF: US Department of Defense Architecture Framework

EA: Enterprise Architecture

SD: System Dynamics

SFD: System Dynamics Stock and Flow Diagram

TOGAF: The Open Group Architecture Framework

US: United States

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