



Definitions, characteristics and measures of IT project complexity - a systematic literature review

Stefan Morcov

Katholieke Universiteit Leuven
Belgium
stefan.morcov@gmail.com

Liliane Pintelon

Katholieke Universiteit Leuven
Belgium
liliane.pintelon@kuleuven.be

Rob Kusters

Open Universiteit Nederland
Netherlands
rob.kusters@ou.nl

Abstract:

As the world of Information Technology (IT) engineering becomes more complex every day, the formal study of project complexity becomes more and more important for managing projects effectively, to avoid poor performance and failure. Complexity is not yet clearly understood nor sufficiently defined and the terminology itself is being overloaded and over-used. This paper is a systematic literature review that attempts to identify and classify proposed definitions and measures of IT project complexity. The results include a map of the identified approaches and definitions, a list of classifications of project complexity, a set of proposed measurement tools and complexity measures available to practitioners. The paper contributes to establishing a common language when discussing complexity, as well as to a better understanding of project complexity and its implications to practical IT engineering projects.

Keywords:

project management; information technology; complex projects; uncertainty; structural complexity.

DOI: 10.12821/ijispm080201

Manuscript received: 6 August 2019

Manuscript accepted: 15 April 2020

1. Introduction

Project Management as well as Information Technology (IT) and Software Engineering are critical disciplines in today's world, well established and recognized by practitioners, with clear standards, methods, tools, certifications and professional bodies. At the same time, complex projects are still poorly understood and face significant challenges and risks. Due to the complexity of today's products, single projects, single departments or even single engineering companies can no longer develop a complete product alone, thus the industry moves towards specialized lifecycles that involve concurrent, distributed, incremental/iterative, agile development [1] [2]. IT engineering projects face significant problems related to the complexity of both the products being developed as well as to the ambiguity and uncertainty related to the methods, tools and technologies employed during the development process. IT projects are recognized by both practitioners and researchers to have a significant risk of failure [3]. One in six IT projects is expected to be a black swan, with a cost overrun of 200% on average [4]. A significant number of projects in the IT industry are reporting incredible losses: Levi Strauss' SAP implementation was a \$5 million project that led to an almost \$200 million loss; the "Toll Collect" project cost Germany \$10 billion in lost revenue; the overall losses incurred by underperforming IT projects in the US is estimated at \$55 billion annually. When the European Commission finally launched the Schengen Information System (SIS II) in 2013, the project was more than 6 years late and 8 times more expensive than the initial estimate, at a final cost of €500 million [5]. Berlin Brandenburg Airport in Germany, scheduled to open in 2011 for 2.5 billion Eur, was delayed until at least 2020 or 2021, with a final bill estimated at 6.6 billion euro [6].

Complexity in IT project management is a relatively new research area, but it draws from theoretical research such as systems, complexity or chaos theories, as well as technical research areas such as system engineering – a domain which experiences similar challenges [7]. The concept of complexity is ancient and traces its roots to Greek philosophy. Thus, Aristotle gave humanity what was probably the first definition of complexity, when arguing that *the whole is something else than the sum of its parts*; a definition simplified by Euclid as the whole being *more* than the sum of its parts [8] [9]. Complexity re-entered mainstream science and research with the theories of holism and gestalt psychology [10] [11]. Complexity is now recognized as critical to a multitude of domains such as mathematics, chaos theory, information and computing science, engineering, biology, ecology, sociology, psychology, education, economics and management.

The approach prevalent in the project management research and community of practice is that complexity affects negatively both project performance and project management performance [12] [13]. Lack of understanding and recognition of system complexity is a critical cause of poor performance of large-scale IT projects [14]. The connection between project performance, project management performance and project complexity is well established [15] [16] [17]. Large-scale, complex projects are expensive. They have a higher risk of not accomplishing objectives and a higher monetary value associated with these risks, hence significant costs are incurred when they fail. They face significant, unpredictable change, similar to Lorenz's "butterfly effect" and Taleb's Black Swan events, and are difficult or impossible to forecast [18] [19].

Therefore, the management of complex IT projects is an expensive activity, requiring special tools, expertise and skills, different from the traditional project management deterministic approaches [20] [21] [22] [23]. The skills and competences of the project manager, already key to the overall project success, become even more important [24]. The identification of complex projects is specifically important to multi-project engineering environments [25]. The traditional project management frameworks do not differentiate between the tools and methods that should be used for complex non-deterministic projects as opposed to simple and deterministic projects. The analysis of complexity allows for categorizing and managing projects more efficiently, by choosing the right framework, tools, techniques and methodologies deployed.

Thus, complexity in project management has become during the past 25 years a topic of major interest [26] [27] [28] [29] [30] [31] [32]. It is extensively described and defined, in various models, in terms of characteristics, causes and effects, a few attempts having been also made at measuring it. At the same time, the words and concepts used are ambiguous, often imported from incompletely developed sciences; they overlap, are synonyms or express different aspects of the same concept. There is no widely accepted definition of complexity itself; it can be understood differently

not only in different fields, but also within the same field; it is not yet defined why it should be measured or how [33] [34] [35]. The terminology itself is not clear - the word “complex” itself is overloaded and over-used.

This paper builds knowledge in understanding complex IT projects and in unifying the language of the domain. It also maps and compares the various approaches proposed by research. The main method employed is a systematic review of the existing literature, followed by a classification of results. The research also consolidates the results of other reviews [32] [36] [37] [38] [39].

The paper presents the research method employed, including sources, results, discussions and conclusions, and potential directions for future research. The results include a structured map of the definitions and approaches to project complexity, with characteristics, definitions, sources, causes, manifestations of complexity in project management, based on their appearance in the literature; as well as the list of classifications of complexity; a list of complexity measurement tools; and a set of measures for IT project complexity.

2. Research method

A rigorous method of identifying, evaluating and interpreting previous research related to complex IT projects was employed. Systematic reviews are relevant methods to validate theoretical hypotheses, to support the creation of a new hypothesis, defining a framework of existing research, including gaps in existing research, in order to position and suggest future research [40]. A systematic review was performed, consisting of two distinct phases: a structured search and a classification of the results.

The search was done on a large database of blind refereed research papers, which includes ScienceDirect, Scopus, Web of Science. No time filter was used. The topic appears in 1993 [41] and is formalized in 1996 [27]. The initial search strategy aimed at narrowing the searched literature to the niche topic of “complex project management”. Each of the two domains “project management” and “complexity” is too broad for the scope of the current research, while their strict intersection is extremely narrow and risks excluding relevant results. Therefore, the main search phrase used was ‘(complex OR complexity) AND (“project management”)', which returns 68,784 peer-reviewed articles for a full-text search. In order to limit the results to a manageable number, while not losing relevant articles by excessive filtering, the search phrase was only applied to the title and abstract of peer-reviewed articles, thus reducing the list to 691 articles. These results were thereafter extensively extended by snowballing – analyzing the reference lists of existing papers and backward-searching on papers who reference existing papers. All papers that matched the topic were retained, including primary and secondary studies: meta-analyses of the topic, descriptions of the industry situation, specific case-studies and structured reviews. Articles that do not match the topic were not retained. The most common cause of topic-mismatch is due to the word “complex” itself being overloaded and over-used, often to mean “large” or “difficult”. The research retained only articles related to project management, while acknowledging the significant results from related domains, including complexity area itself, which provided the classic definition of a complex system: “made up of a large number of parts that interact in a non-simple way” [42]. 116 papers were found to match exactly the topic of this review, proposing definitions, approaches and/or measures of project complexity.

The articles were reviewed and summarized in free text form. The amount of information is very large, highly redundant, has heavy cross-referencing, and the approaches are at times contradictory. The second major phase of the research consisted therefore in structuring the information.

The first information structuring targeted **definitions of project complexity**. A map was created with all definitions, characteristics, sources, causes and manifestations of project complexity, as these appear in the literature. The method used was a formal method of classification. First, we removed double entries: the characteristics were grouped by lexical synonymy, each item being analyzed and either added to an existing category, or a distinct category would be created. Second, these characteristics were grouped by logical synonymy – using abstraction to logically group definitions that describe the same concept or characteristic. Depending on the specific author and approach, aspects of complexity are sometimes considered as definition, sometimes description, cause or effect. Duplicate items were maintained when the authors express different concepts with the same word. The result is a structured table of 27

characteristics, that maps the definitions and approaches, which allows for comparison between various authors (Table 3).

The second information structuring concerned **measurement criteria** and tools (Table 4). The initial inventory enumerated all the measures, criteria, characteristics, factors and indicators proposed for measuring, identifying or categorizing complex (IT) projects. Standard software measurement methodologies specifically include IT/software complexity, therefore all the items related to complexity from 2 major software estimation models were added to this list: 14 General System Characteristics defined by the Function Points Analysis methodology, which are used to compute the Value Adjustment Factor [43] [44] and 15 Cost Driver Attributes defined in COCOMO [45] [46]. This large inventory has 117 items. It includes factors even if specifically excluded from other models, such as size. A large number of items were redundant, and some not relevant. At the same time, compiling a complete inventory of all possible items insured reliability and repeatability of the process, as well as construct validity and internal validity – in order to avoid anecdotic evidence and subjective criteria [47]. In order to arrive at a simple set of usable complexity measures, each item in this initial inventory of measures was further classified using an ordinal scale with 5 ranks, according to the following criteria:

- redundancy (duplication);
- relevance;
- measurability;
- repeatability within an organization;
- repeatability across different organizations;
- predictor of high risk (probability);
- predictor of high cost related to the risk (impact).

The resulted filtered set of measures includes 28 items that are unique, relevant and measurable, i.e. all items that score at least 3 on the first 3 criteria (Table 5).

The redundancy and relevance criteria simplify the list. The measurability and repeatability criteria maintain the focus on practical issues, eliminating subjective or abstract items, thus ensuring the external validity of the results. The criteria Predictor of high-risk and of high-cost express the main motivation for the study of complexity in project management: complexity generates risk. In choosing the criteria used for this classification, certain choices had to be done which may be considered subjective. The classification is relevant for the scope of our research, it is valid and results from a repeatable process. The list is simple enough to be usable, studied and understood. Its items are practical, allow for comparison and measurability and are objective – they do not have multiple interpretations based on context or expert. The result is falsifiable, which ensures its internal validity.

The research did not attempt to assign individual weights to each item in the list, nor compute a quantitative complexity factor. There is significant empirical proof that there are major differences between complexity measures across different industry sectors, therefore the research scope and applicability was limited to IT [48]. Criteria and numeric weights are different across domains, and even between authors, experts or studies within the same field [49]. This suggests that the values of the weights vary across different types of projects, organizational and technological environments. For an assessment tool to be usable, its results must be comparable and repeatable, thus the compared projects should be reasonably similar, in terms of products, processes (technologies, methodologies and tools) and organization (environment, industry, stakeholders, users, size). This conclusion is aligned with the analysis of the effectiveness of formal methods for estimating software projects (COCOMO, FPA, IFPUG). All software estimation methods require heavy calibration using historical data related to the exact specific industry, organization, tool and technology employed for the particular projects measured. Because IT projects are particularly varied and complex [2], such estimation techniques have systematically proven to be unreliable [50]. Software estimation errors of 10% are acceptable, organizations are only concerned by errors above 100% [51]. Therefore, organizations mostly revert to expert judgment for estimation [52]. The assignation of weights to complexity measures at this time would not meet reasonable reliability and repeatability criteria, and also would not fulfill sufficient external validity conditions for the scope of this research.

3. Results

The results are:

- A chronological summary of the definitions and approaches (Table 1);
- A list of classifications and sources of complexity (Table 2);
- A structured map of the characteristics (fragment in Table 3);
- A list of complexity measurement tools (Table 4);
- A simplified set of measures (Table 5).

Table 1. Summary of definitions and historical approaches to project complexity

Author	Approach	Definition/model
[27]	First systematic approach, introducing structural complexity.	Consisting of many varied interrelated parts. Operationalized in terms of differentiation and interdependency. Categorized (mainly) as organizational and technological.
[53] [54] [55] [56] [57] [58] [59] [36]	Complexity of system development. Structural complexity. Uncertainty of goals and methods. Multiplicity and ambiguity.	Dynamic complexity, in addition to detailed (structural) complexity. Ambiguity or uncertainty as sources. Categorized as “task-related” (business, external, organizational) or “system-related” (technological). Multiplicity, i.e. many approaches and end-states. Ambiguity, i.e. conflict and uncertainty in decisions.
[37] [60] [61]	Complexity in social sciences or biology. Complex systems theory.	Complex society is characterized by open systems, chaos, self-organization and interdependence. Emergence, unpredictability.
[62] [63] [25]	Holistic models, delineating definition, sources, manifestations, characteristics of project complexity.	“Difficult to understand, foresee and keep under control”. Ambiguity, uncertainty, propagation and chaos are considered not as sources, but consequences of complexity.
[32]		Five dimensions of complexity: structural, uncertainty, dynamics, pace and socio-political.
[64]		Two dimensions of project complexity (detail and dynamic complexity) and three dimensions of project emergent properties (absorptive, adaptive, and restorative capacities).

Table 2. Classifications of project complexity

#	Classification and source
1.	Technical vs. organizational complexity [27] [54] Also: task-related complexity (business, external, organizational complexity) vs. system-related (technological complexity) [53] Also as: the TOE model - technological, organizational, environmental [65]
2.	Structural vs. dynamic complexity [66] [59] Or: detail vs. dynamic [36] [64] Variation: structural complexity vs. uncertainty [54]
3.	Simple, complicated, complex, really complex projects [36] [39]
4.	Objective (descriptive) vs. subjective (perceived) complexity [67] [68] [69] [70]
5.	Uncertainty in goals vs. uncertainty in methods [41]
6.	Multiplicity (many approaches and end-states) vs. ambiguity (conflict and uncertainty in decisions) [57] [58]

#	Classification and source
7.	Ambiguity (unknown) vs. complexity (unpredictable) [55]
8.	Size, variety, interdependencies, context-dependencies [63] [71]
9.	Ambiguity, uncertainty, propagation and chaos [63]
10.	Size, innovation, interdependencies, variety [56]
11.	Variety vs. variability vs. integration [72]
12.	Uncertainty of faith (uncertainty, uniqueness, unknown), of fact (strong interdependencies), of interaction (politics, ambiguity, multiculturalism) [73] [74]
13.	Structural, technical, directional, temporal [75]
14.	Structural, uncertainty, dynamics, pace and socio-political [32]
15.	Project emergent properties: absorptive, adaptive, and restorative capacities [64]

In addition to Table 2, some variations of classifications were also proposed [12] [21] [76] [77] [78] [79] [80].

Table 3. Structured map of the characteristics of complex projects

Characteristics	(Baccarini, 1996) [27]	(Williams, 1999) [54]	(Vaaland & Hakansson, 2003) [56]	(Bertelsen, 2004) [60]	(Xia & Lee, 2005) [66]	(College of Complex Project Managers And Defence Materiel [81])	(Cooke-Davies, Ciemil, Crawford, & Richardson, 2007) [61]	(Mulenburg, 2008) [82]	(Whitty & Maylor, 2009) [59]	(Vidal, 2009) [63]	(Hertogh & Westerveld, 2010) [36]
1. Multiplicity					SC						
2. Ambiguity					DC			x		Manif.	
3. Uncertainty		x			DC	x		x		Manif.	
4. Details (structural)	x	x						x	x		x
5. Dynamics					DC			x			x
6. Disorder						x					
7. Instability						x				Manif.	
8. Emergence				x		x	x		x		
9. Non-linearity				x		x	x				
10. Recursiveness						x					
11. Irregularity						x					
12. Randomness						x	x				
13. Dynamic complexity = parts interact					SC	x		x			x

Characteristics	Author: (Baccarini, 1996) [27]	(Williams, 1999) [54]	(Vaaland & Hakanson, 2003) [56]	(Bertelsen, 2004) [60]	(Xia & Lee, 2005) [66]	(College of Complex Project Managers And Defence Materiel [81])	(Cooke-Davies, Cicmil, Crawford, & Richardson, 2007) [61]	(Mullenburg, 2008) [82]	(Whitty & Maylor, 2009) [59]	(Vidal, 2009) [63]	(Hertogh & Westerveld, 2010) [36]
14. Uncertainty of objectives and methods	x					x					x
15. Varied stakeholders, competing views			x		SC	x					x
16. Changing objectives				x		x					
17. Adaptive, evolving				x		x	x			Manif	x
18. Involves double-loop learning						x					
19. Explanation of states of stability-instability				x			x				x
20. Size		x								Driver	
21. Variety		x			SC					Driver	
22. Interdependence		x			SC					Driver	
23. Context										Driver	
24. Innovation			x								
25. Difficult to understand										Def.	
26. Difficult to foresee				x						Def.	
27. Difficult to control										Def.	

In Table 3, SC stands for structural complexity; DC: dynamic complexity; Def.: definition; Manif.: manifestation. Various models and tools were proposed for measuring the degree of complexity, defining approaches scales, measures and criteria [66] [33] [83] [84] [85] [86] [25] [87] [67] [88] [39] [71] [89] [90] [65]. Table 4 presents the most recognized complexity measurement tools.

Table 4. Complexity measurement tools

#	Measurement tool
1.	The complexity Assessment Questionnaire proposed by the Project Management Institute [91]
2.	The Crawford-Ishikura Factor Table for Evaluating Roles (CIFTER) supported by the International Project Management Association [92]
3.	The Project Complexity Assessment and Management tool (PCAM) [93]
4.	Hass' Project Complexity Model Formula [86]
5.	Vidal's AHP (Analytic Hierarchy Process) measurement tool [25]
6.	"Acquisition Categorisation" (ACAT) of the Australian Defence - assesses levels of complexity against the attributes: cost (size), project management complexity, schedule complexity, technical difficulty, operation and support, commercial [94]
7.	Project Complexity and Risk Assessment tool (PCRA) of the Treasury Board of the Canadian Government [95]

Tables 5 presents the complexity criteria retained based on uniqueness, relevance, and measurability, classified by family [63] and source (organizational, technological) [27].

Table 5. Simplified set of measures of complex IT projects

#	Criterion	Family	Organizational	Technological
1	Staff quantity (team size)	Size	Yes	
2	Number of stakeholder organizations (subcontractors, customers, partners, investors, users...)		Yes	
3	Size of capital investment (budget), including resources		Yes	
4	Number of deliverables		Yes	Yes
5	Effort (man-days)		Yes	Yes
6	Duration of the project		Yes	Yes
7	Number of business areas involved			Yes
8	Number of function points			Yes
9	Reusability - application developed to meet one or many user's needs	Variety		Yes
10	Geographic distribution of the project team (collaborating frequently)		Yes	
11	Variety of the interests of the stakeholders		Yes	
12	Variety of information systems to be combined (number of application types)		Yes	Yes
13	Variety of skills needed		Yes	Yes
14	Variety of interdependencies			Yes
15	Competing objectives			Yes
16	Uncertainty and stability of the objectives and requirements		Yes	Yes
17	Availability of people, material and of any resources due to scarcity of supply on the market or in the organization	Interdependencies	Yes	
18	Specifications interdependence			Yes
19	Interdependence between the components of the product			Yes
20	Uncertainty of the project plan - level of detail and expected stability			Yes
21	Uncertainty and stability of the methods (clear project management methodology, clear software development methodology, risk management, communication, etc.)			Yes
22	Unknown and/or unstable legal and regulatory environment	Context	Yes	Yes
23	Cultural configuration and variety	Interdependencies /context		Yes
24	Environment organizational complexity (networked environment)		Yes	
25	Environment technological complexity (networked environment)			Yes
26	Knowledge in the organization - organizational (business and industry; e.g. new business or a new type of customer)		Yes	
27	Knowledge in the organization - technical (technology, infrastructure, external interfaces, development platform, tools...)		Yes	
28	Level of change imposed by the project on its environment		Yes	

4. Discussion

The main approaches identified for defining IT project complexity are subjective/objective, size-related, structural and dynamic. They are summarized in Figure 1. The subjective (perceived) complexity paradigm assumes that the complexity of a project system is always improperly understood through the perception of an observer, while the objective (or descriptive) complexity paradigm considers complexity as an intrinsic property of a project system [67] [68] [70].

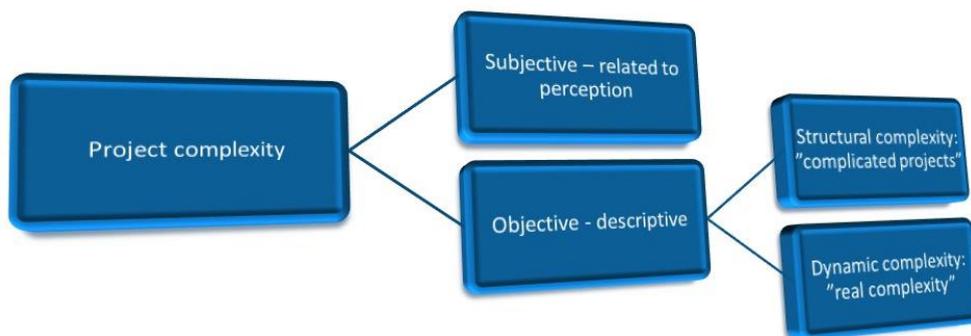


Figure 1. Project complexity paradigms

The simplest approach is based on **size**- large projects are considered more complex. Size may refer to capital, budget, effort, duration, number of stakeholders or technical components [96] [97] [59] [56]. Pure theoretical approaches to project complexity consider that size is not a valid factor, since a large project without interdependencies could theoretically be split into several small simple projects [27]. In practice, size cannot be separated from complexity; it is strongly related to uncertainty [98] and risk exposure [99] [100]. Mega-projects and complex projects have common characteristics [101]. Size is always a strong predictor of complexity. Also, due to budget constraints, only large projects should be treated as complex in practice [63] [102] [71] [67].

Structural, or descriptive, spatial, detailed complexity, is defined as consisting of many varied interrelated or interacting parts – with a strong accent on differentiation (varied) and interdependence [27] [69]. It may refer to technical (product) or organizational complexity [54]. Descriptive complexity considers complexity as an intrinsic property of a project system [68] [67]. Structural complexity allows for objective measures, thus is the most common approach.

Dynamic complexity (or true, real complexity), includes uncertainty, ambiguity, variability aspects [66] [57] [58]. Uncertainty in both goals and methods is typical for complex projects [41] [28] [81] [54] [57] [58] [103]. Complexity arises from ambiguity or uncertainty related to the tasks or the system [53]. It relates to open systems, chaos, self-organization and interdependence, self-modification, upward and downward causation and unpredictability, adaptiveness [37] [60] [75]. They are defined by nonlinearity, continuous interactions with their environment and complex feedback loops [61]. They are emergent, therefore control on individual components does not guarantee the control, nor the overall behavior, of the whole project [59]. They display significant changes provoked by small factors, similar to Lorenz's “butterfly effect” [18].

Structural complexity (complicatedness) may be considered a cause and/or an effect of “real complexity” [59] [38] [39]. Approaches based on cybernetics differentiate between simple, complicated and “really complex” projects, associating structural complexity to mere complicatedness [104] [67], solvable with additional resources and decomposition / divide-et-impera techniques [7].

The described approaches are complementary. Combinations give a more comprehensive perspective [62] [63] [73] [32].

5. Conclusions and implications

IT project managers notice early in their careers that complexity is ubiquitous in their projects and products. Practitioners understand and recognize the importance of complexity, that it cannot be avoided or eliminated completely, that it is highly expensive, and sometimes complexity is useful and/or needed for the success of IT projects and products. The industry recognizes more and more the need for studying complexity in engineering projects, as it needs practical tools and methods for identifying, measuring and managing complexity. The industry is still mostly guided by expert judgment: “You will know it when you see it” [85]. There is no specific framework or methodology for the management of complex IT projects, but collections of guidelines and best practices start to appear. The identification and analysis of complexity still suffer from vague definitions, ambiguity in the terminology employed, confusion between definition, sources, causes, characteristics, manifestations and metrics. These issues affect theoretical research as well as the performance of IT industry projects

Research in project complexity is based on theoretical and empirical methods, starting from systems theory, complexity theory, natural and social sciences, chaos theory. It includes case studies and theoretical models. Limited research has been conducted on metrics and measuring IT complex projects and very little in defining methods for managing them. Most research simply stops at concluding that metrics and tools are required but not available or not reliable.

Even if IT and systems engineering face similar issues as project management regarding the management of complexity, significant success can be observed in these industries, proven by the plethora of very successful and complex products developed daily: the industrial and personal devices around us are more and more complex: smartphones, autonomous vehicles, space shuttles, robots, intelligent home appliances, etc. [7]. The holistic approach adopted by modern systems engineering, including the concept of SoS (System of Systems), would benefit and help advance the project management body of knowledge [105] [106]. While project management practitioners focus on the negative aspects of complexity, they also acknowledge that it is often associated with innovation [12] [107]. We propose therefore to revert to a systems-thinking approach in project management; to acknowledge the relation between project complexity, product, process, and organizational complexity; to acknowledge the importance of complexity in everyday life and accept that systems, both natural and artificial, acquire complexity; and to use this for advancing IT project management. Such concepts as “positive complexity”, “appropriate complexity” and “requisite complexity” [108] will be critical to advancing IT project management, and can constitute key directions for future research. Managing complexity is expensive, but ignoring complexity is even more expensive. Thus, it is even more important for practitioners to recognize, understand, measure and classify complexity and complex projects; to differentiate between different types, sources and effects of complexity. Based on cost-benefit analysis, practitioners will then be able to make informed decisions on how to manage each particular project and each aspect of complexity.

Further research is needed for developing methods and tools for the measurement and management of complex IT projects, in tight correlation and with direct impact in the industry. Research questions are also proposed by authors [109]. Potential directions of research are the analysis of the relation, similarities, and synergies between IT project complexity and complex systems engineering, risk, and vulnerability management [67], or the application of systems theory and systems thinking to IT project complexity management.

6. Limitations and main contributions

While a series of measures were taken for ensuring validity and reliability, several limitations apply. The researched literature was narrowed so that the research remains feasible, while ensuring that relevant articles are not excluded. The Science Direct database was used in the search, as it covers the largest number of journals relevant to the topic. The search phrase was applied only to the titles and the abstract of peer-reviewed articles, so as to limit the number of articles while retaining relevant research. The search was limited to articles in English. The summation of the reviewed articles was done manually, but was documented for each article, in order to ensure traceability and repeatability of the process. Also, each reviewed article was categorized and archived individually.

The literature review was not limited strictly to an industry, but it is focused on IT. The domain of applicability of the complexity measures is especially limited to IT projects, in order to increase specialization therefore usability.

The results are summarized and formatted to be accessible to a wider audience. The summary tables and the Results section indicate the referenced articles.

All models are of course simplifications of reality. They cannot describe reality in all its aspects, but they help us analyze and discuss the topic using a common language and a standardized approach. Important about models is that they should be practical, rather than “correct”. This paper allows the formation of a common language for IT project management practitioners, aligned with mainstream project management terminology and methodologies.

IT project complexity is a challenging and complex issue itself, which requires special consideration for building new knowledge and value for practitioners and industry. This paper constitutes a building block in the study of and research into IT engineering project complexity.

References

- [1] J. v. Moll, J. Jacobs, R. J. Kusters and J. J. M. Trienekens, "Defect detection oriented lifecycle modeling in complex product development," *Information & Software Technology*, vol. 46, no. 10, pp. 665-675, 2004.
- [2] N. B. Moe, T. Dingsøy and K. Rolland, "To schedule or not to schedule? An investigation of meetings as an inter-team coordination mechanism in large scale agile software development," *International Journal of Information Systems and Project Management*, vol. 6, no. 3, pp. 45-59, 2018.
- [3] R. R. Nelson, "IT project management: Infamous failure, classic mistakes, and best practices," *MIS Quarterly Executive*, vol. 6, no. 2, p. 67-78, 2007.
- [4] B. Flyvbjerg and A. Budzier, "Why Your IT Project May Be Riskier Than You Think," *Harvard Business Review*, Sep 2011.
- [5] European Court of Auditors, "Lessons from the European Commission's development of the second generation Schengen Information System (SIS II)," European Court of Auditors, Luxembourg, 2014.
- [6] Baulinks, "The non-opening of the BER costs about 10 million euros per month retrieved," 5 Feb 2018. [Online]. Available: <https://www.baulinks.de/btw/2018/0001.php4>. [Accessed 8 Oct 2018].
- [7] M. Maurer, *Complexity Management in Engineering Design - a Primer*, Heidelberg: Germany, Springer-Verlag GmbH, 2017.
- [8] Aristotle, *Metaphysics*, pp. Book VIII, 1045a.8-10.
- [9] Euclid, *Elements*, pp. Book I, Common Notion 5.
- [10] J. C. Smuts, *Holism and Evolution 2nd Edition*, Macmillian and Co, 1927.
- [11] Koffka, *Principles of Gestalt Psychology*, 1935, p. 176.
- [12] S. Floricel, J. L. Michel and S. Piperca, "Complexity, uncertainty-reduction strategies, and project performance," *International Journal of Project Management*, vol. 34, no. 7, pp. 1360-1383, Oct 2016.
- [13] T. Bjorvatn and A. Wald, "Project complexity and team-level absorptive capacity as drivers of project management performance," *International Journal of Project Management*, vol. 36, p. 876-888, 2018.
- [14] P. Patanakul, "Managing large-scale IS/IT projects in the public sector: Problems and causes leading to poor performance," *Journal of High Technology Management Research*, p. 21-35, 2014.

- [15] C. Ivory and N. Alderman, "Can project management learn anything from studies of failure in complex systems? Worst practices in project management within the television production industry," *Project Management Journal*, vol. 36, no. 3, p. 5–16, 2005.
- [16] V. R. Montequín, V. B. Joaquín, C. F. Sonia María and O. F. Francisco, "Exploring project complexity through project failure factors: Analysis of cluster patterns using self-organizing maps," *Complexity*, p. 17, 2018.
- [17] E. Głodziński, "Performance measurement of complex project: framework," *International Journal of Information Systems and Project Management*, vol. 7, no. 2, pp. 21-34, 2019.
- [18] E. N. Lorenz, "Deterministic Nonperiodic Flow," *Journal of the Atmospheric Sciences*, vol. 20, no. 2, p. 130–141, March 1963.
- [19] N. N. Taleb, D. G. Goldstein and M. W. Spitznagel, "The Six Mistakes Executives Make in Risk Management," *Harvard Business Review*, 2009.
- [20] P. A. Daniel and C. Daniel, "Complexity, uncertainty and mental models: From a paradigm of regulation to a paradigm of emergence in project management," *International Journal of Project Management*, vol. 36, p. 184–197, 2018.
- [21] Q. He, L. Luo, Y. Hu and A. P. Chan, "Measuring the complexity of mega construction projects in China - A fuzzy analytic network process analysis," *International Journal of Project Management*, vol. 33, p. 549–563, 2015.
- [22] E. Ugarte, *Conquering Complexity*, Helmsman Institute, 2015.
- [23] J. Zhu and A. Mostafavi, "Performance Assessment in Complex Engineering Projects Using a System-of-Systems Framework," *IEEE Systems Journal*, vol. 12, no. 1, pp. 262-273, 2018.
- [24] A. P. Ammeter and J. M. Dukerich, "Leadership, team building, and team member characteristics in high performance project teams," *Engineering Management Journal*, vol. 14, no. 4, pp. 3-10, 2002.
- [25] L.-A. Vidal, F. Marle and J.-C. Bocquet, "Measuring project complexity using the Analytic Hierarchy Process," *International Journal of Project Management*, vol. 29, p. 718–727, 2011.
- [26] R. Atkinson, L. Crawford and S. Ward, "Fundamental uncertainties in projects and the scope of project management," *International Journal of Project Management*, vol. 24, no. 8, p. 687–698, 2006.
- [27] D. Baccarini, "The concept of project complexity, a review," *International Journal of Project Management*, vol. 14, no. 4, pp. 201-204, 1996.
- [28] M. Castejón-Limas, J. Ordieres-Meré, A. González-Marcos and V. González-Castro, "Effort estimates through project complexity," *Springer Science+Business Media*, 2010. [Online].
- [29] S. Cicmil, T. Williams, J. Thomas and D. Hodgson, "Rethinking Project Management: Researching the actuality of projects," *International Journal of Project Management*, vol. 24, no. 8, p. 675–686, 2006.
- [30] L. Crawford, P. Morris, J. Thomas and M. Winter, "Practitioner development: From trained technicians to reflective practitioners," *International Journal of Project Management*, vol. 24, p. 722–733, 2006.
- [31] T. Williams, "Assessing and moving on from the dominant project management discourse in the light of Project Overruns," *IEEE Transactions on Engineering Management*, vol. 52, no. 4, pp. 497-508, Nov 2005.
- [32] J. Gherardi, H. Maylor and T. Williams, "Now, let's make it really complex (complicated): A systematic review of the complexities of projects," *International Journal of Operations & Production Management*, vol. 31, no. 9, pp. 966-990, 2011.
- [33] A. Calinescu, J. Efstathiou, J. Schirn and J. Bermejo, "Applying and assessing two methods for measuring complexity in manufacturing," *Journal of the Operational Research Society*, no. 49, p. 723–733, 1998.

- [34] B. Morel and R. Ramanujam, "Through the looking glass of complexity: the dynamics of organizations as adaptive and evolving systems," *Organization*, vol. 10, no. 3, pp. 278-293, 1999.
- [35] M. Padalkar and S. Gopinath, "Are complexity and uncertainty distinct concepts in project management? A taxonomical examination from literature," *International Journal of Project Management*, vol. 34, p. 688–700, 2016.
- [36] M. Hertogh and E. Westerveld, Ph.D. thesis: *Playing with Complexity - Management and organisation of large infrastructure projects*, 2010.
- [37] A. Jaafari, "Project management in the age of complexity and change," *Project Management Journal*, vol. 34, no. 4, pp. 47-57, Dec 2003.
- [38] S. Kiridena and A. Sense, "Profiling project complexity: insights from complexity science and project management literature," *Project Management Journal*, vol. 47, no. 6, p. 56 – 74, 2016.
- [39] J. Bakhshi, V. Ireland and A. Gorod, "Clarifying the project complexity construct: Past, present and future," *International Journal of Project Management*, vol. 34, p. 1199–1213, 2016.
- [40] B. Kitchenham, "Procedures for Performing Systematic Reviews," Keele University, Keele, Staffs, 2004.
- [41] J. Turner and R. Cochrane, "Goals-and-methods matrix: coping with projects with ill defined goals and/or methods of achieving them," *International Journal of Project Management*, no. 11, pp. 93-102, 1993.
- [42] H. Simon, "The Architecture of Complexity," in *Proceedings of the American Philosophical Society*, 1962.
- [43] A. J. Albrecht, "Measuring application development productivity," in *Proceedings of the Joint SHARE, GUIDE, and IBM Application Development Symposium*, Monterey, California, 1979.
- [44] D. H. Longstreet, "Function Points Analysis training course," Feb 2012. [Online]. Available: <http://www.softwaremetrics.com/Function%20Point%20Training%20Booklet%20New.pdf>. [Accessed 13 Mar 2012].
- [45] B. Boehm, *Software Engineering Economics*, Englewood Cliffs, NJ: Prentice-Hall, 1981.
- [46] R. S. Pressman, *Software Engineering - A Practitioner's Approach*, New York: McGraw-Hill, 2001.
- [47] M. Gibbert and W. Ruigrok, "Organizational research methods," Sage, 4 March 2010. [Online]. Available: <http://orm.sagepub.com/content/early/2010/02/01/1094428109351319>.
- [48] M. Bosch-Rekvelde, H. Bakker and M. Hertogh, "Comparing project complexity across different industry sectors," *Complexity*, 2018.
- [49] H. Thamhain, "Contemporary methods for evaluating complex project proposals," *Journal of Industrial Engineering International*, p. 9:34, 2013.
- [50] Q. Cao, V. Gu and M. Thompson, "Using complexity measures to evaluate software development projects: A nonparametric approach," *The Engineering Economist*, 2012.
- [51] S. McConnell, *Software estimation: demystifying the black art (developer best practices)*, Redmond, Washington: Microsoft Press, 2006.
- [52] M. Jørgensen, "Forecasting of software development work effort: evidence on expert judgment and formal models," *International Journal of Forecasting*, vol. 23, no. 3, p. 449, 2007.
- [53] J. D. McKeen, T. Guimaraes and J. C. Wetherbe, "The relationship between user participation and user satisfaction: an investigation of four contingency factors," *MIS Quarterly*, vol. 18, no. 4, pp. 427-451, Dec 1994.
- [54] T. M. Williams, "The need for new paradigms for complex projects," *International Journal of Project Management*, vol. 17, no. 5, pp. 269-273, 1999.

- [55] M. Pich, C. Loch and A. De Meyer, "On Uncertainty, Ambiguity, and Complexity in Project Management," *Management Science*, vol. 48, no. 8, pp. 1008-1023, Aug. 2002.
- [56] T. Vaaland and H. Hakansson, "Exploring interorganizational conflict in complex projects," *Industrial Marketing Management*, vol. 32, pp. 127-138, 2003.
- [57] S. McComb, S. Green and W. Compton, "Team flexibility's relationship to staffing and performance in complex projects: an empirical analysis," *Journal of Engineering Technology Management*, no. 24, p. 293-313, 2007.
- [58] D. M. Kennedy, S. A. McComb and R. R. Vozdolska, "An investigation of project complexity's influence on team communication using Monte Carlo simulation," *Journal of Engineering and Technology Management*, vol. 28, pp. 109-127, 2011.
- [59] S. J. Whitty and H. Maylor, "And then came Complex Project Management (revised)," *International Journal of Project Management*, no. 27, p. 304-310, 2009.
- [60] S. Bertelsen, "Construction management in a complexity perspective," in *The 1st International SCRI Symposium*, University of Salford, UK, 2004.
- [61] T. Cooke-Davies, S. Cicmil, L. Crawford and K. Richardson, "We're not in Kansas anymore, Toto: Mapping the strange landscape of complexity theory, and its relationship to project management," *Project Management Journal*, vol. 38, no. 2, pp. 50-61, 2007.
- [62] B. Edmonds, *Syntactic measures of complexity - Thesis of the University of Manchester for the degree of doctor of philosophy in the faculty of arts*, 1999.
- [63] L.-A. Vidal, *Thinking project management in the age of complexity. Particular implications on project risk management (Ph.D. Thesis)*, Paris: École centrale des arts et manufactures (École centrale Paris), 2009.
- [64] J. Zhu and A. Mostafavi, "Discovering complexity and emergent properties in project systems: A new approach to understanding project performance," *International Journal of Project Management*, vol. 35, pp. 1-12, 2017.
- [65] M. Bosch-Rekvelde, Y. Jongkind, H. Mooi, H. Bakker and A. Verbraeck, "Grasping project complexity in large engineering projects: the TOE (Technical, Organizational and Environmental) framework," *International Journal of Project Management*, vol. 29, p. 728-739, 2011.
- [66] W. Xia and G. Lee, "Complexity of information systems development projects: conceptualization and measurement development," *Journal of Management Information Systems*, vol. 22, no. 1, pp. 45-83, 2005.
- [67] F. Marle and L.-A. Vidal, *Managing complex, high risk projects - a guide to basic and advanced project management*, London: Springer-Verlag, 2016.
- [68] S. L. Schlindwein and R. Ison, "Human knowing and perceived complexity: Implications for systems practice," *Emergence: Complexity & Organisation*, 2004.
- [69] M. Karsky, *La dynamique des systèmes complexes ou la systémique de l'ingénieur*, Ecole Centrale Paris, 1997.
- [70] D. Genlot, *Manager dans la complexité. Réflexions à l'usage des dirigeants*, Paris: Insep Consulting, 2001.
- [71] S. M. Qureshi and C. Kang, "Analysing the organizational factors of project complexity using structural equation modelling," *International Journal of Project Management*, vol. 33, p. 165-176, 2015.
- [72] P. Ribbers and K. Schoo, "Program management and complexity of ERP implementations," *Engineering Management Journal*, vol. 14, no. 2, pp. 45-52, 2002.
- [73] J. G. Geraldi, "What complexity assessments can tell us about projects: dialogue between conception and perception," *Technology Analysis & Strategic Management*, pp. 665-678, 2009.

- [74] J. Geraldi and G. Adlbrecht, "On faith, fact and interaction in projects," *Project Management Journal*, vol. 38, no. 1, pp. 32-43, 2007.
- [75] K. Remington and J. Pollack, *Tools for complex projects*, London: Gower Publishing Ltd, 2007.
- [76] Y. Lu, L. Luo, H. Wang, Y. Le and Q. Shi, "Measurement model of project complexity for large-scale projects from task and organization perspective," *International Journal of Project Management*, vol. 33, p. 610–622, 2015.
- [77] H. Maylor, N. Turner and R. Murray-Webster, "How hard can it be?: Actively managing complexity in technology projects," *Research-Technology Management*, vol. 56, no. 4, pp. 45-51, 2013.
- [78] D. Lessard, V. Sakhrani and R. Miller, "House of project complexity: Understanding complexity in large infrastructure projects," *Engineering Project Organization Journal*, vol. 4, no. 4, p. 170–192, 2013.
- [79] B. Dao, S. Kermanshachia, J. Shaneb and S. Anderson, "Project complexity assessment and management tool," in *International Conference on Sustainable Design, Engineering and Construction*, 2016.
- [80] R. Poveda-Bautista, J. Diego-Mas and D. Leon-Medina, "Measuring the project management complexity: the case of information technology projects," *Complexity*, p. 19, 2018.
- [81] College of Complex Project Managers And Defence Materiel Organisation, *Competency Standard for Complex Project Managers*, Version 2.0 ed., 2006.
- [82] J. Mulenburg, "What Does Complexity Have to Do With It? Complexity and the Management of Projects," in *NASA Project Management Challenge Conference*, Daytona Beach, Florida, 2008.
- [83] K. Nassar and M. Hegab, "Developing a complexity measure for schedules," *Journal of Construction Engineering and Management*, vol. 132, no. 6, p. 554–561, 2006.
- [84] M. Ameen and M. Jacob, "Complexity in projects. A study of practitioners' understanding of complexity in relation to existing theoretical models," *Umea School of Business*, Sweden, 2009.
- [85] K. B. Hass, "Introducing the New Project Complexity Model," 2008a. [Online]. Available: <http://www.projecttimes.com/articles/introducing-the-new-project-complexity-model.-part-i.html>. [Accessed 22 Oct 2011].
- [86] K. B. Hass, *Managing Complex Projects: A New Model*, Vienna, VA: Management Concepts, Inc., 2008b.
- [87] G. Janssens, M. Hoeijenbos and R. J. Kusters, "Complexity impact factors on the integration process of ERP and non ERP systems: a basis for an evaluation instrument," in *ICSOFIT - 6th International Conference on Software and Data Technologies*, Seville, 2011.
- [88] S. Shafiei-Monfared and K. Jenab, "A novel approach for complexity measure analysis in design projects," *Journal of Engineering Design*, vol. 23, no. 3, pp. 185-194, 2012.
- [89] R. J. Chapman, "A framework for examining the dimensions and characteristics of complexity inherent within rail megaprojects," *International Journal of Project Management*, vol. 34, p. 937–956, 2016.
- [90] H. Wood and P. Ashton, "The factors of project complexity," in *TG62-Special Track 18th CIB World Building Congress*, Salford, United Kingdom, 2010.
- [91] PMI, *Navigating Complexity: A Practice Guide*, Newtown Square, PA: Project Management Institute, 2014.
- [92] GAPPS, *A Framework for Performance Based Competency Standards for Global Level 1 and 2 Project Managers*, Sydney: Global Alliance for Project Performance Standards, 2007.
- [93] B. P. Dao, *Exploring and measuring project complexity*, Texas A&M University, 2016.
- [94] Australian Government, Department of Defence, "Defence capability plan - public version," 2012. [Online]. Available: <http://www.defence.gov.au/publications/docs/CapabilityPlan2012.pdf>. [Accessed 19 May 2019].

- [95] Treasury board of Canada secretariat, "Project Complexity and Risk Assessment Tool," 24 Aug 2015. [Online]. Available: <https://www.canada.ca/en/treasury-board-secretariat/services/information-technology-project-management/project-management/project-complexity-risk-assessment-tool.html>. [Accessed 19 May 2019].
- [96] A. Kailash, "Project complexity redux," 2008a. [Online]. Available: <http://eight2late.wordpress.com/2008/07/02/project-complexity-redux/>.
- [97] A. Kailash, "Rumours of a new project management paradigm," 2008b. [Online]. Available: http://eight2late.wordpress.com/2007/11/03/rumours-of-a-new-project-management-paradigm/#project_paradigm_complex_defns.
- [98] R. W. Zmud, "Management of large software development efforts," *MIS Quarterly*, vol. 4, no. 2, pp. 45-55, Jun 1980.
- [99] L. Wallace, M. Keilb and A. Rai, "Understanding software project risk: a cluster analysis," *Information & Management*, vol. 42, no. 1, p. 115-125, Dec 2004.
- [100] S.-J. Huang and W.-M. Han, "Exploring the relationship between software project duration and risk exposure: A cluster analysis," *Information & Management*, vol. 45, no. 3, pp. 175-182, 2008.
- [101] M. Nyarirangwe and O. K. Babatunde, "Megaproject complexity attributes and competences:," *International Journal of Information Systems and Project Management*, vol. 7, no. 4, pp. 77-99, 2019.
- [102] I. Kardes, A. Ozturk, S. T. Cavusgil and E. Cavusgil, "Managing global megaprojects: Complexity and risk management," *International Business Review*, vol. 22, p. 905-917, 2013.
- [103] A. Gilchrist, A. Burton-Jones and P. Green, "The process of social alignment and misalignment within a complex IT project," *International Journal of Project Management*, vol. 36, no. 6, pp. 845-860, 2018.
- [104] N. Wiener, *Cybernetics: or Control and Communication in the Animal and the Machine*, New York: Technology Press, 1948.
- [105] C. Keating, R. Rogers, R. Unal, D. Dryer, A. Sousa-Poza, R. Safford and G. Rabadi, "System of systems engineering," *Engineering Management Journal*, vol. 15, no. 3, pp. 36-45, 2003.
- [106] C. Keating, J. Padilla and K. Adams, "System of systems engineering requirements: challenges and guidelines," *Engineering Management Journal*, vol. 20, no. 4, pp. 24-31, 2008.
- [107] M. Eriksson, J. Lillieskoeld, N. Jonsson and D. Novosel, "How to manage complex, multinational R&D projects successfully," *Engineering Management Journal*, vol. 14, no. 2, pp. 53-60, 2002.
- [108] H. Benbya and B. McKelvey, "Using coevolutionary and complexity theories to improve IS alignment: a multi-level approach," *Journal of Information Technology*, vol. 21, pp. 284-298, 2006.
- [109] N. G. Hall, "An agenda for project management and scheduling research," in *14th International Conference on Project Management and Scheduling*, Munich, Germany, 2014.

Biographical notes



Stefan Morcov

Stefan Morcov specializes in the management of large complex international IT projects, up to hundreds of mil. Eur and millions of stakeholders, such as the European Platform for Adult Education of the European Commission. He is a Ph.D. student at the Katholieke Universiteit Leuven, a Computer Science Engineer (UPB), MBA (Tiffin University US), PMP, and studied project and product management, software engineering, sales, marketing (Open University UK, UB). He received numerous recognitions, including several Best Practice labels from the EC and an IPMA award.



Liliane Pintelon

Liliane Pintelon is a full professor at the Faculty of Engineering Science, Katholieke Universiteit Leuven. She is head of the Centre for Industrial Management - Traffic & Infrastructure, and of the Subdivision Maintenance and Health Care Logistics. Her research interests are in performance modeling of (socio-)technical systems with a focus on risk analysis and management.



Rob J. Kusters

Rob J. Kusters obtained his master's degree in econometrics at the Catholic University of Brabant in 1982 and his Ph.D. in operations management at the Eindhoven University of Technology in 1988. He is a professor of 'ICT and Business Processes' at the Dutch Open University in Heerlen, where he is responsible for the master program 'Business Process Management and IT'. He published over 100 papers in international journals and conference proceedings and co-authored six books. His research focuses on project and process performance, IT governance, software quality and software management.