IT PROJECT COMPLEXITY MANAGEMENT BASED ON SOURCES AND EFFECTS: POSITIVE, APPROPRIATE AND NEGATIVE

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Abstract. IT project complexity increases continuously, in synchrony with technological complexity, making projects difficult to manage and control. Despite a growing importance and priority in research, there is still a strong need for solutions to the significant challenges posed by complexity. This paper presents an exploratory qualitative research process based on design science, that expands the current theoretical foundations of IT project management by providing insights into the positive, appropriate, and negative aspects of complexity, and supports practice with newly designed tools for the analysis and management of complexity and response strategy planning, based on complexity sources and effects. The design and validation were performed with semi-structured interviews with experts, based on actual complex IT project cases.

Key words: complex IT projects, project management, structural complexity, uncertainty, positive complexity, appropriate complexity.

1. INTRODUCTION

Complexity is becoming a topic of major importance to IT project management [1]. Complexity impacts negatively the project budget, schedule, scope, and quality (hereafter referred to as cost). The cost of this complexity may compound to huge values at completion. All IT projects have a degree of complexity, but some are particularly large and complex. IT project complexity is associated with high cost and significant risk of failure – one in six IT projects being expected to be a black swan with an average budget overrun of 200% [2, 3, 4]. Some famous examples are Levi Strauss' SAP implementation, a $5 million project that led to an almost $200 million loss; the "Toll Collect" project cost Germany $10 billion in lost revenue, or the Schengen Information System II of the European Commission – 6 years late and 8 times more expensive than the estimate [5].

Complex IT projects cannot be managed with traditional deterministic, monolithic, top-down approaches [6, 7, 8]. They face significant, unpredictable change, similar to Lorenz's "butterfly effect" [9]. Complexity increases the likelihood of occurrence of Black Swan events and reduces significantly the effectiveness of traditional tools such as forecasting [10].

The identification and analysis of project complexity is relevant throughout all project phases, but is particularly important at 2 specific moments: during project approval (or Project Initiation), and during Project Planning. This paper presents the design of new tools for understanding IT project complexity; and more specifically the identification, analysis, and response strategy planning. It introduces the concepts and provides insights into the positive, appropriate, and negative aspects of project complexity. The results expand the current theoretical foundations of project complexity. It will thus benefit both project management researchers and practitioners, consolidating the theoretical foundations of project management, and supporting practice.

The research is based on design science. It builds on recent evolutions in project management, project complexity, systems theory, and Systems and IT Engineering. A qualitative validation with semi-structured expert interviews was performed, based on actual complex IT project cases.

2. LITERATURE REVIEW

The literature review phase of our research started from the search phrase: '(complex OR complexity) AND ("project management")', applied to the title and abstract on a large database of blind refereed research papers, extended by snowballing and additional areas such as Systems and IT Engineering. The systematic literature review is in press [11].

The underlying theoretical model used in this research is integrative: *project complexity is the property of a project which makes it difficult to understand, foresee and manage its behavior, even when given reasonably complete information about the project system.* The model includes *ambiguity, uncertainty, propagation, and chaos,* as the most important associated *phenomena,* or *manifestations*, of project complexity, covering thus both structural and dynamic complexity aspects [12, 13].

Structural (or detail) complexity is defined as consisting of many varied interrelated parts [14], operationalized as differentiation and interdependency, and expressed in terms of size, variety, and interdependence of project components. Cybernetics considers structural complexity as mere complicatedness [15, 16], solvable with additional effort and resources [17]. The ***dynamic (or "real") complexity paradigm*** analyzes uncertainty (of goals and methods); multiplicity; ambiguity [18, 19], open systems, chaos, self-organization, interdependence, emergence, and unpredictability [20, 21, 11].

2.1. A new paradigm: Complexity of Complexities – a holistic approach

Systems theory argues for a holistic approach. Complexity in project management may be tamed by systems thinking [22]. Complexity can be analyzed from high-level perspectives such as organizational or technological complexity, or niche aspects [23]. Systems engineering research focuses on product complexity. Marketing research focuses on the external environment. Management research targets the complexity of organizations and processes. IT experts develop complex IT products for complex markets in complex organizations with complex processes through complex projects (Fig. 1).
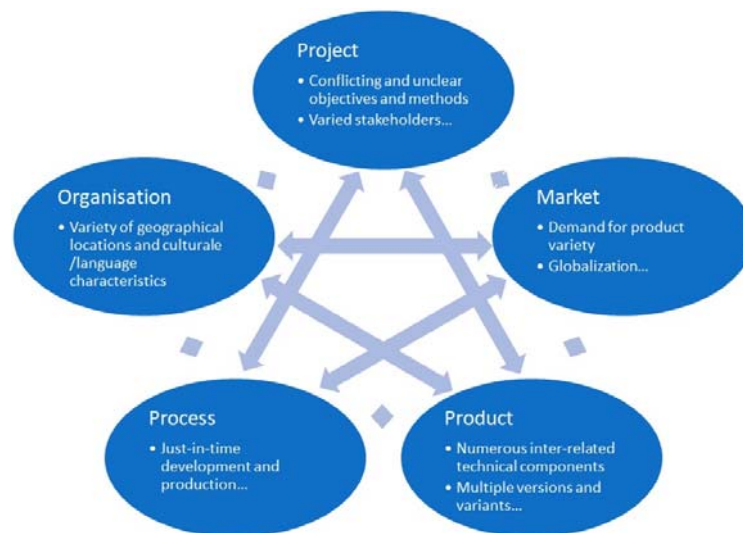

Fig. 1 – The Complexity of Complexities paradigm. An extension to "Complexity fields in engineering" [17].

IT project complexity can be described as a **Complexity of Complexities**. *An IT project is an ecosystem formed of complex sub-systems, interrelated and influencing each other in ways we cannot predict, nor control based on what we know about each complex sub-system individually.* This holistic approach is aligned with systems and complexity theory, which argue that the whole is more, and even different, than the sum of the parts [24, 25, 26, 27], as well as with the observation that complex IT projects can be described as System-of-Systems [1]. While phenomena associated with dynamic complexity manifest within each sub-system, systems theory shows that the complexity of each sub-system propagates also to different sub-systems, as confirmed also by empirical evidence such as: Conway's law: organizations design

systems that mimic their communication channels [28]; the business/IS alignment principle, or the *law of requisite complexity* [29]; complex products and organizations drive project complexity [30, 17].

The main benefits of this paradigm are the correct identification of the real sources of complexity and the correlation between sources and effects; supporting the selection of the best mitigation strategies. Perceived complexity is often generated in a distinct sub-system, not in the one observed. Because of propagation phenomena associated with complexity, actions in a sub-system have (un)desired effects in others. Traditional problem-solving or dependency-modeling techniques are effective only in the same sub-systems [17]. Systemic-level solutions are needed for events that cover more than one subsystem.

2.2. The ubiquitousness of complexity, and its positive aspects

Traditional project management literature as well as practice focus only on the negative effects of complexity, hence on how to reduce or eliminate it. This is similar to the history of risk management, which is yet to fully incorporate the management of opportunities into practice. Research strongly correlates project complexity with project failure and poor project management performance [4, 31].

At the same time, systems theory and engineering management provide new insights and original approaches to IT project complexity. In order to be innovative, creative, and adaptable, a system must be taken away from equilibrium, and should make use of disorder, irregularity and difference for driving change [32]. Complexity is often associated with innovation [4]. In order to remain viable, systems must acquire complexity [33], e.g. to match the complexity of the external environment, and even create excess complexity in order to be "efficaciously adaptive" [34].

Systems and IT/software engineering are highly effective domains, that develop increasingly complex products; they deliver valuable results with increasingly more complex processes. Complexity is a ubiquitous reality, that creates risk as well as opportunity: *"Complexity works! Nature, animals and humans are highly complex systems"* [17]. Technology will necessarily become more and more complex as it evolves. The next-generation computer, space shuttle, phone, watch or car will be *smarter,* and thus more complex, in order to provide more functionality, benefits, value; to remain competitive and relevant on the market. The organization and processes of the research, marketing, sales, and delivery departments will be more and more complex, so as to offer new products to new users on new markets. Artificial Intelligence, Data Science and Machine Learning are solving more and more industrial and societal challenges, with a level of complexity already far beyond our understanding. Also, complexity has sometimes positive unexpected or unintended effects: SMS, Facebook, Coca-Cola, and Viagra are famed examples of emergence and innovation in complex R&D projects: they are highly successful products, but different, or used differently, than originally intended.

We conclude that the fundamental mission of the project manager is not to eliminate complexity, but to *make complexity work.* We thus introduce the concepts of positive and appropriate complexity.

3. METHODS

Armed with the new paradigms formulated above, we designed and validated new tools to support the identification and analysis of IT project complexity. The research process took a qualitative exploratory approach. Design science is a valid research methodology to develop solutions for practical engineering problems [35]. Qualitative research helps develop initial understanding in a less explored area [36, 37]. The data collection methods used were interviewing and collecting project cases data [38]. Face-to-face, open interviews support qualitative exploratory research, considering the novelty of the research questions and the overloaded non-standardized terminology. Our research methodology followed a pragmatic constructivist approach to solving problems, with an iterative-incremental 2-rounds design, with trial-and-error cycles, based on the *design cycle* of the *engineering cycle* [39]:

P1. Problem formulation: we started with a general research question, on how to manage IT Project Complexity, operationalized as the design of new tools to support identification and analysis.

P2. Investigation: literature review on project complexity literature [11], systems theory, systems and IT engineering, to establish the theoretical and practical foundation for the design.

P3. Initial design of the tools: development of the initial design concepts, based on the literature review, and refined through interviews with experts and analysis of actual complex IT project cases.

P4. Preliminary validation with semi-structured interviews, based on actual project cases.

P5. Detailed design of the tools – based on the validation phase.

P6. Final validation of the tools, in a second round of interviews with the same experts.

During our research and design process, we embraced the fact that qualitative research is a personal journey [37]; that ideas and findings get reconceptualized with each writing [40]. To increase usability, we followed intensively the principles of minimalism and simplicity (Occam's Razor).

Expert opinion is a validation technique suitable to our exploratory research. Experts must have a thorough understanding of the topic. The selection criterion for the experts was practical experience of more than 20 years in personally managing or supervising complex IT projects, defined as: size of the managed team; number and variety of project stakeholders; execution and delivery in international/multi-cultural environments; significant impact on the project environment.

In qualitative research, stronger importance must be placed on negative than on positive feedback, in order to uncover new insights, challenge preconceptions, and avoid self-confirmation bias [39]. Triangulation has been shown to both prove convergence, as well as to explore divergent but possibly new relevant insights. Multiple case studies are suitable for building new theories and their external validation [41]. Face-to-face interviews are suitable for the niche topic, to obtain new insights and increase innovation and creativity. The interviews were structured in a standardized questionnaire, with open questions to drive exploratory qualitative research, but also with fixed-choice Likert and yes/no questions to increase reliability. The questionnaire had the following sections (the full questionnaire is available on request from authors):

A. Introduction: to establish a common language and understanding.

B. Project case description: performed before, when possible, and finalized after the live interview.

C. Analysis of how complexity was managed in practice in the actual project case.

D. Hypothetical "what-if" section regarding the potential value of the proposed tools, *as if* they would have been deployed in the actual project.

E. Validation of the final versions of the conceptual designs – phase p6. Final validation.

Detailed extensive notes were taken during each interview. The answers and notes were shared with the interviewees for approval. Due to confidentiality reasons, the discussions were not audio recorded. Each interviewee asked for a different degree of confidentiality: some project information and expert names cannot be disclosed, while some information is fully available.

3.1. Design limitations, validity, and reliability

While a series of measures were taken for ensuring construct, internal and external validity, as well as reliability, several limitations may impact the results, related to the design and validation phases.

The domain of applicability was restricted to IT, in order to increase specialization therefore usability. The number of cases was limited due to the qualitative research method, thus the results may not be generalized easily beyond the stated conditions. All project cases were implemented in Europe, but across many different countries. A sufficient number of case studies and interviews were conducted, to ensure sufficient data points, the required level of variation of the results and responses, to allow for analytical generalization and ensure external validity, to minimize subjectivity, and to validate convergence. The approach was cross-sectional – the project cases were analyzed at a specific moment, i.e. at completion (with one exception near completion). The cases were analyzed from a single perspective, so the level of objectivity of the interviewee about the projects cannot be established (with one exception analyzed from several perspectives). Due to their interactive nature, face-to-face interviews limit replication, hence reliability, and are susceptible to self-confirmation bias. Not all invited experts participated in the research. The participants had limited time available – between 40–120 minutes for each live interview, for an overall average of 82 min.

The iterative approach of the design process helped ensure internal validity and the avoidance of "anecdotalism". Each iteration was documented to ensure construct validity, using configuration management. After each iteration, a configuration baseline was established. The intermediate versions were documented for traceability and for ensuring construct validity.

4. RESULTS

4.1. Positive, Appropriate, Negative Complexity. The Complexity Effect Scale tool (CES)

We define **Project Complexity Management** as *the project management Knowledge Area that includes processes to understand, plan strategy and responses, and manage project complexity* – aligned with the standard body of knowledge [42]. *Its objective is to support project success, by enhancing positive complexity and reducing negative complexity.* Similarly to risk analysis, the Cost and Benefits refer to the negative and positive impact on the budget, but also on schedule, scope, and quality.

Table 1

Positive, appropriate, negative complexity. The Complexity Effect Scale tool (CES)

	Positive complexity	**Appropriate complexity**	**Negative complexity**
Definition	*Adds value to the project. Its contribution to project success outweighs its negative manifestations.*	*Needed for the project to reach its objectives. Its contribution to project success balances the negative effects, or the cost of mitigation outweighs negative manifestations.*	*Hinders project success.*
Description	Desirable, should be embraced and enhanced	Not desirable, but accepted because required, or because too expensive to mitigate	Not desirable – should be eliminated or reduced
Measurement	Benefits > Cost	Benefits ≃ Cost	Benefits < Cost

4.2. The Complexity Source/Effect Segmentation Matrix tool (CoSM)

The CoSM tool supports the identification of the source and effects, in order to select the proper management strategy, to solve the causes, or to mitigate the impact. The approach is similar to the SWOT tool, used successfully in risk management, strategy, and marketing. The tool is different from SWOT in several ways: focus on complexity not risks; on systems and systemic behavior rather than on individual events; and on transforming weaknesses and threats in opportunities, and using them rather than reacting to them.

CoSM segments complexity on 2 dimensions:

Effects E = {positive, appropriate, negative};
Sources S0 = {internal, external}.

E is based on the Complexity Effect Scale. S0 is used for simplicity and usability. A comprehensive list of possible classifications of sources was proposed by [11].

Notable segmentations are S1 = {market, organization, process, product, project} (Fig. 1); S2 = {external environment, internal environment, product}; S3 = {technical, organizational}.

Table 2

The simplified Complexity Source/Effect Segmentation Matrix tool (CoSM)

Effects / Sources	**Positive & Appropriate**	**Negative**
Internal	*e.g. Diverse expertise within the project team. Many products and tools available, with complementary/different functionality. New products for current markets.*	*e.g. The organization has many different, conflicting processes and standards. Large project team, distributed geographically (with potential communication problems)*
External	*e.g. Product used differently than intended. A product goes viral. New markets for the current product portfolio. Markets need new products or features.*	*e.g. Strong numerous competitors on the market. Many varied stakeholders with divergent objectives.*

4.3. Mitigation Strategies Matrix (MSM)

Using the Complexity Effect Scale, and drawing from risk and vulnerability management [13, 16], we identified 5 strategies for planning responses to IT project complexity (Table 3: Mitigation Strategies Matrix – MSM). For preventing and mitigating negative complexity, traditional project management proposes rigorous project preparation, risk management, decomposition/divide-et-impera, dependency modeling [17]. The response strategies for *positive* complexity can be paralleled with *opportunities* in risk management; this similarity supports the validity of the proposed construct.

Table 3

Mitigation Strategies Matrix (MSM)

	Response strategy	Complexity Effect		
		Positive	Appropriate	Negative
a.	Create, enhance	X		
b.	Use (exploit)	X		
c.	Accept / ignore	X	X	X
d.	Simplify / reduce			X
e.	Avoid / eliminate			X

4.4. Validation

The validation phase was performed with semi-structured interviews with experts selected based on their experience and expertise in the domain, and with actual project cases managed personally or supervised directly by the participants. The cases analyzed were IT projects with many varied activities; complex products; large-scale, geographically distributed; many varied external and internal dependencies; many varied types of deliverables (up to tens of thousands); many varied stakeholders (millions of decision-makers and users, with varied professional, cultural and language backgrounds and interests); long durations (8–10 years); large budgets (between 2.4 and 300 mil. Eur). The project cases included 3 very large trans-European projects, critical to the functioning of the European Union; 1 large trans-European capacity building project; 2 projects implemented in 2 different countries, at national level, in 700 / 15,000 sites.

The results of the validation phase were:

R1. The importance of the topic of IT project complexity was confirmed. *"IT has an inherent complexity; any software is complex",* was one of the comments received. The concept of complexity is not standardized; the terminology is overloaded.

R2. All experts recognize the need to measure and classify project complexity.

R3. Experts partially agree that the **complexity of complexities** paradigm would be useful in practice. They recommend offering practitioners several possible segmentations for the COSM tool.

R4. Practitioners already use **tools to manage IT project complexity**, such as project management frameworks or formal communication. Complexity relates to risk management: *"Complexity is always a risk".*

R5. Practitioners confirm **positive complexity**, and associate it with opportunities. *"Complexity is always a compromise". **Appropriate complexity*** brings clarity in the theoretical model, but is difficult to distinguish from positive in practice – similarly with *requisite complexity* [34]. *"Appropriate complexity requires a level of precision in measurement that makes me feel uncomfortable"*, was an observation.

5. DISCUSSION

The results support the need for a structured systematic approach to complexity management.

The Sources of complexity are linked to its Effects through two types of processes: 1) processes, tools, and methods under the control of the IT project manager; and 2) complexity-related phenomena, typically difficult to understand, predict, or control.

1. **The tools and strategies to deal with complexity always relate to cost** (i.e. impact on budget, schedule, scope, and quality). The effects propagate exponentially with a high compound rate, therefore

decisions should be based on the analysis of *cost-benefit at completion*. In practice, impact forecasts for complex systems do not correlate well with results [10].

Implementing **complex projects as programs** was proven useful both by theory and practice.

2. Complexity-related processes refer to structural (complicatedness), but also to subjective and dynamic aspects. Structural complexity is less abstract, thus more discussable, measurable, and manageable. Dynamic complexity aspects, on the other hand, are usually "unknown unknowns"; difficult to identify or plan; behave like Black Swans and follow "Butterfly Effect" patterns [9, 10]. Still, dynamic complexity must be identified, and projects must be prepared for it; e.g. by deploying tools such as monitoring for change, deploying vulnerability management [16] or redundancy to increase resilience [10].

The two types of processes overlap: some dynamic complexity-related phenomena, external environment variables, or impact can be controlled; and also actions undertaken by the project manager (i.e. from the project sub-system), are likely to propagate to other sub-systems of the Complexity of Complexities model.

At the same time, dedicated complexity management tools should be deployed only for large projects, due to their overhead. Misuse/overuse of project management tools can be a source of project failure [43]. Size is a strong predictor of complex projects [13, 44].

6. CONCLUSIONS

The research approach described in this paper was a cross-disciplinary, iterative-incremental, pragmatic journey, based on design science.

The paper proposes an innovative paradigm of IT project complexity, with both theoretical and practical implications. It introduces new concepts and offers new insights into the effects and benefits of complexity, especially its positive and appropriate aspects. It supports the development of a common language.

The results include original theoretical constructs and practical tools:

- the Complexity Effect Scale tool (CES);
- the Complexity Source/Effect Segmentation Matrix tool (CoSM);
- the complexity Mitigation Strategies Matrix (MSM), with potential response strategies: a) create/enhance; b) use/exploit; c) accept/ignore; d) simplify/reduce; e) avoid/eliminate complexity.

The major benefit to practitioners is to support practitioners to better understand, analyze, and manage complexity. The proposed tools will align project management with System and IT Engineering, which already recognize the importance of complexity and the need to manage and to exploit it, rather than merely avoid or reduce it.

Future research directions include the development, validation, and evaluation, through a longitudinal study, of a detailed framework for IT Project Complexity Management, with a comprehensive inventory of tools and methods, and examples of managing specific individual complexity aspects and related risks.

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