

Socio-Technical Assessment of Complexity

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Summary

TNO-ESI's socio-technical roadmap identified the need for capabilities that can help researchers and industrial partners recognize, diagnose and address socio-technical complexity in engineering challenges. The roadmap proposed a toolbox consisting of three connected elements: 1) an approach to assess socio-technical complexity, 2) a guide to select suitable methods and interventions, and 3) a monitoring capability to evaluate impact over time. In this report, we will describe the development of the first concrete step – the Socio-Technical Assessment of Complexity (STAC).

Existing socio-technical and systems approaches offer rich theoretical foundations and powerful methodologies, but often require substantial effort, expertise and stakeholder engagement before value becomes visible. To reduce this barrier, we developed the STAC scan: a lightweight approach that helps project teams identify where socio-technical complexity may reside before committing to deeper analysis. STAC is not intended to replace more comprehensive methods. Its novelty lies in acting as a low-threshold entry point: it creates awareness, supports structured team discussion, and identifies where deeper socio-technical analysis is valuable.

The assessment combines systems thinking concepts, the Seven Samurai model, insights from complexity science, and selected elements from the INCOSE Complex Systems Tradecraft Guide. The result is a process that starts with team alignment on the different systems the project connects with, an individual survey to identify complexity levels in those different systems; and a collective result visualization through automated heatmaps that shows complexity hotspots, areas of disagreement within the team and potential topics requiring further investigation.

The approach was iteratively developed and evaluated through multiple pilots with TNO-ESI project teams. Results show that STAC can create productive discussions in project teams beyond a narrow technical focus towards a more holistic understanding of the systems in which their interventions must ultimately operate, while remaining lightweight enough to be used within ongoing projects. This study represents the first building block of the socio-technical toolbox and provides the foundation for future work linking diagnosed complexity patterns to appropriate socio-technical intervention methods.

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1 Introduction

1.1 Background and Motivation

High-tech systems increasingly operate as socio-technical systems that combine people, organizations and technology to achieve a common purpose [1]. As scale, scope and interconnectedness increase, these systems converge, interact and depend on one another, requiring engineers to consider technical and social issues in an integrated manner [2]. TNO-ESI's partners are facing challenges related to engineering productivity, adoption of new methods, digital transformation, model-based engineering, AI-supported engineering, collaboration across disciplines and companies, and long-term embedding of research results, etc. These challenges cannot be fully understood as technical problems only; they are socio-technical in nature [3].

The TNO-ESI socio-technical roadmap [4] argued that TNO-ESI needs to develop capabilities to address this increasing socio-technical complexity in its research projects. The roadmap positions applied socio-technical research as a way to improve both the quality and the embedding of TNO-ESI results. The ambition is not only to develop scientifically and technically sound methods, but also to ensure that these methods fit the organizational and operational context in which they are expected to be adopted and create value. This is especially relevant because adoption of TNO-ESI methodologies in industry is not a given. Previous experience shows that even technically strong methods may not be taken up if stakeholder needs, organizational routines, decision structures, cultural conditions, user practices or ecosystem dependencies are insufficiently understood [4]. The socio-technical roadmap therefore proposed a toolbox that supports TNO-ESI researchers in analysing complexity, selecting appropriate socio-technical methods that can address it and monitoring impact over time. This study focuses on the first element of that toolbox: an assessment method to help project teams recognize where socio-technical complexity may exist and where deeper analysis may be needed. The goal is not merely to produce a scan, but to build organizational capability and increase the perceived value of socio-technical approaches within TNO-ESI and, eventually, with industrial partners.

1.2 Research Questions

Three research questions guided this project and this report is structured to answer them directly:

RQ1. What is the state of the art in assessing socio-technical system complexity?

This question is addressed by reviewing relevant systems engineering, complexity and socio-technical approaches, including the INCOSE Complexity Primer [5], the INCOSE Tradecraft Guide [6], Jackson's systemic perspectives [7] and broader socio-technical systems methods.

RQ2. What is the state of practice in assessing socio-technical complexity and associated tools or frameworks?

This question is addressed by examining how these approaches are currently framed for practical use, including methods for bounding problems, assessing task difficulty, analysing culture and authority, using systemic perspectives and supporting repeated learning loops.

RQ3. How can existing socio-technical complexity assessment approaches be tailored to increase awareness, support adoption and improve the embedding of systems engineering innovations in the TNO-ESI context?

This question is addressed through the design, development and initial application of STAC as a lightweight socio-technical complexity assessment approach tailored to the characteristics, constraints and adoption challenges of TNO-ESI research projects and their industrial contexts.

1.3 Intended Impact

The intended impact of STAC is broader than the development of a questionnaire. Our plan positioned the assessment tool as a way to increase the perception of value of socio-technical thinking and to support adoption of a more balanced socio-technical approach in TNO-ESI research.

The expected impact can be described at four levels:

- 1. For project teams:** STAC should create awareness of socio-technical complexity early in a project and help teams discuss stakeholders, boundaries, dependencies and adoption conditions more explicitly.
- 2. For researchers:** STAC should provide a structured and accessible way to include socio-technical reasoning in predominantly technical research projects.
- 3. For TNO-ESI and project management:** STAC should provide an aggregated view of socio-technical hotspots and divergence across projects, supporting project steering and portfolio-level reflection.
- 4. For industry partners:** STAC should provide a low-effort entry point for identifying and discussing socio-technical challenges in the design, development, deployment and adoption of engineering systems, helping organizations better understand the broader context in which technical solutions are developed, adopted, and used. This can support more informed decision-making regarding organizational change, engineering collaboration, adoption support, and capability development.

1.4 Structure of this Report

The report follows the progression from understanding existing approaches, through method development, to initial application and evaluation.

Chapter 2 reviews the state-of-the-art and state-of-practice in socio-technical complexity assessment. It examines relevant concepts from systems engineering, complexity science and socio-technical systems research, and identifies the gap that motivated the development of STAC.

Chapter 3 describes the approach used to design STAC. It explains its intended role within the TNO-ESI socio-technical roadmap, the design principles that guided its development and the conceptual foundations on which it is based.

Chapter 4 presents the development of the scan itself. It describes the iterative design process, the lessons learned from successive versions, and the creation of automated heatmap analysis.

Chapter 5 discusses the results from STAC applied in TNO-ESI project settings, including partner representatives. It presents observations from the pilots, illustrates the type of insights generated by the scan and reflects on its perceived value.

Finally, Chapter 6 discusses the findings in relation to the research questions and objectives, reflects on the limitations of the current work, evaluates the degree to which the intended

project outcomes were achieved and outlines future work required to realize the broader socio-technical roadmap.

2 State-of-the-art and state-of-practice

This chapter addresses the first two research questions by reviewing the state-of-the-art and state-of-practice in assessing socio-technical complexity. It explores how socio-technical systems and complexity are understood within systems engineering, reviews practical approaches used to characterize complexity, and identifies the gap that motivated the development of STAC. Particular attention is given to the four characterization lenses used in the INCOSE Tradecraft Guide [6]: culture, difficulty, systemic perspectives and lifecycle adaptation. Together, these lenses inspired the design of the STAC assessment.

2.1 Socio-technical Systems and Complexity in Systems Engineering

Baxter and Sommerville define socio-technical systems as systems that combine people, organizations and technology to achieve a common purpose [1]. Their definition emphasizes that system behaviour emerges not only from technical components, but also from the interaction between technologies, people, organizational structures, processes, policies and wider environmental influences. As these elements continuously influence and adapt to one another, socio-technical systems exhibit characteristics typically associated with complexity. This perspective is highly relevant for engineering systems. Modern high-tech systems rarely operate in isolation [2] [8]. They must function within larger ecosystems of users, operators, maintainers, suppliers, regulators and organizational stakeholders. Similarly, the engineering organizations responsible for creating these systems are themselves socio-technical systems requiring coordination across multiple disciplines, departments and companies. Engineering therefore increasingly takes place within interconnected networks of technical and social systems rather than within isolated technical domains.

The systems engineering community has extended this view by describing engineering systems as socio-technical systems characterized by technical complexity, organizational complexity, human behaviour, uncertainty and long operational lifecycles. Examples include transportation systems, healthcare systems, energy systems, communication infrastructures and global supply chains. Such systems must continuously balance technical performance with organizational, societal and environmental concerns [2] [8].

The INCOSE Complexity Primer further emphasizes that complexity does not reside solely in the technical system being developed [5]. Complexity can emerge from interactions between the system, its context, its stakeholders and the organizations involved in its realization and use. The Primer distinguishes complicated systems, whose cause-effect relationships can be unfolded and understood with sufficient effort, from complex systems, where relationships are woven together in ways that generate uncertainty, emergence and insufficient certainty between cause and effect. Complex systems are characterized by interdependence, multiple perspectives, adaptation, emergence, uncertainty and context sensitivity [5] [9].

Importantly, this does not imply that systems engineering traditionally ignores social aspects. Stakeholders, operational concepts, lifecycle considerations and organizational constraints already play a central role in many systems engineering approaches. We therefore do not argue that systems engineering currently takes a purely technical perspective. Rather, we

argue that the social and organizational dimensions often remain implicit. Making these dimensions more explicit helps practitioners better understand the systems in which technical systems exist, surface hidden assumptions, identify stakeholder perspectives and develop interventions rather than focusing solely on technical solutions [1] [10].

This perspective is directly applicable to TNO-ESI. The high-tech systems addressed within TNO-ESI research are developed within engineering ecosystems involving customers, suppliers, architects, domain specialists, decision makers and end users. Likewise, TNO-ESI research projects themselves can be viewed as socio-technical systems requiring collaboration between researchers, industrial partners and multiple stakeholder groups. The success of a methodology, model or tool therefore depends not only on its technical quality but also on how well it fits diverse organizational needs, stakeholder expectations, existing work practices and broader ecosystem conditions.

2.2 The INCOSE Tradecraft Guide as a Complexity Characterization Framework

A wide range of approaches have been proposed to help practitioners understand and address complexity. These include Systems Thinking [11], System Dynamics [12], Soft Systems Methodology [13], Critical Systems Thinking [10], the Cynefin framework [14], and the INCOSE Complexity Primer [5]. While these approaches differ in terminology and emphasis, they share a common principle: before selecting methods or solutions, practitioners should first understand the nature of the situation they are dealing with.

The INCOSE Tradecraft Guide for Systems Engineers brings many of these traditions together into a practical framework intended to help practitioners select appropriate practices for difficult and complex situations. Rather than prescribing a single methodology, the guide advocates that using multiple perspectives gives a better overall understanding and proposes a pluralistic approach in which problem situations are first bounded and characterized before interventions are selected. The proposed process consists of defining and bounding the problem, assessing culture and leadership authority, characterizing task difficulty, characterizing systemic challenges, identifying lifecycle context, selecting suitable practices, and continuously reassessing the situation as learning occurs [15] [9].

Four characterization lenses are particularly important within this framework: culture and leadership authority; task difficulty; systemic perspectives; and lifecycle and learning. Together, these lenses provide complementary views on where complexity resides, why it emerges and how organizations may respond to it. As discussed in the following sections, these four lenses provided an important foundation for the development of STAC.

2.2.1 Culture and Leadership Authority

Complexity is not determined solely by the characteristics of a problem. It is also influenced by the ability of an organization to recognize, discuss and respond to the challenges it faces. Organizational culture therefore represents an important dimension of socio-technical complexity.

Schein [16] describes organizational culture as a set of shared assumptions that guide behaviour and shape how organizations perceive and respond to their environment. Similarly, organizational learning researchers, such as Argyris and Schön [17], argue that meaningful adaptation requires organizations to continuously challenge assumptions, learn from feedback and adjust their behaviour. Organizations differ significantly in their capacity to do so. Some actively support learning and reflection, while others discourage deviation from established routines.

The Tradecraft Guide incorporates this insight through its culture assessment. It distinguishes between supportive, tolerant and resistant systems engineering cultures. Supportive cultures encourage systems thinking, learning, trade-off analysis and reflection. Tolerant cultures neither actively promote nor oppose systems engineering practices, leaving their application largely to the initiative of individual practitioners. Resistant cultures tend to favour local optimization, narrow technical solutions and rapid action over holistic understanding. The guide further recognizes leadership authority as a critical enabling condition. Even when socio-technical issues are identified, effective intervention depends on whether individuals possess sufficient authority and support to influence decisions and initiate change [6].

This focus on culture aligns with the broader systems thinking literature. Sterman argues that many organizational failures emerge not from a lack of technical expertise but from limitations in learning, mental models and feedback interpretation [12]. Similarly, Senge identifies organizational learning as a prerequisite for successfully navigating complexity. In this view, culture influences not only what organizations know, but also what they are capable of doing with that knowledge [18].

2.2.2 Task Difficulty

A second recurring theme concerns the sources of difficulty that make complex situations challenging to understand and influence.

The Tradecraft Guide includes a Difficulty Assessment Tool (DAT) which distinguishes between four categories of difficulty: intricacy, unpredictability, unfamiliarity, and constraints. These dimensions are assessed across organizational, technical, and environmental domains. Rather than asking whether a situation is complex, the tool seeks to understand why it is difficult and where that difficulty originates [6].

This distinction is consistent with broader complexity literature. The INCOSE Complexity Primer emphasizes that uncertainty, emergence, adaptation, and interconnectedness increase the challenge of understanding system behaviour [5]. Cynefin similarly distinguishes between four types of environments: simple, complicated, complex, and chaotic. In the first two, cause and effect relationships can be understood, and in complex environments understanding emerges only through experimentation and learning. In chaotic environments, there is no clear way to understanding system behaviour [14].

Recent work within the INCOSE Complex Systems Working Group further separates intrinsic complexity from confounding factors. The PLEKO framework [19] proposes that complexity is influenced both by the intrinsic intricacy of a system and by external factors such as novelty, unfamiliarity, dynamicity, unpredictability, constraints, and stakeholder diversity. A technically manageable problem may therefore become difficult because of contextual factors, while technically intricate systems may remain manageable when supported by sufficient expertise and stable conditions [9].

Systems thinking literature reinforces this view. Sterman argues that many challenges arise not only because systems are complicated, but because feedback loops, delays, adaptation and unintended consequences make system behaviour difficult to predict. Complexity therefore emerges as much from interactions and uncertainty as from technical sophistication alone [12].

2.2.3 Systemic Perspectives

A third important lens is provided by Michael Jackson's work on systemic perspectives. Jackson argues that different forms of complexity become visible depending on the perspective from which a situation is viewed. No single perspective is sufficient to fully understand a

complex situation. Instead, practitioners should deliberately examine multiple perspectives before deciding how to intervene [10] [7].

Jackson identifies five systemic perspectives. Taken together, these perspectives suggest that socio-technical complexity can emerge from multiple sources simultaneously. Complexity may arise from conflicting stakeholder interests, unclear goals, hidden dependencies, adaptation pressures or broader societal consequences. Jackson therefore argues that practitioners should consciously explore situations through multiple perspectives rather than relying on a single technical viewpoint.

- **Mechanical Perspective:** the mechanical perspective focuses on goals, performance, efficiency and control. Systems are viewed as goal orientated and should transform inputs into desired outputs effectively and predictably. This perspective aligns closely with traditional engineering and operations management approaches [10].
- **Interrelationships Perspective:** The interrelationships perspective emphasizes feedback structures, dependencies and unintended consequences. It focuses on understanding how interactions between system elements influence behaviour over time. This perspective is strongly associated with systems thinking and system dynamics and highlights the importance of feedback loops and leverage points [10] [20] [12].
- **Organismic Perspective:** The organismic perspective focuses on adaptation, resilience, viability, and survival. Systems are viewed as living entities that must continuously adapt to changing environments while preserving their identity. This perspective is closely related to cybernetics, organizational adaptation, and the Viable System Model [10].
- **Purposeful Perspective:** The purposeful perspective emphasizes people, worldviews, politics, meaning and stakeholder interests. Different stakeholders may hold different interpretations of the same situation and may define success in different ways. This perspective strongly influenced Soft Systems Methodology and highlights the importance of understanding diverse stakeholders [10].
- **Societal and Environmental Perspective:** The societal and environmental perspective extends attention beyond immediate stakeholders to include ethical considerations, inclusion, sustainability and long-term impacts. It examines who benefits, who is disadvantaged, and what assumptions define system boundaries. This perspective aligns closely with Critical Systems Thinking and Critical Systems Heuristics [10].

2.2.4 Lifecycle and Continuous Learning

A final recurring lens concerns adaptation and learning over time.

Many traditional engineering approaches implicitly assume that problems can be fully understood before solutions are developed. Complexity research fully challenges this assumption. Complex systems evolve, stakeholders change, environments adapt and interventions frequently reshape the situations they are intended to influence. As a result, understanding must be continuously updated rather than treated as a one-time activity [5].

The Tradecraft Guide explicitly incorporates this principle through repeated characterization and learning loops. After implementing practices, practitioners are encouraged to reassess the situation, identify what has changed and adjust their approach accordingly. Importantly, this does not imply continuous reassessment in the literal sense. In practice, organizations rarely

have the time or resources to constantly update their understanding of a project situation. Instead, reassessment is typically triggered by meaningful events such as project phase transitions, major decisions, emerging risks, changes in stakeholder expectations, significant learning outcomes, or the availability of new information. These moments act as natural opportunities to revisit assumptions and evaluate whether the original understanding of the situation is still valid.

Systems thinking literature similarly views learning as central to managing complexity. Senge [18] describes learning as the foundation for adapting to changing conditions, while Sterman [12] highlights the importance of feedback in improving mental models and avoiding policy resistance. From this perspective, successful intervention is less about finding the correct solution and more about creating the capability to continuously learn and adapt.

2.3 Lessons from Existing Approaches

The reviewed approaches differ in scope, terminology and intended application. Some contribute primarily to the state of the art by providing theoretical foundations for understanding socio-technical systems and complexity, while others contribute to the state of practice by providing practical frameworks that help practitioners recognize, discuss and respond to complexity in real project environments. Together, they demonstrate that socio-technical complexity can be explored through structured reflection on culture, difficulty, systemic perspectives and adaptation rather than through technical analysis alone.

Several common themes emerge.

First, socio-technical complexity extends beyond the technical system itself. Understanding stakeholders, organizations, contexts and ecosystems is essential for understanding engineering challenges.

Second, complexity is multidimensional. The reviewed approaches consistently emphasize culture, difficulty, interdependencies, multiple perspectives and adaptation as important contributors to system behaviour. Complexity therefore cannot be reduced to a single metric or viewed solely as a technical property.

Third, successful intervention depends on learning. Complex situations require continuous sense-making, adaptation and reassessment rather than linear problem-solving approaches.

At the same time, many existing approaches require significant expertise, facilitation effort, and organizational commitment. While highly valuable for detailed diagnosis and intervention design, they often present a substantial entry barrier for teams that are unfamiliar with socio-technical approaches. For TNO-ESI, this revealed a clear need for a lightweight assessment capability that preserves the core insights of existing approaches while lowering the threshold for initial socio-technical reflection.

This observation became the starting point for the development of the Socio-technical Assessment of Complexity (STAC), described in the following chapter.

3 Approach

This chapter describes how the findings from the literature and practice review were translated into the design of STAC. It explains the principles that guided its development and the conceptual foundations from which the scan was derived.

3.1 Design Principles

The literature review and the early pilots revealed a recurring challenge. Existing socio-technical approaches provide rich theoretical foundations and powerful diagnostic capabilities, but many require significant time, facilitation expertise and organizational commitment before their value becomes visible. This is particularly challenging in engineering project environments where teams are primarily focused on delivering technical outcomes and may initially perceive socio-technical assessment as an additional activity competing for limited project resources.

The objective of STAC was therefore not to create a more comprehensive socio-technical methodology. Instead, the goal was to develop a lightweight entry point that would enable project teams to start discussing socio-technical complexity without requiring extensive prior knowledge or preparation. The resulting design principles reflect both the findings from the literature review and the lessons learned during the iterative development of the assessment.

The development of STAC was guided by five principles:

1. Lightweight before comprehensive

The assessment should be easy enough to complete with limited effort and without extensive preparation. If the first step requires too much time or expertise, project teams are unlikely to participate or perceive sufficient value in the activity.

2. Awareness before intervention

The primary purpose of STAC is not to prescribe solutions but to help teams recognize socio-technical complexity and discuss it explicitly. Before selecting methods or interventions, teams first need a shared understanding of where complexity may reside.

3. Individual reflection, collective sense-making

Team members complete the assessment individually so that different observations, assumptions and perspectives are captured. The results are then interpreted collectively because the objective is not to evaluate individuals but to understand the project situation as a whole. This approach also allows the assessment to reveal where alignment and misalignment may exist within the team.

4. Shared language

A recurring finding from the pilots was that participants often interpreted "the system" differently. The assessment therefore requires a common vocabulary that enables participants to discuss system boundaries and relationships consistently. The Seven Samurai framework was introduced to provide this shared language.

5. Immediate value

The assessment should generate visible outputs that are useful to project teams. Visualizations such as heatmaps allow participants to immediately identify complexity hotspots, divergence in perspectives and topics that may justify further discussion.

Together, these principles translate the insights from the literature review into a practical assessment approach. The first three principles address adoption and usability challenges

identified in existing approaches, while the latter two focus on creating a shared understanding and actionable output. These principles directly influenced the selection of the assessment dimensions described in the next section and the overall structure of the STAC process.

3.2 Assessment Dimensions

The review of the state-of-the-art literature and practitioner-oriented frameworks revealed that although different methodologies use different terminology, many of them assess similar underlying characteristics of socio-technical complexity. Rather than directly adopting a single methodology, STAC was designed by identifying recurring themes across the reviewed approaches and translating them into a lightweight assessment structure suitable for TNO-ESI research projects.

The resulting framework consists of four dimensions: Agreement, Dependencies, Difficulty and Feasibility, discussed in the following subsections. The dimensions do not attempt to replace the richer diagnostic capabilities of the existing methodologies. Instead, they capture a minimal set of indicators that can be assessed quickly while remaining grounded in established complexity and socio-technical systems theory. They therefore provide the conceptual bridge between the state-of-the-art and the lightweight assessment approach developed in STAC.

3.2.1 Agreement

The first recurring theme concerns the degree to which stakeholders share an understanding of the problem being addressed. The Tradecraft Guide starts with defining and bounding the problem, emphasizing stakeholder viewpoints, assumptions and shared understanding before any intervention is selected. Similarly, Jackson's purposeful perspective highlights the role of different worldviews, interpretations, and success criteria in shaping system behaviour. Soft Systems Methodology also treats differing stakeholder perceptions as a central source of complexity [13] [10] [6].

These observations led to the first STAC dimension: Agreement. The purpose of this dimension is not to determine whether a team is correct, but whether key actors are working from sufficiently similar assumptions regarding stakeholders, success criteria, problem framing and project boundaries. A lack of agreement is treated as a potential indicator of socio-technical complexity because successful intervention becomes difficult when different actors are effectively addressing different problems.

3.2.2 Dependencies

A second recurring theme concerns interdependence and system boundaries. The Complexity Primer identifies connectivity, interactivity and contextual influences as defining characteristics of complex systems. Similarly, systems thinking approaches emphasize that behaviour emerges from relationships between system elements rather than from individual components alone. The Tradecraft Guide explicitly recommends analysing dependencies across organizational, technical, and environmental systems before selecting methods [20] [12] [5].

These insights led to the second STAC dimension: Dependencies. This dimension seeks to identify where complexity resides by assessing the degree to which success depends on actors, decisions, resources, processes or conditions beyond the project's direct control. Rather than asking whether a project is complex, the intention is to identify in which system and across which boundaries complexity is most likely to emerge.

3.2.3 Difficulty

The literature consistently distinguishes between the existence of complexity and the reasons complexity becomes difficult to address. The Tradecraft Guide's Heat-Grid and Difficulty Assessment Tool differentiate among intricacy, uncertainty, unfamiliarity, and constraints. The Complexity Primer similarly identifies characteristics such as unpredictability, emergence, adaptability, and unfamiliarity as sources of complexity that challenge traditional engineering approaches [6] [9].

This led to the third STAC dimension: Difficulty. While the dependency dimension identifies where complexity may exist, the difficulty dimension explores why managing that complexity may be challenging in practice. The questions therefore focus on aspects such as change resistance, unpredictability, and unfamiliarity because these characteristics repeatedly appear in both complexity science and socio-technical systems research as important contributors to project difficulty.

3.2.4 Feasibility

A final recurring theme concerns the ability of a system to adapt. Across complexity theory, organizational cybernetics, systems innovation approaches, and the Tradecraft Guide, adaptation is considered a critical capability for working with complexity [5] [16] [10] [2]. Systems are not static; stakeholders change, environments evolve, and interventions frequently reshape the situations they are intended to influence. Consequently, successful interventions depend not only on understanding complexity, but also on the ability of the surrounding system to respond to new information and changing conditions. This perspective is reflected in the Tradecraft Guide through its emphasis on culture, leadership authority, learning loops, and iterative reassessment of problem situations [6]. Similarly, the Complexity Primer emphasizes adaptation, feedback, and learning as essential strategies for dealing with complexity [5].

These observations led to the fourth STAC dimension: Feasibility. While adaptation is the desired capability, adaptation is only possible when certain enabling conditions are present. Project teams may recognize complexity and generate useful insights, but these insights have little value if they cannot be acted upon. The Feasibility dimension therefore assesses whether the project environment provides the conditions necessary to translate learning into action. This includes the receptiveness of the surrounding culture, whether concerns and observations are heard and acted upon, and the degree of autonomy available to change course when new information emerges. In this sense, Feasibility does not refer to the technical feasibility of a solution, but to the practical feasibility of adapting behaviour, decisions, or direction in response to what the project learns.

3.3 Use of the Seven Samurai

The development of STAC required clarity in the various systems being assessed. We used Martin's Seven Samurai framework [21], originally proposed to broaden the scope of systems engineering beyond the immediate technical system under development. Martin argues that systems engineers frequently focus on the intervention system—the technical solution being designed—while paying insufficient attention to the broader network of interacting systems that ultimately determine whether the solution succeeds in practice.

This observation closely mirrors a recurring challenge encountered in TNO-ESI projects. Technical methods, tools and models are often evaluated primarily from a technical perspective, while factors related to stakeholders, organizational embedding, ecosystem

dependencies, sustainment and adoption may remain implicit. As a result, technically sound solutions can struggle to create value when introduced into real-world environments. STAC therefore adopts the Seven Samurai framework as a mechanism for making these broader system relationships more visible.

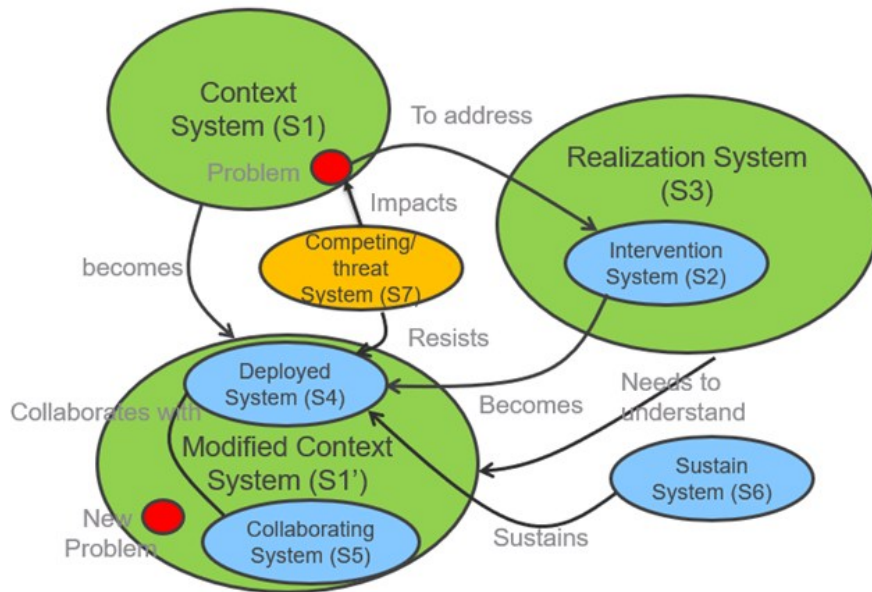


Figure 1 - Seven Samurai framework

The framework identifies seven interconnected systems that should be considered when understanding a problem situation:

- **S1. Context System**

The Context System represents the broader environment in which the problem exists. It includes stakeholders, organizational structures, policies, market conditions, technological trends and other environmental factors that influence the situation. Martin argues that systems engineers must first understand the context before meaningful intervention can occur because problems are often symptoms of broader environmental conditions rather than isolated technical deficiencies [21]. For STAC, the Context System helps teams explore project boundaries, stakeholder landscapes, and external influences.

- **S2. Intervention System**

The Intervention System is the system being designed or modified to address the identified problem. This is the primary focus of traditional systems engineering activities and includes the method, process, tool, architecture or technological solution being developed [21]. Within TNO-ESI projects, this often corresponds to the methodology, framework, or engineering solution under development.

- **S3. Realization System**

The Realization System consists of the people, organizations, processes, tools and resources responsible for creating the intervention. Martin emphasizes that the quality of the intervention depends heavily on the capability and structure of the realization system itself. People, funding,

organizational processes and collaboration arrangements are therefore not merely supporting factors but integral components of system success [21]. This perspective is particularly relevant for research projects, but also to any project or change initiative, because the effectiveness of an intervention depends not only on the solution being developed, but also on the capability of the system responsible for developing, implementing and sustaining it.

- **S4. Deployed System**

Once introduced into its operational environment, the intervention becomes a Deployed System. Martin highlights that deployed systems rarely behave exactly as originally intended. The interaction between the intervention and its environment often produces adaptations, workarounds, unexpected uses, and emergent behaviours that were not anticipated during development [21]. This observation is consistent with socio-technical research on technology adoption, organizational change, and complex adaptive systems, which repeatedly demonstrates that users actively reshape technologies through use [1] [12].

- **S5. Collaborating Systems**

The Collaborating Systems are external systems with which the deployed system must interact. These may include partner organizations, supporting technologies, suppliers, customers, regulatory bodies or adjacent operational processes. Even when the intervention itself performs as intended, successful outcomes may depend on interactions with these collaborating systems [21]. For TNO-ESI projects, collaborating systems frequently include industrial partner organizations, engineering processes, modelling environments and organizational decision-making structures.

- **S6. Sustainment System**

The Sustainment System provides the capabilities required to maintain, support, and evolve the deployed system throughout its lifecycle. Examples include training, maintenance, support structures, governance processes, knowledge management, and continuous improvement mechanisms. Martin argues that sustainment considerations are frequently underestimated despite being essential for long-term success [21]. This perspective resonates strongly with adoption challenges observed in engineering practice, where successful deployment does not automatically result in sustained usage.

- **S7. Competing Systems**

The last system described is the Competing System. These are alternative solutions, approaches or technologies that address the same underlying need. Martin emphasizes that interventions do not exist in isolation and must compete for resources, attention, legitimacy, and organizational support. Even technically superior approaches may fail if competing alternatives are perceived as easier, cheaper, or more aligned with stakeholder needs [21]. This dimension is particularly relevant for TNO-ESI methodologies, which often compete with existing engineering practices, established organizational routines, and other improvement initiatives.

3.3.1 Relevance for STAC

The Seven Samurai framework extends traditional systems engineering boundary thinking by encouraging practitioners to explore multiple interacting systems rather than focusing exclusively on the solution under development. This aligns closely with socio-technical systems

theory [1], which argues that system behaviour emerges from interactions between technical, organizational, and human elements rather than from technical components alone. It is also consistent with engineering systems research [2] [8], which views engineering challenges as embedded within broader socio-technical systems characterized by technical complexity, organizational complexity, human behaviour, and uncertainty.

Within STAC, the Seven Samurai framework mainly serves as a boundary-framing and sense-making mechanism. It provides a shared language that helps participants identify stakeholders, dependencies, organizational influences and lifecycle considerations that might otherwise remain hidden. The framework was therefore not incorporated as a formal assessment dimension, but as a conceptual foundation used to develop questions and support interpretation of results. By explicitly examining multiple interacting systems, STAC aims to increase awareness of where socio-technical complexity may reside and to reduce the risk of oversimplifying complex project situations. This supports the broader objective of the assessment: helping project teams move beyond a narrow technical focus towards a more holistic understanding of the systems in which their interventions must ultimately operate.

4 STAC Development

This chapter describes the iterative development of STAC. Rather than designing the assessment entirely upfront, the scan was developed through repeated application, feedback, and refinement. The chapter presents the different development cycles, explains the rationale behind major design decisions, and describes how the final questionnaire and analysis approach emerged.

4.1 Iterative Development Process

STAC was developed iteratively through application, feedback, and refinement. This approach reflects the nature of the problem itself: because socio-technical complexity is context-dependent, the scan could not be designed fully upfront. It had to be tested with project teams and adapted based on how people understood, used, and discussed it. The development followed several cycles.

4.1.1 First Version: Offline Guided Use

The first version was used with guidance from the STAC team. At this stage, the Seven Samurai model was not yet integrated. This created several issues. Participants were sometimes unsure which system the questions referred to. Some interpreted the context as the project, others as the industrial partner, and others as the technical domain. This made it difficult to compare answers and revealed that system definition was itself a source of complexity.

Another lesson was that group-based assessment can create a feeling of evaluation. Participants may hesitate to express uncertainty or concerns openly if they feel that their answers are being judged. This reinforced the decision to move toward individual completion with aggregated group results.

4.1.2 Second Version: Online Individual Assessment

The next iteration moved the scan into an online individual format. This had two important benefits.

First, it allowed the scan to capture multiple perspectives within the project team. In socio-technical systems, differences in perception are not noise; they are potentially meaningful signals. Second, it reduced the pressure to converge too early. Team members could provide their own view before seeing the group pattern.

The results were then treated as group-level results. This distinction is important. STAC does not aim to assess individual competence or correctness. It aims to surface the range of interpretations present in the project team.

4.1.3 Third Version: Adding Seven Samurai and Improving the Questions

Based on feedback, the Seven Samurai model was added to the instructions. The questions were also rephrased to improve clarity and completeness. This version documents several

improvements, including clearer instructions, shorter and clearer questions, revised answer scales, and additional questions on problem boundaries and culture receptiveness.

This iteration improved the scan in two ways. First, it made the questions more accessible. Second, it strengthened the theoretical grounding by explicitly linking questions to system boundaries, dependencies, context changeability, culture, and adaptation capacity.

4.1.4 Automated Heatmap Generation

A key development was the creation of an automated analysis script. The scan uses qualitative answer options, which are mapped to numerical scores through a lookup file. Scores range from 1, indicating low complexity, to 4, indicating high complexity. “Don’t know / Not applicable” is mapped to 0 and excluded from valid complexity calculations. The Python script processes the exported form responses and generates heatmaps. The analysis highlights two types of signals:

1. Complexity hotspots: questions where the average score is high.
2. Divergence: questions where the range between the highest and lowest valid score is equal to or greater than 2 (divergence is determined using a range-based threshold rather than standard deviation. The range offers a robust and intuitive indicator of substantive differences in perception, while standard deviation is used as a complementary measure to visualize the overall spread of responses).

This divergence rule is important. A high average score indicates that the team broadly sees an area as complex. Divergence indicates that the team may not share the same understanding. Both are relevant. In socio-technical complexity, disagreement about what is going on may be as important as the level of difficulty itself.

4.1.5 Final Version

Several participants indicated uncertainty about the purpose of the assessment, how the results would be used, or whether the exercise would generate actionable outcomes. Such concerns are not unique to STAC and mirror the broader challenge identified in the literature review: many socio-technical approaches require an investment before their value becomes visible.

Several measures were introduced to lower this threshold. First, the assessment was deliberately designed to remain lightweight in terms of completion effort. Second, the heatmap visualizations were developed to provide immediate and tangible feedback to participants. Rather than collecting information without visible outcomes, the assessment now returns a graphical representation of complexity hotspots and divergence that can be used directly in project discussions. Third, the introduction of the Seven Samurai alignment session helped participants better understand the purpose of the assessment and reduced confusion regarding system boundaries. Finally, STAC was increasingly positioned not as a reporting or evaluation instrument, but as a conversation support tool intended to help teams reflect on their own project situation.

The current STAC logic can be summarized as follows:

- Teams have a session to align on the 7 samurai for their project.
- Each team member completes the scan individually.
- Qualitative answers are mapped to scores.
- Scores are aggregated at team level.
- Heatmaps show complexity intensity.
- Divergence flags show where team members differ significantly.
- The team uses the results to discuss where deeper analysis may be needed.

The output is therefore not a final diagnosis. It is a structured starting point for sense-making.

5 STAC Results

The purpose of this chapter is to explore whether STAC provides useful insights when applied in real project settings. The chapter discusses the observations that emerged from the results and reflects on the extent to which the assessment contributes to awareness creation, team alignment, and the identification of socio-technical complexity.

Interpreting the STAC Heatmaps

To support interpretation of the assessment results, the STAC analysis generates three visualizations: a heatmap showing average scores per question, a heatmap showing average scores per assessment dimension, and a divergence chart showing differences in responses between team members. The colours range from green (low complexity) to red (high complexity), corresponding to the 1–4 scoring scale used in the assessment.

The number shown inside each heatmap cell represents the average score for that question or dimension. The value *n* indicates the number of valid responses included in the calculation. Responses marked as "Don't know", "Not applicable", or otherwise not mappable to a complexity score are excluded from the average and reported separately. Consequently, the number of valid responses may differ between questions even when the same number of participants completed the assessment.

Topics marked with an asterisk (*) indicate high divergence between respondents. Divergence is flagged when the difference between the highest and lowest valid score is two points or more on the four-point scale. Within STAC, divergence is considered an important signal because it may indicate differing assumptions, interpretations of the system, or stakeholder perspectives. High divergence does not necessarily indicate a problem, but it often highlights topics that justify further discussion within the team.

The heatmaps should therefore not be interpreted as objective measurements of complexity. Instead, they serve as a conversation aid that helps identify possible hotspots, areas of uncertainty, and differences in perspective that may warrant further exploration.

5.1 Project A

5.1.1 TNO-ESI only, [second version](#) (4.1.2)

An application of STAC was conducted in a newly starting project involving three respondents, without a dedicated alignment session using the Seven Samurai framework.

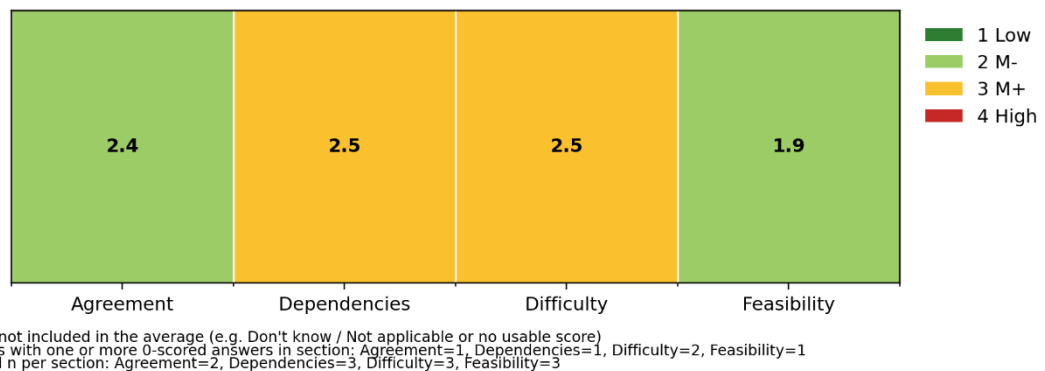


Figure 2 - Project B - average heatmap per section

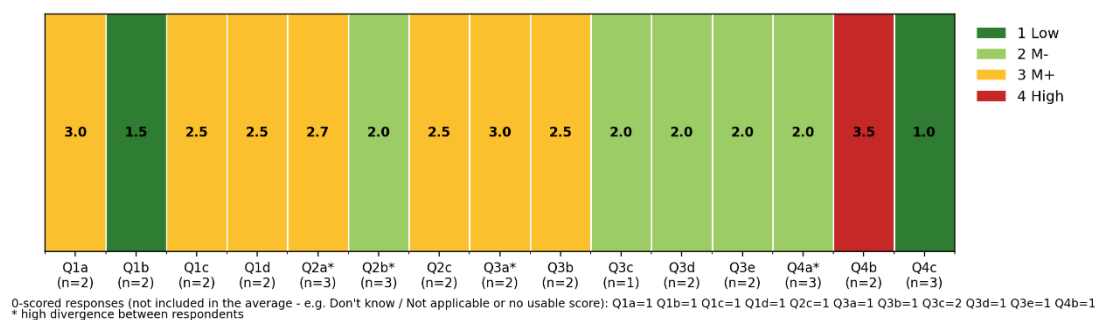


Figure 3 - Project B - average heatmap per question

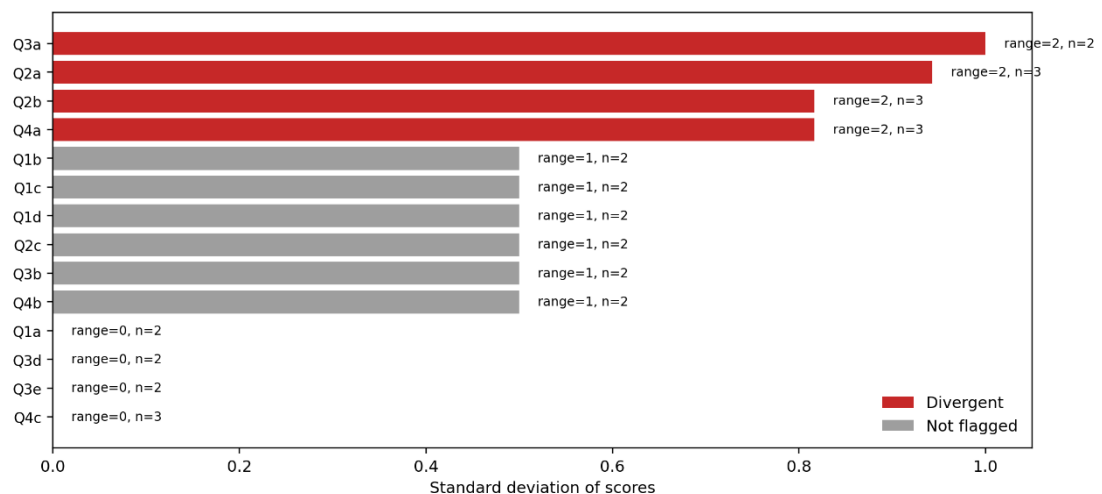


Figure 4 - Project B - divergence by question

The results provided an important learning opportunity for the further development of STAC. Although the heatmaps showed several potentially interesting signals, the number of usable responses was relatively low. Multiple questions received one or more "Don't know" responses, resulting in a reduced sample size for several questions and dimensions. This made interpretation of the results difficult and reduced confidence in the conclusions that could be drawn from the assessment.

At an aggregated level, the Complexity and Difficulty dimensions showed the highest average scores (both 2.5), while Feasibility showed the lowest average score (1.9). Several questions also exhibited substantial divergence between respondents. However, because of the limited number of valid responses, it was difficult to determine whether these differences reflected

genuine differences in perspective or resulted from participants assessing different systems or using different assumptions as their frame of reference.

This observation aligned with feedback received during the pilot. Participants indicated uncertainty regarding the scope of the assessment and the systems to which some questions referred. As the project was still in its early stages, several respondents lacked sufficient information to provide confident answers. The assessment therefore highlighted an important prerequisite for meaningful complexity assessment: participants need a shared understanding of the system being assessed.

Rather than focusing on the project-specific findings, this pilot was therefore used primarily to evaluate and improve the assessment process itself. The experience reinforced the importance of conducting a Seven Samurai alignment session before applying the scan. By establishing a common understanding of the different systems involved, participants are better positioned to interpret the questions consistently and provide meaningful responses.

The pilot also resulted in further refinement of the questionnaire. Based on participant feedback and observations from the analysis, an additional question was included in a later version of the scan to strengthen the assessment of problem framing and to help distinguish between perceived problems and potential underlying causes. This addition was motivated by recurring observations from both the literature and the pilot applications that project teams may show agreement on a stated problem while still differing in their interpretation of the underlying issue. Because the combination of limited valid responses, high uncertainty, and lack of prior system alignment reduced the reliability of the findings, the results were not further discussed with the project team. Instead, the pilot was used internally to improve the assessment itself and strengthen the supporting guidance for future applications.

This pilot generated three important lessons for the further development of STAC:

1. A shared understanding of system boundaries is a prerequisite for meaningful assessment.
2. A high number of "Don't Know" responses can itself be a useful indicator, reflecting either limited project maturity or insufficient understanding of the system under consideration and guide concrete topics where the team needs to collect information for.
3. Assessments of agreement should address not only whether stakeholders agree on a problem description, but also how confident they are that the identified problem accurately reflects the underlying situation.

These lessons directly informed the next iteration of STAC and further reinforced the role of the Seven Samurai framework as an essential preparation step rather than a supplementary aid.

5.2 Project B

5.2.1 TNO-ESI only, [second version](#)

Three respondents from TNO-ESI completed the second version of the assessment without pre-aligning on the 7 Samurai.

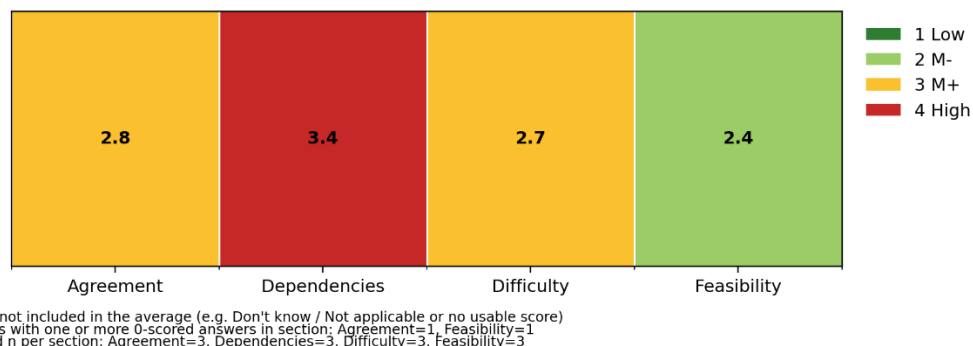


Figure 5 - Project B TNO-ESI - average heatmap per section (n=3)

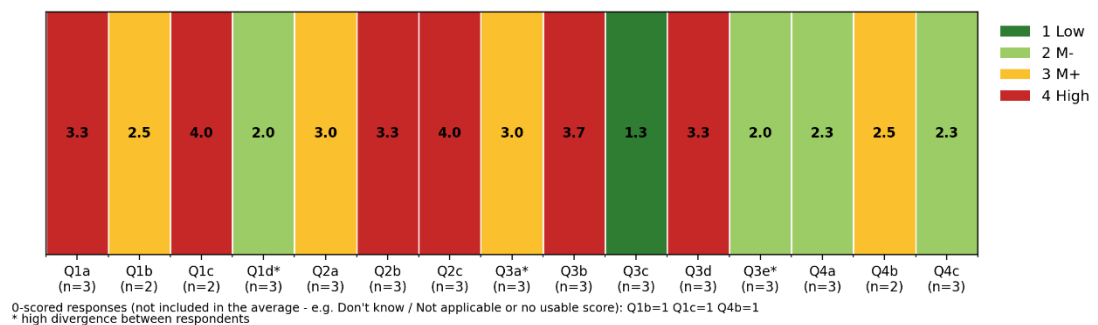


Figure 6 - Project B TNO-ESI - average heatmap per question

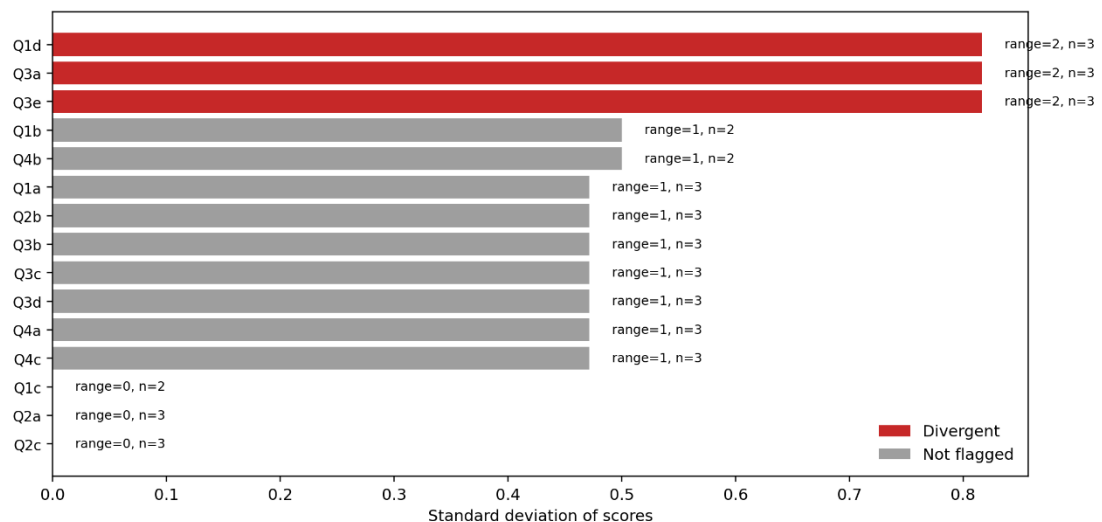


Figure 7 - Project B TNO-ESI - divergence by question

Agreement

The scan surfaced uncertainty about identifying the people who can stop, change or adopt the project outcome. Respondents also showed differences in how they interpreted success and project boundaries. Comments indicated that the multi-company nature of the project made it difficult to define the relevant context system and stakeholder set.

This finding is relevant because stakeholder ambiguity and boundary ambiguity are typical socio-technical complexity signals. They affect not only project framing, but also adoption, ownership, and long-term value.

Dependencies

The dependency questions showed consistently high complexity. Respondents indicated that both the intended solution and long-term success depend on actors, decisions, and conditions outside the direct control of the project team.

This is important because the project operates in a consortium context with multiple companies, different priorities and external coordination structures. The scan therefore helped locate complexity not only in the technical topic of model management, but in the ecosystem required to make model management useful and sustainable.

Difficulty

The difficulty dimension showed concerns about context changeability, unpredictability, and unfamiliarity of the intended solution. Some respondents described resistance not as personal opposition, but as organizational inertia and the challenge of aligning multiple business, architecture, process, and organizational perspectives. This is a good example of why socio-technical language matters. What may appear as “resistance” can be better understood as structural change difficulty.

Feasibility

The feasibility questions suggested moderate concern. The team may have some ability to act, but decision rights and adaptation possibilities are constrained by project governance and partner alignment. This matters because socio-technical insight only creates impact if it can translate into decisions. If a project can diagnose complexity but has limited authority to adapt, the next intervention should focus not only on analysis but also on sponsorship, governance and decision pathways.

This project showed that STAC can create value in at least three ways. First, it surfaced relevant socio-technical topics that may otherwise remain implicit, such as stakeholder ambiguity, dependency on partner contexts, and uncertainty about adoption conditions. Second, it revealed divergence in interpretation, especially around system boundaries. This validated the need for the Seven Samurai reference. Third, it showed that a lightweight scan can generate a meaningful project conversation without requiring a full socio-technical analysis upfront.

5.2.2 TNO-ESI and Industry, [third version](#)

The third version of STAC was applied in the same project with participation from both TNO-ESI researchers and industry representatives (4 responses). In contrast to previous applications, this version incorporated the refinements introduced after earlier pilots, including clearer instructions, additional questions related to problem framing, and a structured alignment session based on the Seven Samurai framework prior to completing the assessment. The resulting dataset consisted of four valid responses and contained significantly fewer “Don’t know” answers compared to earlier applications.

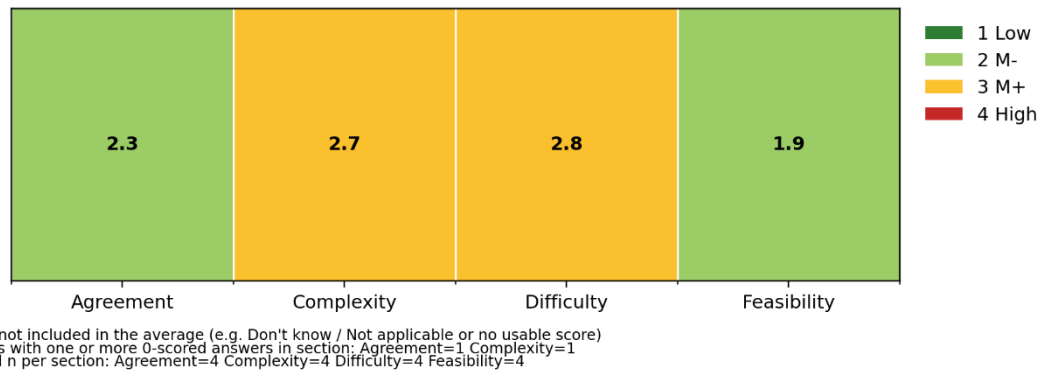


Figure 8 - Project B TNO-ESI + Industry - average heatmap per section (n=4)

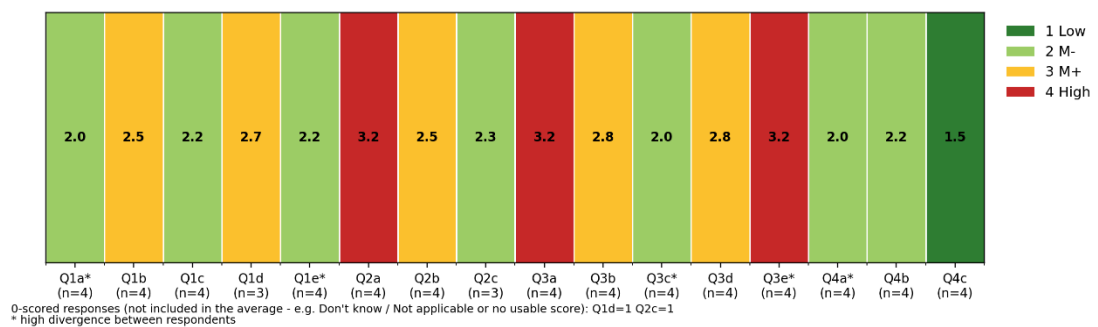


Figure 9 - Project B TNO-ESI + Industry - average heatmap per question

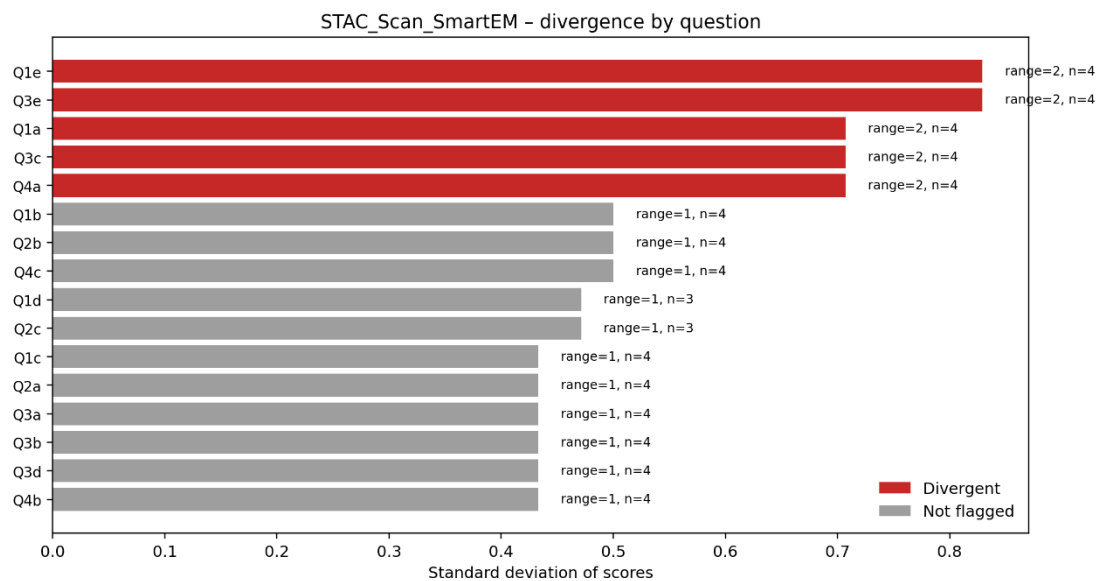


Figure 10 - Project B TNO-ESI + Industry - divergence per question¹

Agreement

The Agreement dimension showed a moderate complexity score (2.3), suggesting that participants shared a reasonable understanding of the project context, stakeholders, and objectives. However, several agreement-related questions still showed high divergence,

¹ Divergence is flagged based on the range between the lowest and highest valid score, while the divergence chart displays the standard deviation. Therefore, questions with the same range and the same number of valid responses can still have different bar lengths, depending on how the remaining responses are distributed between the minimum and maximum values.

particularly those related to stakeholder perspectives and system boundaries. This indicates that although participants were largely discussing the same project, they did not necessarily interpret the surrounding socio-technical system in the same way.

From an assessment perspective, this can be viewed as a positive result. The objective of STAC is not to force consensus, but to surface differences in assumptions that may otherwise remain hidden. In socio-technical systems, such differences often reflect the different positions, responsibilities and interests of stakeholders.

Dependencies

The Dependencies dimension showed one of the highest average scores (2.7), indicating that project success depends substantially on actors, decisions and conditions outside the direct control of the project team. This finding is consistent with the nature of multi-organizational collaboration, where technical outcomes depend on alignment between different organizations, processes, and decision-making structures.

Compared to the TNO-ESI-only assessment, participants appeared to have a richer understanding of these dependencies, likely because industry representatives were able to contribute perspectives on organizational, operational, and adoption-related constraints that are less visible from within the project team itself.

Difficulty

Difficulty showed the highest overall score (2.8). Several questions reached average scores above 3.0, indicating concerns regarding uncertainty, changeability, and the challenge of influencing the broader environment in which the project operates. These findings suggest that the perceived complexity of the project does not only stem from the technical challenge itself, but also from the difficulty of realizing change across organizational boundaries.

The results reinforce one of the central assumptions behind STAC: complexity often originates in the interaction between technical and organizational systems rather than in the technical solution alone.

Feasibility

Feasibility received the lowest average score (1.9), suggesting that participants generally believed the project possessed a reasonable ability to respond to emerging insights and adapt its approach when required. Nevertheless, divergence observed in some feasibility-related questions indicates that different participants had different views on the degree of influence available to the project and on the willingness of the surrounding environment to act on new information.

Divergence

Five questions exceeded the divergence threshold and were therefore flagged for discussion. Interestingly, most of these questions were not among the highest-scoring complexity hotspots. This illustrates an important characteristic of STAC: disagreement may be just as informative as a high complexity score.

The flagged questions mainly concerned stakeholder understanding, dependencies, adaptation and the broader project context. Rather than indicating a problem with the assessment, this divergence can provide a starting point for discussion during the collective interpretation session.

Comparison with the TNO-ESI only Application

Both applications identified Dependencies and Difficulty as the most prominent dimensions. This consistency strengthens confidence that these topics represent genuine characteristics of the project rather than artifacts of the assessment process.

Divergence remained present even after introducing the Seven Samurai alignment session. However, the nature of the divergence changed. In the earlier application, divergence appeared primarily linked to uncertainty about what system was being assessed. In the later application, divergence appears more likely to reflect genuine differences in stakeholder perspectives. This can be considered a sign of increased maturity in the assessment process, as participants were discussing the same systems while still bringing different viewpoints to the conversation. Finally, the combined application demonstrated one of the intended strengths of STAC: creating a structured setting in which technical and organizational perspectives can be discussed together. Rather than producing a single complexity score, the assessment serves as a catalyst for collective sense-making and reflection.

5.3 Observations

A recurring challenge throughout the study was obtaining participation from project teams. Across multiple applications, completion of the assessment required repeated reminders and active follow-up from the STAC team. Despite the relatively limited effort required to complete the questionnaire, the activity was often perceived as competing with project priorities and deadlines.

This observation is interesting from a socio-technical perspective because it may itself be interpreted as a signal. Teams generally prioritize activities that are perceived as directly contributing to project objectives. Reluctance to invest time in a socio-technical assessment may therefore indicate that the value of socio-technical analysis is not yet sufficiently visible or established within the project environment.

The observed resistance reinforces the original motivation for STAC. If project teams already hesitate to invest limited time in a lightweight assessment, it is unlikely that many will immediately adopt more comprehensive socio-technical methods. This suggests that creating awareness and demonstrating immediate value remain critical prerequisites for broader adoption of socio-technical approaches within TNO-ESI and its partner ecosystem.

5.4 Initial Value Indicators

At this stage, the evidence should be interpreted as early evaluation rather than full validation. The initial applications suggest that STAC contributes to:

- awareness of socio-technical complexity;
- explicit discussion of system boundaries;
- identification of project assumptions;
- visibility of team divergence;
- structured reflection on dependencies and feasibility;
- a more concrete basis for deciding whether deeper socio-technical analysis is warranted.

These are aligned with our objective of increasing the perception of value of socio-technical approaches and creating conditions for adoption within TNO-ESI.

6 Discussion and Conclusions

This chapter brings together the findings from the literature review, the development process and the pilot applications. It revisits the research questions, evaluates the outcomes against the objectives defined in the KIP proposal, discusses the contribution of STAC to the broader socio-technical roadmap and outlines the next steps required to further mature the approach.

6.1 Answers to Research Questions

RQ1. What is the state of art in assessing socio-technical system complexity?

The state-of-the-art shows that socio-technical complexity is increasingly recognized in systems engineering and complexity science. Existing work emphasizes that complexity arises from interdependence, uncertainty, emergence, adaptive behaviour, multiple perspectives, and unclear system boundaries. The INCOSE Complexity Primer [5] and Jackson's systemic perspectives [10] provide strong conceptual grounding for understanding these issues.

RQ2. What is state of practice in assessing socio-technical complexity and associated tools or frameworks?

The state of practice includes a growing set of practitioner-oriented frameworks for understanding and discussing complexity in engineering contexts, particularly from the INCOSE Tradecraft Guide. These approaches focus on helping practitioners bound problems, characterize complexity, explore stakeholder perspectives and identify potential intervention strategies [6]. However, most still require significant facilitation effort and systems thinking maturity for first use by project teams that are not yet convinced of the value of socio-technical analysis. This creates a practical gap between theory and adoption.

RQ3. How can existing socio-technical complexity assessment approaches be tailored to increase awareness, support adoption and improve the embedding of systems engineering innovations in the TNO-ESI context?

For TNO-ESI, the main tailoring need was to create a lightweight, accessible, and actionable first step. STAC addresses this by combining selected concepts from existing approaches into a scan that project teams can complete individually and interpret collectively. The use of Seven Samurai [21] supports shared system definition, while the heatmap analysis makes complexity hotspots and divergence visible. This tailoring is the main novelty of the work. STAC does not claim to be a complete socio-technical methodology. Its contribution is that it makes socio-technical complexity visible early enough and lightly enough to support adoption.

6.2 Next Steps

Some ambitions are partially delivered at this stage:

- broader validation with external partners;
- systematic management use across a portfolio of projects;
- long-term monitoring of progress over time;
- automated linking of scan results to recommended socio-technical methods from the Tradecraft Guide.

These are logical next steps. The first phase focused on creating and testing the assessment capability. The roadmap already anticipated that assessment, method selection, and monitoring would develop as connected but distinct capabilities

The most important next steps are:

5. Further pilot STAC across TNO-ESI projects

Apply the scan in more contexts to test clarity, usefulness and repeatability and assess its value.

6. Develop guidance for interpreting heatmaps

Help facilitators and teams translate hotspots and divergence into meaningful discussion questions. Improve the “Don’t know/ Not applicable” fields.

7. Connect STAC outcomes to the Tradecraft Guide

Link specific patterns to candidate methods, such as stakeholder mapping, Rich Pictures, CATWOE, causal loop diagrams, dependency mapping, OODA loops, or culture/authority analysis.

8. Develop a management dashboard

Explore how aggregated STAC results can support project steering and portfolio-level insight without oversimplifying project realities.

9. Test industry partner- facing use

Use STAC with selected partners to open discussions about socio-technical research topics.

6.3 Conclusion

STAC was developed to address a specific adoption challenge: socio-technical approaches are valuable, but often too heavy to introduce before teams have experienced their relevance. By creating a lightweight, theoretically grounded and practically usable scan, this project lowers the threshold for socio-technical reasoning in TNO-ESI research projects.

The value of STAC is not only in the heatmap it produces. Its value is in the conversations it enables: about who matters, what success means, where dependencies sit, why change may be difficult, and whether the project has the conditions to adapt.

In that sense, STAC is more than a scan. It is the first step toward building a socio-technical way of working at TNO-ESI: one that helps researchers and partners address complexity earlier, more explicitly, and with greater awareness of the systems they are trying to change.

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Appendix

A.1 Socio-Technical Assessment of Complexity (STAC) Scan

This is an individual scan to surface where sociotechnical complexity might affect a project before we invest in heavier analysis. The result that will be shared is an aggregated heatmap and not individual answers. These answers are your view on the topic to identify which aspects might need further discussion within the team. It's important that you give an honest response without overthinking.

How to answer: For each question, first define the “Samurai system(s)” in your project. In the beginning of each section there is a different description of the aspect we are referring to, please read it carefully. Then select the answer for each question that better reflects your view according to the scale and indicators provided and add any comments when relevant.

1. AGREEMENT

This set of questions checks whether we are aligned on the problem and its intended outcomes. Before assessing complexity or difficulty, it is important to confirm that key actors are talking about the same problem, the same success criteria, and the same situation. Differences here do not mean the problem is unsolvable—but indicate a source of complexity. These questions focus on problem ownership, problem framing, and agreement on success.

Q1a. To what extent can you identify the people who can stop/change/adopt the outcome of this project (S1)?

- 1 — Mostly clear
- 2 — Somewhat clear
- 3 — Somewhat unclear
- 4 — Mostly unclear
- 5 — Don't know / Not applicable

Comments (optional) – Use this space to add examples, explain your score, or clarify if you selected “Don't know / Not applicable”

Q1b. To what extent do the people who can stop/change/adopt the outcome of this project (S1) and/or the project team (S3) describe the problem (red dot in S1) the same way?

- 1 — Same narrative
- 2 — Some differences
- 3 — Several interpretations coexist
- 4 — Fundamentally different framings
- 5 — Don't know / Not applicable

Comments (optional) – Use this space to add examples, explain your score, or clarify if you selected “Don’t know / Not applicable”

Q1c. How confident are you that the initial problem as described by the people who can stop/change/adopt the outcome of this project (S1) is actually the problem you need to address (S2) and not a symptom of something else?

- 1 — Very confident
- 2 — Quite confident
- 3 — I have doubts
- 4 — Not at all
- 5 — Don’t know / Not applicable

Comments (optional) – Use this space to add examples, explain your score, or clarify if you selected “Don’t know / Not applicable”

Q1d. To what extent do the people who can stop/change/adopt the outcome of this project (S1) and/or the project team (S3) agree on what “success” looks like (S1’)?

- 1 — Common view
- 2 — Some differences
- 3 — Clear differences in expectations/priorities
- 4 — Divergent expectations/priorities
- 5 — Don’t know / Not applicable

Comments (optional) – Use this space to add examples, explain your score, or clarify if you selected “Don’t know / Not applicable”

Q1d. To what extent is it clear what this project is responsible for and what sits outside of it?

- 1 — Mostly clear
- 2 — Somewhat clear
- 3 — Somewhat unclear
- 4 — Mostly unclear
- 5 — Don’t know / Not applicable

Comments (optional) – Use this space to add examples, explain your score, or clarify if you selected “Don’t know / Not applicable”

2. DEPENDENCIES

In this set of questions we look at dependencies - something that must keep behaving in a certain way for success to continue, but that the project does not control (people or roles, decisions or approvals, data, tools, or infrastructure, processes, policies, or incentives, shared meanings or interpretations). Rather than asking why things are hard, these questions help locate which system boundaries are most affected across the intervention (S2), the realization system (S3) and the deployed system (S4).

Q2a. How much does the intended solution (S2) depend on things outside our control?

- 1 — Dependencies are few, stable, and loosely coupled
- 2 — Dependencies exist and require occasional coordination or clarification, but remain predictable and manageable.
- 3 — Dependencies are numerous and/or tightly coupled, often crossing organizational or system boundaries.
- 4 — Dependencies are tight, opaque, volatile, or asymmetric, and cross boundaries in unpredictable ways.
- 5 — Don't know / Not applicable

Comments (optional) – Use this space to add examples, explain your score, or clarify if you selected “Don't know / Not applicable”

Q2b. How much does the project team (S3) depend on external decisions, coordination or alignment?

- 1 — Dependencies are few, stable, and loosely coupled
- 2 — Dependencies exist and require occasional coordination or clarification, but remain predictable and manageable.
- 3 — Dependencies are numerous and/or tightly coupled, often crossing organizational or system boundaries.
- 4 — Dependencies are tight, opaque, volatile, or asymmetric, and cross boundaries in unpredictable ways.
- 5 — Don't know / Not applicable

Comments (optional) – Use this space to add examples, explain your score, or clarify if you selected “Don't know / Not applicable”

Q2c. Once the result is in use (S4 -> S1'), how much does success depend on ongoing conditions outside the project's control?

- 1 — Dependencies are few, stable, and loosely coupled
- 2 — Dependencies exist and require occasional coordination or clarification, but remain predictable and manageable.
- 3 — Dependencies are numerous and/or tightly coupled, often crossing organizational or system boundaries.
- 4 — Dependencies are tight, opaque, volatile, or asymmetric, and cross boundaries in unpredictable ways.
- 5 — Don't know / Not applicable

Comments (optional) – Use this space to add examples, explain your score, or clarify if you selected “Don't know / Not applicable”

3. DIFFICULTY

This set of questions explores why the dependencies identified above are hard to manage in practice. Even when dependencies are known, systems may be difficult to work with because: the context is hard to change, the effects of change are unpredictable or key aspects of the domain, intervention, or tools are unfamiliar. These questions explore system properties and dynamics that increase effort,

uncertainty, and risk, particularly in the transition from the current context (S1) to the modified context after change (S1'). Together, they help distinguish between complexity driven by rigidity, emergence, and learning demand.

Q3a. How difficult will it be to modify the context where the problem lives (S1)?

- 1 — No resistance
- 2 — Some resistance
- 3 — Significant resistance
- 4 — Strong resistance
- 5 — Don't know / Not applicable

Comments (optional) – Use this space to add examples, explain your score, or clarify if you selected “Don't know / Not applicable”

Q3b. How unpredictable is what will happen in the context where the problem lives (S1) if we change something?

- 1 — Mostly predictable
- 2 — Somewhat predictable
- 3 — Somewhat unpredictable
- 4 — Mostly unpredictable
- 5 — Don't know / Not applicable

Comments (optional) – Use this space to add examples, explain your score, or clarify if you selected “Don't know / Not applicable”

Q3c. How unfamiliar is the problem domain (red dot)?

- 1 — Mostly familiar
- 2 — Somewhat familiar
- 3 — Somewhat unfamiliar
- 4 — Mostly unfamiliar
- 5 — Don't know / Not applicable

Comments (optional) – Use this space to add examples, explain your score, or clarify if you selected “Don't know / Not applicable”

Q3d. How unfamiliar is the intended solution (S2)?

- 1 — Mostly familiar
- 2 — Somewhat familiar
- 3 — Somewhat unfamiliar
- 4 — Mostly unfamiliar
- 5 — Don't know / Not applicable

Comments (optional) – Use this space to add examples, explain your score, or clarify if you selected “Don't know / Not applicable”

Q3e. How unfamiliar are the techniques/tools/methods (to be) used by the project team?

- 1 — Mostly familiar

- 2 — Somewhat familiar
- 3 — Somewhat unfamiliar
- 4 — Mostly unfamiliar
- 5 — Don't know / Not applicable

Comments (optional) – Use this space to add examples, explain your score, or clarify if you selected “Don't know / Not applicable”

4. FEASIBILITY

This set of questions assesses whether the system can respond effectively to what it learns. Complexity and difficulty do not automatically lead to failure, but they do require the ability to observe, decide, and act in a timely way. These questions examine whether: decision rights allow course-correction when new information appears and signals from the work are translated into decisions and action across organizational boundaries.

Q4a. How receptive is the culture of the context of the people who can stop/change/adopt the outcome of this project (S1) to systems engineering–type of practices?

- 1 — Mostly receptive
- 2 — Somewhat receptive
- 3 — Somewhat unreceptive
- 4 — Mostly unreceptive
- 5 — Don't know / Not applicable

Comments (optional) – Use this space to add examples, explain your score, or clarify if you selected “Don't know / Not applicable”

Q4b. When issues/insights are raised by the project team (S3) in the context of the people who can stop/change/adopt the outcome of this project (S1) are they heard and acted on?

- 1 — Always
- 2 — Often
- 3 — Heard, but not acted on
- 4 — Not heard or acted on
- 5 — Don't know / Not applicable

Comments (optional) – Use this space to add examples, explain your score, or clarify if you selected “Don't know / Not applicable”

Q4c. How much can the project team decide on their own to change direction when/if new information appears?

- 1 — Easily
- 2 — In some circumstances
- 3 — In very few circumstances
- 4 — Almost never
- 5 — Don't know / Not applicable

Comments (optional) – Use this space to add examples, explain your score, or clarify if you selected “Don’t know / Not applicable”

5. ADDITIONAL COMMENTS

Q5. Anything else you would like to share?

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