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Portfolios of Agile Projects: A Complex Adaptive Systems' Agent Perspective

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Abstract

While agile approaches can be extremely effective at a project level, they can impose significant complexity and a need for adaptiveness at the project portfolio level. While this has proven to be highly problematic, there is little research on how to manage a set of agile projects at the project portfolio level. What limited research that does exist often assumes that portfolio-level agility can be achieved by simply scaling project level agile approaches such as Scrum. This study uses a complex adaptive systems lens, focusing specifically on the properties of projects as agents in a complex adaptive portfolio to critically appraise current thinking on portfolio management in an agile context. We then draw on a set of 30 expert interviews to develop 16 complex adaptive systems (CAS)-based propositions as to how portfolios of agile projects can be managed effectively. We also outline an agenda for future research and discuss the differences between a CAS-based approach to portfolio management and traditional approaches.

Keywords

agile, project portfolio management, complex adaptive systems

Introduction

The last 20 years has seen the emergence of agile software project management approaches in information systems (IS). These approaches are highly prevalent (Abrahamsson, Conboy, & Wang, 2009; Conboy, 2009). They are used in some form across 95% of software teams in diverse environments such as regulated, large scale, and distributed projects (Abrahamsson et al., 2009; Dingsøyr & Moe, 2013; Hobbs & Petit, 2017). The benefits of agile are also well documented with, for example, one study showing dramatic improvements, such as increased ability to manage changing priorities (87%), increased productivity (85%), and improved project visibility (84%) (VersionOne, 2016**)**. Agile approaches also featured prominently in the research communities of project management, information systems, and software engineering, with dedicated conferences, such as *Agile*, *XP,* and *LESS,* and special issues in journals, such as the *European Journal on Information Systems* (Dingsøyr, Nerur, Balijepally, & Moe, 2012).

While the body of research on agile approaches is expansive and thorough, its initial focus has been on small colocated projects carried out by single teams (Abrahamsson et al., 2009; Hoda, Kruchten, Noble, & Marshall, 2010). Little research has examined the impact agile approaches have on the management of the project portfolio within which these reside (Dingsøyr & Moe, 2013; Unterkalmsteiner et al., 2016). Project portfolio management (PPM) is the management of multiple projects with shared resources to maximize business benefits and achieve strategic alignment (Blichfeldt & Eskerod, 2008; Cooper, Edgett, & Kleinschmidt, 1999; Meskendahl, 2010). PPM is critical to align projects with organizational strategy, allocate resources appropriately, achieve business value, and manage any associated risks. In the context of this study, when we refer to *agile* and *PPM,* we are not referring to the scaling of agile project practices (e.g., standup meetings, pair programming) to the project portfolio level. Instead, we are referring to how project portfolios can be managed when they contain a set of agile projects. While agile approaches reduce the occurrence of project failure (Abrahamsson et al., 2009; Conboy, 2010; Dybå & Dingsøyr, 2008), they actually increase difficulties for the management of the project portfolio within which they reside (Rautiainen, Von Schantz, & Vähäniitty, 2011; Stettina & Hörz, 2015). This is primarily due to two overarching reasons.

First, agile projects result in a high degree of *complexity* at the portfolio level. While software projects rarely operate in isolation and generally contribute to some broader portfolio or

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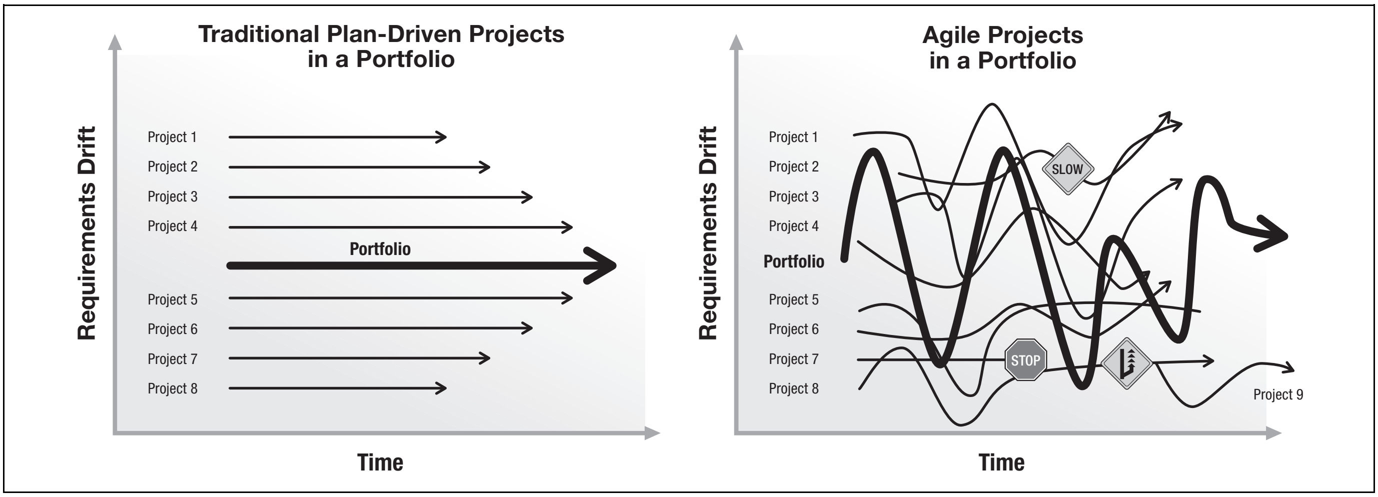

Figure 1. Differences between portfolios of plan-driven projects and agile projects.

organizational agenda (De Reyck et al., 2005; Hatzakis, Lycett, & Serrano, 2007), agile project management increases the number of interactions at the portfolio level. This is because agile's increased focus on the customer increases complexity at the portfolio level, as agile projects in a portfolio must reconcile tensions between customer needs and organizational strategy (Sweetman & Conboy, 2013). In addition, the autonomy and improvisation inherent in agile approaches have implications for a portfolio of interdependent agile projects, as greater coordination is needed between dynamic projects to ensure the emergent portfolio remains aligned to the intended portfolio. Furthermore, the commitment of agile to "*people over processes*" (Fowler & Highsmith, 2001) increases the interactions both within and between projects and poses challenges for management at the portfolio level. These constant improvisations and interactions, potentially across hundreds of projects, result in a highly complex portfolio that cannot be managed by a traditional top-down portfolio approach.

Secondly, agile approaches increase the need for *adaptiveness* at the portfolio level. The iterative, dynamic nature of agile approaches combined with a focus on change, improvisation, and self-organization (Conboy, 2009; Highsmith 2002; Schwaber & Beedle, 2002) inherent in agile projects imposes change at the project portfolio level (Stettina & Hörz, 2015).

Figure 1 illustrates the impact of agile at the project level on a project portfolio. On the left side of the figure is a set of plan-driven predictable projects. It is clear that portfolio governance and direction are stable over time. On the right side of the figure, we see a set of agile projects; each pulled in different directions by its own demanding and diverse range of customers, and a continuously changing set of legitimized requirements. Over time, each agile project drifts away from its original requirements specification. While each project may itself be successful, such complexity and adaptiveness result in a project portfolio that is disjointed, incoherent, and in conflict if not governed effectively.

Unfortunately, PPM is often enacted in a top-down, centralized, and plan-driven way (Daniel, Ward, & Franken, 2014; Hansen & Kræmmergaard, 2014), which is at odds with the complexity and adaptiveness illustrated above. Existing attempts at portfolio-level agility have been criticized by agile pioneers as being overly complicated and rigid (Schwaber, 2014) as well as being "relentlessly top-down," with no consideration of organizational agility (Jeffries, 2014). Given these challenges, further research is required to investigate how project portfolio practices themselves can be tailored or redeveloped to effectively manage the *complexity* and *adaptiveness* required at a project portfolio level (Dingsøyr & Moe, 2013; Hobbs & Petit, 2017; Stettina & Hörz, 2015). Therefore, this study seeks to address the following question:

How can project portfolio management be enacted to manage the complexity and adaptiveness arising from a portfolio of agile projects?

Complex adaptive systems (CAS) theory emerged from the natural sciences and helps explain the behavior of nonlinear dynamic systems comprising many interacting parts that must adapt to a changing environment. CAS already provides insights into how agile projects acting as complex adaptive systems are both emergent and adaptive to their environment (Jain & Meso, 2004; Vidgen & Wang, 2009) and has implications for their effective management (Cooke-Davies, Cicmil, Crawford, & Richardson, 2008; Farrell & Twining-Ward, 2004). CAS has been used as a lens to study PPM in general (Perry, 2012) and PPM in the construction industry (Aritua, Smith, & Bower, 2009). Because of the complex and adaptive nature of portfolios of agile projects and its effective application in similar domains, CAS is considered an appropriate lens to address our research question. However, CAS is a multifaceted theory whose application in information systems has proven challenging (Vidgen & Wang, 2006). Therefore, we have followed the advice of Levin et al. (2013) and tailored its application to focus on the agents that make up a CAS.

This study contributes to the PPM literature by describing agile projects as agents. It addresses the gap around the management of portfolios of agile projects with a set of 16 propositions. This article is laid out as follows. The next section outlines existing attempts to reconcile agile project management with PPM. It then introduces CAS and justifies the specific focus on agents. The properties of agents are explained and used to examine agile projects in PPM. The research method for the study is then presented. The results section presents CAS-based propositions, derived from expert interviews, which explain how agile projects must act to enable effective PPM. The following section discusses the difference between a CAS-based approach to PPM and traditional approaches. We conclude with a discussion of practical and theoretical implications of the study, as well as limitations and opportunities for future research.

Background

PPM and Agile Projects

PPM has proven especially problematic when the portfolio includes a set of agile projects (Stettina & Hörz, 2015). The improved project success often associated with agile (VersionOne, 2016) has not led to improvements at the portfolio level (Kalliney, 2009; Stettina & Hörz, 2015). Indeed, because portfolios are complex, individual project success is no guarantee of portfolio success (Billows, 2001; Conboy, 2010), especially in agile projects, where success may be measured from the customer's perspective, not the organization's.

However, few empirical studies have addressed this issue, and the methods that exist simply attempt to address the issue by scaling agile project practices to the project portfolio level (Rautiainen et al., 2011; Stettina & Hörz, 2015). There are two prominent approaches, namely the SAFe approach and the "Agile Portfolio Management" approach. Both approaches are discussed as follows.

The Scaled Agile Framework (SAFe) (Leffingwell, 2007) was developed to implement agile practices at the enterprise level. The framework has three levels (portfolio, program, and team) and four values (alignment, code quality, transparency, and program execution). The portfolio management team prioritizes the backlog and allocates resources. Product managers participate in program prioritization, and at the team level, five to ten agile teams deliver projects. However, this framework has been criticized by agile pioneers as overly rigid and "relentlessly top-down" (Jeffries, 2014; Schwaber, 2014). The focus on execution of programs as prioritized at the portfolio level can impair the enterprise's capacity to either react to change or learn from it (Conboy, Dennehy, Morgan, & Sweetman, 2017).

"Agile Portfolio Management" is another approach proposed by Krebs (2008). It seeks to deliver a dynamically managed portfolio based on agile principles, with a dashboard recommended to monitor the whole portfolio. Key proposed metrics include progress, quality, and team morale. Resource transparency and the establishment of a project management office (PMO) are considered key to agile portfolio management.

The literature shows, however, that there has been little experimental validation of these frameworks to date (Stettina & Hörz, 2015). Indeed, the little research that does exist highlights problems with their application (Hodgkins & Hohmann, 2007; Kalliney, 2009; Rautiainen et al., 2011). Furthermore, these approaches are also based on the assumption that the issue of managing a portfolio of agile projects can be addressed by simply scaling agile practices to the portfolio level. This ignores the emergent properties inherent in complex portfolios. However, little research, as far as we are aware, has applied a CAS lens to solve the problem arising from managing a portfolio of agile projects.

Complex Adaptive Systems Theory

Complex adaptive systems (CAS) theory examines how interactions between the individual and autonomous parts of a system and their environment enable the system to adapt to its environment and yield higher-level emergent behavior (Webb, Lettice, & Lemon, 2006). CAS takes a bottom-up approach, focusing on the individual parts of the system and how they interact (Anderson, 1999). The application of CAS is challenging in information systems because of the multifaceted nature of the literature (Kautz, 2012; Vidgen & Wang, 2006). Levin (1998) advises that researchers must tailor its application to each individual study. While there are varying explanations of CAS in the literature (Gell-Mann, 1994; Levin, 1998), most interpretations of CAS include *agents*, the *environment*, *interactions*, *feedback loops,* and *emergent system-level properties*.

While CAS theory is broad, it is the behavior of agents that determines the nature of the system as a whole. Agents are central to all CAS models (e.g., Anderson, 1999; Dooley, 1997; Gell-Mann, 1994) and refer to the individual actors or "entities of action" in a CAS (Nan, 2011). Agents can be individuals, teams, projects, divisions, or the entire organization, depending on the scale of analysis (Choi, Dooley, & Rungtusanatham, 2001; Nan, 2011; Sato, Dergint, & Hatakeyama, 2015). In a software PPM context, agents could be conceived as individuals, teams, or projects. This study specifically interprets agents as the projects comprising the portfolio.

The Project as an Agent

Agents are the focus of this study for three reasons: First, as the basic entity of action in a system, agents provide an effective unit of analysis to study the system (Choi et al., 2001; Gell-Mann, 1994; Holland, 1992a; Nan, 2011). Researchers have examined CAS using many different entities as agents, for example, trees (Seidl, Rammer, Scheller, & Spies, 2012), insects (Karwowski, 2012), and even software artifacts (Kauffman, 1993). Second, because this is an exploratory study, focusing on agents provides a way to begin a systematic exploration of the topic, while remaining open to the possibility of other approaches emerging that will require further investigation as part of the broader research agenda that this study contributes to. Third, as stated below, this study takes a qualitative, interpretive approach. In social systems, the agent is often assumed to be the individual who can be interviewed to provide the rich data required to understand the system from the perspectives of the participants who make up the system. However, it must be recognized that agents can combine into meta-agents, which in turn can form even more aggregated agents following a “box-in-a-box” principle (Holland, 1992a; Simon, 1969). Examples of aggregated agents include hospitals, pharmacies, and laboratories (Tan, Wen, & Awad, 2005); groups or coalitions of groups (Anderson, 1999); firms (Benbya & McKelvey, 2006; Choi et al., 2001; Nan, 2011); and projects (Sato et al., 2015). In reality, the appropriate choice of agent depends on the scale of analysis and the problem being addressed (Choi et al., 2001; Levin et al., 2013; Nan, 2011). For example, one study looking at the diffusion of innovations across a sector treats organizations as agents (Guo & Guo, 2011), whereas another study looking at technology adoption within the organization treats individuals as the agents (Nan, 2011). Because CAS require different models and rules to describe different levels within the system (Grimm et al., 2005), it is important that we focus on the agents that comprise the level of the system we are studying.

This is relevant in this study as agile software projects can be considered as a CAS (Kautz, 2012; Vidgen & Wang, 2006), comprising individual developers and managers. However, by definition, a portfolio of individual CAS is, in fact, a CAS itself, with each CAS acting as a meta-agent, comprising agents at a lower level (Holland, 1995). Furthermore, agile projects have a high degree of autonomy and adapt to improve their performance or fitness, meeting the criteria for agents established by Holland and Miller (1991). Therefore, the agile project plays a much more formative role in the enactment of the portfolio, so is the appropriate agent for this study.

The Properties of Agents

Drawing on the CAS literature, this section identifies six key properties that agents in a CAS should exhibit. Agents in complex adaptive systems are capable of *self-organizing* (Holland, 1992a). They share an understanding of what the *common purpose* of the system is (Choi et al., 2001; Dooley, 1997). They have a degree of *autonomy* (Gell-Mann, 1994). They are *adaptive* to their environment (Holland, 1992b). They have *requisite variety* for their environment (Gell-Mann, 2002; Holland, 1992a). Finally, they *exchange resources* in the pursuit of their own goals (Cilliers, 2000). If an agent in a CAS must exhibit these properties, then logically a project must exhibit these properties within a CAS comprising agile projects. These properties are now described in more detail and used to critically appraise the portfolio management literature from an agile perspective, highlighting areas where the PPM literature is deficient. Figure 2 illustrates a portfolio of agile projects as a CAS. Each of the agent properties is described in detail below, and their treatment in the PPM literature is appraised. This serves to highlight areas to explore in the empirical phase of the study.

Self-Organizing

First, agents in a CAS *self-organize* into robust informal structures in response to events or changes in the environment, without the intervention of a central controller (Anderson, 1999; Lichtenstein, 2000). Self-organization means agents group together and act cohesively as meta-agents who in turn display all the properties of agents (Holland, 1995). For example, animals self-organize into herds in response to predators.

This study is interested in the phenomenon of self-organization across projects in the pursuit of *portfolio goals*, whereas the existing agile literature has focused mainly on self-organization within the project (e.g., Beck, Cockburn, Jeffries, & Highsmith, 2001; Hoda, Noble, & Marshall, 2013; Moe, Dingsøyr, & Dyba, 2009; Schwaber & Beedle, 2002). While research shows that self-organizing agents can create the structures and processes needed to create better IT across the organization (Benbya & McKelvey, 2006), self-organization is at odds with traditional PPM, and there are only a small number of studies that acknowledge the role of self-organization at the portfolio level (Dingsøyr & Moe, 2013, 2014). For example, case reports describe how Spotify employees are grouped into “squads” that facilitate collaboration between projects as well as sharing knowledge, tools, and code (Kniberg & Ivarsson, 2012); Google, Yahoo, and Apple encourage the emergence of new projects from collaboration between existing projects (Amberland, 2013; Tate, Ellram, & Golgeci, 2013). However, these reports are exceptional, rather than representative of the agile literature. Instead, it has been argued that there is a “*clear tension between large software companies and the agile process model of self-organization*” as the self-organizing teams require control over the business (Kettunen & Laanti, 2008). Therefore, while there is some evidence of portfolio-level self-organization happening in practice, more research is required to identify the mechanisms that support it.

Common Purpose

According to CAS, the individual agents in a CAS cohere to some common purpose, as each one responds in its own way to the constant change created by other agents and the dynamic environment. This common purpose consists of *shared understanding as to what the goal of the system is*. For example, all the bees in a hive are committed to the hive surviving the winter. This common purpose enables the CAS to act in a coordinated fashion in response to rapid change (Curseu, 2006) and helps each agent improve its fitness to the overall system (Choi et al., 2001).

While customer value, goal-driven work, and purpose are defining features of agile approaches (Beck & Fowler, 2001;

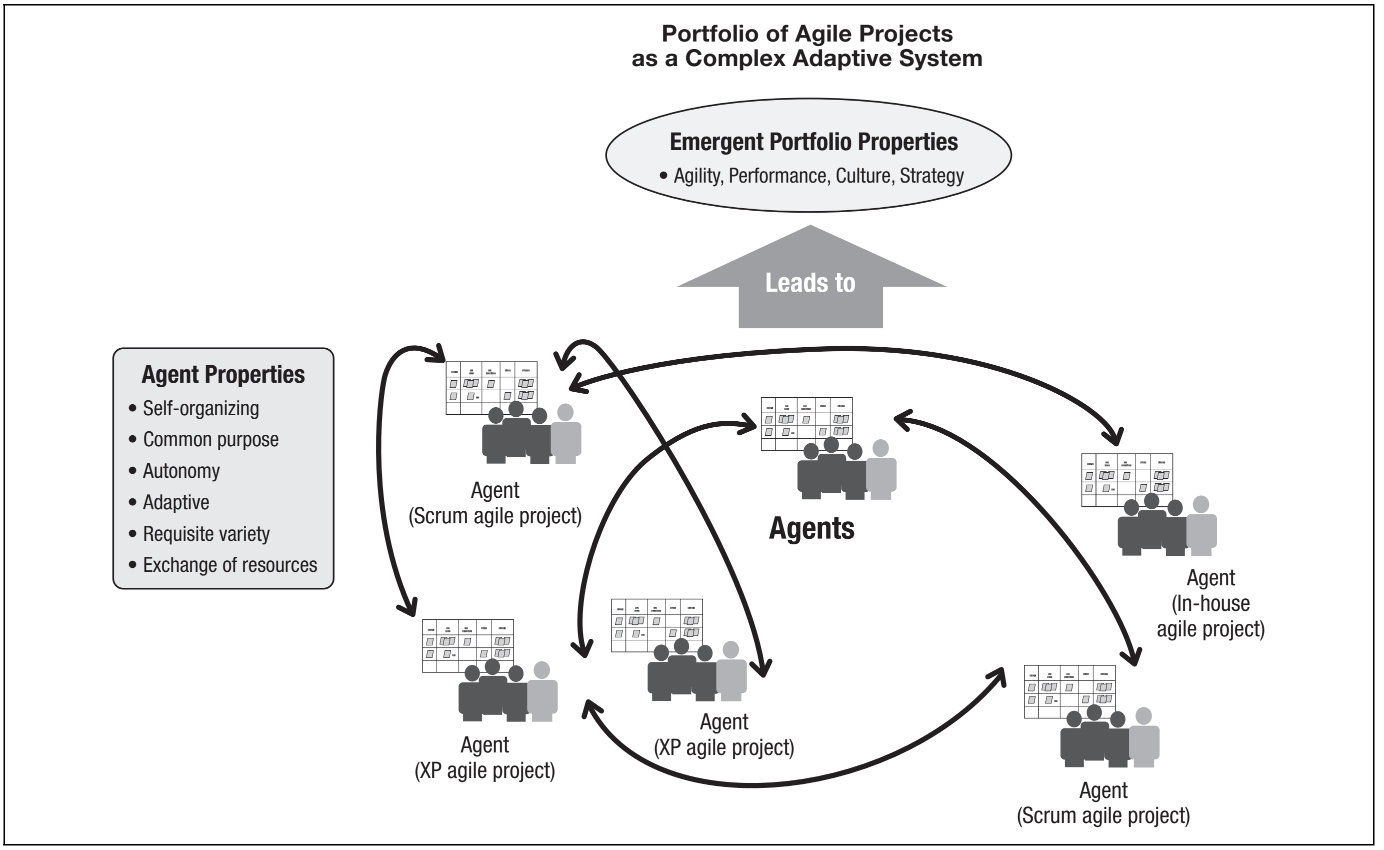

Figure 2. Projects as agents in a complex adaptive portfolio.

Schwaber & Beedle, 2002), very little research has examined or offered guidance on how to establish a common purpose across an agile portfolio of projects. Indeed, projects not tightly aligned to the articulated strategy of the organization are seen as "*waste*" (Steindl, 2005). This makes portfolio-level agility hard to achieve, as corporate strategy may change relatively slowly even in a dynamic environment (Rumelt, 2011). The research that does look at common purpose suggests that the articulation and sharing of purpose are particularly challenging in agile where individual projects, operating myopically in silos, may prioritize individual customer needs above the portfolio (Sweetman & Conboy, 2013). Furthermore, software departments are often viewed as "order takers" (Thomas & Baker, 2008), limiting the need for a common vision across the software program. There could be substantial value in knowing how a common purpose could be established across a portfolio of agile projects.

Autonomy

Agents require some degree of *autonomy* for a CAS to function effectively (Benbya & McKelvey, 2006). In a complex social system, agents must be free to pursue their own individual goals and capable of conscious action to alter the world around them (Benbya & McKelvey, 2006; Bristow & Healy, 2014). This means that influence is decentralized throughout the system (Anderson, 1999; Bristow & Healy, 2014). For example, foraging ants are free to choose where to explore for food.

Again, it is important to clarify that we are interested in autonomy at the portfolio level, as opposed to within projects, where it is accepted that autonomous teams produce better software (Highsmith, 2002). From a portfolio perspective, the degree of autonomy afforded to projects can vary depending on both the degree of centralization in the portfolio governance structure (Frey & Buxmann, 2011) and the project methodology being used (Dybå & Dingsøyr, 2008). However, rather than embracing project autonomy, the agile portfolio management literature is concerned that increased autonomy can reduce the ability to coordinate effectively between projects, leading to unclear responsibilities and poor decision making (Dingsøyr & Moe, 2014; Frey & Buxmann, 2011). Existing approaches to agile portfolio management are considered rigid (Schwaber, 2014) and "relentlessly top-down" (Jeffries, 2014). While the need for control appears to arise where the focus is on speed rather than flexibility (Thomas & Baker, 2008), there are no clear guidelines as to what level of project autonomy is appropriate to enable portfolio-level agility.

Adaptiveness

Agents in a CAS are *adaptive* (Holland, 1995). *Adaptiveness is the evolutionary process whereby agents improve their fitness* *within the system* (Dobzhansky, 1968). Agents adapt by learning about their environment and recombining the elements of previously successful behaviors (Holland, 1995). Furthermore, agents that are unable to adapt to changes in the environment quickly die out. For example, animals are subject to predation unless their camouflage changes as the environment changes.

In this study, our focus is on how projects adapt to improve their fitness to the portfolio, as opposed to against individual project goals. Existing agile literature has focused on how the project adapts to satisfy the customer (e.g., Malgonde, Collins, & Hevner, 2014). Thomas and Baker (2008) argue that a "widget engineering" mindset, where projects are selected in advance, forms a barrier to genuine portfolio-level adaption, and the literature looking at portfolio-level adaption is limited to a couple of contributions. Steindl (2005) found that short feedback loops allow projects to adapt their measurement system to overall portfolio goals. He also suggests that by understanding the critical path for business benefits across a group of projects, the projects can adapt to improve their fitness to the portfolio. Kalliney (2009) argues that the Scrum of Scrums presents an opportunity for projects to share information and learn from each other to improve their alignment with the portfolio. However, it is not clear that these portfolio techniques will scale beyond teams of eight to ten people (Rautiainen et al., 2011). Furthermore, most existing agile-based portfolio management approaches focus on the rapid execution of a backlog of projects with little guidance given how to enable projects within the backlog to adapt to changing portfolio needs (Hodgkins & Hohmann, 2007; Thomas & Baker, 2008).

Requisite Variety

For a system to be complex and adaptive, it must consist of a *requisite variety of heterogeneous agents with diverse forms and abilities* (Holland, 1995). For example, a population requires a sufficient level of genetic diversity to remain healthy. In systems that lack requisite variety, there will be little difference between the fittest and the weakest agents, making the system vulnerable to shocks (McKelvey, 1999).

In PPM, we are interested in a variety of projects across the portfolio, as opposed to diversity within the project (e.g., skills). We found no evidence that *requisite variety* has been examined in the agile portfolio management literature. Indeed, because project selection in portfolio management is influenced by business strategy (Thomas, Seddon, & Fernandez, 2007), project outcomes can be highly correlated (Burke & Shaw, 2008; Drake & Byrd, 2006), resulting in a lack of diversity. However, CAS theory warns that a system lacking diversity will not be able to cope with sudden changes in the environment (McKelvey, 1999), and there is a need for research into how project diversity can be supported across a portfolio of agile projects.

Table 1. Properties of Agents in CAS

Properties	Definition
Autonomy	*Agents are free to apply ingenuity and effort to alter the world around them*
Common purpose	*Consists of shared understanding as to what the goal of the system is.*
Self-organizing	*Agents coalesce into clusters resulting in cooperative behavior without the intervention of a central controller*
Requisite variety	*System must consist of a large number of heterogeneous agents with diverse forms and abilities*
Adaptiveness	*The evolutionary process whereby agents improve their fitness*
Exchange of resources	*Agents interact to procure resources more valuable to them in the pursuit of their own goals*

Exchange of Resources

Agents engage in the *exchange of resources* with each other and the environment *to procure resources more valuable to them in the pursuit of their own goals* (Beck & Plowman, 2014). For example, countries trade with each other for goods they need but cannot produce. While individual agents interact for selfish reasons, the exchange of resources can result in massive increases of the productivity of the system as a whole (Benbya & McKelvey, 2006; Choi et al., 2001).

This study is interested in the exchange of resources *between* projects in the pursuit of portfolio goals, as opposed to *within* projects in the pursuit of project goals. There is only limited evidence of portfolio-level agile practices facilitating the exchange of resources between projects. Hodgkins and Hohmann (2007) suggest that the greater visibility provided by a "roadmap of roadmaps" allows business leaders to move resources to where they are needed. The need for visibility and clear prioritization was echoed by Rautiainen et al. (2011) who showed that visibility enables projects to share resources with higher priority projects reducing their time to market. However, even in agile portfolios, the exchange can be a top-down, centralized process (Benefield, 2010; Rautiainen et al., 2011), whereas the exchange of resources in a CAS is a decentralized process managed by the individual agents. Furthermore, evidence suggests that the agile approach where the product owner advocates for resources for their project breaks down when faced with limited resources (Hodgkins & Hohmann, 2007) and more research is required to show how the exchange of resources between projects in an agile portfolio can be facilitated.

The six agent properties are summarized in Table 1. By understanding how these properties manifest themselves in an effective CAS, we will develop insights and derive propositions as to how a portfolio of agile projects should be managed.

Research Method

An exploratory, qualitative approach was chosen to frame this study for three reasons. First, little is known about the management of portfolios of agile projects in practice and the application of CAS to IS PPM is new. It is, therefore, appropriate to seek empirical evidence rather than the simple testing of hypotheses. Second, the rich, revelatory data associated with a qualitative approach (Miles & Huberman, 1996) allows us to search for nuanced relationships between the six agent properties and portfolio management. Third, a qualitative approach is appropriate for theory building, using induction from observations to develop propositions that can later be tested (Klein & Myers, 1999). To develop propositions as to how PPM can be effectively enacted as a CAS comprising agile projects, an analogical approach (Hesse, 1966) was deemed appropriate. This approach uses similarities between two systems to develop propositions that other similarities exist. Analogical reasoning carries great scientific credibility, but its outcomes must be subject to further testing (Gentner, 1980; Rosenhead, 1998).

To create the analogy between CAS and IS PPM, we found it helpful to integrate knowledge from both domains. The study used the expert interview method recommended by Bogner, Littig, and Menz (2009). This was because expert judgment is considered useful when experimental data are lacking (Meyer & Booker, 2001). While it is up to the researcher to interpret and analyze the data, one individual's interpretation can be tested in subsequent interviews with experts holding more specific domain knowledge.

Potential CAS-based approaches to PPM were identified by open-ended explorative interviews with CAS academic experts. Initial findings were simultaneously contextualized and operationalized by more-structured systematizing interviews with PPM practitioners who had experience with agile projects. Both sets of interviews were carried out in parallel, allowing triangulation and corroboration between the groups. The two approaches were combined in a responsive approach (Rubin & Rubin, 2012). The interviews were scheduled so that experts with overlapping knowledge of both domains were interviewed last. This allowed the researchers to confirm that theoretical saturation had been obtained and the propositions made sense to both CAS and IS PPM experts.

Data were collected through 30 face-to-face interviews. A purposeful sampling strategy was used (Figure 3)[1]. Agent properties provided a set of "intellectual bins" (Miles & Huberman, 1996) to structure the interview script and analysis of practitioner data. Without this structuring mechanism, the multitude of concepts and practices that make up CAS and PPM would have made analysis unwieldy. Following the advice of Wengraf (2001), the script was sent to interviewees in advance, allowing participants the time to consider their responses. The explorative interview questions for the academic experts were more open-ended to facilitate identification of possible propositions. In contrast, the systematizing interviews that sought to contextualize CAS for PPM required a more detailed topic list that arose from the explorative interviews (Bogner et al., 2009). Interviews lasted between 40 and 130 minutes and were recorded and transcribed with the consent of the interviewee. The transcripts were proofread and annotated by the researchers, and, where necessary, clarifications were sought from the interviewee.

Data analysis was started as soon as each interview was completed, allowing subtle changes to subsequent interviews. Framework analysis (Ritchie & Spencer, 2002) was chosen as the appropriate strategy, as this is a qualitative study with a specific objective and a predefined sample of professionals and experts (Srivastava & Thomson, 2009). It is also considered an effective tool to assess practices from the perspectives of the people they affect (Srivastava & Thomson, 2009), which is appropriate for this study that uses expert practitioners. Framework analysis provides a flexible five-step approach to analyzing data (Ritchie & Spencer, 2002; Srivastava & Thomson, 2009). The five steps are: (1) *Familiarization*, the process where the researchers listen to recordings and read the transcripts to immerse themselves in the data (Silverman, 2015). (2) *Identifying a thematic framework*, the combination of the a priori framework with additional themes that emerged during the familiarization process to form a set of codes that were used for the nVivo analysis. (3) *Indexing,* the identification and coding of portions of the transcripts that relate to particular themes. Identification codes were attached to each piece of text extracted from the transcripts. This served to protect the anonymity of participants. Each of the academics was assigned a random code A1–A15, and the practitioners P1–P15. (4) *Charting,* the aggregation of pieces of data under each of the themes, bringing together thematically comparable data from different themes. (5) *Mapping and interpretation*—the stage where theoretical abstraction occurs as associations between the data are identified and propositions developed.

Results

The six properties of agents described above are now used to analyze and synthesize the expert interviews with academics and practitioners. A number of themes emerged for each property. For each theme, the existing literature is discussed, then the relevant data from the academic experts are presented, followed by the data from the expert practitioners. A proposition relating to how PPM should be enacted from a CAS perspective is derived. Tables summarizing each property and providing suggestions for future research are presented.

Self-Organization

The existing portfolio management literature acknowledges that tensions exist between traditional PPM methods in large organizations and self-organization (Kettunen & Laanti, 2008). Three themes relating to self-organization emerged from the expert interviews: *standardization*, *level of resources*, and *flexible structures.* Each of these themes is now explored in turn. The propositions derived from the self-organization themes are

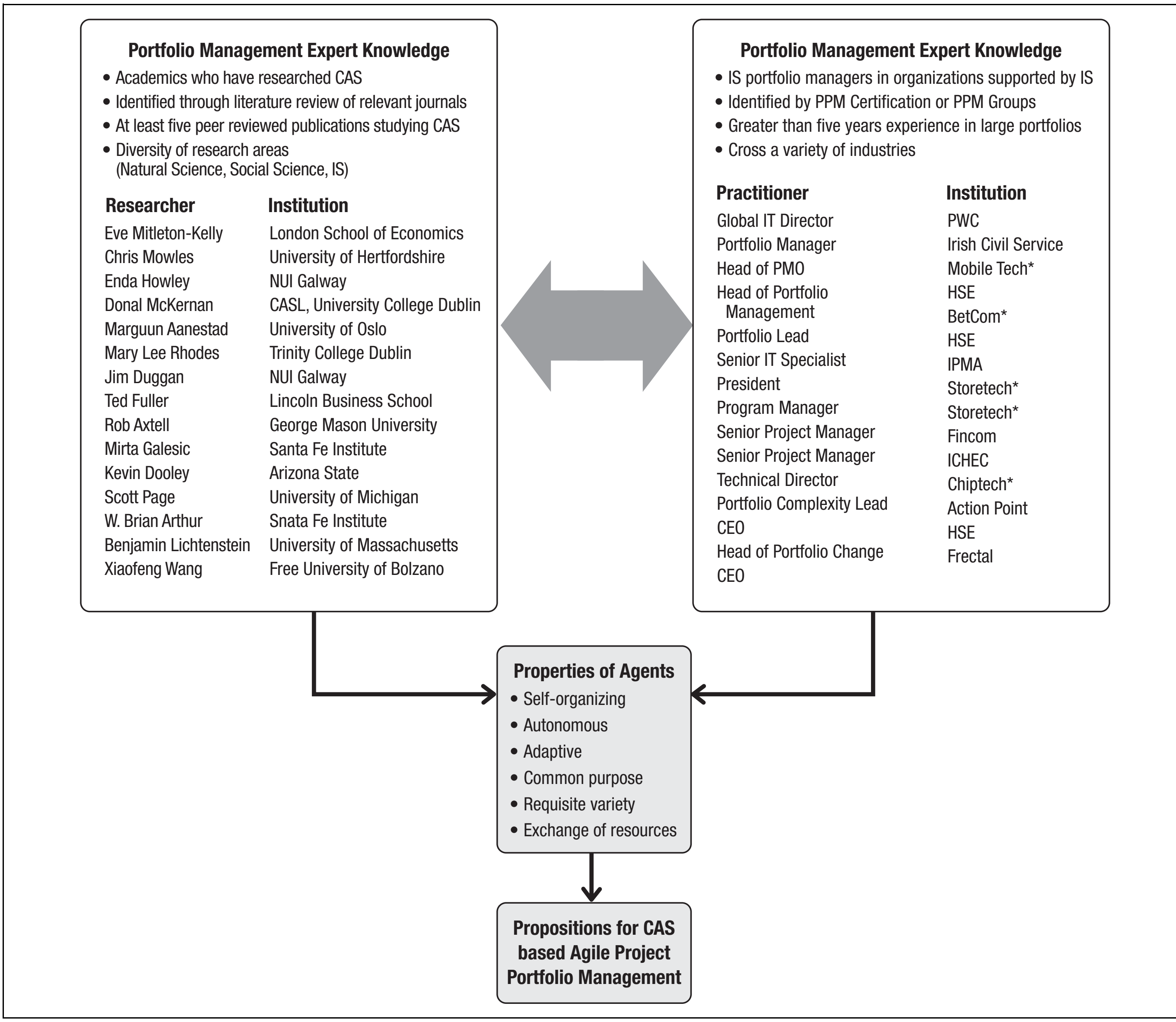

Figure 3. The research approach.

numbered SO1–SO3. The existing literature, academic and practitioner data, propositions and potential research questions are then summarized in Table 2.

Standardization

While the role of standardization in enabling self-organization in mature agile portfolios has been acknowledged (Benefield, 2010), this has only been applied through top-down imposition. No research to date has examined how such standards can be designed and implemented in a collaborative manner required in a CAS environment.

However, the academic experts highlighted the importance of standards as an enabler of self-organization. They argued that even extremely large complex systems are built from relatively small and simple standardized building blocks (A11, A8, A7). For example, experts explained how fundamental blocks in music allow jazz musicians to collaborate in incredibly complex improvised sessions (A1) and how the Roman army was self-organized around standardized units of 8 men (A11). It was argued that systems comprising repetitive DNA or even LEGO blocks can exhibit infinite complexity, whereas systems comprising nonstandard components cannot be scaled (A1, A15). Agents can self-organize into larger and larger structures by combining modularized components without management overhead (A7, A8). There was evidence to support the need for standardization in the expert practitioner data (P1, P8, P5, P9). Some practitioners argued that the overarching primary role of the portfolio was to provide a standardized platform that enabled projects to work together (P1, P10).

Table 2. Self-Organization in Portfolios of Agile Projects

Finding	Summary of Existing Literature	Academic Evidence	Practitioner Evidence	Proposition
Standardization	Standardization imposed rather than allowed to evolve in a way consistent with CAS	Standardization supports the scaling of self-organization	Basic portfolio level standards and architecture across agile projects are necessary for self-organization	SO1. Portfolio level standards enable self-organization between agile projects
Level of resources	Existing PPM assumes plentiful resources encourage self-organization across agile teams	Scarce resources force agents to cooperate	Agile projects must work together to overcome resource deficiencies	SO2. Scarcity of portfolio resources encourages self-organization between projects
Need for flexible structures	Existing PPM recommends defined centralized portfolio structures	Self-organization has no preconceived plan or fixed leader.	Self-organization is not pre-planned. Instead, flexible structures allow agile projects cooperate in response to a new challenge	SO3. Flexible structures are required to enable self-organization across projects

Proposition	Example Research Questions
SO1.	How do common portfolio standards contribute to self-organization? How does a PPM executive decide what aspects of the project portfolio to standardize and not? How can standards be enforced and encouraged in an agile context? How is standardization maintained across a set of evolving agile projects?
SO2.	How does scarcity of resources contribute to self-organization? How can scarcity be managed given it is often driven by external factors?
SO3.	What is the appropriate organizational structure for self-organization at the portfolio level? How can flexible structures at portfolio level operate effectively with non-flexible organizational structures?

The practitioners warned that while this reduced the capacity of teams within projects to tailor their methods (P2, P3), it enabled collaboration between projects (P1, P8). Furthermore, it was argued that standardization supports self-organization by enabling projects to rapidly merge or collaborate without portfolio actors having to acquire new skills (P5, P14). This was supported by another practitioner who lamented the time lost in integrating large agile projects built to different standards (P9). This evidence led to the following proposition:

SO1. Portfolio-level standards enable self-organization between agile projects.

Level of Resources

The existing PPM literature has only examined the impact of plentiful resources as an enabler of self-organization (Amberland, 2013; Tate, 2013). There is concern that resource scarcity leads to selfish behavior preventing collaboration (Hodgkins & Hohmann, 2007).

In contrast, the evidence from the academic experts suggests that self-organization is most likely to occur when there are more agents than can be sustained by existing resources (A14, A5, A12). For example, hunter animals are forced to cooperate when resources are scarce and are able to take larger prey than if they attack individually. It was argued that scarcity forces surplus agents to take advantage of new opportunities to avoid being eliminated by natural selection (A5, A12). The idea that scarce resources encourage self-organization was also supported by practitioner data (P6, P2, P1, P5, P3). Many practitioners interviewed had experienced severe budget cuts and were struggling to maintain service levels. They argued that this forced projects to cooperate and identify synergies across the portfolio (P3, P1, P14, P4). According to these practitioners, this leads to the emergence of new cross-functional projects and programs to alleviate resource shortages (P6, P1, P2, P5, P3). Some projects had self-organized informal forums where "*horse trading could occur*" (P1). Another practitioner argued that scarcity forced projects to be much more careful with whom they collaborated, resulting in more effective self-organization (P11). This evidence led to the following proposition:

SO2. Scarcity of portfolio resources encourages self-organization between projects.

Flexible Structures

While the agile portfolio literature calls for flexibility, it generally refers to project flexibility (Dingsøyr & Moe, 2014), and has little to say on the importance of a flexible project portfolio structure, other than suggesting mature portfolios have centralized, top-down structures (Benefield, 2010; Rautiainen et al., 2011).

According to the academic experts, self-organization does not arise around a prescriptive plan or structure but when there is great flexibility (A1, A2, A3). This often occurs around an agent that can satisfy a temporary need (A2). One academic expert depicted CAS self-organization as a flock of birds where

Table 3. Common Purpose in Portfolios of Agile Projects

Theme	Summary of Existing Literature	Academic Evidence	Practitioner Evidence	Proposition
Emergent purpose	Focus of PPM is on tight alignment of agile projects with organizational strategy	Agents take direction from the center and all other agents	Both portfolio managers and individual agile projects contribute to portfolio purpose	CP1. The portfolio purpose is created and shaped by both portfolio managers and individual agile projects.
Visualization and stories	Cross-project use of visualization and stories limited to operational matters	Visualization and stories essential to share common purpose between agents	Visualization and stories help agile projects communicate the portfolio purpose	CP2. Stories and visual images help agile projects communicate the portfolio purpose
Rewarding altruism	Rewards understudied in PPM and focus is on coping with selfish behavior	Common purpose is reinforced by rewarding altruistic behavior	Rewarding agile projects for altruistic behavior reinforces portfolio purpose	CP3. Rewarding altruistic behavior by agile projects helps reinforce the portfolio purpose

Proposition	Example Research Questions
CP1	How can contribution to portfolio purpose be measured?
CP2	To what extent can artifacts from project-level agile be reconfigured to aid agile at the PPM level, e.g. user stories, Kanban boards, cumulative flow diagrams?
	How can purpose be shared in an agile portfolio?
CP3	How are projects rewarded in an agile portfolio?

there is neither a plan nor a fixed leader: "*In fact, the leader is constantly changing and being reabsorbed back into the pack, and no one knows where the flock will go.*" The group manages itself, and "*if there is a leader, it emerges from the group and will change when the group deems it appropriate*" (A1). The importance of flexibility to enable self-organization across the portfolio was also recognized in the practitioner data (P5, P7, P2, P6). The expert practitioners argued that flexibility enables rapid prototyping through hackathons (P5) and "*knock it up*" sessions (P2). This leads to solutions that projects can self-organize around providing the most appropriate person at any level is willing and able to take leadership responsibilities (P5). Expert practitioners argued that dynamic environments require fast responses that can only be satisfied by a flexible self-organizing structure, not a rigid, hierarchical one (P5, P7, P13). For example, another practitioner explained how, when faced with a crisis, they relaxed formal HR processes and let staff create new projects and programs around loosely defined strategic goals (P1). This evidence led to the following proposition:

> **SO3.** Flexible structures are required to enable self-organization across projects.

Common Purpose

The idea of a flexible portfolio purpose that provides coherence to individually changing projects has not been found in the portfolio literature. Three themes relating to common purpose emerged from the expert interviews: *emergent purpose*, *visualization and stories*, and *altruism.* Each of these themes is now explored in turn. The propositions derived from the common purpose themes are numbered CP1. – CP3. The existing literature, academic and practitioner data, propositions and potential research questions are then summarized in Table 3.

Emergent Purpose

The focus of PPM is on tight alignment with a centrally determined organizational strategy (Hodgkins & Hohmann, 2007; Leffingwell, 2007; Steindl, 2005). Projects that may contribute to an overall purpose, but conflict with the clearly articulated strategic goals of the organization are considered "waste" (Steindl, 2005).

However, the academic experts advised that because there is no central controller in a CAS, a common purpose must be collectively created by the agents in a "*bottom-up*" organic manner (A11, A2, A6). Experts compared this to "*a flock of birds who take direction not only from the center of the flock but also from all the birds around them*" (A1) or a hive of bees where the whole colony is involved in deciding any new course of action (A10). No individual agent needs to understand the whole purpose but instead contributes to it from its own understanding of the environment. Agents are the system's eyes, gathering information about the environment and constantly pressuring for the purpose to change (A15, A6). Similar to a flock of birds, the portfolio takes direction from a central agent, such as the portfolio manager. However, the expert practitioner evidence also supported the idea that individual agile projects contribute to and shape the portfolio purpose (P7, P1, P3). One practitioner explained that in traditional portfolios the strategy is too closely aligned to the organizational power structure, whereas an agile portfolio needs a purpose that is genuinely shared by all the projects (P7) and serves as a "*fulcrum*" to align the project portfolio with the continuously evolving environment (P3). The experts argued that top-down control is severely limited in an agile portfolio that crosses divisional boundaries (P3, P5, P2). Therefore, it essential that this purpose is created collaboratively by both the projects and portfolio managers (P3). This evidence led to the following proposition:

> **CP1:** The portfolio purpose is created and shaped by both portfolio managers and individual agile projects.

Visual Images and Stories

While storytelling techniques, such as *epics* (Cohn, 2014), *user stories,* and *personas* (Haikara, 2007; LeRouge, Ma, Sneha, & Tolle, 2013) are prevalent in information systems development (ISD), they typically deal with visualization at a micro-level within projects. Their cross-project application is restricted to operational matters like work in progress (Rautiainen et al., 2011) and there is no research to identify how stories or images could be used to help the portfolio manager share strategic objectives or purpose.

However, several of the academic experts argued that in complex social systems, *visual images and stories* are a highly effective way of sharing the purpose from agent to agent (A10, A3). For example, a bird in a flock imitates the visual cues from other birds around it (A1). Others described how more sophisticated human agents take on the role of storytellers to share the purpose through a "*lore*" (A3), encoded in legends passed on from one generation to the next (A3, A9, A10, A14). The expert practitioners also described the importance of stories and images in sharing portfolio purpose between projects (P1, P6, P3, P2, P9). One practitioner argued that the portfolio manager is merely the "*custodian of the vision*" (P3), who articulates a *"story*" of a common purpose (P1, P3, P4) that is easily shared by all the projects in the portfolio. Another manager created a series of shareable videos that captured the purpose of the portfolio with stories about its users and how important projects helped them (P17). Practitioners described how they display the portfolio purpose prominently in spaces shared by multiple projects to reinforce and facilitate sharing across the portfolio (P2, P9). Dynamic, changing visual imagery exhibited the full characteristic of CAS, highlighting when projects were losing coherence with the portfolio purpose. For example, screens showing project status enabled other projects to intervene if projects were losing alignment (P16). This evidence led to the following proposition:

> **CP2:** Stories and visual images help agile projects communicate the portfolio purpose.

Rewarding Altruism

No reference to rewarding projects for altruistic behavior was found in the portfolio management literature. Instead, PPM relies on eliminating unaligned projects (Steindl, 2005) and coping with selfish or political behavior (Frey & Buxmann, 2012).

In contrast, the academic experts argued that the common purpose in a CAS is positively reinforced by rewarding altruistic behavior (A3, A12, A2). This is exemplified by the parable of "*The Tragedy of the Commons,*" where a village must cooperate to raise enough pigs on the commons. Those that forgo their grazing rights are rewarded with a share of the meat produced by others (A2), and common purpose is strengthened by rewarding all agents when individual agents successfully meet system goals (A10, A1). The role of rewarding altruism in reinforcing purpose was supported by the expert practitioner data (P1, P3, P2). Practitioners argued that by rewarding projects for their contribution to the portfolio or other projects, they strengthened portfolio purpose (P17, P1, P3). For example, in one portfolio, projects were evaluated and rewarded when their features were adopted by other projects (P3). Other practitioners argued that by allowing all projects share in the rewards when one project is really successful, it encourages projects to help each other (P7, P8, P9). Furthermore, projects that continually focused on their own self-interest over the portfolio were deprioritized and unlikely to be continued (P2). This evidence led to the following proposition:

> **CP3:** Rewarding altruistic behavior by agile projects helps reinforce the portfolio purpose.

Autonomy

There is concern in the portfolio management literature that increased project autonomy associated with agile, can lead to portfolio-level problems (Dingsøyr & Moe, 2014). Three themes relating to common purpose emerged from the expert interviews: *exploration*, *need for control*, and *collective decision making.* Each of these themes is now explored in turn. The propositions derived from the autonomy themes are numbered AA1–AA3. The existing literature, academic and practitioner data, propositions and potential research questions are then summarized in Table 4.

Exploration

Existing portfolio literature has focused more on how to reprioritize the existing roadmap of projects as opposed to creating autonomy to facilitate exploratory behavior (Hodgkins & Hohmann, 2007). Indeed, even in portfolios purporting to be agile, it can take months to get a new project accepted (Rautiainen et al., 2011). In contrast, the academic expert data highlights how *autonomy* is critical to allow agents to continuously explore their fitness landscape to discover higher fitness peaks (A11, A13, A14, A1). For example, a migrating species will send autonomous scouts to identify better habitats. One expert explained that unsuccessful forays are an important part of the learning process and that the agents conducting them should be rewarded, not punished (A3). The academic experts highlighted the particular importance of exploration in the technology sector where "*increasing returns*" make it is impossible to calculate the long-term value of projects (A13, A8). Expert

Table 4. Autonomy in Portfolios of Agile Projects

Theme	Summary of Existing Literature	Academic Evidence	Practitioner Evidence	Proposition
Exploration of the landscape	Focus of PPM is selection and prioritization, not exploration	Autonomy is necessary to enable agents to search for better solutions	Autonomous exploratory agile projects can achieve radical improvements in portfolio performance	AA1 Agile projects must have sufficient autonomy to change the direction of the portfolio through exploration.
The need for control	Portfolio management literature wedded to maintaining control even in an agile context	Agents can become dependent on control and must be prepared for autonomy	Portfolio managers must empower agile projects for change	AA2 Portfolio managers must find the appropriate balance between control and autonomy in agile projects.
Collective decision making	Portfolio level decision making deferred and centralized	CAS needs mechanisms for fast collective decision making	Cannot impose decisions on autonomous agile projects so require mechanism for decisions	AA3. Portfolios of agile projects require mechanisms for simple, fast and collective decision making

Proposition	Example Research Questions
AA1.	How can appropriate resources be allocated to exploratory projects in times of scarcity? How can exploration and exploitation be balanced across a portfolio? How can PPM cater for the fact that most projects have a mix of both exploration and exploitation? How can new exploratory projects be accepted into the portfolio roadmap?
AA2.	What is the appropriate balance between autonomy and control in an agile portfolio?
AA3	How can simple, fast, collective decision making be enabled in agile PPM? How can we evaluate the effectiveness of such practices in a CAS context?

practitioners identified continuous exploration as particularly necessary in IT, where it is often radically new ideas, not incremental improvement, that create success (P6, P3, P2, P3). These new projects are intended to help the portfolio match the rate of change in the environment and to disrupt itself before its competitors can. Furthermore, the portfolio must be prepared to change direction in response to successful exploration. This evidence led to the following proposition:

> **AA1:** Agile projects must have sufficient autonomy to change the direction of the portfolio through exploration.

Need for Control

The portfolio management literature remains wedded to maintaining control even in an agile context (Dingsøyr & Moe, 2014). The academic experts acknowledged that agents are often uncomfortable with autonomy and feel safer with *control* (A1, A5, A14, A15). For example, it is difficult for some species of animals raised in captivity to survive if released into the wild. Similarly, it was argued that the notion of control is too ingrained in people to be abandoned easily, and a "*protective space*" to prepare for autonomy can help (A1). For some, it is a need to be in control; for others, a need to be controlled (A1, A5). The need to overcome portfolio staff's desire for control was echoed in the practitioner data (P6, P2, P1, P3, P4). For example, one practitioner warned that portfolio managers are often concerned about the lack of oversight with agile projects (P6), whereas others fear autonomy and prefer the certainty inherent in a plan-driven approach with a tightly defined backlog (P4, P3). However, it was also argued that agile approaches do not require excessive control and the focus should be on empowering projects (P3). Another practitioner argued that in dynamic environments, stakeholders must relax control and accept that some projects will fail (P14). It was argued that while control may stabilize the portfolio, it reduces both performance and the ability of the portfolio to adapt to change (P9). This evidence led to the following proposition:

> **AA2:** Portfolio managers must find the appropriate balance between control and autonomy in agile projects.

Collective Decision Making

The limited literature that addresses decision making in portfolios of agile projects calls for "fact-based" decision making, delayed "as late as possible" (Steindl, 2005). Furthermore, portfolios often have centralized governance structures that require portfolio-level decisions to be made by senior managers (Frey & Buxmann, 2011).

In contrast, the academic experts argued that autonomy means no individual agent can "*play God*" (A2) or dictate the behavior of other agents. Therefore, agents need a mechanism for collective decision making (A7, A3, A2). For example, when bees are swarming, they engage in a voting exercise through dance and "head bumping" to decide on the best location for the new hive. Within minutes, tens of thousands of bees can collectively and effectively choose the best location (A15). However, one expert explained that humans are messy and often irrational decision makers (A6). Therefore, they need a

Table 5. Adaptiveness in Portfolios of Agile Projects

Theme	Summary of Existing Literature	Academic Evidence	Practitioner Evidence	Proposition
Fitness	Very little literature looking at fitness or performance of portfolios of agile projects	Fitness function measures suitability of agents to their environment	Agile projects contribution to portfolio performance must be measured across multiple metrics	AD1. A constantly evolving portfolio-level multivariate fitness function measures how well projects are adapted to portfolio goals
Natural selection	Literature suggests it is hard to cancel agile projects	Fitness function used to exclude all but high-performing agents	Only the highest performing projects should be retained	Agile projects with lower levels of portfolio fitness should be cancelled
Constant process	Focus is on completing high priority projects	Even high-performing agents must continue to adapt	High-performing projects must continue to adapt	Even high-performing projects must constantly embrace change

Proposition	Example Research Questions
AD1.	What metrics make up a portfolio fitness function? How can an agile PPM fitness function trade off competing variables?
AD2.	When is the best time to stop projects in an agile portfolio? What 'grace period' or supports should be provided to projects before cancelling?
AD3.	How do we encourage good projects to continue to adapt?

system for collective decision making around simple rules that allow them to work through their disagreements and make rapid decisions to prevent the system descending into chaos (A2, A3) in what one expert described as "*the fog of war*" (A13). The requirement for a collective decision-making process is reflected in the practitioner data (P6, P5, P3, P2). One expert argued that regardless of the seniority of the portfolio manager, the complex, multifaceted nature of software portfolios means they will inevitably have to work with projects outside their span of control, meaning decisions must arise from consensus (P6). Others supported this, suggesting portfolio managers must broker agreements in a portfolio, often without complete information (P7), and often involving projects with conflicting agendas. Practitioners argued that the dynamic nature of the software environment means decision making needs to be quick, informal, and collective (P3, P5, P9). Several experts discussed how gamification supported collective decision making in their portfolios (P2, P7). By simulating decisions as games, points or even "*pseudo-currencies*" were used to evaluate options and achieve consensus. This evidence led to the following proposition:

> **AA3:** Portfolios of agile projects require mechanisms for simple, fast, and collective decision making.

Adaptiveness

The ability to change is central to the concept of agility at both the project and portfolio levels. Three themes relating to adaptiveness emerged from the expert interviews: *fitness*, *natural selection*, and *constant process.* Each of these themes is now explored in turn. The propositions derived from the adaptiveness themes are numbered AD1–AD3. The existing literature, academic and practitioner data, propositions and potential research questions are then summarized in Table 5.

Fitness

The concept of fitness has not been investigated in the PPM literature. Indeed there is very little literature looking at the performance of portfolios of agile projects, other than an acknowledgment that it contains multiple components (Dingsøyr & Moe, 2014). Furthermore, performance is measured episodically against factors that rarely change (Jeffery & Leliveld, 2004).

The concept of *fitness function* is important in CAS, however, and was raised in many academic interviews (A7, A13, A14, A3, A1). This function is used to continuously measure and rank how well agents are adapted to their environment (A7, A2), providing objective feedback to agents on their ability to adapt to survive (A6, A1). At its simplest, a fitness function focuses on the key metrics around what the system needs and ranks agents against it (A2). However, it is often complex, with multiple variables to be considered and weighted appropriately. This makes the development of a fitness function challenging (A2). Furthermore, the fitness function must change over time in response to the dynamic environment (A3). The practitioners also showed awareness of the need to measure project performance and alignment across a range of portfolio metrics (P1, P3, P2). One expert explained that projects can be unaware or in denial about their own contribution to the portfolio, as they may be focused exclusively on their own project, highlighting the need for objective data (P2). Practitioners described how each project's contribution to the portfolio is measured by variables such as their contribution to other failing projects, innovation, quality, and financial return (P1, P3). The dynamic nature of fitness was considered particularly important in an agile context where the portfolio's ability to react to environmental change was considered as important as project performance (P2, P5). Practitioners described how the fitness function must be tuned to the changing environment, by changing its variables and their respective weightings. One practitioner explained how this was used to prioritize short-term projects with a quick payback period during a financial crisis (P8). This evidence led to the following proposition:

> AD1: A constantly evolving multivariate portfolio-level fitness function measures how well projects are adapted to portfolio goals.

Natural Selection

Rautiainen et al. (2011) argue that decisions should be made to stop projects on a "per sprint basis." However, other approaches suggest delaying decisions around projects as late as possible (Steindl, 2005), and the elimination of poorly performing projects has proven problematic, especially in an agile context where project teams believe they are adding value.

According to the academic experts, agents with a low level of fitness that fail to adapt cannot survive in a CAS. (A7, A11). Natural selection eliminates agents poorly adapted to their environment as they do not survive long enough to reproduce. For example, giraffes with short necks died out because only giraffes with longer necks were better able to reach scarce food. While a human complex system can adapt more quickly, simply by eliminating bad behaviors, rather than the agents responsible for them, this will only work if the threat of extinction exists for those who refuse to change (A3, A12). The expert practitioner data also emphasized the need for the ongoing threat of selection to encourage projects to improve their fitness levels. Practitioners noted that many portfolios are struggling with this. According to one practitioner, problem projects "*are put in a holding pattern*" (P13) or "*marginalized*" (P1), and are difficult to end or "*kill*" as support from the top of the organization is required (P1). However, canceling agile projects can prove particularly problematic in practice, where customer involvement, team empowerment and constantly changing requirements help failing projects justify their continued existence (P1, P3, P14). However, in genuinely agile portfolios, projects should compete with each other with only the highest performing ones retained and extended (P2, P5). This evidence led to the following proposition:

> **AD2:** Agile projects with lower levels of portfolio fitness should be quickly cancelled.

Constant Process

The existing literature focuses on how to get high-priority projects finished quickly. However, in some cases, a high-performing project could be considered a low priority and be made to contribute resources to other struggling projects, impairing its ability to adapt (Rautiainen et al., 2011).

According to the academic experts, any high levels of fitness are temporary in a changing environment (A3, A11, A14, A1). For example, for fishermen, a large boat is optimal when fish are plentiful. However, if fish stocks collapse, only those fishermen with small boats and low overheads can make a profit (A3). The academic experts explained that this means adaptiveness is constantly necessary for both high- and low-performing agents (A3, A1). Another academic warned against agents committing exclusively to seemingly successful strategies, suggesting it was "*like marrying your first date because it went well*" (A12). This was reflected in the expert practitioner data (P2, P11, P12, P5). Because of the customer-focused, iterative nature of agile, projects may not have a definite end date, but even high-performing projects can become outdated and fail to embrace new opportunities (P2). Another expert argued that in a fast-paced environment *"it is the job of projects to disrupt their own portfolio before the competition does"* (P5). In some cases, certain projects have become so optimized that other previously high-performing projects in the portfolio become a bottleneck (P2, P9). This evidence led to the following proposition.

> **AD3:** Even high-performing projects must constantly embrace change.

Requisite Variety

There is little reference to variety in the PPM literature. Instead, the focus is on creating a "balanced" portfolio (Steindl, 2005; Stettina & Hörz, 2015). Indeed, software portfolios are characterized by the high level of correlation between projects (Kundisch & Meier, 2011) (Burke & Shaw, 2008). Two themes relating to *requisite variety* emerged from the expert interviews: *novelty* and *source of food.* Each of these themes is now explored in turn. The propositions derived from the requisite variety themes are numbered RV1–RV2. The existing literature, academic and practitioner data, propositions and potential research questions are then summarized in Table 6.

Novelty

While the literature has acknowledged that organizations struggle to match their portfolio against the complexity of its environment (Benefield, 2010), the focus remained on ensuring that projects were selected to get the best use of existing resources and to control risk (Thomas & Baker, 2008) and there is little evidence that portfolios create novelty.

According to the evidence provided by the academic experts, variety provides the *novelty* necessary to overcome complex problems (A11, A3, A1, A12). One of the experts explained that while homogenous agents can tackle simple repetitive problems efficiently, they struggle to overcome new challenges (A12). Instead, variety ensures the potential solutions to changes in the environment already exist within the system (A1). For example, the diversity of species in a rainforest enables it to overcome challenges such as drought and

Table 6. Requisite Variety in Portfolios of Agile Projects

Theme	Summary of Existing Literature	Academic Evidence	Practitioner Evidence	Proposition
Novelty	Focus of project selection is to make the best use of resources	Variety of agents ensures system has novelty to address complex problems	Portfolios need a range of projects to overcome the various challenges posed by the environment	RV1. For a portfolio to survive in a changing environment, its' diversity of projects must match the complexity of the environment
Supply of food	Plentiful supply of resources important to prevent selfish behavior	Systems rich in food have a high level of agent diversity	Limited resources prevent the creation of exciting projects	RV2. Project diversity requires a plentiful supply of portfolio resources

Proposition	Example Research Questions
RV1.	What is the appropriate level of project diversity in agile PPM? Is diversity required in every project or just at the portfolio level?
RV2.	How can resources be used to build project diversity? How can one evaluate effective diversity from too much diversity?

forest fires. DNA contains many unused features that can become active if the environment changes. The need for sufficient diversity was echoed in the practitioner data (P5, P3, P6). Several experts pointed out how software portfolios need a range of projects that can be combined to overcome the challenges faced (P5, P3, P6). According to another expert, this is particularly important in software PPM as "*leading-edge change programs require a range of projects*" (P2). Furthermore, it was argued that the need for project diversity increases in dynamic environments (P5), as there is no time to create new projects when crisis strikes (P1, P5, P7). This evidence led to the following proposition:

> **RV1.** For a portfolio to survive in a changing environment, its diversity of projects must match the complexity of the environment.

Supply of Food

While the literature suggests that sufficient resources prevent political behavior (Hodgkins & Hohmann, 2007), there is no guidance as to how these resources could be directed toward increasing project diversity.

According to the academic experts, diversity cannot be maintained without a plentiful supply of food to support different agents (A5, A11). For example, a rainforest rich in food has much greater diversity than a desert. One of the experts, using the Apple App Store as an example, explained how a rich ecosystem attracts agents, which can, in turn, create the food for other agents. Apple created a platform where app developers were drawn to a large customer base creating a virtuous circle where more and more customers and developers were attracted (A8). Another academic expert considering PPM as a CAS comprising agile projects suggested that exciting problems as well as resources "*could act as food*" for agents who would create more and more ambitious projects (A12). This was reinforced by practitioners, one of whom admitted that because their portfolio was not considered well resourced, they could not attract and retain enough talented engineers to create a diverse array of projects. Instead, the best engineers were "*much more likely to go to Google*" (P2). Other practitioners confirmed that limited resources blocked them from creating a diversity of projects (P3, P1, P2) as it proved challenging to divert resources, such as budgets or equipment, away from existing projects "*when money is tight*" (P1). This evidence led to the following proposition:

> **RV2:** Project diversity requires a plentiful supply of portfolio resources.

Exchange of Resources

The exchange of resources between projects has received little attention in the PPM literature. Two themes relating to *exchange of resources* emerged from the expert interviews: *holistic approach* and *simple rules.* Each of these themes is now explored in turn. The propositions derived from the exchange of resources themes are numbered ER1–ER3. The existing literature, academic and practitioner data, propositions and potential research questions are then summarized in Table 7.

Holistic Approach

According to the literature, a system-wide view of resources can save portfolios huge amounts by eliminating unnecessary work (Kersten & Verhoef, 2003). However, this is challenging because system-wide information about the return of resources is scarce in IS PPM (De Reyck et al., 2005),

The academic experts agreed that the system can benefit by agents taking a holistic view of resource allocation (A2, A10, A9, A12). One expert explained that local optimization leads to

Table 7. Exchange of Resources in Portfolios of Agile Projects

Theme	Summary of Existing Literature	Academic Evidence	Practitioner Evidence	Proposition
Holistic Approach	System-wide view of resource allocation eliminates redundancies	The system benefits when agents take a holistic view of resource allocation	The portfolio must be considered as a single system when allocating resources	ER1. A system-wide approach to resource management is supported by sharing the benefits it creates between projects
Simple Rules	"Rules of thumb" enable sharing of resources	Exchange of resources facilitated by simple rules	Simple shared rules allow rapid decisions around resource sharing	ER2. The exchange of resources between projects is facilitated by simple rules

Proposition	Example Research Questions
ER1.	How are the benefits of cooperation shared between projects? How can such a dynamic resourcing model operate in practice?
ER2.	What are the rules that will enable the sharing of resources between projects? How can complex problems and environs be effectively deconstructed into simple rules?

a waste of resources (A6). Others argued by looking at the system as a whole, synergies can be identified, and agents can swap ideas as to how to use resources (A10, A11). This is again illustrated by "*the parable of the pig*" from the "*Tragedy of the Commons*," whereby everyone benefits by taking a collective approach (A2). The academic experts suggested that agents are more likely to take a system-wide view if they get to share the benefits (A9, A7). The idea of a holistic view of resource allocation was widely supported by the practitioner experts who are used to thinking of the portfolio as a single system (P1, P5, P7). Practitioners argued that much more can be achieved by sharing (P5, P7), but facilitating this is difficult. Projects must be rewarded with a share of the benefits accruing from cooperation (P6, P4, P5) and be made to understand the cost of not sharing (P3, P7). One practitioner explained how screens around the office highlighted each project's priority and the problems it was facing, thereby encouraging other projects to share resources as they were needed (P17). This evidence led to the following proposition.

> **ER1:** A system-wide approach to resource management is supported by sharing the benefits it creates between projects.

Simple Rules

There is some evidence to support the use of simple rules around the exchange of resources. For example, Rautiainen et al. (2011) argue that portfolios need "rules of thumb," such as projects sharing resources with higher priority projects.

According to the experts, the exchange and use of resources are facilitated by simple shared rules or heuristics that have evolved over time (A2, A9, A6, A8). This is exemplified by the rules and rituals that have evolved to govern the allocation of water in rice-farming collectives. While these rules do not lead to optimum distribution in any single year, over time they prove robust and reliable (A9). These rules are often "*simple*" or "*fast and frugal,*" which means exchanges can be quickly agreed without management overhead (A8, A9). This was also supported by the practitioner data (P1, P6, P3). Practitioner examples included a simple rule that ensured unexpected additional work was shared equally (P1), automatically reallocating resources from parked projects to the highest priority project (P3), and the simplicity of rituals such as Scrum of Scrums (P3). It was also argued that commonly accepted informal rules lead to faster decisions (P3, P1). This evidence led to the following proposition:

> **ER2:** The exchange of resources between projects is facilitated by simple rules.

Discussion

The propositions derived from the expert interviews raise some interesting points. First, it should be noticed that, as sometimes happens in IS, practice leads theory (Mingers, 2004). The expert practitioner data is far closer to a CAS-based approach than the PPM literature is. Even when the practitioners were speculating what a CAS-based approach to PPM would look like, they were able to provide real examples of supporting practices. Second, it should be noted that some propositions appear inconsistent. For example, scarcity is proposed to aid self-organization (SO2) whereas a plentiful supply of resources is proposed to improve diversity (RV2). However, in a CAS, relationships are rarely simple or linear, and it should be recognized that all parts of a CAS are interrelated (Stacey, 2010). If agents are lacking some of the other properties discussed above, such as common purpose to align agent behavior, scarcity could lead to conflict or extra resources could be wasted. So while we used the individual properties of agents to explore the data, there were overlaps between them. For example, propositions highlight a complex relationship between requisite variety and adaptiveness. Third, the portfolio may have to choose between conflicting objectives, depending on its circumstances. An important challenge in managing complex systems is the management of tensions between conflicting goals (Lewis, 2000).

Complex adaptive systems exist on a spectrum, ranging from highly ordered to disordered, chaotic systems. Effective complex systems balance the need for order and freedom by positioning themselves in the region known as the "edge of chaos" (Langton, 1992). However, the appropriate position on this spectrum for any individual CAS depends on its environment. This is also true for portfolios of agile projects. Not all portfolios need to be able to reconfigure on a weekly basis, and the application of the propositions must be tailored to the individual circumstances of each portfolio. This is consistent with many methods in IS and agile in particular (Conboy & Fitzgerald, 2010; Fitzgerald, Russo, & Stolterman, 2002). While there is broad overlap between some of the propositions and existing PPM practice (e.g., the propositions relating to exchange of resources), this study highlights divergences between a CAS-based approach to PPM and traditional approaches. These differences are now discussed.

The Use of Rewards and Punishments

In a CAS-based approach, rewards are constantly used to incentivize projects to contribute to the portfolio as a whole (CP3). However, in existing approaches to IS PPM, there is little support, as rewards are infrequently applied, generally in response to individual achievements. There is some evidence to suggest that control mechanisms often fail to reward altruistic behavior (Conboy, 2010; Hansen & Kræmmergaard, 2012). Similarly, projects often escape the consequences of actions that do not support the portfolio as a whole. In contrast, in a CAS approach projects that weaken the system are eliminated (AD2). All actions good or bad in a CAS have consequences that act as constant feedback, helping both agents and the system to improve.

Decision Making and Control

In IS PPM, there is an acceptance that decisions are made by managers who control the portfolio with formal rules (Jeffery & Leliveld, 2004). This is in contrast to a CAS-based approach, where the projects are free from control (AA2), and decisions to share resources are made collectively around simple regularly revised heuristics (AA3, ER2). Resources in IS PPM are owned by certain units and are only swapped through formal processes.

Different Time Horizons

An effective CAS balances multiple time horizons to ensure both the short- and long-term survival of the system. IS PPM is focused on short-term business cycles with little concern for long-term consequences (Daniel et al., 2014). Reviews and changes generally occur in line with the business cycle, which is often based on arbitrary reporting deadlines (Jeffery & Leliveld, 2004). In a CAS, the cadence of reviews is matched to the rate of environmental change, and the application of fitness functions (AD2) or the review of resources happen continuously (ER2). An effective CAS embraces constant change (AD3). By exploring new solutions (AA1) and constantly scanning the environment for new threats and opportunities—even in times of apparent stability—the system is in a constant state of flux.

Structure

An effective CAS has a flat, peer-to-peer structure, based on individual relationships, that enables information and resources to flow through it (SO1, ER2). Because the system is often colocated, agents can move around it to find the best place for their abilities, and the structure constantly evolves in response to changes (AD3). In contrast, IS PPM tends to have a fixed top-down structure, and even when it is decentralized, the structure can be rigid, with little capacity for mobility.

Conclusions, Limitations, and Future Research

Despite the high level of problems experienced by PPM practitioners with agile projects, there is a dearth of research in the area. Using CAS theory and a set of 30 expert interviews with CAS researchers and experienced PPM practitioners, we developed a set of propositions to address *how project portfolio management can be enacted to manage the complexity and adaptiveness arising from a portfolio of agile projects.*

From our interview data, we developed 16 propositions from the six properties of CAS agents. These propositions will help identify areas for future research and provided example research questions. Our research showed that the properties of CAS map well to the problems faced by PPM practitioners.

This study makes some important contributions to theory. First, it is one of the first studies to apply CAS to PPM, and it contributes to the PPM literature by theorizing projects as agents. Second, it addresses the gap around the management of portfolios of agile projects with a set of 16 propositions. Furthermore, the study developed an extensive research agenda for PPM. This research also impacts on practice by enabling practitioners to understand the implications of managing portfolios of agile projects in dynamic environments, and by linking the theoretical knowledge of CAS to the real world of PPM and agile projects.

This study has the limitations associated with qualitative research generally, and semi-structured interviewing specifically (Saunders, Lewis, & Thornhill, 2012). In interpretive research, validity comes from the strength of reasoning in drawing conclusions as opposed to statistical generalization (Klein & Myers, 1999), so a rigorous research design was used and great care was taken in the conduct and analysis of the interviews. However, the list of propositions could not be considered exhaustive.

While the examples and evidence given by respondents, along with the derived research questions are useful, this research was exploratory. It could be used, however, by future researchers as a basis for explanatory research to determine the extent to which the practices contained in the 16 propositions are prevalent across the PPM community, and indeed to validate the extent to which these practices contribute to agility at the portfolio level. For example, in-depth cases are needed to truly validate these propositions and provide richer descriptions as to how each proposition can be operationally enacted in practice. Longitudinal cases would be particularly useful to examine the ability to immediately and continuously communicate a continually changing purpose, as is required in a portfolio of agile projects. Furthermore, research is required to investigate the contradictions apparent between some of the propositions.

This study focused on the concept of projects as agents within a portfolio. Future research could apply other CAS concepts to agile PPM, such as the *environment*, *interaction, feedback loops,* and *emergent system-level properties*. Reference to these concepts did arise during the study but only in the context of the agent concept. The literature review suggests that existing PPM approaches are limited to eight to ten agile projects. CAS could be used to investigate how to scale PPM beyond this sweet spot. Finally, this study focused specifically on PPM comprising a set of agile projects. Future research could apply a CAS lens to traditional PPM environments or regulated environments where agile approaches are considered to be less suitable.

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Note

1. A number of practitioners participated in the study on the condition that either their own names or those of their companies would not be used. Therefore, only job titles of the practitioners are shown and pseudonyms are provided for the organizations marked with an asterisk.

References

Abrahamsson, P., Conboy, K., & Wang, X. (2009). Lots done, more to do: The current state of agile systems development research. *European Journal of Information Systems*, *18*(4), 281–284.

Amberland, D. (2013). *The real problem in working from home (it's not what you think)*. Retrieved from http://www.forbes.com/sites/netapp/2013/06/24/working-from-home/

Anderson, P. (1999). Complexity theory and organization science. *Organization Science*, *10*(3), 216–232.

Aritua, B., Smith, N. J., & Bower, D. (2009). Construction client multi-projects—A complex adaptive systems perspective. *International Journal of Project Management*, *27*(1), 72–79.

Beck, K., Cockburn, A., Jeffries, R., & Highsmith, J. (2001). *Agile manifesto*. Retrieved from http://www.agilemanifesto.org

Beck, K., & Fowler, M. (2001). *Planning extreme programming*. Boston, MA: Addison-Wesley.

Beck, T., & Plowman, D. A. (2014). Temporary, emergent interorganizational collaboration in unexpected circumstances: A study of the Columbia Space Shuttle response effort. *Organization Science*, *25*(4), 1234–1252.

Benbya, H., & McKelvey, B. (2006). Toward a complexity theory of information systems development. *Information Technology & People*, *19*(1), 12–34.

Benefield, R. (2010). *Seven dimensions of agile maturity in the global enterprise: A case study*. Paper presented at the 43rd Hawaii International Conference on System Sciences (HICSS), Hawaii.

Billows, D. (2001). *Managing complex projects* (8th ed.). Denver, CO: The Hampton Group.

Blichfeldt, B. S., & Eskerod, P. (2008). Project portfolio management—There's more to it than what management enacts. *International Journal of Project Management*, *26*(4), 357–365.

Bogner, A., Littig, B., & Menz, W. (2009). *Interviewing experts*. Basingstoke, UK: Palgrave Macmillan.

Bristow, G., & Healy, A. (2014). Regional resilience: An agency perspective. *Regional Studies*, *48*(5), 923–935.

Burke, J. C., & Shaw, M. J. (2008. *IT portfolio management: A case study*. Paper presented at the AMCIS 2008 Proceedings, Toronto, Canada.

Choi, T. Y., Dooley, K. J., & Rungtusanatham, M. (2001). Supply networks and complex adaptive systems: Control versus emergence. *Journal of Operations Management*, *19*(3), 351–366.

Cilliers, P. (2000). What can we learn from a theory of complexity? *Emergence*, *2*(1), 23–33.

Cohn, M. (2014). *Agile user stories, epics and themes*. Retrieved from https://www.scrumalliance.org/community/spotlight/mike-cohn/march-2014/agile-user-stories-epics-and-themes

Conboy, K. (2009). Agility from first principles: Reconstructing the concept of agility in information systems development. *Information Systems Research*, *20*(3), 329–354.

Conboy, K. (2010). Project failure en masse: A study of loose budgetary control in ISD projects. *European Journal of Information Systems*, *19*(3), 273–287.

Conboy, K., Dennehy, D., Morgan, L., & Sweetman, R. (2017). Agility in information systems development. In R. Galliers & M. Stein (Eds.), *The Routledge companion to management information systems*. London, England and New York, NY: Routledge.

Conboy, K., & Fitzgerald, B. (2010). Method and developer characteristics for effective agile method tailoring: A study of XP expert opinion. *ACM Transactions on Software Engineering and Methodology (TOSEM)*, *20*(1), 1–30.

Cooke-Davies, T., Cicmil, S., Crawford, L., & Richardson, K. (2008). We're not in Kansas anymore, Toto: Mapping the strange landscape of complexity theory, and its relationship to project management. *Engineering Management Review, IEEE*, *36*(2), 5–21.

Cooper, R. G., Edgett, S., & Kleinschmidt, E. (1999). New product portfolio management: Practices and performances. *Journal of Product Innovation Management*, *16*(4), 333–351.

Curseu, P. L. (2006). Emergent states in virtual teams: A complex adaptive systems perspective. *Journal of Information Technology*, *21*(4), 249–261.

Daniel, E. M., Ward, J. M., & Franken, A. (2014). A dynamic capabilities perspective of IS project portfolio management. *The Journal of Strategic Information Systems*, *23*(2), 95–111.

De Reyck, B., Grushka-Cockayne, Y., Lockett, M., Calderini, S. R., Moura, M., & Sloper, A. (2005). The impact of project portfolio management on information technology projects. *International Journal of Project Management*, *23*(7), 524–537.

Dingsøyr, T., & Moe, N. B. (2013). Research challenges in large-scale agile software development. *ACM SIGSOFT Software Engineering Notes*, *38*(5), 38–39.

Dingsøyr, T., & Moe, N. B. (2014). Towards principles of large-scale agile development. In T. Dingsøyr, N. B. Moe, R. Tonelli, S. Counsell, C. Gencel, & K. Petersen (Eds.), *Agile methods: Large-scale development, refactoring, testing, and estimation* (Vol. 199, pp. 1–8). Heidelberg, Germany: Springer.

Dingsøyr, T., Nerur, S., Balijepally, V., & Moe, N. B. (2012). A decade of agile methodologies: Towards explaining agile software development. *Journal of Systems and Software*, *85*(6), 1213–1221.

Dobzhansky, T. (1968). On some fundamental concepts of Darwinian biology. In T. Dobzhansky, M. K. Hecht, & W. C. Steere (Eds.), *Evolutionary biology* (Vol. 2, pp. 1–34). Boston, MA: Springer.

Dooley, K. J. (1997). A complex adaptive systems model of organization change. *Nonlinear Dynamics, Psychology, and Life Sciences*, *1*(1), 69–97.

Drake, J. R., & Byrd, T. A. (2006). Risk in information technology project portfolio management. *Journal of Information Technology Theory and Application*, *8*(3), 1–11.

Dybå, T., & Dingsøyr, T. (2008). Empirical studies of agile software development: A systematic review. *Information and Software Technology*, *50*(9), 833–859.

Farrell, B. H., & Twining-Ward, L. (2004). Reconceptualizing tourism. *Annals of Tourism Research*, *31*(2), 274–295.

Fitzgerald, B., Russo, N. L., & Stolterman, E. (2002). *Information systems development: Methods in action*. Maidenhead, UK: McGraw-Hill Education.

Fowler, M., & Highsmith, J. (2001). The agile manifesto. *Software Development*, *9*(8), 28–32.

Frey, T., & Buxmann, P. (2011). *The importance of governance structures in IT project portfolio management*. Paper presented at the 19th European Conference on Information Systems, Helsinki, Finland.

Frey, T., & Buxmann, P. (2012). *IT project portfolio management—A structured literature review*. Paper presented at the 20th European Conference on Information Systems, Barcelona, Spain.

Gell-Mann, M. (1994). Complex adaptive systems. In G. Cowan, D. Pines, & D. Meltzer (Eds.), *Complexity: Metaphors, models and reality* (Vol. 19, pp. 17–45). Reading, MA: Addison-Wesley.

Gell-Mann, M. (2002). What is complexity? In A. Q. Curzio & M. Fortis (Eds.), *Complexity and industrial clusters* (pp. 13–24). Heidelberg, Germany: Springer.

Gentner, D. (1980). *The structure of analogical models in science* (BBN Tech. Report No 4451). Cambridge, MA: Bolt, Beranel and Newman Inc.

Grimm, V., Revilla, E., Berger, U., Jeltsch, F., Mooij, W. M., Railsback, S. F., . . . DeAngelis, D. L (2005). Pattern-oriented modeling of agent-based complex systems: Lessons from ecology. *Science*, *310*(5750), 987–991.

Guo, B., & Guo, J.-J. (2011). Patterns of technological learning within the knowledge systems of industrial clusters in emerging economies: Evidence from China. *Technovation*, *31*(2), 87–104.

Haikara, J. (2007). *Usability in agile software development: Extending the interaction design process with personas approach*. Paper presented at the Agile Processes in Software Engineering and Extreme Programming Conference, Como, Italy.

Hansen, L. K., & Kræmmergaard, P. (2012). *Project portfolio management: Control problems in a public organization*. Paper presented at the Transforming Government Workshop (tGov2012), Brunel University, UK.

Hansen, L. K., & Kræmmergaard, P. (2014). Discourses and theoretical assumptions in IT project portfolio management: A review of the literature. *International Journal of Information Technology Project Management*, *5*(3), 39–66.

Hatzakis, T., Lycett, M., & Serrano, A. (2007). A programme management approach for ensuring curriculum coherence in IS (higher) education. *European Journal of Information Systems*, *16*(5), 643–657.

Hesse, M. B. (1966). *Models and analogies in science* (Vol. 7). Notre Dame, IN: University of Notre Dame Press.

Highsmith, J. (2002). What is agile development? *The Journal of Defense Software Development*, *15*(10), 4–9.

Hobbs, B., & Petit, Y. (2017). *Agile approaches on large projects in large organizations*. Newtown Square, PA: Project Management Institute.

Hoda, R., Kruchten, P., Noble, J., & Marshall, S. (2010). *Agility in context*. Paper presented at the ACM Sigplan Notices, Reno, NV.

Hoda, R., Noble, J., & Marshall, S. (2013). Self-organizing roles on agile software development teams. *IEEE Transactions on Software Engineering*, *39*(3), 422–444.

Hodgkins, P., & Hohmann, L. (2007). *Agile program management: Lessons learned from the Verisign Managed Security Services Team*. Paper presented at the Agile Conference (AGILE), Washington, DC.

Holland, J. (1992a). Complex adaptive systems. *Daedalus*, *121*(1), 17–30.

Holland, J. (1992b). *Complex adaptive systems adaptation in natural and artificial systems an introductory analysis with applications to biology control and artificial intelligence*. Cambridge, MA, & London, England: MIT Press.

Holland, J. (1995). *Hidden order: How adaptation builds complexity*. Redwood City, CA: Addison Wesley Longman Publishing Co.

Holland, J., & Miller, J. (1991). Artificial adaptive agents in economic theory. *American Economic Review*, *81*(2), 365–370.

Jain, R., & Meso, P. (2004). *Theory of complex adaptive systems and agile software development*. Paper presented at the Tenth Americas Conference on Information Systems, New York, NY.

Jeffery, M., & Leliveld, I. (2004). Best practices in IT portfolio management. *MIT Sloan Management Review*, *45*(3), 41–49.

Jeffries, R. E. (2014). *SAFe—Good but not good enough*. Retrieved from http://ronjeffries.com/xprog/articles/safe-good-but-not-good-enough/

Kalliney, M. (2009). *Transitioning from agile development to enterprise product management agility*. Paper presented at the Agile Conference, AGILE'09, Chicago, IL.

Karwowski, W. (2012). A review of human factors challenges of complex adaptive systems: Discovering and understanding chaos in human performance. *Human Factors*, *54*(6), 983–995.

Kauffman, S. A. (1993). *The origins of order: Self-organization and selection in evolution*. Oxford, UK: Oxford University Press.

Kautz, K. (2012). *Beyond simple classifications: Contemporary information systems development projects as complex adaptive systems*. Paper presented at the Thirty Third International Conference on Information Systems, Orlando, FL.

Kersten, B., & Verhoef, C. (2003). IT portfolio management: A banker's perspective on IT. *Cutter IT Journal*, *16*(4), 27–33.

Kettunen, P., & Laanti, M. (2008). Combining agile software projects and large-scale organizational agility. *Software Process: Improvement and Practice*, *13*(2), 183–193.

Klein, H. K., & Myers, M. D. (1999). A set of principles for conducting and evaluating interpretive field studies in information systems. *MIS Quarterly*, *23*(1), 67–93.

Kniberg, H., & Ivarsson, A. (2012). *Scaling agile@ spotify*. Retrieved from https://dl.dropbox.com/u/1018963/Articles/SpotifyScaling.pdf

Krebs, J. (2008). *Agile portfolio management*. Redmond, WA: Microsoft Press.

Kundisch, D., & Meier, C. (2011). *A new perspective on resource interactions in IT/IS project portfolio selection*. Paper presented at the 19th European Conference on Information Systems–ICT and Sustainable Service Development, Dublin, Ireland.

Langton, C. G. (1992). Life at the edge of chaos. *Artificial Life II*, *10*, 41–91.

Leffingwell, D. (2007). Scaling software agility: Best practices for large enterprises. Boston, MA: Addison-Wesley.

LeRouge, C., Ma, J., Sneha, S., & Tolle, K. (2013). User profiles and personas in the design and development of consumer health technologies. *International Journal of Medical Informatics*, *82*(11), e251–e268.

Levin, S. A. (1998). Ecosystems and the biosphere as complex adaptive systems. *Ecosystems*, *1*(5), 431–436.

Levin, S. A., Xepapadeas, T., Crepin, A.-S., Norberg, J., De Zeeuw, A., Folke, C., . . . Walker, B., (2013). Social-ecological systems as complex adaptive systems: Modeling and policy implications. *Environment and Development Economics*, *18*(2), 111–132.

Lewis, M. W. (2000). Exploring paradox: Toward a more comprehensive guide. *The Academy of Management Review*, *25*(4), 760–776.

Lichtenstein, B. M. B. (2000). Emergence as a process of self-organizing—New assumptions and insights from the study of non-linear dynamic systems. *Journal of Organizational Change Management*, *13*(6), 526–544.

Malgonde, O., Collins, R., & Hevner, A. (2014). *Applying emergent outcome controls to mitigate time pressure in agile software development*. Paper presented at the Twentieth Americas Conference on Information Systems, Savannah, GA.

McKelvey, B. (1999). Avoiding complexity catastrophe in coevolutionary pockets: Strategies for rugged landscapes. *Organization Science*, *10*(3), 294–321.

Meskendahl, S. (2010). The influence of business strategy on project portfolio management and its success—A conceptual framework. *International Journal of Project Management*, *28*(8), 807–817.

Meyer, M. A., & Booker, J. M. (2001). *Eliciting and analyzing expert judgment: A practical guide* (Vol. 7). Philadelphia, PA: Society for Industrial and Applied Mathematics.

Miles, M., & Huberman, A. (1996). *Qualitative data analysis*. London, England: Sage Publications.

Mingers, J. (2004). Real-izing information systems: Critical realism as an underpinning philosophy for information systems. *Information and Organization*, *14*(2), 87–103.

Moe, N. B., Dingsoyr, T., & Dyba, T. (2009). Overcoming barriers to self-management in software teams. *Software, IEEE*, *26*(6), 20–26.

Nan, N. (2011). Capturing bottom-up information technology use processes: A complex adaptive systems model. *MIS Quarterly*, *35*(2), 505–532.

Perry, M. P. (2012). Business driven project portfolio management: Conquering the top 10 risks that threaten success. *Project Management Journal*, *43*(4), 83.

Rautiainen, K., Von Schantz, J., & Vähäniitty, J. (2011). *Supporting scaling agile with portfolio management: Case Paf.Com*. Paper presented at the 44th Hawaii International Conference on Systems Sciences (HICSS), Hawaii.

Ritchie, J., & Spencer, L. (2002). Qualitative data analysis for applied policy research. In M. Huberman & M. Miles (Eds.), *The qualitative researcher's companion* (Vol. 573, pp. 305–329). Thousand Oaks, CA: Sage Publications.

Rosenhead, J. (1998). *Complexity theory and management practice* (Vol. 19). London, England: London School of Economics.

Rubin, H. J., & Rubin, I. S. (2012). *Qualitative interviewing: The art of hearing data*. Los Angeles, CA: Sage Publications.

Rumelt, R. (2011). *Good strategy bad strategy: The difference and why it matters* (Vol. 64). London, England: Profile Books Ltd.

Sato, C. E. Y., Dergint, D. E., & Hatakeyama, K. (2015). *Project-based organizations as complex adaptive systems*. Retrieved from https://www.researchgate.net/publication/251874050_Project-Based_Organizations_as_Complex_Adaptive_Systems

Saunders, M., Lewis, P., & Thornhill, A. (2012). *Research methods for business students* (6th ed.). Harlow, UK: Pearson.

Schwaber, K. (2014). *Unsafe at any speed*. Retrieved from https://kenschwaber.wordpress.com/2013/08/06/unsafe-at-any-speed/

Schwaber, K., & Beedle, M. (2002). *Agile software development with Scrum*. Upper Saddle River, NJ: Prentice-Hall.

Seidl, R., Rammer, W., Scheller, R. M., & Spies, T. A. (2012). An individual-based process model to simulate landscape-scale forest ecosystem dynamics. *Ecological Modelling*, *231*, 87–100.

Silverman, D. (2015). *Interpreting qualitative data*. London, England: Sage Publications.

Simon, H. A. (1969). *The sciences of the artificial* (Vol. 136). Cambridge, MA: MIT Press.

Srivastava, A., & Thomson, S. B. (2009). Framework analysis: A qualitative methodology for applied policy research. *Journal of Administration and Governance*, *4*(2), 72–79.

Stacey, R. D. (2010). *Complexity and organizational reality: Uncertainty and need to rethink*. London, England: Routledge.

Steindl, C. (2005). *From agile software development to agile businesses*. Paper presented at the 31st EUROMICRO Conference on Software Engineering and Advanced Applications, Porto, Portugal.

Stettina, C. J., & Hörz, J. (2015). Agile portfolio management: An empirical perspective on the practice in use. *International Journal of Project Management*, *33*(1), 140–152.

Sweetman, R., & Conboy, K. (2013). *Exploring the tensions between software project portfolio management and agile methods: A research in progress paper*. Paper presented at the Lean Enterprise Software and Systems, Galway, Ireland.

Tan, J., Wen, H. J., & Awad, N. (2005). Health care and services delivery systems as complex adaptive systems. *Communications of the ACM*, *48*(5), 36–44.

Tate, R. (2013). *Google couldn't kill 20 percent time even if it wanted to*. Retrieved from http://www.wired.com/2013/08/20-percent-time-will-never-die/

Tate, W. L., Ellram, L. M., & Golgeci, I. (2013). Diffusion of environmental business practices: A network approach. *Journal of Purchasing and Supply Management*, *19*(4), 264–275.

Thomas, G., Seddon, P. B., & Fernandez, W. (2007). IT project evaluation: Is more formal evaluation necessarily better? In Z. Irani & P. Love (Eds.), *Evaluating information systems: Public and private sector* (pp. 78–97). Amsterdam, the Netherlands: Elsevier.

Thomas, J., & Baker, S. W. (2008. *Establishing an agile portfolio to align IT investments with business needs*. Paper presented at the Agile 2008 Conference, Toronto, Canada.

Unterkalmsteiner, M., Abrahamsson, P., Wang, X., Nguyen-Duca, A., Shah, S., Bajwa, S. S., . . . Yagüeg, A. (2016). Software startups—A research agenda. *e-Informatica Software Engineering Journal*, *10*(1), 89–123.

VersionOne. (2016). *VersionOne (2016) the 10th annual state of agile report*. Retrieved from http://www.agile247.pl/wp-content/uploads/2016/04/VersionOne-10th-Annual-State-of-Agile-Report.pdf

Vidgen, R., & Wang, X. (2006). *Organizing for agility: A complex adaptive systems perspective on agile software development process*. Paper presented at the 14th European Conference on Information Systems, Goteborg, Sweden.

Vidgen, R., & Wang, X. (2009). Coevolving systems and the organization of agile software development. *Information Systems Research*, *20*(3), 355–376.

Webb, C., Lettice, F., & Lemon, M. (2006). Facilitating learning and innovation in organizations using complexity science principles. *Emergence: Complexity & Organization*, *8*(1), 30–41.

Wengraf, T. (2001). *Qualitative research interviewing: Biographic narrative and semi-structured methods*. London, England: Sage Publications.

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