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Toward an integrated project complexity narrative – A case study of academic organizations

Knut Robert Fossum[1] | **Evelyn Honoré-Livermore**[2] | **Erik Veitch**[3] | **Cecilia Haskins**[4] | **Erika K. Palmer**[5]

[1]NTNU Samfunnsforskning, CIRIS, Trondheim, Norway

[2]Department of Electronic Systems, Norwegian University of Science and Technology, Trondheim, Norway

[3]Department of Design, Norwegian University of Science and Technology, Trondheim, Norway

[4]Department of Science and Industry systems, University of South-Eastern Norway, Kongsberg, Norway

[5]Systems Engineering Program, Cornell University, Ithaca, New York, USA

Correspondence
Knut Robert Fossum, NTNU Samfunnsforskning, CIRIS, 7491 Trondheim, Norway.
Email: knut.Fossum@ciris.no

Abstract

The last decade has seen a growing interest in the benefits of applying project management (PM) and system engineering (SE) in an integrated way toward complex projects and programs. The concept of project complexity dimensions, with roots in both disciplines, is suggested as a component of an integrated project complexity narrative. This paper investigates how such a project complexity narrative is reflected when informants talk about the role of PM and SE in two academic organizations. Most informants address uncertainty and social-political risks as part of their work, but any consistent use of a project complexity narrative is related to environmental and technical systems. The findings also indicate difficulty differentiating between the concepts of complicated and complex. The paper further contemplates how these findings inform efforts to manage complex research projects and programs.

KEYWORDS

academia, project complexity, project management, systems engineering

1 | INTRODUCTION

Project-based research has become the prevailing practice for funding and organizing research efforts, and collaborative research projects have emerged as a particular form of academia–industry interaction.[1] This projectification of academia[2] adds universities to the list of organizations that conceive, design, and undertake complex projects. Industries and society are facing increasing connectivity to systems, both technical and social, outside traditional controls. We need to have appropriate language, constructs, and organization to deal with emergent behaviors and usages that are expanded beyond the original designs of system components.

Now, more than ever, successful research projects rely on the capacity to manage interactions between people, organizations, technology, stakeholder politics and business interests in a cohesive and holistic manner. Concurrently, these challenges associated with complex research projects have received limited research attention and theory development, creating a research gap.[3–5]

INCOSE's *Systems Engineering Vision* 2035[6] specifically calls out that managing complexity is a significant factor that requires new skillsets. The development of such new skillsets, and mindsets, is of importance for those with intentions to apply system engineering (SE) and project management (PM) to complex projects in an integrated way.[7,8] Prominent contributions toward integrated PM and SE include the combined team efforts of representatives from the Project Management Institute, the International Council on Systems Engineering, and the Massachusetts Institute of Technology (PMI/INCOSE/MIT) focused on integration at the program level,[8,9] and the INCOSE chartered working group (in 2016) focused on integration at both program and project levels.[10]

The identification of the characteristics of complex systems and potential methods to deal with complexity in system development has received considerable attention.[11–14] Watson et al. [15] describe and define distinguishing characteristics that can be used to differentiate between complex and non-complex systems and discuss how complexity can be managed in light of these characteristics. Potts et al.[16] provide a review of literature related to challenges in system complexity evaluations and discuss challenges involved in operationally embedding complexity evaluations within an organization. For example, does the organization evaluate the technical system to be developed, the project to realize the technical system or both? How is the boundary of the system of interest (SoI) defined; is it limited to the technical system interfaces, the environmental context of the implemented system or does it also include an extended strategic and business context?

The seminal analysis within the project complexity research field by de Rezende et al.[5] suggests that project complexity is defined by dimensions that include structural, uncertainty, novelty, dynamics, pace, social–political, and regulative. Sheard and Mostashari[17] provided one of the early explorations of relationships between such types of complexity, that is, three types of structural complexity (size, connectivity, and architecture), two types of dynamic complexity (short-term and long-term), and socio-political complexity. Rebentisch and Prusak[8,p.349] provide a Call to Action for academic organizations that emphasizes the role of the individual faculty members. Only by living and embodying the transformation can faculties demonstrate to students the criticality of being interprofessional and interdisciplinary.[18]

The objective of this paper is to investigate the extent to which academics draw upon a project complexity narrative when they talk about PM and SE in their work and discuss how these findings inform efforts toward the management of complex research projects and programs. In doing so, this paper does not compare or set integration of PM and SE in industry and academic settings against each other because the conceptualization of project complexity dimensions as part of a project complexity narrative is arguably applicable in both academic and industrial settings. In this paper, we present the results of a case study to achieve this objective while accounting for relevant contextual factors of academic organizations in general and academic organizations with Scandinavian socio-cultural contexts specifically.

The following section provides some contextual aspects of academic research organizations relevant for the project complexity discourse. This section also introduces the project complexity discourse in view of the larger system complexity literature, focusing on the concept of project complexity dimensions.

Section 3 describes our methods and research approach. Section 4 presents the analysis of the interviews. Section 5 discusses the findings and how they inform efforts to manage complex research projects and programs. Section 6 presents the conclusions and recommendations for future work.

2 | BACKGROUND

Siegenfeld and Bar-Yam[12] propose that problems arise from mismatches between the complexities of a task to be performed and the complexities of the system performing that task. This multiscale version of the Law of Requisite Variety[19] is illustrated in Bar-Yam[20] by considering military conflicts. Siegenfeld and Bar-Yam[12] use the organization of academic departments as a further example of such mismatch, that is, that subdivisions within the problem do not match the subdivisions within academia.

The proliferation of interdisciplinary research centers and collaborative research initiatives represents a response to this mismatch. Known management challenges for collaborative research include facilitation of mutual learning, enabling shared goal definition, creating rules for cooperation and synergy, managing heterogeneity, planning integration, and balancing personal attitudes and careers of the involved researchers.[21] Subdivisions in academic organizations made to address a specific type of complexity problem may influence other types of complexity, for example, high uncertainty in goals or methods may result in more changes during the project. Increased change may increase the dynamic complexity, which again may bring increased structural complexity. High structural complexity of the organization may increase the socio-political complexity.[22]

PM methodologies, such as network charts and Gantt charts, are arguably a form of systems thinking and govern how projects relate to complexity. However, Fowler et al.[2] found a schism in the application of such PM methods in academia. While formal PM methodology and terminology were used by specially appointed research managers as a structure for reporting to funding agencies and other external parties, most researchers carry out their work without applying PM methods. Rather, they approached the work without much coordination or planning, in a so-called “fuzzy” manner.

Thus, while academic organizations are themselves complex, and many science disciplines address complex problems and have developed theories and methods to deal with complexity, there is limited evidence of applying PM or SE techniques to manage academic research projects, or programs, and their complexities.

To provide the context for the case study presented in this paper, in the following sections, we position the project complexity discourse in view of the larger system complexity discourse (Section 2.1) and provide an account of project complexity dimensions and their roots in system and project complexity discourse (Section 2.2).

2.1 | Project complexity and the system complexity discourse

Throughout its history, SE has been the primary method for engineering in the face of complexity.[11] As such, SE is the engineering of complexity.[23] The SE discipline has evolved its practices via experientially developed principles and heuristics.[24] However, an expanding literature on networks, complexity, and complex adaptive systems theory has been developed to support the SE approach to complex systems.[15,24–28] As with any expanding field of knowledge, the "theory – practice gap" is known, that is, busy systems engineers and project managers rarely have the time to keep up with the literature, which often is diffused across the many interdisciplinary applications of complex systems science.[29]

An early description of complexity appeared in Weaver's seminal paper in 1948, titled: "Science and complexity", in which the concept of organized and disorganized complexity was introduced.[13,30] Since then, efforts have been made to identify different metrics of complexity in terms of description, creation and organization[31,32] and a review of "complex systems" definitions suggests terms such as statistical complexity, hierarchical complexity and disorder to characterize systems complexity.[33] Fischi et al.[34] review complexity in engineered systems and propose dynamic complexity measures to evaluate and compare system designs. Yang et al.[35] investigated how ontologies support SE and aimed to ascertain to what extent they have been applied. They further suggest a classification of SE knowledge areas where system fundamentals feature as a key SE knowledge area, with system, behavior, complexity, and emergence as sub-groups.

Sauser and Boardman[36] offer the *systemigram* as a method for modeling complexity to achieve a shared mental model[37] based on the soft systems methodology (SSM) of Checkland[38] The SSM and systemigram are often used to model systems in which the complexity has a sociotechnical aspect, or structural and dynamic complexity. The objective is to generate visualizations that reflect understanding of the needs of the stakeholders. Sauser and Boardman[36] review the different methods of visualizing system complexity. There are inherent limitations when modeling systems with pictures, links, and words, where the resulting model is a static representation and cannot easily characterize emergent behavior and uncertainties, especially when describing a System of Systems (SoS).

Potts et al.[39] discuss how reductionism is not sufficient for understanding complex systems because of the potential to lose the understanding of the system-as-a-whole, especially in the context of SoS. Some guiding principles for architecting complex systems using graph theory are suggested.[39] By addressing practical approaches toward complexity, complex systems and complexity science Simpson and Simpson,[40] Sheard, et al.,[11] Watson, et al.,[15] Siegenfeld and Bar-Yam,[12] and Grumbach and Thomas[41] make important contributions to bridge the "theory-practice gap".

Rousseau[42] addresses the state of systems science, its relationship to complexity theory, and puts forward the need for a general systems theory to act as a foundation for SE and systems practice. However, one can question if systems science needs SE more than SE needs systems science and general systems theory.[43] This implies the need to embrace a broader research agenda for SE, including how we introduce SE to the future engineers.[35,44] By introducing a project complexity narrative that supports sense-making as a collaborative and iterative process one can sidesteps the challenges associated with the lack of any single, agreed definition of system complexity.[11,16]

The PM literature has several definitions of project complexity, but an agreed comprehensive definition is lacking, and no generally accepted framework has emerged to support the analysis of highly complex and innovative projects.[3,5] As such, complexity is an important and controversial topic in the PM discourse.[45] Brady and Davies[46] reviewed the PM literature on project complexity and further developed the framework introduced by Geraldi and colleagues[22] focusing on structural and dynamic complexity and how these might be managed in practice. Most of the PM discourse agrees that factors caused by unfamiliarity and the lack of knowledge ought not be associated with project complexity.[45] This aligns with a general acceptance, across important differences in epistemological orientation, of the notion of actor farsightedness,[47] that is, managers are expected to have a qualified view on how the future unfolds.

In their review of 420 scientific papers, Bakhshi et al.[45] distinguish between three distinctive schools of project complexity: the Project Management Institute (PMI) view, the SoS view and the Complexity Theories view.

The PMI view tends to focus on multiple stakeholders and ambiguity as two key characteristics of project complexity.[48] Until recently, the PMBOK[49] did not define or use the term "uncertainty", nor did it mention "complexity". Most researchers who tend toward the PMI view emphasize structural complexity, uncertainty and socio-political elements rather than other complexity dimensions.[45] The 2017 update of the PMBOK[50] introduces the PMI Talent Triangle as part of its effort to ensure that its certifications are relevant to the needs of industry and organizations.[51] These expectations toward the skill sets of project managers reflected in the talent triangle arguably support efforts to decode project complexity. The PMBOK 7th Edition released in 2021 introduces a further shift from "process-based project management" to "principle-based project delivery", further aligning PMI to the changing dynamics of the management profession.

The shift from a process and predictability focus toward a dynamic and adaptability[52,53] focus is likely motivated by the increasing number of organizations confronted with challenges of engineering complex System-of-Systems (SoS), or engineering a system that operates in a complex SoS context.[6,54] There are several definitions of SoS that depend on the particularity of the application area.[5,55–57] System of Systems Engineering (SoSE) has been considered by some as an opportunity for the SE community to define the complex systems of the 21st century.[57] In general, SoSE requires considerations beyond those usually associated with engineering to include socio-technical and sometimes socio-economic phenomena.[56] However, Ireland[58] suggests that any important contribution of research in SoSE has been based mainly in technology domains and relatively neglected the social and political areas.

A key aspect that distinguishes the SoS view from the PMI view is the lack of centralized control in managing autonomous and independent systems, both technical and organizational. Interest for the SoS view within the project complexity discourse has been rapidly increasing, and SoSE are employed in many large industries.[45,56] This view on SoS, as an approach to complex systems and projects, finds support in Cynefin,[59,60] a sense making model that proposes four categories: obvious, complicated, complex, and chaotic. As such, the Cynefin framework provides a potent tool to distinguish the complicated projects from the complex projects.

"The Complexity Theories view" is the term Bakhshi, et al.[45] used to group research papers that did not fit within the PMI and SoS view. This category accounts for a multitude of research that considers project or system complexities using various theories, for example, contingency, network, chaos, and complexity theory.[45] Most characteristics discussed in their research are time-dependent, observer-dependent, and problem-dependent, and as such difficult to further synthesize and generalize. It may seem that much of this research is motivated by a growing realization that classical PM techniques, for example, breakdown structures, network analysis, Program Evaluation Review Technique (PERT) and critical path analysis, are most effectively applied in obvious or complicated problem contexts.[59,61]

In their bibliometric network analysis of 50 years of project complexity research de Rezende, et al.[5] conclude that PM research is changing from project control to project adaptability when dealing with complex projects. This is aligned with the call to complement mechanistic and modernist views with their false promises of prediction, certainty and control,[51] with a worldview that is made up of interconnected technical and social entities that more often produce behaviors that cannot be predicted by analyzing the behavior of a single part in isolation or by simply aggregating the behavior of the parts.[54,62] Addressing complexity organically rather than mechanistically represents such a shifting view.[55]

de Rezende and Blackwell[56] use seven dimensions to define and introduce a project complexity framework to allow researchers and practitioners to better understand projects and make more informed decisions. The following section elaborates on these different views on project complexity dimensions.

2.2 | Project complexity dimensions

The notion that a conceptualization of project complexity dimensions represents a contribution toward an integrated project complexity narrative for PM and SE disciplines springs from the roots that these concepts have in both disciplines, that is, in the context of both system and project complexity discourse. However, the concepts usually are not referred to as dimensions. Sheard and Mostashari[17] and Sheard and Mostashari[63] explored specific measures of complexity that could be compared and tracked to identify and mitigate risks in complex systems or development programs. They proposed a framework that includes structural complexity, dynamic complexity and socio-political complexity.[64] Others have also provided extensive reviews of different definitions further highlighting the diverse conceptual landscape.[31,33] The notion of referring to these concepts as dimensions can be attributed to Geraldi et al.[22] They described complexity of projects in five dimensions; *structural*, *uncertainty*, *dynamics*, *pace*, and *socio-political* complexity. In their seminal review, de Rezende et al.[5] suggest that project complexity is defined by seven dimensions that include structural, uncertainty, novelty, dynamics, pace, social-political, and regulative. In the following we address the five dimensions of Geraldi, et al.[22] and propose to subordinate the novelty and regulative dimensions of de Rezende, et al.[5] to the uncertainty and socio-political dimensions, respectively.

The concept of *structural complexity* made its first appearance in PM literature in the 1990's[65–67] and has since been accepted as a feature of project complexity. Geraldi et al.[22] found size (or number), variety and interdependence to be key attributes of structural complexity. This aligns with the three types of structural complexity described by Sheard and Mostashari[17] that is, size, architecture and connectivity. It is also the type of complexity that has seen the most extensive development of complexity metrics[16,68,69] and the concept with the most mentions in both project and system complexity literature. Structural complexity should be understood as applicable to both engineered systems and the organizations put in place to deliver them. Brady and Davies[46] compare the complexity of two successful construction megaprojects – the Heathrow Terminal 5 and the London 2012 Olympic Park – by considering differences in the approach to managing structural and dynamic complexity. They conceptualize structural complexity as the "arrangement of components and subsystems into an overall system architecture" and dynamic complexity as the "changing relationships among components within a system and between the system and its environment over time" (p. 24).

As such, it is useful to characterize *dynamic complexity* as "a change in any of the other dimensions of complexity[22]" (p. 980). The attributes for dynamic complexity are less developed and specific than those for structural complexity, but dynamic behavior is a prevalent aspect of complex projects and is often linked to uncertainty of variables. Fischi et al.[34] address dynamic complexity measures for use in complexity-based system design and Sterman[70] brings several concepts, tools and examples of system dynamics to solve complex problems, including complex projects. Sheard and Mostashari[63] describe two types of dynamic complexity that suggest a distinction between sudden rapid change in system behavior (short term) and changes in the number and types of things and their relationships (long term).

Uncertainty, and its relationship to risk, has been present in the management literature for almost 100 years and was proposed as a component of project complexity.[67] Uncertainty can be defined as the result of not having accurate or sufficient knowledge of a situation.[71] Uncertainty about project inputs affects the modeling, evaluation and control of projects and establishes the objectives of time, cost, quality, and safety. Uncertainty is also found when there are unknown variables of the project output,[65] for example, in "mega-projects[72]" or in research projects.[73] The system complexity discourse includes different views on the question of whether complexity is, or should be understood as, observer dependent, or not.[74,75] It is not our intention to answer this question here, but uncertainty is a project complexity dimension that addresses this point when asking "uncertain for whom?" This is also why we assert that novelty is better addressed as an aspect of uncertainty, rather than to conceptualize it as a separate project complexity dimension, for example, as de Rezende, et al.[5] suggest. When considering uncertainty as a dimension of project complexity we suggest rating the uncertainty on a scale from highly intrinsic to highly contextual.

Pace, together with structural complexity, represents a tangible construct with several commonly accepted indicators. It essentially refers to the rate of planned delivery of projects or systems, that is, urgency and criticality.[76] Often it is difficult to operationalize metrics since pace is always relative to some reasonable or optimal measure. What is reasonable, or rational, is relative to goals and context.[77] Increasing pace by delivering systems sooner (e.g., 1 year instead of 2 years) can result in increasing complexity, while introducing and pacing iterations could help smooth aspects of the other complexity dimensions.

Sheard and Mostashari[17] consider *socio-political complexity* as the effect of individuals or groups of people on complexity and include sociological phenomena, such as fads and marketing, or the fields of economics, environmental sustainability, and politics. They suggest that the primary rationale to group these phenomena together is that most engineers have neither the education nor aptitude to deal with them. In PM discourse, the socio-political dimension of complexity was introduced by Geraldi and Adlbrecht[78] and Remington and Pollack,[79] and it is considered a key area of skillsets that project managers need to develop to manage effectively.[80] The socio-political dimension of project complexity is frequently related to stakeholder engagement, both project internal and project external stakeholders.[81,82] Socio-political complexity more often relates to decisions regarding "doing the right project" rather than "doing the project right." The socio-political dimension also includes "behavioral complexity" emerging from the interactions between people within organizations, involving aspects such as transparency, empathy, variety of languages, cultures, disciplines, etc.[22] While de Rezende et al.[5] suggest regulative, that is, control or directive according to rule, principle, or law, as a seventh project complexity dimension, we suggest including such aspects as sub-groups of socio-political complexity dimension: interpersonal/behavioral, societal/political, and organizational (intra- and inter-). Although socio-political complexity is straightforward to broadly conceptualize, it is complicated to operationalize and is often considered as a cradle for "wicked problems."[81]

This notion of project complexity dimensions represent a compromise between a paralyzing holistic view and an over-simplified reductionistic view of complexity.[22] The notion of project complexity dimensions does not contradict the theories of complexity. Rather it enables more precise sense making and collaborative description, which will lead to a more informed approach to managing the complexities of projects and systems.

3 | RESEARCH APPROACH

This paper reports from an ongoing effort to investigate the perceptions and application of SE and PM in academia.[83,84]

The research objective of this paper is to investigate to what extent academics draw upon a project complexity narrative when they talk about PM and SE in their work and discuss how these findings inform efforts toward the management of complex research projects and programs.

The research objective and following discussion of the results are informed by the systematic literature review presented in Section 3.1. The empirical results in this paper originate from case studies in two Scandinavian organizations (Section 3.2). Section 3.3 accounts for the reliability and validity of the research approach.

3.1 | Literature review

The notion of developing new valuable contributions toward system engineering was triggered by a literature review in this journal. Relevant research papers were identified using the keywords "system complexity" (18 papers) and "project complexity" (seven papers). The comprehensive literature reviews by Bakhshi et al.[45] and de Rezende et al.[5] were used to select relevant project complexity papers, that is, by the "snowballing" method. The inspiration toward an integrated PM and SE approach has its roots in research and literature generated from a joint PMI, INCOSE and MIT project and documented by Rebentisch and Prusak[8] and the INCOSE chartered working group (in 2016) focused on integration at both the program and project levels.[10]

3.2 | Interviews – Data collection

The data were collected from semi-structured interviews of 45–50 min with 18 informants. The number of informants adequately represent the boundaries of the case study. To ensure this, we used a key-informant sampling method[85] that guided the selection of participants based on their involvement in space projects at two academic institutions. The space projects undertaken by the different groups mainly focus on technology development in applied research. Nine informants are employed at an independent research institute and the other nine are employed at the faculty of engineering at a public university. The informants all have an MSc degree, and most have PhD degrees in either natural science or engineering, but not SE or PM. The organizations are in the same region and influenced by Scandinavian socio-cultural norms. The informants were anonymized, and interviews were transcribed in their given language, either Norwegian or English.

See Table 1 in the appendix for the semi-structured interview guide. The informants were not asked questions that contained the word complicated, complex, or any grammatic variation of complexity, emergence, or dynamic behavior.

The interviews and transcripts are available in the informants' mother tongues but for the purpose of this paper the excerpts presented are translated to English.

3.3 | Reliability and validity

Lincoln and Guba[86] introduced four criteria for research trustworthiness commonly applied among social science researchers to attribute reliability and validity to the specific nature of qualitative research. In qualitative research, *dependability* is often used similarly to reliability in quantitative research while *credibility, transferability and confirmability* are considered in the research design and data collection as consistent with internal validity, external validity and construct validity in quantitative research.[87] The use of case study as a methodological approach has some inherent limitations toward transferability, that is, limitations toward the extent to which the findings can be analytically generalized to other situations.[88]

4 | CASE STUDY RESULTS: ANALYZING THE INTERVIEWS

The findings are presented in five sections that present the authors' consensus evaluation of the informants' answers regarding the position of SE and PM in their work.

The analysis indicates to what degree the five complexity dimensions, that is, *structural, uncertainty, dynamics, pace and socio-technical*, are represented in the answers. All quotations reflect the opinions of the respective informant and do not necessarily reflect the views of the authors.

Each section includes a table (Table 2,3,4,5 to 6) with results from a search in the interview transcripts for relevant key words. Words are only included if they are used in context of projects, programs, systems, engineering or organization.

4.1 | Structural complexity

When informants were asked to reflect on SE, its application and the meaning of the term, the typical answers were related to aspects of structural complexity, specifically the benefits of organized and holistic approaches to complicated systems. For example, Subject 1 described how SE is concerned with seeing the whole system holistically and reducing it into manageable parts to identify and increase the understanding of relationships between its parts, while still maintaining the overall overview.

> Subj1: So, it [Systems engineering] is about seeing the whole system, but in a more holistic way where you reduce the system into manageable parts where you can see the relationships between the different systems and how they influence and interact with each other. But without it becoming a mess where everything is dependent on everything.

Other answers also reflected a systematic, reductionistic view on how SE could support the management of information in complicated project deliveries.

> Subj2: (…) a way to systematically manage large amounts of information. A type of methodology that can help you with that. To sort and prioritize complicated systems. If you must build or deliver something.

It is interesting to note that none of the informants addressed aspects of structural complexity when asked about research projects, nor was the word "structural complexity" used by the informants. However, the characteristics associated with structural complexity were often mentioned by informants when prodded about their understanding of SE.

4.2 | Uncertainty

Uncertainty and relevant characteristics were often used by the informants. The intrinsic uncertainty about the outcome of research projects, and the resulting uncertainty about data and resource availability and planning for the next iteration/cycle of the research process, were all frequent aspects of the informants' answers, for example, the resulting challenges of planning the availability of relevant personnel, laboratory resources and procurement of materials and technical services.

> Subj12: Given the resources we have I understand that there is a lot of frustration. You want something to work straight away if it stops working. If you have an idea, you want the answer immediately. All waiting leads to frustration. As a whole, I think we [the department] have enough resources for technical support. You could discuss what is the optimal organization of the technical resources. How do you distribute them? That is a continuous discussion. But as a whole we cover the most important areas. The challenge is that it is a large department and there are many needs that should be satisfied concurrently. We have to figure out how to ensure that.

There appears to be a demarcation line between how informants approach projects in the research domain and engineering domain. Decisions under uncertainty in the engineering domain are usually mitigated by selecting approaches where solutions can be validated and verified against requirements, that is, the process aims to prove that the selected solution is good enough. In the research domain, there is never a final answer or solution, even though the research project finishes. There will always be a new problem or question to address with new methods or materials to push the research boundary.

> Subj13: This is how I distinguish between research and development. Development continues even though we are unsure if the prototype is good enough. You have to make a decision, do as well as you can. This is the available information, the available components – do as good as you can. Research is more like..“hmm..is it possible to make this a little tiny bit better” – let's work 5 years on making it a little tiny bit better.

4.3 | Dynamics

None of the questions asked resulted in relevant reflections around the phenomena of dynamics or adaptability. However, change was frequently mentioned. It is interesting to note that although several of the informants work with complexity and emergence within the field of cybernetics, and most of the informants are seasoned project managers used to handle socio-political aspects, dynamics did not come up in either the context of PM or SE.

4.4 | Pace

Pace was frequently brought up by the informants. However, pace was predominantly addressed as a temporal phenomenon. Although several informants have experience with agile methods and processes, informants did not associate increased pace of cycles or iterations, for example, use of rapid prototyping as an approach to cope with complexity.

> Subj18: And what I have tried now is to do this quicker (build a system). So that we can uncover what is wrong quicker. That it shouldn't take that long before something breaks. But to show, to be able to answer why we do this. Is this design so much better than that design? Some of the engineers working on this system will do incredible things. But then you have to explain that yes, if we had infinite time, we could do amazing things. Now, we try to do what is good enough. We want to make this measurement campaign. Or we try to do something amazing and never make the measurement campaign. And this trade-off with keeping people sufficiently enthusiastic and giving them enough freedom, while at the same time ensuring that they will deliver at some point.… that is hard in academia. People are used to getting what they want. I've experienced that we don't have good tools or methods. And no support. I have had to do everything on my own. We don't have an organization for this [building systems].

Informants' answers indicate relatively relaxed attitudes toward milestones and deliveries, for example, when comparing themselves with industry settings.

> Subj4: In industry you are more concerned with ensuring that this will be a product with an actual reliable lifespan, also concerning maintainability and all the other costs associated with maintaining a product. We don't take that into account in research, we just want it to work. For a company, you would sign your own death sentence if you develop something you can't maintain and support during its lifespan.

It is worth noting that informants were selected due to their association with space projects. Space projects often include hard deadlines such as a fixed, pre-paid, launch campaign. An increase in pace would arguably result in increased complexity. Several informants were positive toward shorter, often more defined projects.

> Subj1: I would say that the timespan of this project is much shorter than the previous project I was involved with. It is easier to work in a project with an actual timespan. I think that is one of the definitions of a project, that it has a defined timespan. While something that was set up as a program, will not be a project. The other project turned into a program. (…) I think the mixture of trying to be a project and a program made it difficult to work with.

4.5 | Socio-political complexity

Informants frequently addressed topics related to socio-political complexity and the challenges they pose in any continuous research effort. However, there were limited reflections on the influence of PM or SE on a project generally or use of SE and PM tools and methods specifically, for example, stakeholder analysis or "onboarding", to address this category of complexity.

Socio-political complexity is arguably the dimension with most challenges toward achieving a commonly agreed, operationalized ontology.[17,22,56] For simplicity, we analyzed the interviews with respect to three groups: Interpersonal/behavioral characteristics, societal/political characteristics and organizational (intra- and inter-) characteristics.

4.5.1 | Interpersonal/behavioral

When the informants were asked how they perceive culture in their organizations, answers frequently addressed collaboration in teams of colleagues or interpersonal aspects derived from cultural norms and backgrounds.

> Subj17: We have a Northern European work culture if that is descriptive. We have partners all over the world. And one notices that there is a different culture, especially when it comes to deliverables. There is a different way of complying to milestones in Northern Europe than in Southern Europe. Also, when it comes to replying to emails.

4.5.2 | Societal/political

When asked about their roles and responsibilities, informants addressed the socio-political complexity for research projects that actively involve the greater society as a stakeholder. Approaches toward socio-political complexity seem different than those used in structural or uncertainty dimensions. The reductionist and relativistic reasoning that is clearly present when addressing characteristics of structural complexity are lacking in this context. Responses suggest that the form and nature of communications to this category of stakeholder must be tailored to special interests that may, or may not, be the primary motivators for the project team.

> Subj4: Yes, a lot [interaction with representative users]. There are many projects involving for example design students working with interaction design to students working with the politicians. We have a long road ahead of us. Convincing the politicians is probably the biggest hurdle. I am trying to disengage myself a bit right now to make sure we deliver on the technical side.

4.5.3 | Organizational (intra- and inter-)

When informants were asked how they perceive management within their own organizations and collaborating organizations, answers often addressed characteristics such as power, engagement, and support elements of socio-political complexity.

> Subj11: There are many administrative hurdles, it is not easy to get administrative support for everything. … There are many things we need to figure out, and we don't get good support far down in the project organization. We have to organize everything about getting support at the labs. And that is not necessarily a part of the research, depending on how you view it. But it is not a part of research that we have to run around and get offers for manufacturing parts or for some equipment you need in the lab. Even though your research depends on it. And it is not very transparent how much money a project has or how much you have used. Only some people know this. And maybe we don't need to know that, but it would be nice to have a ballpark overview. And I've been involved in many projects where you have to do everything yourself. You don't get much administrative or technical support. I think that is the biggest challenge. Technical, judicial and financially it could have been more structured.

5 | DISCUSSION

There is a long history of strong heuristic SE and PM tools and processes that provide actionable insights by describing and analyzing complexity.[23,80] Interest in complexity and the use of holistic approaches by practitioners to manage complexity in systems and projects is not new.[89–94] The remaining significant challenges towards addressing the current research gaps identified by Shenhar, et al.[3] and Potts, et al.[16] are the lack of any single, agreed definitions of system complexity[11] and project complexity.[5]

We subscribe to an understanding of complexity as discussed by Sheard and Mostashari,[17,24] that is, complexity can be viewed as the inability to predict the behavior of a system due to large numbers of constituent parts within the system and dense relationships among them.[95] In complex projects and systems, these constituent parts may be technical, economic, social and cultural in nature and contribute toward *structural, dynamic, and social-political* complexity.[16,22,54] The large body of literature addressing structural, dynamics and socio-political complexities motivated us to follow Geraldi, et al.[22] and include two additional categories to conceptualize project complexity dimensions, that is, *pace* and *uncertainty*.

A growing volume of discourses recognize that traditional dictionary definitions of complicated, complex, or chaotic, do not provide sufficient support toward describing and addressing contemporary problems that exhibit these attributes. A complex problem area requires a different approach than a complicated one. That is, solving a complex problem as if it were merely complicated risks delivering unsatisfactory solutions with low effectiveness and poor or inadequate performance. In turn, organizations that recognize these distinctions realize a better understanding of the interplay of scientific and heuristic pathways driving the emergence and evolution of system principles and methods across science and engineering fields.[26] We assert there are benefits, both practical and philosophical, for organizations to embrace an integrated project complexity narrative that addresses the challenges associated with contested definitions of systems complexity[15,68] and project complexity.[5,54]

We propose that as a first step toward embedding system and project complexity thinking within a wider learning cycle, academic organizations should focus on project complexity dimensions, rather than complexity factors, characteristics, or (contested and context dependent) definitions. This focus should enable lessons to be identified, learned and shared across disciplinary domains and thematic contexts.

The concept of dimensions is commonly associated with a measurable attribute of a particular kind, such as length, breadth, depth, or height, for example, "the final dimensions of the system were 235 × 543 cm." Such structural aspects of complexity are connected more readily to some metrics. However, for aspects such as socio-political aspects of complexity one may need to apply expert judgement to assign any value or measure, for example, number and type of stakeholders relevant for a project.

In the next section we discuss how the five complexity dimensions are reflected when our informants talk about PM and SE. In the Section 5.2, we discuss how conceptualization of the project complexity dimensions contribute toward an integrated project complexity narrative for PM and SE, that is, how it contributes toward a "better reflection on project complexity". In Section 5.3, we discuss the trustworthiness of the research presented.

5.1 | Project complexity dimensions in our case studies

We found *structural complexity* to be the most familiar dimension for our informants. It is arguably the dimension where reductionistic theory and methods are most efficiently and effectively applied. While there are recognized SE and PM capabilities that lend themselves to be applied to the structural complexity dimensions, there are known barriers to employing them, such as a lack of training or culture.

The intrinsic *uncertainty* of the research process and the resulting challenges in timely planning and acquisition of needed resources could be seen as an example of the mismatch in the multiscale complexity of academic organizations.[12] The temporal aspect of planning the needed resources often does not match that of the iterative learning cycle, that is, the *pace*, of most research processes. As such, academic organizations would benefit from an "organizing rather than an organization" focus. Introducing a shift from "farsighted" governance toward "spontaneous" governing would be one way of engaging uncertainty via increased dynamics. Increasing the capabilities to manage *dynamic complexity* in an organization could be one approach to engage both structural complexity and uncertainty.

Our findings also indicate that the concept of multiscale complexity of academic organizations,[12] for example, ambiguously coupled behavior, relationships, and structures on many scales, offers a novel approach to understanding known *socio-political* barriers toward SE and PM practices in complex research projects and programs.[21,73]

We suggest that conceptualization and application of project complexity dimensions support the development and comparison of individual mental models with a shared narrative for articulating our understanding of the dynamic and interconnected nature of a complex research project. However, since individual rationality is bounded in unique ways, depending on personal, cognitive capabilities, social and cultural background and professional training and experience, there will always be a point where the question: "for whom is this system too complex to comprehend and thereby to manage?" needs to be addressed.

5.2 | Toward an integrated project complexity narrative for SE and PM

Technical systems are composed of elements that can be described at various scales, for example, materials, components, unit assemblies, subsystems. Likewise, academic organizations can be described at various levels of hierarchy, for example, faculties, departments, research groups, support staff.

Understanding that behavior, relationships, and structure are not reducible to only one level but rather exist on many levels and are ambiguously coupled across multiple entities. As such, the hard problems often arise from mismatches between the complexities of a task to be performed, that is, design and deliver a complex system, and the complexities of the system performing that task, that is, project-based organizations.

Thus, to understand and communicate project complexity one should not start by focusing too much or too little on complexity, at any scale, but rather focus on the consideration whether the complexity of the project and program organization is tailored to address the complexity of the problem to be addressed and systems to be developed. We propose that an integrated narrative for project complexity with the five dimensions as a foundation would support SE and PM practitioners to become key facilitators for such efforts. Facilitators should be placed deliberately in the key positions required for successfully managing both system and project complexity in the wider organizational context.

Although this paper represents a very limited selection of organizations and informants because it is a case study, our research suggests a general lack of practice in identifying and discussing the implications of project and program complexity. Moreover, the language used by informants when talking about SE and PM suggests a critical gap in the understanding of SE and PM as disciplines with powerful potential toward coping with the challenging characteristic of project and system complexity. We suggest that the conceptualization of project complexity dimensions represent a potent platform for SE and PM disciplines to foster an integrated narrative for complexity, both for academics and for other organizations and practitioners.

The conceptualization should enable lessons to be identified, learned, and shared across organizational and discipline domains and contexts. There are some advantages associated with a low number of concepts, when introducing new initiatives in any organization. As such, the five project complexity dimensions represent an advantageous entry level to discussing both project and system complexity.

5.3 | Trustworthiness of the research

In line with Lincoln and Guba,[86] Bryman,[96] and Wahyuni[87] we discuss the dependability, credibility, transferability and confirmability of the results as a measure of the trustworthiness of the research.

Dependability, that is, reliability that promotes replicability or repeatability, is an inherent challenge of case-based research, and in this study applies in equal measure to the evaluators, that is, authors, stance and experience. However, the research approach reported in this paper allows for other researchers to reproduce the interviews, with their own set of participants. The *credibility* of the results was considered in the key informant sampling method and selection of the semi-structured interview guide. By evaluating the informants' answers for references to the different project complexity dimensions[54] and complexity characteristics[15] one can, with credibility, say something about the position of complexity thinking in relation to PM and SE in our case study organizations. The *transferability* of the research, that is, the applicability of results into other settings or situations, have limitations linked to the characteristics of the case organizations, that is, academic organizations with Scandinavian socio-cultural norms. However, our findings align with the larger project and system complexity discourse, and as such indicate a problem area, and corresponding solution space, that is applicable across sectors and jurisdictions. *Confirmability* of the study is methodologically sound but limited by decisions made due to both practical and legal aspects. The interviews and transcripts are only available in the participant's mother tongue, that is, Scandinavian languages. Privacy regulations and nature of the consent given by informants also limits sharing the research data.

6 | CONCLUSIONS AND FUTURE WORK

Academic organizations display a high degree of multiscale complexity, from the individual researchers, research projects, the department's academic discipline, to their role as educators of the future workforce for society. As such, managing project complexity requires multiple perspectives dependent on the context. Project complexity dimensions represent potent concepts to initiate assessments of such context.

Our findings indicate that any consistent differentiation between concepts of complicated and complex is lacking. Furthermore, when addressing characteristics of project complexity informants focused on physical and logical systems. Although most informants address aspects of uncertainty and socio-political aspects of their work, such narrative challenges could inhibit groups from greater effectiveness in managing social-political risks in their work.

PM and SE are disciplines that were developed as a response to practical engineering and management challenges, and many of these challenges are symptoms of complexity. As such, PM and SE have been, and are, about coping with the complexity of our systems, organizations, and society. However, our findings suggest that PM and SE practices are not pervasive within academic organizations. This means that complex research projects and programs should not be studied solely based on an á priori assumption that there is a discrete set of organizational artefacts and actors formally associated with PM and SE governance.

Discourse on explorative projects and the role of system thinking in the context of academia-industry collaboration is a promising agenda and venue for further evolving multidisciplinary discussions on complexity, both in SE and PM. Future work should address the relationship between complexity dimensions, complexity characteristics and complexity factors, as well as ontology development. More exhaustive literature review, and larger, international surveys are required as part of the future work.

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DATA AVAILABILITY STATEMENT

The data are not publicly available due to privacy or ethical restrictions.

ORCID

Knut Robert Fossum https://orcid.org/0000-0002-1020-730X
Evelyn Honoré-Livermore https://orcid.org/0000-0002-5664-330X
Erik Veitch https://orcid.org/0000-0001-6049-8136
Cecilia Haskins https://orcid.org/0000-0002-2506-8808

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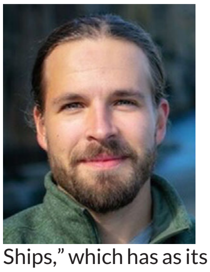
AUTHOR BIOGRAPHIES

Knut Robert Fossum is a research manager at Centre for Interdisciplinary Research in Space – CIRiS, NTNU Samfunnsforskning AS. He holds an MSc in biotechnology and PhD in Production and Quality Engineering. Fossum has worked with European space sector since 1997, mainly related to development, integration, and operation of scientific payloads for the International Space Station (ISSS). He has 20 years' experience with space project management and research- and human resources management responsibilities. He was responsible manager for the definition and establishment of N-USOC (www.n-usoc.no) and CIRiS (www.ciris.no). From 2010 to 2017 he served as senior advisor and national delegate to the European Space Agency (ESA). Resent work and field of interest is related to the integral role of human dependability for the safe, reliable and efficient organization and management of complex sociotechnical projects, in specific the application of System Engineering methodology for development and operation of autonomous systems.

Evelyn Honoré-Livermore is a Systems Engineer at the Division of Space Surveillance at Kongsberg Defense and Aerospace. She is the project manager of three microsatellites for maritime surveillance. She is also a PhD candidate at the Department of Electronic Systems at the Norwegian University of Science and Technology (NTNU). She received her MSc in Electronics Engineering in 2012 from NTNU, and a Master of Business Administration from Yonsei University in Seoul in 2017. Evelyn has experience as a project manager and systems engineer from the industrial space sector (2012—2017). She is researching systems engineering and project management methods for academic research projects. She was also the project manager of the small satellite HYPSO-1 (www.hypso.space).



Erik Veitch is a doctoral candidate at the Department of Design at the Norwegian University of Science and Technology in Trondheim, Norway. His field of research is about designing and testing technology interactions. Erikt's PhD project is called "Land-based Operation of Autonomous Ships," which has as its goal the development and testing of interaction solutions for supervisory control of autonomous ships. Erik's research goal is to contribute to design that supports seamless collaboration between humans and machines. Erik has a master's degree in Ocean and Naval Architectural Engineering from Memorial University of Newfoundland (2018).

Cecilia Haskins is a part-time mentor, consultant, author and volunteer, having recently retired. Her career includes 35-years as a practicing systems engineer followed by 22 years in academia where she taught organizational management, project management and systems engineering courses at all levels of higher education. She is recognized as an INCOSE Certified Systems Engineering Professional since 2004. Her educational background includes a BSc in Chemistry from Chestnut Hill College, an MBA from Wharton, University of Pennsylvania, and a PhD from the Norwegian University of Science and Technology (NTNU). Currently she has emeritus status with both NTNU and the University of Southeastern Norway. Her research interests include issues regarding sustainable development and excellence in engineering education.

Erika K. Palmer is a Senior Lecturer in the Systems Engineering Program at Cornell University, specializing in transdisciplinary social/sociotechnical systems engineering. She holds a PhD in Systems Engineering and Social Policy from the University of Bergen (Norway), an MSc in Industrial Ecology from the Norwegian University of Science and Technology (NTNU), an MSc in Biological Anthropology from University College London (UCL) and a BA in Psychology from the University of Maryland, College Park. Dr. Palmer is the founder and co-chair of the Social Systems Working Group (SocWG), the Americas lead for Empowering Women Leaders in Systems Engineering (EWLSE) at INCOSE and represents Cornell on INCOSE's Academic Council. She is also the Thread Chair for Psychology and Human Behavior for the International System Dynamics Conference (ISDC).

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APPENDIX

TABLE A1 Semi-structured interview guide

Q1: What do you know about systems engineering and what it is?
Q1.1. What are systems engineering to you?
Q1.2. Can you give me an example of what you mean?
Q1.3. What do you find helpful in systems engineering?
Q1.4 Where do you think one can benefit from it? Be overwhelmed by it?
Q2: What challenges do you see with systems engineering considering the (project) culture and how the tasks of (the department) is?
Q2.1 How do you experience the tasks at (the department)?
Q2.2 What do you think about doing projects for (space industry)?
Q2.3 Do you have goals related to such projects?
Q2.4 What do you think about the project process?
Q2.5 How do you think you do research at (the department)?
Q2.5 How do you think it is supported in the projects you work on?
Q2.6 How do you think you can work with project and research at the same time?
Q2.7 What mechanisms must be in place?
Q2.8 How is the culture for this in the organization?
Q2.9 What about the culture in (space industry) projects?
Q3: Follow-up questions
Q3.1 What do you think is helpful with systems engineering in light of what we have discussed today?
Q3.2. What you have said is very interesting. Can you embellish?
Q3.2 How do you see yourself using systems engineering in the future?

TABLE A2 Keyword search in the interviews relevant to the structural complexity dimension

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Structure	2	4	2		11	3	2			1				4		1		
Number			1				1									2		
Size	2			2	3	2	2	2	7	3	2					5	3	1
Architecture		1	8						2						1			

TABLE A3 Keyword search in the interviews relevant to the uncertainty dimension

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Uncertainty			1	1			1											
Cost			6		5	1	2						4				2	3
Control		4		1		2		2	1	2				1			1	
Risk			2		10	5		1		2				1			1	

TABLE A4 Keyword search in the interviews relevant to the dynamic dimension

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Change	1	1		10	6	4	4			5	2	2			4		6	4
Dynamic			2										1	1				
Variability																2	3	
Adaptability					1				1	2	1					1	1	

TABLE A5 Key word search in the interviews relevant to the pace dimension

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Time	5	5	3	10	8	2	6	8	8	8	13	1	5	7	35	4	11	6
Frequency																		
Rhythm																		
Tempo																		
Speed						1												

TABLE A6 Keyword search in the interviews relevant to the socio-political dimension

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
People		12	23	3	9	1	6	6	8	12		6	4	16	17	2	22	8
Socio				2							1							
Political			3														2	
Language					3	1							1	1				
Communication	2		2	1	1	4		4	1	2		1			1	1		
Person		2	3	2	3			7	1	3	4	3	3	2	3	2	4	7