CONNECTING SYSTEMS SCIENCE, THINKING, DYNAMICS AND ENGINEERING TO SYSTEMS PRACTICE FOR MANAGING COMPLEXITY

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ABSTRACT

Few organizations are fully integrated, program and engineering disciplines often work in isolation, and most organizations have misgivings in their ability to manage complexity. On the other hand, there are a few bright spots by way of mature forward-looking organizations that have achieved limited integration through Systems Thinking, advanced models and tools. This requires overcoming the hurdles of resistance to change and adopting new best practices.

Complexity is inherent in the organization, its stakeholders and in its cross-functional processes. In large technical projects, complexity exists within the product design and its interrelated components. Adding to this complexity, how the techno-socio-economic and cultural factors affect the organization, its processes and product are not well understood.

This disconnectedness and inability to understand underlying relationships have led to project cost overruns, rework and delays. Despite the use of traditional discipline specific-tools and models, product and project failures continue. When problems occur, shifting the burden from an optimal solution to a quick symptomatic solution can often occur without easy-to-use integrated decision support tools, as well as the processes for using them.

It has been recognized that integrated decision support tools and models are needed to overcome the challenges in managing complexity. However, for these tools to be useful, they need to address the complexities of the organization, processes, product and the practical hurdles that affect them. As well, these tools need to monitor the emergent behaviour and performance of these connected entities throughout the product lifecycle.

There are a number of foundational pillars proposed for the integration of organizations and the development of integrated tools. These pillars include Systems Thinking, dynamics, engineering and a digital thread between discipline specific models and tools.

Systems Thinking provides for a new perspective and appreciation of the interrelationships within an organization, its processes and its product design. System Dynamics (SD), as a rigorous tool for Systems Thinking, provides for an understanding of the factors and complexity in these interrelationships. Systems Engineering (SE) looks at the design, integration and management of complex systems. With advancement of data analytics, visualization and intelligence augmentation comes easier construction of digital threads for connecting disparate models and tools. Integrated management models can facilitate and add rigor to Systems Thinking and reduce complexity through a better understanding of interrelationships. Moreover,

a well constructed integrated model can provide for the gaming of change scenarios, trade studies, knowledge growth, and a decision support tool for optimal solutions.

Standards are in the works for developing digital threads and frameworks to enable integration. However, the challenge is much broader than just solving the digital thread interconnection issue. With use of existing technology, Systems Thinking and systems dynamics, an integrated decision-support model was developed and presented at the International Council on Systems Engineering Project Management (PM) and Systems Engineering (SE) Integration Working Group (Jonkers 2020, INCOSE PM-SE WG). However, the authors of the current paper experienced resistance from SE and PM practitioners and senior leadership at this forum. Similar resistance was experienced during presentation of the model to mature engineering companies that designed and manufactured safety critical products. These hurdles and potential ways to overcome them are discussed in this paper.

Partially integrated models and tools exist in systems engineering, project management and the social sciences. Model-based systems engineering and integrated model-based tools have made inroads predominately in the aerospace industry, but for the most part, there has been reluctance to adopt such tools. While a structured approach by way of foundational pillars has been proposed, it can be difficult for organizations to decide what tools to adopt without a roadmap or process to guide them.

As a first step, increasing knowledge in Systems Thinking is viewed as a catalyst in moving toward integration of people, processes and the product. Systems Thinking has been viewed as the cornerstone to enabling positive outcomes including shared perspectives and a shared vision, knowledge growth and a learning culture.

The next step involves shaping a governance framework based on proposed foundational pillars for integration. This framework includes best practices by associations that offer practical tools for integration. These associations include those who follow a systematic planned approach such as six-sigma methodology and systems engineering.

INTRODUCTION

Studies reveal that only 16 percent of organizations are fully integrated and that over 60 percent of complex projects fail in terms of cost overruns and delays. The lack of planning, authorities not clearly defined and conflicting practices were noted as the top three sources leading to project management and systems engineering unproductive tension, where unproductive tension is defined as any issues between the different disciplines that might negatively affect performance (Rebentisch 2017). Conflicting practices can arise from different discipline processes, practices, models and tools. These disciplines can often work in isolation where the lack of communication and collaboration can lead to cost overruns and schedule delays in complex projects.

Connecting systems science, thinking, dynamics and engineering to systems practice for managing complexity

The integration of PM and SE disciplines has been defined as:

> *"a reflection of the organization's ability to continue program management and systems engineering practices, tools and techniques, experience and knowledge, in a collaborative and systematic approach, in the face of challenges, in order to be more effective in achieving common goals/objectives in complex program environments"* (Rebentisch 2017).

From this definition, it's clear that the elements of tools, models, collaborative practices, and knowledge are important factors in developing an integrated model and practice for product and project success.

While there are philosophical requirements and concepts for this integration, the challenge remains in understanding the underlying interrelationships, hidden influences and how to put theory into practice. Moreover, it is not apparent that there has been research into a single standard, practical approach, common language or platform for this integration.

In the current study, the integration of the product, disciplines, their respective processes, and key models and tools is viewed as positive step toward increasing collaboration, product and project performance, and decreasing unproductive tension.

Integration of disciplines has been viewed as an enabler to project success with the key elements of integration consisting of rapid decision-making, collaborative work, information sharing, and a culture of risk management (Rebentisch 2017).

In a survey conducted by the Project Management Institute (PMI), more than half of organizations expressed doubt in managing complexity. It was highlighted that ambiguity in expectations and managing multiple stakeholders were rated as top defining characteristics of complexity (Cooke-Davies 2013).

There can be complexity in the entities of the product, organization, environment and management processes. Systems Science, Systems Thinking, SD and SE can be used together to connect these entities to better understand their complexity. In order to solve complex problems, it has been recognized that an integrated systems approach needs to include Systems Science, Systems Thinking and SE (INCOSE 2015).

It has been widely accepted that Systems Thinking is critical in addressing social and economic challenges. As systems evolve, Systems Thinking can help in realizing options in decision-making and help to transcend disciplines and culture (Meadows 2008).

BACKGROUND

In previous work, Systems Thinking, SD, SE and a digital thread were applied in bringing the different engineering and program management elements together as a whole within an integrated management model, namely a Management Flight Simulator (MFS). These elements included data, sub-models, cross-functional processes, and the techno-socio-economic and cultural factors affecting product, organizational and program management performance (Jonkers & Shahroudi 2021).

The MFS provides a different perspective on measuring and visualizing this performance, with several variables, parameters and attributes that may be captured and shared using SE and PM models and tools. The linking of these models is achieved through a unique digital thread or knowledge graph of transformational variables, as depicted in Figure 1.

The framework for the MFS is built on seven integration pillars, consisting of: Systems Thinking and SD, integration factors and requirements, selection and integration of sub-models, a digital thread of linkages, set-based design approach for a robust design, action learning and agile principles for proactive risk and design change management, and inter-disciplinary informed decision-making.

The MFS and its decision support system (DSS) incorporate the design attributes of performance, survivability and operational capability. The extension of these attributes well into a project and beyond, using a Multi-Attribute Tradespace Exploration (MATE) model, provides a new value space that is of importance in the design and lifecycle management of complex systems.

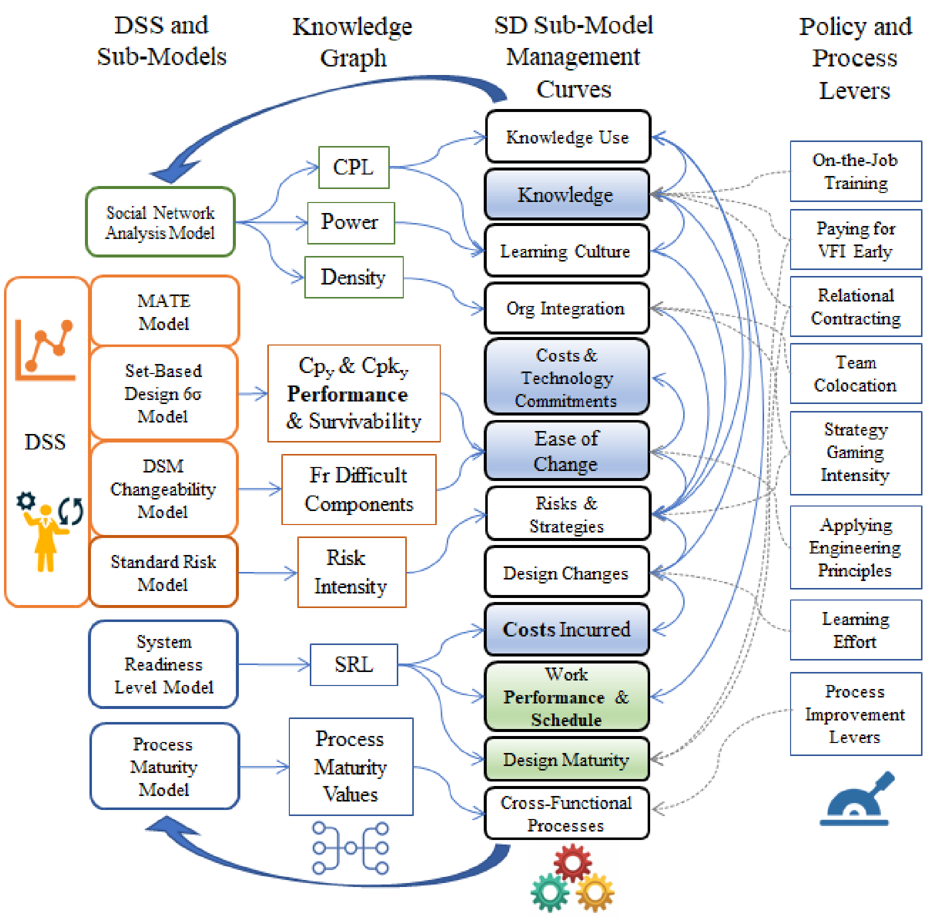


Figure 1. Management Flight Simulator Elements and Linkages

The DSS includes a novel integrated Standard Risk Matrix (SRM), Design Structure Matrices (DSM) and a component changeability dynamic chart. The MFS is supported by a SD model that captures several lifecycle management curves. Other key supporting models include a Systems Readiness Level (SRL) model, Social Network Analysis (SNA) model and a Process Maturity Model (PMM). Each of these integrated models has an important function that addresses the challenges and techno-socio-economic-cultural factors in design change, new technology management and in managing complexity. Complexity may be managed through multiple views and through managing the impact from system changes (INCOSE 2015). The MFS provides a platform for multiple perspectives and the gaming of solutions in response to technical and programmatic risks.

The MFS working prototype was presented at the INCOSE IW2020 WG, with PM and SE members participating in a survey following its presentation. The purpose of the PM-SE sub-working group is to identify and promote opportunities associated with the effective integration of PM and SE disciplines. This includes exploring the linkages necessary to create effective integration and collaboration between these disciplines.

Common themes for integration requirements were translated into survey questions, as listed in Table 1. These eleven questions pertain to the purpose, requirements, and potential benefits from using an integrated systems approach and the MFS in the real world.

Table 1. Survey Questions Related to Integration Requirements and Benefits

Q	How do you rate (*Low 1 to Very High 5*) the potential of the Management Flight Simulator to:
Q1	Improve Communication and Collaboration?
Q2	Increase early Knowledge, Learning and provide Mental Models?
Q3	Proactively address risks and promote a Risk Management culture?
Q4	Promote learning and application of Systems Engineering and its models?
Q5	Provide different Perspectives for addressing Complexity?
Q6	Enhance Tradeoff Analysis and Optimize design change Decisions?
Q7	Increase Product Quality?
Q8	Improve Project Performance and foster Continuous Improvement?
Q9	Address techno-socio-economic and cultural factors?
Q10	Represent real world systems, predict and analyze behavior?
Q11	Advance the field of Systems Engineering and Project Management integration?

The response to these questions was based on a rating from low (1) to very high (5) in terms of satisfying the integrated systems approach and ability of the MFS to meet key integration requirements, the results are depicted in Figure 2.

One of the lowest rated responses was Q10 (represent real world systems, predict and analyze behavior). The response to Q10 in the current survey reinforces the challenge in achieving model credibility and highlights the resistance to adopt integrated models, like the MFS.

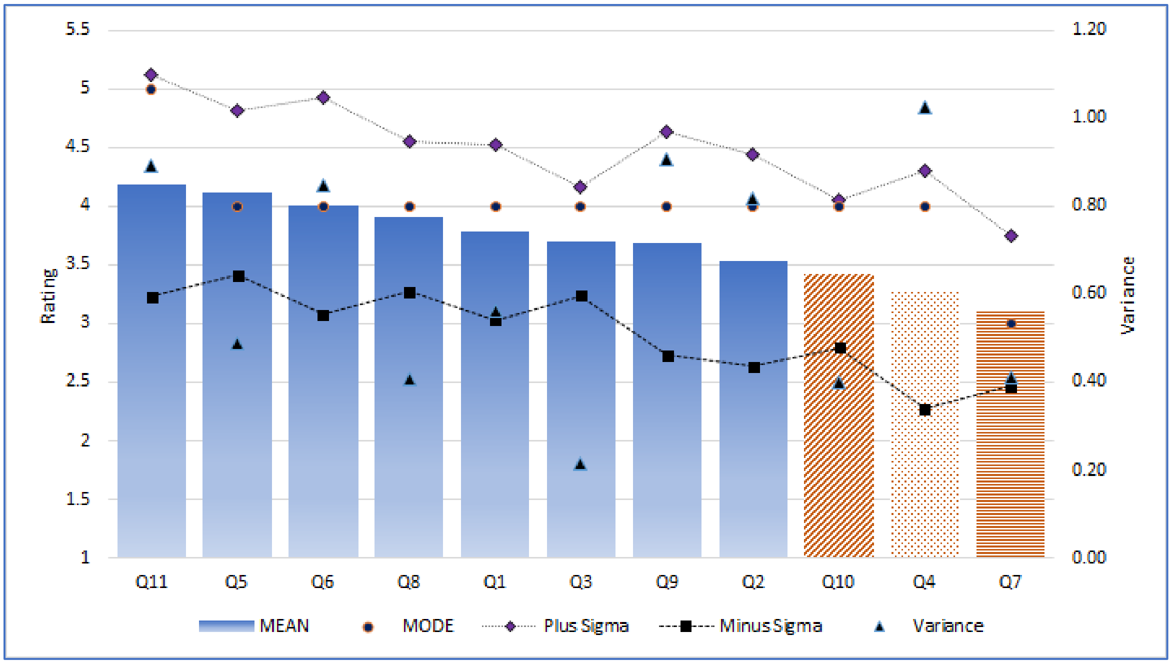


Figure 2. Statistical Measures for The Eleven Survey Questions

As noted in a separate survey, only three percent of high technology organizations use model-based systems engineering tools to capture data and only 29 percent use a MBSE approach (Cameron 2018). In the same survey, the quality of great models most difficult to achieve in MBSE was noted as model credibility.

Another response that was rated relatively low was Q7 (increase product quality). This may be related to a lack of understanding of how the complexity in products and projects can be better understood and managed with a systems approach and integrated models and tools. Moreover, there may be a narrow perspective on product quality in terms of existing limited standardized management systems.

Also, in the bottom three, Q4 (promote learning and application of SE and its models) was rated relatively low. The return on investment from applying systems engineering efforts has been investigated in other research where 14.4 percent of program costs invested in systems engineering was assessed as optimal for project success (Honor 2013). The effort expended in using the MFS and the gaming of design change scenarios is estimated at well below 14.4 percent.

The remaining survey questions and responses were rated relatively high and are relevant to the current study. This includes a systems approach and integration of the product, organization and its processes, models and tools.

Challenges with proposed processes to integrate project complexity and risks include limited support from senior management and the requirement to populate sophisticated models with data (Qazi 2016).

This resistance may be translated into a lack of knowledge in Systems Science, Systems Thinking, SD, SE and the benefits that the integrated systems approach and model can offer in addressing complex problems. Moreover, the level of effort in developing, implementing and sustaining such a model can present a major challenge without a single standard and a guidance document to put it into practice.

In order to develop this standard and practice, a systems approach, and the entities and processes integrated within the MFS are investigated.

DISCUSSION

Systems Approach

In the natural Systems Science world, there exist systemic governance, collaboration and mechanisms in place to ensure sustainability of the system (Mobus 2015). In the man-made world of engineering and program management, cooperation and collaboration require formal coordination of multiple entities through systematic structured governance.

In Complex Systems Science, there is a focus on how components within a system are related to one another, these systems can be physical, biological and social. Conceptual frameworks do not hold for many complex systems and alternative frameworks are needed to understand the properties, emergent behaviour and patterns of complex systems. At the same time, the general properties of systems as a whole can be sufficient to develop a suitable framework for discovering new ideas, applications and connections. Taking a step back and considering a space of different system behaviours can not only be applied to physical systems but also to biological and social ones (Siegenfeld and Bar-Yam 2020).

In previous work, high-level attributes in the MFS were captured for a ‘non-toy’ Integrated Power System (IPS) case study (Jonkers & Shahroudi 2021). The framework for the MFS provides a holistic perspective of the interconnected technical, social and management processes.

There are many perspectives on what Systems Thinking, SD and SE are and what they consist of. Systems Thinking draws from the fields of philosophy, sociology, organizational theory and feedback thought. SD simulates systems, predicts future behaviour and is a mechanism to practice Systems Thinking. It has been stated that SD methodology is the best tool for a diverse range of problem situations. SE is systematic rather than systemic as it decomposes the problem and analyzes each component. (Caulfield & Maj 2001).

It has also been stated that Systems Thinking helps to ensure the correct system boundary and attributes for trade-off analysis in the design process, it concerns understanding the system in a social and human intention context. Key elements of Systems Thinking include whole system thinking, and understanding dynamic behaviour and stakeholder interests (Sillitto 2014).

Systems Thinking may also be thought of as a set of tools and knowledge that allow individuals to see patterns more clearly so that they may act on these patterns. It includes looking at patterns from a holistic viewpoint rather than small unrelated manageable parts (Senge 1990).

It has been stated that systems, including organizations, have integrity and that their character depends on the whole. This requires looking at the whole picture, including major functions, issues and interactions in order to understand the most challenging managerial issues (Senge 1990). When managers and leaders divide organizations into parts, the interactions and the whole can become obscure, resulting in a lack of information, integration and collaboration; Figure 3 depicts this problem.

In this cartoon, several blind men interact with a different part of the elephant, assuming that what they are interacting with is the whole elephant. They do not see that they are interacting with one piece of something larger and more complex.

It takes a systems approach and the right integrated models to help enable collaboration amongst stakeholders, an appreciation of different stakeholder perspectives, and to understand that the elephant consists of all the parts that they describe.

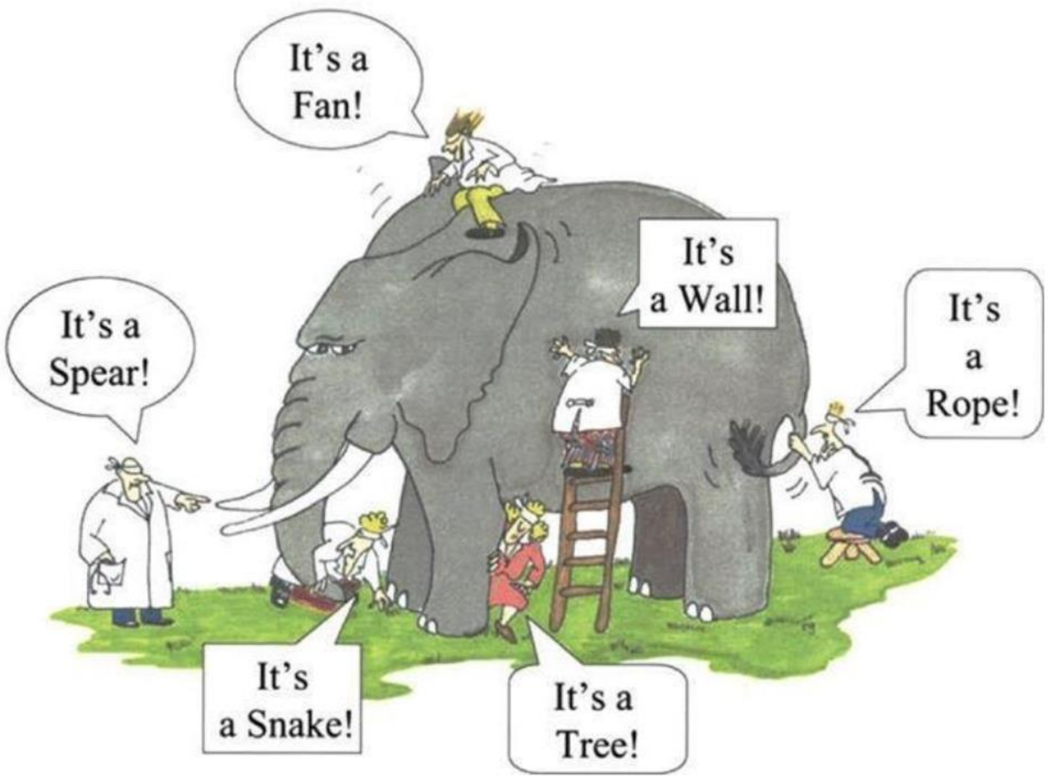


Figure 3. The Challenge of Enabling Diverse Stakeholders to See The Big Picture (Jones 2020).

The principles of managing patterns and seeing the whole picture were applied to the MFS in terms of capturing dynamic physical system attributes for trade-off analysis, as depicted in Figures 4 and 5. The outputs from this DSS were used as inputs into management curve SD models within the MFS.

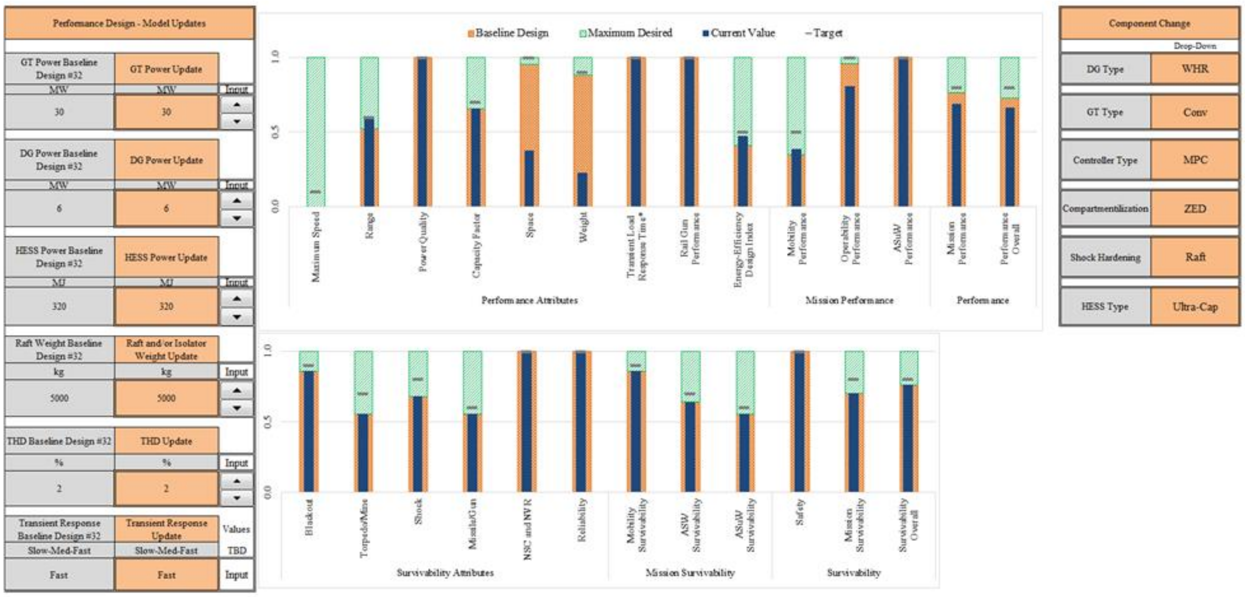
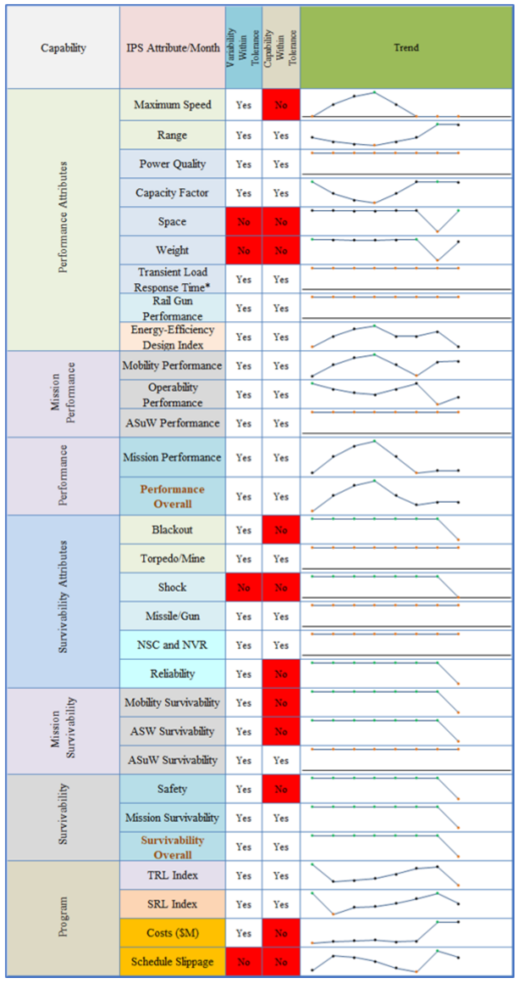


Figure 4. Decision-Support System Attribute Trade-Off Dynamic Interactive Dashboard



Capability	IPS Attribute/Month	Variability Within Tolerance	Capability Within Tolerance	Trend
Performance Attributes	Maximum Speed	Yes	No	
	Range	Yes	Yes	
	Power Quality	Yes	Yes	
	Capacity Factor	Yes	Yes	
	Space	No	No	
	Weight	No	No	
	Transient Load Response Time*	Yes	Yes	
	Rail Gun Performance	Yes	Yes	
	Energy-Efficiency Design Index	Yes	Yes	
Mission Performance	Mobility Performance	Yes	Yes	
	Operability Performance	Yes	Yes	
	ASuW Performance	Yes	Yes	
Performance	Mission Performance	Yes	Yes	
	Performance Overall	Yes	Yes	
Survivability Attributes	Blackout	Yes	No	
	Torpedo/Mine	Yes	Yes	
	Shock	No	No	
	Missile/Gun	Yes	Yes	
	NSC and NVR	Yes	Yes	
	Reliability	Yes	No	
Mission Survivability	Mobility Survivability	Yes	No	
	ASW Survivability	Yes	No	
	ASuW Survivability	Yes	Yes	
Survivability	Safety	Yes	No	
	Mission Survivability	Yes	Yes	
	Survivability Overall	Yes	Yes	
Program	TRL Index	Yes	Yes	
	SRL Index	Yes	Yes	
	Costs ($M)	Yes	No	
	Schedule Slippage	No	No	

Figure 5. Decision-Support System Trending of Physical System Attributes

Four key management curves from the MFS SD models and levers of influence are depicted in Figure 6. The SD models represent predicted states of management curve behaviour based on inputs from other sub-models within the MFS. This dynamic set of SD models and interactive levers provide for the gaming of solutions and what-if scenarios in response to risks and product changes.

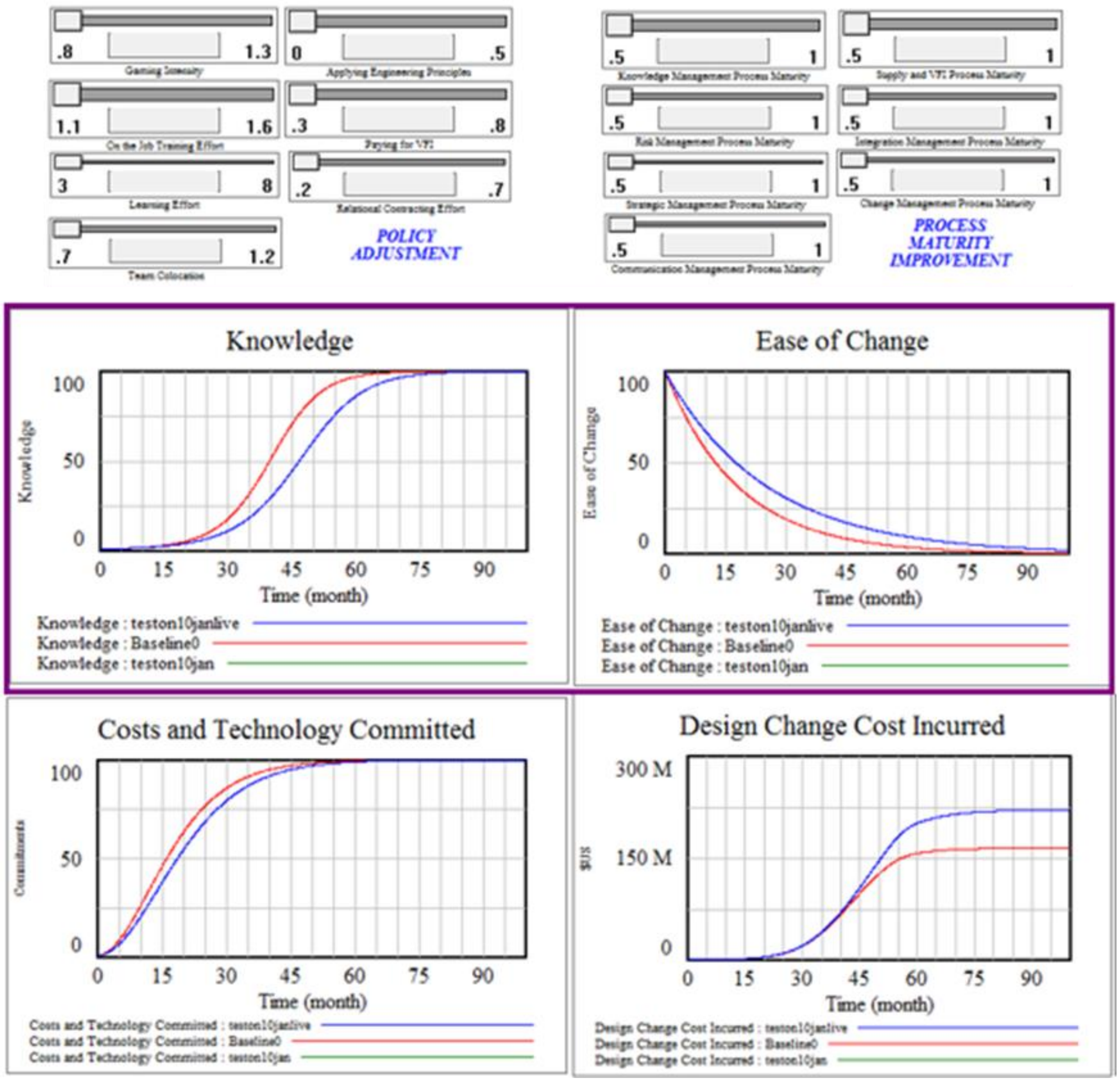


Figure 6. Predicted System Dynamic Management Curve Behaviour and Levers of Influence

There were several causal-loop diagrams (CLD) and SD models developed within the MFS that rely on a number of inputs including those from the DSS design attribute trends, SNA, SRL, and process maturity sub-models. One of these SD models is depicted in Figure 7, it predicts work performance, provides a new perspective, and serves as a complementary tool to traditional project management tools.

In SD model development, flows and stocks are determined (Sterman 2000). Feedback loops can be either positive reinforcing (R) loops or negative balancing (B) loops. The behavior of a stock level (S), or management curve within the MFS, may be described by the integral of inflows minus the outflows, and an initial stock level (S_{t0}).

$$S = \int_{t_0}^{t} (Inflows - Outflows)\, dt + S_{t_0} \tag{1}$$

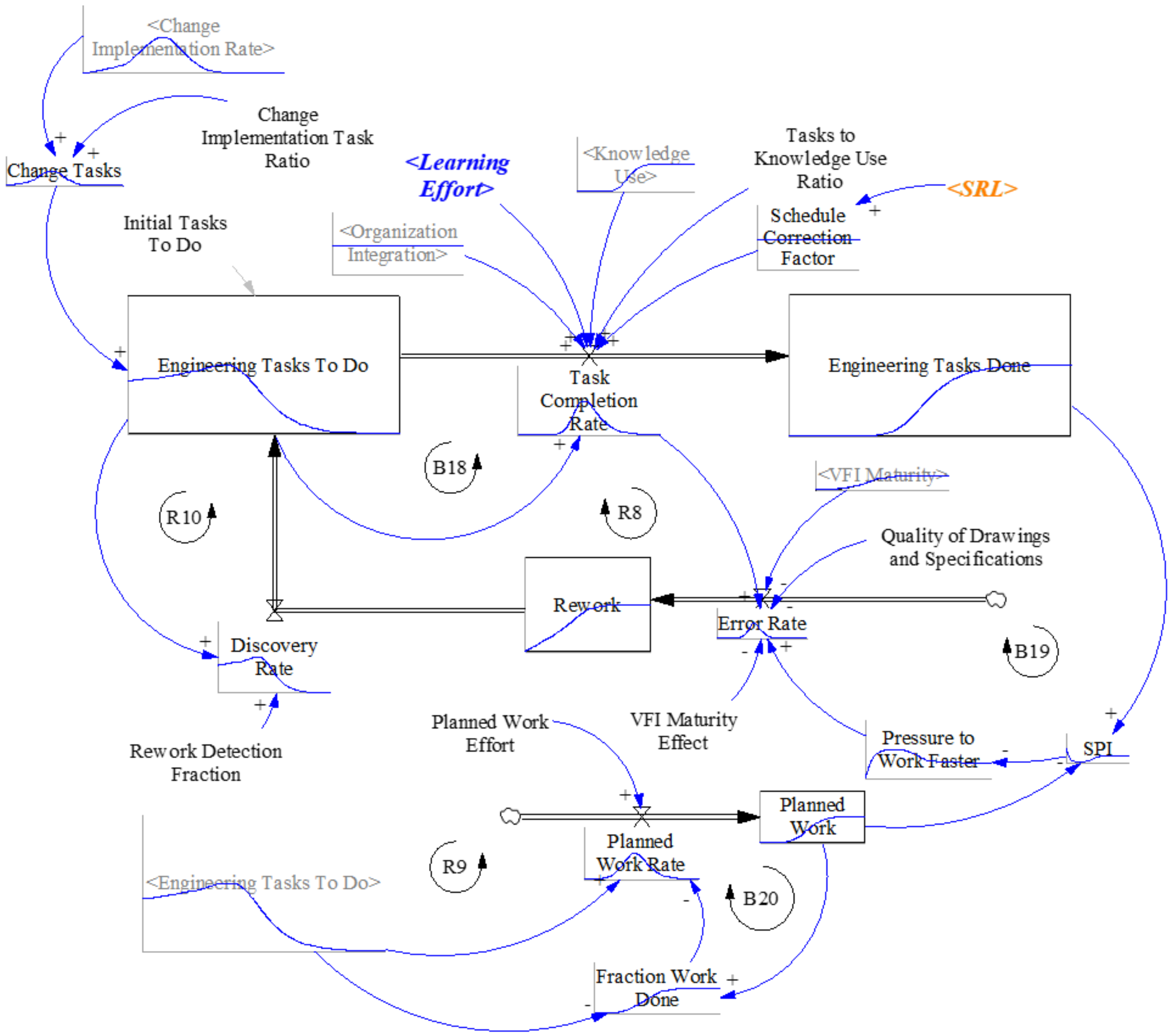


Figure 7. System Dynamics Sub-Model Example for Work Performance

SE can be viewed as an interdisciplinary approach, concerned with the function, behaviour and performance of the system in meeting stakeholder needs. SE depends on Systems Thinking to understand the characteristics of the system and to identify purpose, value and stakeholder alignment (Sillitto 2014).

Not only does SE and SD rely on Systems Thinking, project management and Systems Thinking have overlap that in turn can produce benefits. However, project managers do not use System Thinking tools even though they can provide benefits in framing and solving problems that arise from multiple relationships and perspectives. Both project management and Systems Thinking share a lifecycle and have transitioned to including softer side people-centric issues such as motivation, team forming, stakeholder management, communication and leadership (Sankaran, Haslett & Sheffield 2010).

Connecting systems science, thinking, dynamics and engineering to systems practice for managing complexity

The steps in Systems Thinking may include defining the problem, structures, events and patterns, mental models, root causes, and assessing improvement (Kim 1999). These steps have overlap with SE, SD and the elements of complexity, as depicted in Figure 8. System and management curves of performance exhibit patterns and emergent behaviour that may be examined using SE and SD models and tools. Events can include environmental factors, issues or changes to the physical system. The gaming of solutions within the MFS, in response to risk events and likely design changes, can help predict the consequences of change prior to action and commitments.

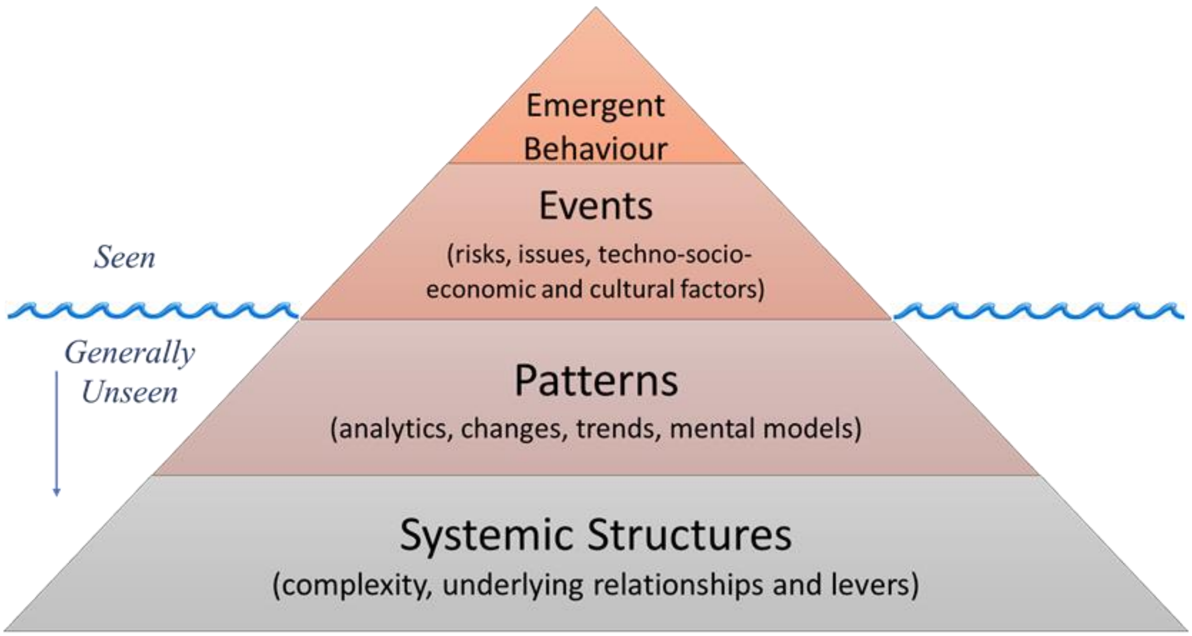


Figure 8. The Systems Iceberg (Adapted Kim 1999)

One study indicated that these steps are not adequate for studying complex systems where conditions are constantly changing and that a new framework is required. In response, a theoretical framework was proposed, called The Flow System (TFS) consisting of complex thinking, distributed leadership and team science (Turner, Thurlow & Rivera 2020). On the other hand, SD modeling can allow for changes in system state over time, this was included as a key component in the MFS. While the TFS appears to have merit, additional elements were included in development of the MFS as part of the seven foundational integration pillars.

Complex projects continue to incur cost overruns and delays despite the use of traditional models and tools. Traditional program management and performance measurement tools have failed to solve persistent project problems. The associated measures are viewed as lagging and can lead to late awareness of problems and poor project performance. Monitoring complex projects is difficult using traditional measures and do not consider the techno-socio-cultural factors (Sterman 2000 & Walworth 2016).

There can be complexity in the entities of the product, organization, environment and management processes. These entities are interconnected and are affected by techno-socio-economic and cultural factors.

Connecting systems science, thinking, dynamics and engineering to systems practice for managing complexity

Complexity in these interconnected entities and factors can be difficult to understand without a new way of thinking and new integrated models and tools. Furthermore, there can be resistance to introduce these models and tools without a governance structure for their development, implementation and sustainment. This governance structure must include a best practice in a systems approach and a standard for integrating the product, disciplines, models and tools.

The use of Systems Thinking, the MFS, SE tools, decision-support systems (DSS) for trade-off analysis, and SD models is viewed as mechanism to navigate and address complexity.

Complexity

Project complexity can evolve and may be found in organizational structure and size, competency requirements, threats and opportunities, and in the consequences from decision-making. Factors contributing to project complexity include the environment, resources and the number of entities in the workflow. Other factors include organizational objectives, the different stakeholders and interrelationships, division of labour, technology and specialization, and the overlap of management processes and work practices (San Cristóbal 2018). This overlap of processes and practices can cause confusion and make it difficult to implement integrated models like the MFS.

Project complexity can also relate to the physical elements and their interaction across technical, organizational and environmental domains (Qazi 2016). Within the MFS, an integrated complex physical system was studied in terms of its interaction across these domains.

There has been a significant increase in organizational complexity over the years. One study proposed an "index of complicatedness" as a measure of this complexity. This measure considers the number of company requirements, procedures, organizational elements, coordination bodies, and decision approvals (Morieux 2011). The same study revealed, through a survey of over 100 companies, that in the last 15 years complicatedness has increased by 50 to 350 percent. In response, it was proposed that an environment be established for organizational members to create solutions to complex problems rather than increase complicatedness. This environment can include the use of integrated models like the MFS to help bring multiple disciplines together to solve complex problems. Moreover, it can support creative tension, as opposed to unproductive tension, in closing the gap between vision and current reality. It has been stated that creative tension can create better ideas and outcomes (Senge 1990).

Organizational complexity can include the different disciplines and relationships that exist in social networks. Contingency theory states that the organization behaves in a manner to fit the environment. The environment can be complex due to demands placed on members in the organization and level of technology in the product. The consequences of organizational and environmental complexity can include error-making, loosely coupled members, use of multiple communication channels, escape and building barriers (Dooley 2002). Within the MFS, a dynamic social network analysis (SNA) sub-model was incorporated to help manage organizational complexity.

Descriptions of complexity may also be found through a review of complexity models. These models can help organizations better position themselves in understanding, addressing and managing complexity. Moreover, developing an integrated standard and practice for using the integrated model in the current study can provide a structured approach for managing complexity.

Some complexity models appear to be more practical than others. The Cynefin Framework provides four spaces for situating projects: complex, chaotic, ordered-simple, and ordered-complicated (Snowden 2010). However, this model is dimensionless and merely provides high-level context of where a project may reside so that strategies may be taken to address difficult problems. On the other hand, there are several other complexity models with assigned dimensions to help frame product, organizational and project complexity.

Complexity Models

As depicted in Figure 9, the Goals and Methods Matrix is based on how well-defined the goals and methods are within a project. Typically, engineering and construction projects fall within type 1 projects, product development projects within type 2, software development and research and development (R&D) within type 3, and organizational change projects within type 4 projects (San Cristóbal 2018). This model is related to the SRM sub-model with the MFS and the integration pillar of proper selection of models and tools.

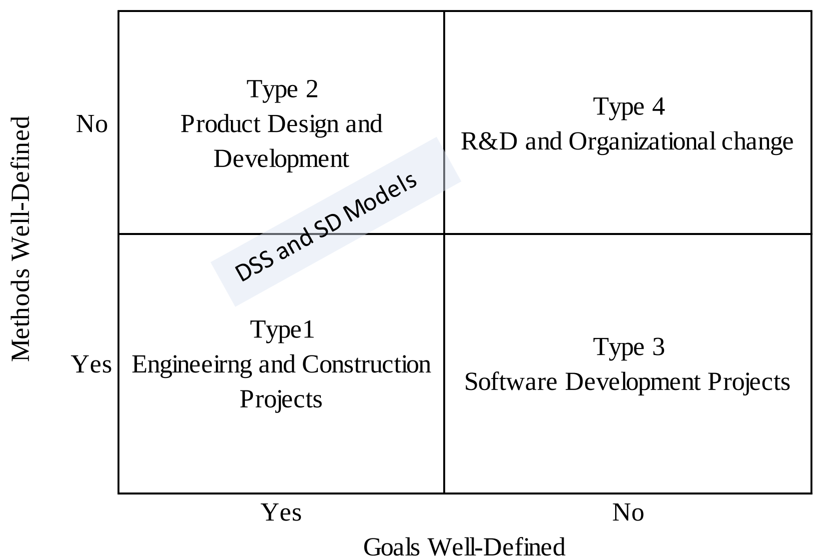


Figure 9. Goals and Methods Matrix (Adapted San Cristóbal 2018)

As depicted in Figure 10, the Stacey Complexity Model provides a tool to help select different management approaches dependent on the type of project (Agile Practice Guide 2018). The vertical axis represents uncertainty in agreement to requirements or decisions. The horizontal axis represents uncertainty in outcomes, solutions, knowledge or the technology required to meet requirements or address an issue. When there is a high degree of uncertainty in requirements and technical solutions, DSS and SD sub-models within the MFS are viewed as useful tools to navigate and address complexity. In particular, the technical degree of uncertainty relates to the integrated SRM-DSM, component changeability and SRL sub-models within the MFS.

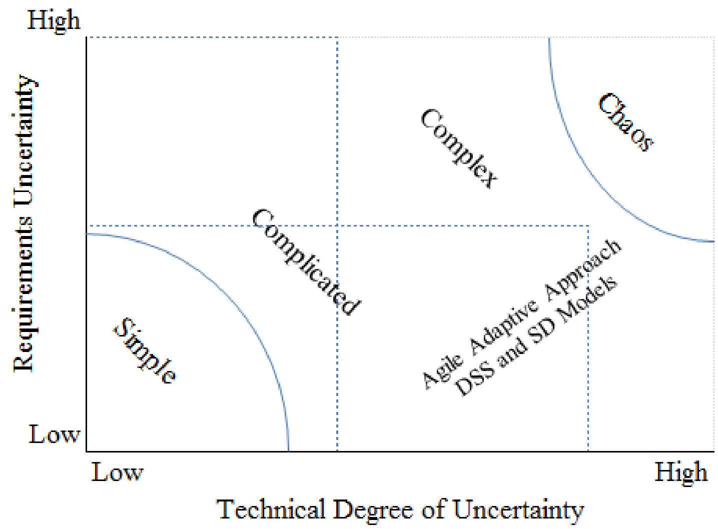


Figure 10. Stacey Complexity Model (Adapted Agile Practice Guide 2018)

Ashby's Space, in Figure 11, depicts a balance between variety in responses and variety in disturbances. The disturbances or risks can be categorized in terms of chaotic, complex and ordered information. In the complex region, disturbance information is a mix of the other two regions where additional resources are required to adapt and address disturbances. With increased capacity for social collaboration, the adaptive frontier may be expanded (Boisot 2011). The use of tools such as DSS, SNA and SD models within the MFS is viewed as a way to increase collaboration and find solutions to complex problems. The gaming of solutions in response to risks is viewed as collaborative thinking, utilizing the MFS for trade-off analysis.

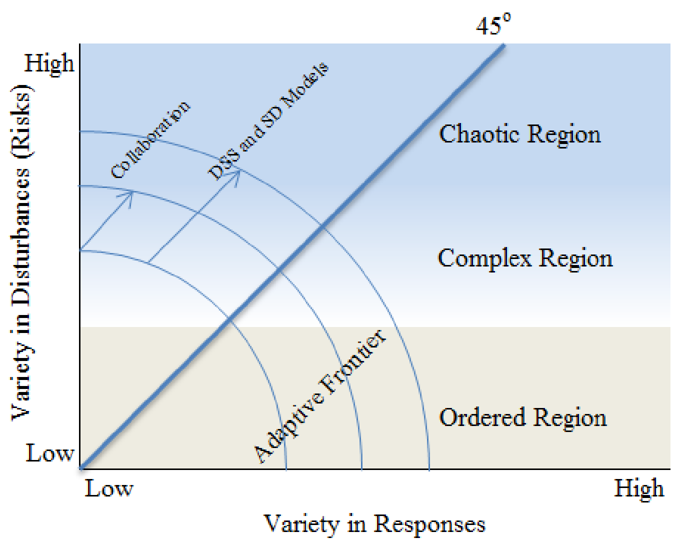


Figure 11. The Ashby Space and Integrated Management Model (Adapted Boisot 2011)

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The William's Model includes the dimensions of structural complexity and uncertainty, each having two sub-dimensions, number and interdependency of elements, and uncertainty in goals and methods, respectively (San Cristóbal 2018). This model appears to be a cross between the Goals and Methods and Stacey complexity model. This model is also related to the SRM-DSM sub-model within the MFS.

In the Kahane's U-process model, complexity is described in terms of dynamic complexity: cause-and-effect, generative complexity: past experience, and social complexity: people participating, creating and implementing solutions (San Cristóbal 2018). This model appears to bring in the aspects of the SD sub-models, SNA and organizational complexity, and the gaming-of-solutions feature within the MFS.

The UCP model classifies projects according to uncertainty, complexity, and pace. Uncertainty is broken down into four levels of technological uncertainty: low, medium, high, and super high-technology projects. Complexity is broken down into three levels of system scope based on a hierarchy of systems and subsystems. Pace is broken down into three levels: regular, fast-competitive, and critical-blitz projects (San Cristóbal 2018). This model captures technological uncertainty, similar to the Stacey model. The UPC models adds the dimensions of physical system complexity and time. The UCP complexity model is related to aspects of the SRM-DSM, SD and SRL sub-models within the MFS.

Complexity Models, a Systems Approach and the Management Flight Simulator

In all of these models, thinking about complexity in terms of the different dimensions is related to Systems Thinking, system dynamics and systems engineering. The dimensions in these models can be managed with use of the MFS, an integrated standard and best practice guidance. The MFS presented in the current study may be scaled and customized in accordance with the type and level of dimensions assessed during the different phases of the product design and project.

Some approaches leaders take in addressing complexity include creating experiments that allow patterns to emerge, using methods that generate ideas and increase levels of interaction and communication (San Cristóbal 2018). The gaming-of-solutions and trade-off analysis within the MFS provides a mechanism to help generate ideas and increase collaboration.

The integrated model in the current study provides a mechanism to bring stakeholders together on a common platform where they can game design and program change scenarios, risks, analyze trade-offs, trends and patterns, gain knowledge and generate ideas; thereby applying aspects of Systems Thinking and methods to address complexity.

There is a recognized gap in terms of the integration of project complexity, risks and risk thinking. Project managers rely on their intuition and experience in dealing with risks (Qazi 2016). The MFS provides a tool to help avoid resorting to ill-informed decision-making. The MFS can support the pursuit of the fundamental optimal solution to symptomatic problems. It can do this through the automation of information, accessibility, transparency in results and ease of use.

Shifting the Burden

When problems occur in complex systems, the intuitive response is to find quick and easy solutions rather than long term effective solutions. This dilemma is apparent in the struggle between the systems engineer, project manager, engineering disciplines, and other stakeholders in the project (INCOSE 2015). Resorting to quick solutions may be caused by a stressful environment with time pressures or reluctance to apply cognitive effort. Whatever the reason, when recurring similar problems arise, shifting-the-burden from finding a fundamental optimal solution to quick symptomatic solutions can occur (Bellinger 2020).

As shown in Figure 12, adapting from a symptomatic quick solution to a fundamental optimal solution involves two balancing (B) loops and one reinforcing (R) loop (Bellinger 2020). The time delay or resistance in avoiding the fundamental solution leads to pursuing the quick solution. With this, side effects can reinforce the problem including design and programmatic issues. This forms a vicious reinforcing loop making it difficult to solve symptomatic problems. This reinforcing loop can create rework, cost overruns, and delays.

While the quick solution may temporarily solve the problem, nothing has been done to alter the system and factors that caused the event. The different levels of perspectives framed by the Systems 'Iceberg' and MFS can help go beyond responding to events and look for long-lasting optimal solutions.

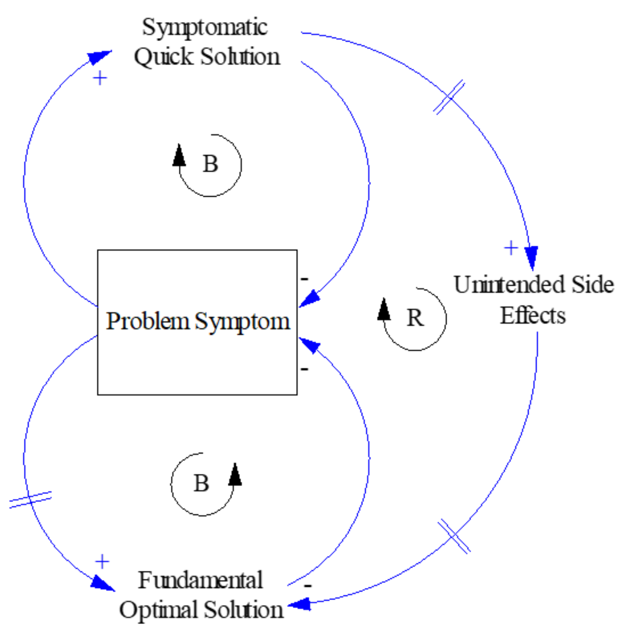

Figure 12. Shifting the Burden (Adapted: Bellinger 2020)

Connecting systems science, thinking, dynamics and engineering to systems practice for managing complexity

The fast pace of today's business and social environment can force organizations to make quick decisions based on multiple unknown variables. With this, there can be limits to what can be predicted and planned for. With traditional project management approaches, there can be unrealistic estimations, ignoring multiple feedback processes and nonlinear relationships within the project. This requires project managers to pay attention to non-linear influences so that they can be better understood and acted upon (San Cristóbal 2018). This also requires managers to use a different way of thinking, with more integrated approaches, models and tools for planning, executing and controlling projects.

SD provides a method to better understand dynamic non-linear relationships within complex projects, product and services, the organization and its processes. SD also provides for mental models for more constructive informed decision-making.

Case study analysis has shown that process tools and walk-throughs support forming mental models of both the organization and its products, an aspect of Systems Thinking (Lamb & Rhodes 2007). The MFS incorporates mechanisms to help form mental models for both learning and informed decision-making.

Governance for Implementing a Systems Approach and Integrated Model

In a survey of 400 construction leaders, 62 percent of respondents stated that the biggest cause of project delays was due to the lack of collaboration and digital transformation (Finalcad 2020]. The MFS is built on a digital thread of discipline-specific and novel sub-models that promote collaboration.

An underlying requirement for addressing complexity and its various dimensions is coordination and collaboration of multiple disciplines using various methods, models and tools. The role of a standard process can be to enable collaborative Systems Thinking.

Collaborative practices include continuous improvement, use of external best practices, use of knowledge, mutual learning and social networking, and a structured support system (Lee, Shiba & Wood 1999). This structured support system includes a best practice and integrated standard for implementing a systems approach and integrated model, like the MFS.

While this standard does not exist to enable collaborative Systems Thinking, there exists the International Organization for Standardization (ISO) 44001:2017, Collaborative business relationship management systems - requirements and framework. This standard provides guidelines for collaboration and for formalizing stakeholder relational practices. However, it does not specify how contractual and relational mechanisms should be developed and implemented (Chakkol, Selviaridis & Finne 2017).

Guidance on the use of practical mechanisms, integrated models and tools is not evident in current systems engineering and project management standards and best practices. Moreover, there does not exist a single integrated standard or practice for the application of Systems Thinking, SD, and SE, as a systems approach.

Standards may not address all management issues but they can guide processes and organizational structures to address issues in a systematic manner. With a continuous improvement focus, standards can improve product quality, collaboration and support fact-based risk-based thinking. Furthermore, standards provide a framework for management topics, approaches and integrated management systems. For example, ISO 9001 - quality management systems, is built on the principles of customer focus, leadership, engagement of people, a process approach, improvement, evidence-based decision-making and relational management (Kohl 2020). These principles are built into the MFS along with the seven pillars for integration.

Management system standards specify requirements, but not the design of the organization's management system. Establishing a management system that is compliant with standards can be straight forward; on the other hand, designing a system that is efficient and effective for improving the overall program can be a challenge. Moreover, it's important that a sufficient number of people in the organization have knowledge and skills in essential tools and how to establish, implement, maintain and improve the management system. Six-sigma methodology offers a navigation system through the improvement process, however complex it may be. (Kohl 2020).

In terms of a systematic methodology for a systems approach and integrated models like the MFS, six-sigma is a proven approach to project management and problem solving (Kohl 2020). Six-sigma methodology and its process variability analysis tools were used to construct the MFS. In solving problems, this methodology follows the steps of define, measure, analyze, improve, and control (DMAIC). In designing new processes, the methodology follows the steps of define, measure, analyze, design, and verify (DMADV).

There can be several complementary standards in an integrated management system (IMS); similarly, there can be a number of standards associated with an integrated management model, like the MFS. As listed in Table 3, separate standards exist for many of entities, levers and processes captured within the MFS.

Table 3. Systems Approach and Management Flight Simulator Mapped Standards

SD Policy Lever	Related Standard
On-the-Job Training Effort	Limited Guidance: ISO 21001 Management System for Educational Organizations
Relational Contracting Effort	ISO 44001 Collaborative Business Relationship Management System
Paying for VFI	ISO 44001 Collaborative Business Relationship Management System
Gaming Intensity	Not applicable
Learning Effort	Not applicable
Team Colocation	Not applicable
Applying Engineering Principles	Not found but Required
Process Improvement Lever	**Related Standard**
Knowledge Management	ISO 30401 Knowledge Management Systems

Design Change Management	ISO 22316 Organizational Resilience ISO 10007 Guidelines For Configuration Management
Risk Management	ISO 31000 Risk Management Guidelines
Communication Management	ISO 9001 Quality Management Systems – Requirements
Integration Management	ISO 44001 Collaborative Business Relationship Management System
Supply and Vendor-Furnished-Information (VFI) Management	ISO 9001 Quality Management Systems – Requirements
Strategic Management	ISO 9001 Quality Management Systems – Requirements
MFS Sub-Model Entities	Related Standard
Systems Readiness Level	Required. Limited Guidance: ISO 16290 Space Systems - Definition of the Technology Readiness Levels (TRLs) and Their Criteria of Assessment
Process Maturity	Capability Maturity Model Integration (CMMI)
SD Program Management Curves	ISO 21500 Guidance on Project Management
Decision Support System (Risks, Change Propagation and Trade-Off Analysis)	Not found but Required
Social Network Analysis	Not found but Required
Systems Approach	Related Standard
System Dynamics	Not Found but Required
Systems Thinking	Required. Limited Guidance: ISO 9001 Quality Management Systems – Requirements
Systems Engineering	ISO 15288 Systems and Software Engineering - System life cycle processes ISO 26702 Systems Engineering - Application and Management of the Systems Engineering Process
Six Sigma Approach and Tools	ISO 13053 Quantitative Methods in Process Improvement - Six Sigma

This disparate set of standards can make it difficult to govern the IMS as related to both the systems approach and MFS.

Best practices for the different disciplines include the Engineering Management Body of Knowledge (EMBoK), the INCOSE SE Handbook, the SE Body of Knowledge (SEBoK), the PM Body of Knowledge (PMBoK), the Business Analyst Body of Knowledge (BABoK), the Business Architecture Body of Knowledge (BIZBoK), and Six-Sigma methodology handbooks. However, these disparate practices can create confusion in terms of what to use for a systems approach and for development, implementation and sustainment of integrated management models and tools.

While these disparate standards and best practices can be difficult to navigate, they provide a foundation for developing an integrated standard and best practice guidance for the systems approach and integrated model.

In order to develop this standard and best practice, the handbooks, various Bok's, and the standards outlined in Table 3 should be reviewed and leveraged for this purpose. Furthermore, several best practice institutions have collaborated on integration initiatives. The INCOSE PM-SE Integration sub-working group have adopted a charter in support of integration of SE and PM. The outputs from this working group and others should be collected and reviewed in terms of inputs into a standard for the systems approach and integrated model discussed in this paper.

While this governance is aimed at increasing awareness of the benefits of a systems approach in developing an integrated model, there are practical hurdles yet to be overcome.

Practical Hurdles

From presentations to the INCOSE IW2020 PM-SE sub-working group, as well as to mature industrial companies, the authors of this paper experienced resistance and lack of interest in adopting the integrated model (MFS); it was perceived as comprehensive, sophisticated and overly complicated. This included negative factors related to its initial investment, training and useability.

Although, the overall results from the INCOSE IW2020 were favourable, follow-on discussions revealed apprehension in adopting the integrated model. This resistance was conveyed through the notion that adopting such a model would have to wait until enough companies and suppliers had successfully tested and trialed the model first.

The perceived mindset is that a tried and proven off-the-shelf model can somehow solve their problems whereas, the principal challenge is due to the lack of Systems Thinking and a systems approach toward developing the right models and tools.

CONCLUSION

Thinking in new ways through a systems approach can facilitate the development of practical integrated systems, models and tools to address complexity. This systems approach uses Systems Science, Systems Thinking, SD and SE collectively.

In order to institutionalize and socialize this systems approach and integrated models like the MFS, a single integrated standard and best practice is considered a viable option. This option can help overcome the resistance by organizations to adopt integrated model-based tools and shed light on the benefits of a systems approach and integrated model to address complex problems.

This hurdle is actually higher than the one of simply purchasing the right software; it is one that involves following the right philosophy and principles in Systems Thinking. For a very long time, managers and leaders have divided up organizations for some good and seemingly practical reasons. Because of this, they have naturally gravitated toward traditional tools that are designed purely to match the existing divisions of the organization. They hope that improving the different parts of the organization will somehow result in improvement of the whole.

Even if leadership roles of mature companies may be on-board with using the latest and greatest fashionable systems terminology, they can be totally blind to the system principle that the whole is more than the sum of the parts.

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