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Complexity in Information Systems Project Portfolio Management: An Emergent Properties Perspective

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ABSTRACT

While much research has examined project management methods and their ability to handle complexity and change, little such research exists at level of project portfolio management. This is somewhat surprising given that portfolio management must, by definition, cope with the cumulative changes and complexities of the projects contained within it. Complex adaptive systems theory (CAS) has provided useful insights into the management of unpredictable emergent system level properties in a number of disciplines. This exploratory study uses 30 expert interviews with complexity scholars and IS portfolio practitioners to identify portfolio management practices from emergent properties of real world CAS. The findings show that portfolio managers can learn from CAS how to manage and shape emergence. 15 complexity based practices are identified, along with examples how experienced practitioners achieve them. For example, just as a bee-keeper can predict swarming, portfolio agents can be trained to identify weak signals predicting major change.

Keywords

Project portfolio management, emergence, emergent properties, complex adaptive systems, project selection, resource management, strategic alignment, performance management

INTRODUCTION

Despite the increasing strategic importance of information systems (IS) and the continued evolution of contemporary project management methodologies, an estimated 75% of programs and portfolios of IS projects fail to meet budget, time and performance expectations (Whittaker, 1999, Keil et al., 2000, Bartis and Mitev, 2008, Gartner, 2014, Singh et al., 2009, Pervan, 1998) costing over six trillion dollars a year globally (Sessions, 2009). In order to reduce the frequency and impact of IS project failure, project portfolio management (PPM) is seen as critical (Hatzakis et al., 2007, De Reyck et al., 2005). However, the application of portfolio theory in IS has failed to match benefits achieved in other disciplines such as finance (Fabozzi et al., 2002) and research and development (Stummer and Heidenberger, 2003).

High IS project portfolio failure rates require examination of potential flaws in existing PPM practices. Firstly, many organizations have no formal portfolio management process. One study reports only 20% of organizations maintain an active IS portfolio management process (Maizlish and Handler, 2010). Secondly, most IS PPM (and PPM generally) is restricted to portfolio selection, with little research looking to improve day to day PPM (Cooper and Edgett, 1997, Meskendahl, 2010, De Reyck et al., 2005). Thirdly, where PPM is practiced it often takes a centralized top-down view that ignores how complex IS project portfolios are enacted. Frequent changes to requirements across projects can have very significant implications for individual projects, project interdependencies and the overall portfolio itself. IS projects are often terminated, paused, restarted, or forced to alter direction in response to the turbulent, complex environments within which they operate (Frey and Buxmann, 2012).

The constant interaction between projects, teams and the environment leads to the emergence of portfolio level properties. Emergent properties are properties created collaboratively, but irreducible to individual action (Sawyer, 2005). Furthermore, while emergent properties often appear to be stable, they can change suddenly and dramatically, creating both challenges and opportunities for managers (Miller and Page, 2007, Anderson, 1999) Systems that display emergent properties cannot be managed by the traditional centralized approach (Clark, 1999). Complex Adaptive Systems (CAS) is a predominant theory in contemporary social systems research (Anderson, 1999, Miller and Page, 2007) that has proven effective in studying emergence in a number of disciplines, e.g. management (Snowden, 2000), sustainable tourism (Farrell and Twining-Ward, 2004) and defence (Grisogono and Ryan, 2007).

There are numerous calls for similar research in the management of projects and portfolios (Cooke-Davies et al., 2008, Pollack, 2007, Aritua et al., 2009). Furthermore, because information systems artefacts are considered complex adaptive systems (Highsmith and Cockburn, 2001, Meso and Jain, 2006) the CAS lens is particularly apt to study the portfolios of projects that create them (Merali, 2006, Benbya and McKelvey, 2006, Vidgen and Wang, 2009).

According to CAS emergent system level properties arise from interactions between agents that make up the system and their environment and are regulated by feedback loops. However, the focus of this paper is limited to *emergent* properties and not the other CAS concepts. The objective of the research is:

> *to apply the CAS concept of emergent system properties to identify IS PPM practices for project selection, resource management, strategic alignment and performance management.*

The next section introduces IS PPM and the theory of CAS. The expert interview data collection and analysis is then explained. Findings are then presented followed by a description of the theoretical and practical contributions, limitations of the study and suggestions for future research.

BACKGROUND

The Components of IS Project Portfolio Management

PPM is defined in terms of its principal activities and characteristics. There are a number of key studies which classify the components underpinning PPM. For example, the PMI break portfolio management into five knowledge areas (PMI, 2013), whereas Pennypacker (2005) identifies six components. Based on a review of the IS PPM literature (Table 3) this study identifies four main components: (i) the identification selection and prioritization of projects; (ii) resource management; (iii) strategic alignment and (iv) performance management. It defines IS PPM as:

> *The* ***ongoing identification, selection, prioritization*** *and* ***management*** *of the complete set of an organizations information systems projects that share* ***common resources,*** *in order to* ***maximise returns*** *to the organization and* ***achieve strategic business objectives*** *(Meskendahl, 2010, Cooper et al., 1999, Blichfeldt and Eskerod, 2008, PMI, 2013).*

Table 3 Components of IS PPM

PPM Component	PMI (2013)	Pennypacker and Retna (2009)	Pennypacker and Dye (2005)	Rajegopal(2013)	Kendall and Rollins (2005)	Levine(2007)
Identification, selection and prioritization	- Portfolio Risk management	- Evaluating investment in projects	- Opportunity Assessment - Selection and Prioritization	- Determine appropriate mix of projects	- Determine a viable project mix - Balance the portfolio - Evaluating new opportunities	- Contribute to future as well as present returns - Consistent with firms values
Resource management		- Resource optimization - Capacity for change	- Portfolio Resource management	- Resource Optimization		- Projects must effectively use resources
Strategic alignment	- Portfolio strategic			- Matching projects to		- Projects must be

	management .			***strategy***		***aligned with strategic goals***
Performance management	***- Portfolio performance management - Portfolio communication management - Portfolio Governance management***	***- Measure execution - Measuring benefits***	***- Portfolio performance management - Portfolio and Project communication - Governance***	***- Impact on share price***	***- Monitor the planning and execution of chosen projects - Provide information and recommendations - Analysing portfolio performance***	***- Projects must contribute to cash flow***

The four components are explained briefly below.

The ***identification, selection and prioritization of projects*** is an ongoing process aimed at ensuring the portfolio is made up of the "right projects (Pennypacker, 2005). Project selection and prioritization involves both the quantitative and qualitative evaluation of potential projects (Jeffery and Leliveld, 2004) Despite the overall immaturity of IS PPM literature, there are many contributions that look specifically at this activity.

Resource management in IS PPM involves aligning resources to opportunities that provide the greatest strategic benefit (Milosevic et al., 2009) as well as the maximisation and utilisation of resources available to the portfolio (Lycett et al., 2004). This is critical because available resources act as a limit on the number of projects that can be completed (PMI, 2013, De Reyck et al., 2005). Furthermore, portfolios generally suffer from a lack of competent people (Elonen and Artto, 2003) highlighting the need for portfolios to develop the people they have.

Strategic Alignment

Strategic alignment ensures projects link to overall organisational strategic goals (De Reyck et al., 2008, Jeffery and Leliveld, 2004). In many organizations strategy is defined at a very high level (Pennypacker and Retna, 2009). However, a top down approach to strategic alignment does not acknowledge that teams working closely with customers can be more aware of the changing environment than senior management whose intended strategy often changes slowly (Rumelt, 2011).

Portfolio performance management is about ensuring the portfolio succeeds in fulfilling its objectives (Cooper et al., 1999)). The literature identifies four elements to this. Firstly, to ensure that the portfolio is contributing to the share price and cash flow of the organization (Rajegopal, 2013, Levine, 2007). Secondly, to ensure the projects which comprise the portfolio are performing to plan and realising the anticipated benefits (Pennypacker and Retna, 2009). Thirdly, to identify and fix problems (Levine, 2007). Fourthly, to communicate information to key stakeholders (Pennypacker, 2005, PMI, 2013).

Complex Adaptive Systems

CAS originated in the natural sciences, and examines how interactions between the individual and autonomous parts of a system and their environment yield higher level emergent behaviour (Stacey, 2007, Webb et al., 2006). CAS takes a bottom up approach, focusing not on the system as a whole but its individual parts and how they interact (Anderson, 1999). However, CAS has not been utilised in a coherent manner in IS research (Kautz, 2012, Vidgen and Wang, 2006). Levin (1998) argues that a single unified CAS framework is futile. Instead, researchers must use it in a way that is appropriate for each individual study. Therefore, it was necessary to review the CAS literature in order to develop a conceptual framework for CAS in IS PPM. The different characteristics of CAS were distilled into a set of concepts and integrated into a unified conceptual framework (Figure 4). Where there was inconsistency between different concepts, both were considered and the most appropriate one used. The main concepts are now briefly discussed.

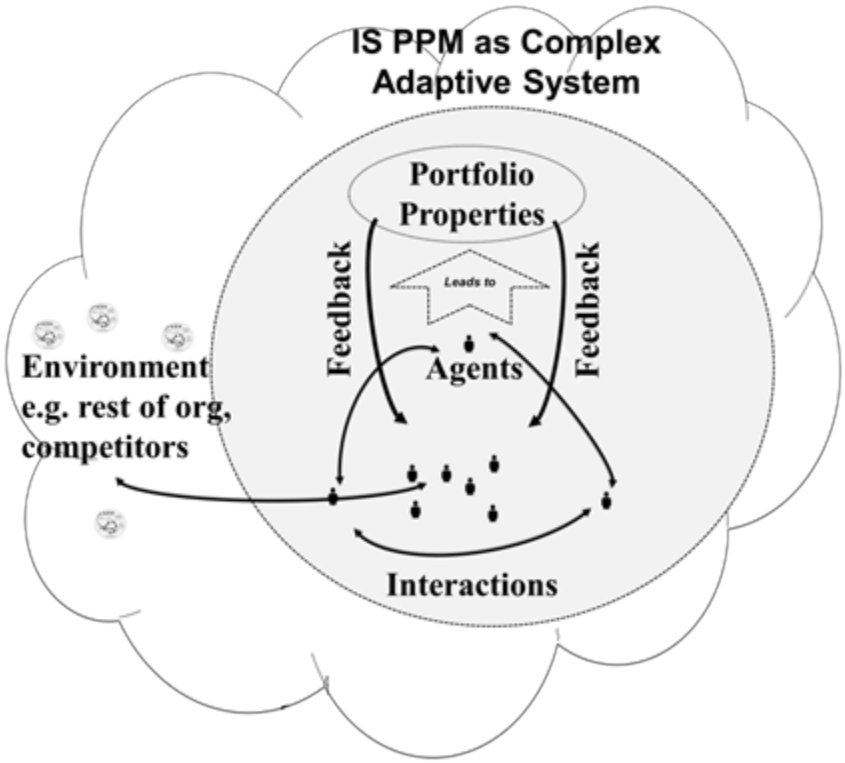

Figure 4 Conceptual Framework for CAS

***Agents**:* Agents are central to all CAS models (e.g. Gell-Mann, 1994, Dooley, 1997, Anderson, 1999). Agents are the individual actors or 'entities of action' in a CAS (Nan, 2011). In organizational studies, agents can be individuals, teams, projects, divisions or the entire organization, depending on the scale of analysis (Choi et al., 2001). This study considers agents to be the individuals and teams whose efforts are directed towards the achievement of project portfolio goals.

*The **environment**:* It is impossible to study a CAS without looking at its environment (Nair et al., 2009, Kautz, 2012) - the setting in which the CAS operates in and interacts with (Nan, 2011). This study considers the portfolio environment as the setting in which the IS project portfolio operates in and interacts with e.g. competitors, customers and the resources required to sustain the portfolio.

***Interactions**:* Interactions are the reciprocal actions or influences between agents in a CAS as they pursue their goals (Beck and Plowman, 2014). They describe the mutually adaptive behaviour of agents (Nan, 2011, Beck and Plowman, 2014). In a portfolio, interactions occur when portfolio agents are changed by exchanging information and resources.

Feedback loops: Feedback loops arise when a process is modified by its own results and are core to CAS (Benbya and McKelvey, 2006). Interacting agents result in system level properties (below) which feedback into the agents, modifying their behaviour. A feedback loop exists in IS PPM when portfolio level properties influence the agents whose behaviour create them.

***Emergent system level properties**:* Emergent system level properties are collective phenomena collaboratively created by individual agents, but irreducible to individual action. Therefore, they are only observable at the system level (Sawyer, 2005). These properties are of great interest to both researchers and practitioners in their own right and in their influence on individual agents (e.g. culture). This study considers system level properties as properties observable at the portfolio level that arise from the collective behaviour of portfolio agents but not explicable by the behaviour of individual portfolio agents. The literature review identified four main characteristics of emergent system level properties which are now explained.

Firstly, system level properties tend to exist in ***attractor states.*** These attractor states are relatively stable states that the system will remain in unless perturbed. The system level properties of a CAS have the qualitative properties of the attractor state it exists in (Goldstein, 1999). Mathematically, attractor states are defined as states where the energy function for the system is minimised for a particular configuration of system variables (Curşeu, 2006).

Secondly, emergent properties are ***resilient***. Resilience implies that system level properties maintain a sense of identity over time and are immune to variations in the behaviour of individual agents (Miller and Page, 2007). Emergent properties in a CAS are resilient for many reasons. Firstly, agents are prepared to adapt in order to maintain their ability to function (Edson, 2012). Secondly, feedback reinforces patterns that contribute towards the system's survival (Edson, 2012). Thirdly, redundant connections allow the system to function even if some of the connections are broken (Heylighen, 2001).

Thirdly, system level properties are ***unpredictable*** and can result in behaviours previously unseen in the system (Corning, 2002, Goldstein, 1999). This unpredictability arises because system level properties arise from a degree of random behaviour across agents, not by the decision rules of individual agents (Heylighen, 2001). This random nature of interactions combined with amplification of seemingly insignificant events by positive feedback results in unexpected, non-linear outcomes (Goldstein, 1999, Anderson, 1999).

Fourthly, system level properties are ***path dependent.*** Path dependence arises because a CAS has a memory of its history. The unique final states of the system are extremely sensitive to the initial conditions (Schneider and Somers, 2006). Furthermore the system retains a knowledge repository distributed through the organisation which creates a path-dependence that shapes how the system develops in the future (Holland, 1992, Benbya and McKelvey, 2006, Uhl-Bien et al., 2007).

RESEARCH METHOD

Given that there has been little study into complexity in IS PPM and the research around IS PPM in general lacks cohesion, an interpretative exploratory approach was deemed suitable. Furthermore, Anderson (1999) argues that complexity theory allows interpretivist researchers' clear ways to describe the meanings that actors, in a particular complex situation, construct together. This study takes an analogical approach (Hesse, 1966), that uses similarities between CAS and IS PPM identified above to identify practices that enable IS PPM to manage emergent portfolio properties.

Expert interviews were used as experts are uniquely positioned to provide access to, and interpret knowledge from, niche domains (Bogner et al., 2009). A panel of experts consisting of 15 CAS academics and 15 IS PPM practitioners was selected using a purposeful sampling strategy (Table 2).

Table 4 Criteria for Identifying Experts

Desired Background	*Means Of Expert Identification*	*Minimum Selection Criteria*	*Diversity Criteria*
IS Project Portfolio Managers	***- PPM Certification (e.g. IPMA certified project director PMI PfMP) - Membership of PPM LinkedIn Group***	***- Greater than five years' experience as a project portfolio manager - Works for leading technology company - Large number of employees in the portfolio***	***- Select managers with a range experience - Select managers from a range of industry sectors***
Academics who have researched Complex Adaptive Systems	***- Literature review of relevant academic and practitioner journals and conferences***	***- Greater than five peer reviewed conference/journal papers studying management of CAS***	***- Social and Natural Sciences - Some who have researched within IS***

To combine knowledge from academics and practitioners, a mix of exploratory and systematizing interviews (Bogner et al., 2009) were used to identify CAS based practices and operationalise them for IS PPM. The two approaches are combined in a responsive, flexible approach, allowing the researchers tailor the interviews to the specific knowledge of each expert (Rubin and Rubin, 2012). Scheduling ensured that experts with overlapping knowledge of both domains were interviewed last, allowing researchers to confirm that theoretical saturation had been obtained and practices transferred appropriately.

Interviews were carried out between November 2015 and April 2016 and were recorded and transcribed immediately. Coding was conducted in parallel with interviews so findings could be collaborated or rejected based on subsequent interviews. Interviews were coded using Nvivo. To protect anonymity, ID codes were assigned to each participant (A1…A15 for academics, P1…P15 for practitioners). Classification coding used the concepts and their properties from the conceptual framework. Data relating to each property and its sub-codes was summarised in a set of four tables which illustrate how high level practices and their examples were derived from the theory, academic and practitioner data. Practices included needed to be consistent with the conceptual framework and supported by both academic and practitioner evidence. The analysis process is illustrated in Figure 3.

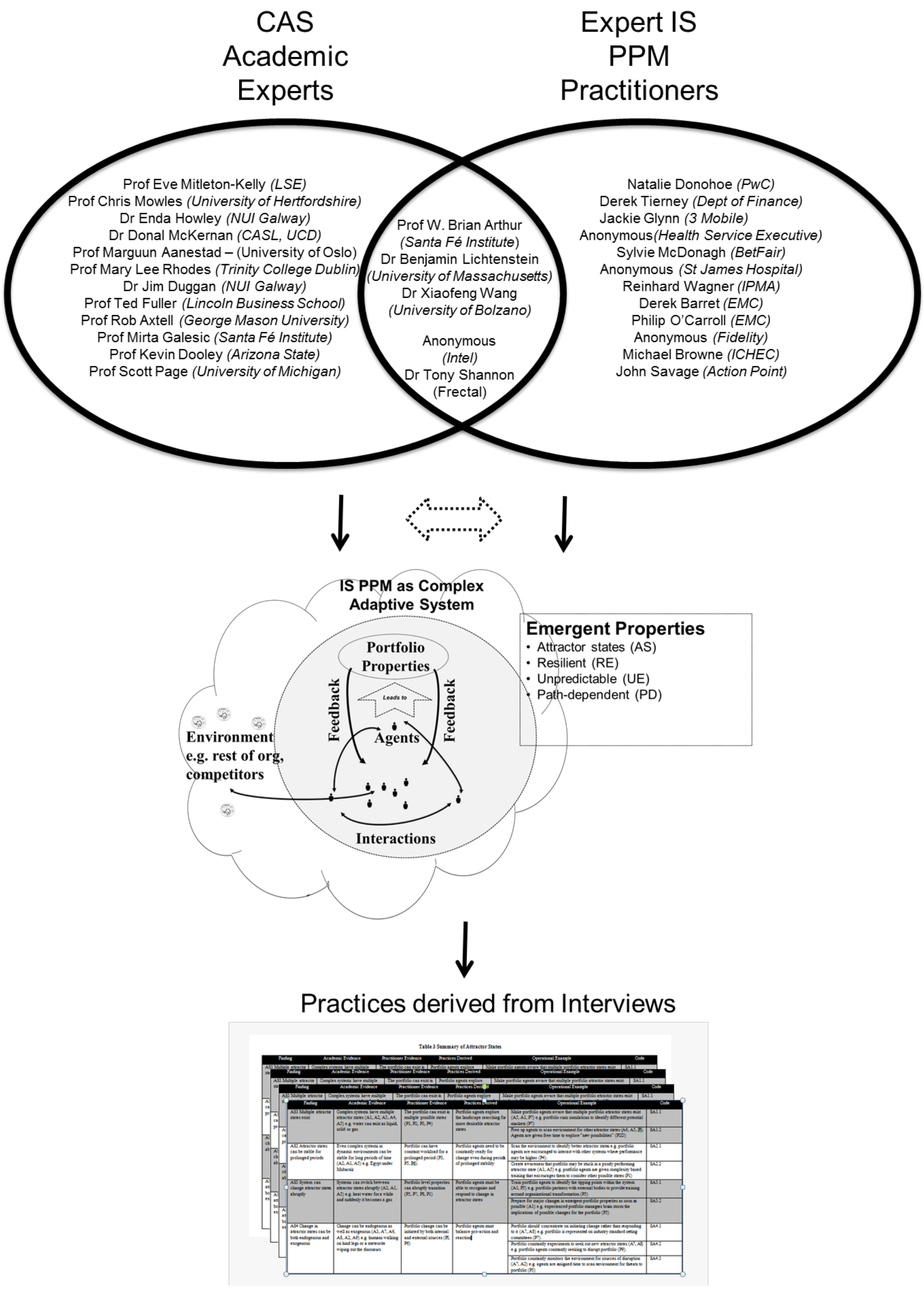

Figure 5 Integration and Analysis of Academic and Practitioner Data

FINDINGS

The following subsections present the data relating the four properties of emergent system properties identified in the conceptual framework (Figure 4). Each subsection has a table summarising the key findings followed by the evidence supporting the practices identified. Examples of how these practices are enacted in IS PPM are then presented and grouped into four "bins" or components of PPM (PS=project selection, RM=resource management, SA=strategic alignment and PM=performance management).

Attractor States (AS)

Table 5 Summary of Attractor States for Emergent Properties

Finding		Academic Evidence	Practitioner Evidence	Practice Derived	Operational Examples	Code	Bin
AS1	Multiple attractor states exist	Complex systems have multiple attractor states e.g. Population has many potential states that can be attained through changes such as genetic adaption	The portfolio can exist in multiple possible states determined by initial conditions and capabilities	Engage in continuous exploration, experimentation and adaption to identify or create more desirable states	Portfolio runs simulations to identify potential markets	AS1.1	PM
					Agents are given free time to explore "new possibilities"	AS1.2	RM
					Resources are constrained to encourage innovative new projects	AS1.3	PS
AS2	Attractor states can be stable for prolonged periods	Even complex systems in dynamic environments can be stable for long periods of time e.g. earthquakes or volcanoes	Portfolio be stable for a prolonged period e.g. stable product range	Agents must be prepared for change even during prolonged periods of apparent stability	Benchmark portfolio against other high performing systems	AS2.1	PM
					Portfolio agents constantly scanning for threats and opportunities	AS2.2	PS
AS3	Attractor states can change suddenly	Systems can switch between attractor states abruptly e.g. 10,000 bees can switch hive in minutes	Portfolio level properties can abruptly transition e.g. rapid reduction in customer satisfaction	Agents must seek to identify change as quickly as possible and respond appropriately	Train portfolio agents to identify weak signals that predict major change	AS3.1	RM
					Regular brainstorming sessions to identify potential responses to major potential changes	AS3.2	SA
AS4	Causes of	Change can be	Portfolio change	Agents must seek to both	Portfolio should concentrate on initiating	AS4.1	SA

	change both endogenous and exogenous	***endogenous as well as exogenous e.g. a fishing fleet co-operating or a meteorite wiping out the dinosaurs***	***can be initiated by both internal and external sources***	***pro-actively create change and react to it***	***change not responding to it e.g. involvement in industry committees***		
					Portfolio agents constantly seeking to disrupt portfolio	***AS4.2***	***PS***
					Portfolio constantly monitors the environment for sources of disruption	***AS4.3***	***PM***

AS1 Multiple attractor states exist. The academics argued that because a system is naturally drawn back to a default equilibrium, it can appear that only a single attractor exists. However, multiple potential attractor states can exist where wildly different performance is possible. (A11,A3,A2,A7,A6). For example, Europe's cold winters limited population; however, changes to genetics and behaviour facilitated new attractor states where large populations were possible. The experts agreed that agents must *engage in continuous exploration, experimentation and adaption to identify or create more desirable states* (A14,A6,A11). Many practitioners echoed the idea of their portfolio having multiple attractor states and needing to identify more appropriate ones (P14, P6, P5, P1). For example, one practitioner described trying to move his portfolio from "firefighting" to "delivering" (P1). IS PPM practices identified to *identify or create new attractor* states include simulations to identify new markets (SM,P8), "free time" for experiments (A1,P5) and constraining resources to encourage innovation (A14,P11).

AS2 Attractors can be stable for long periods. The academic experts explained that the CAS can be quite stable within an attractor state (e.g. the San Andreas fault) (A3,A11). However, this apparent stability provides little incentive for adaption and may blind agents to imminent threats (A6,A11,A3). The experts advised that *agents must be prepared for change even during prolonged periods of apparent stability* (A11,A6,A8). The practitioner data also highlighted how portfolios appear stable for prolonged periods, e.g. a stable range of products and projects (P1,P9,P14). They argued that this stability can lead to over control (P9), over-specialisation (P14) or short-term reporting (P8,P9,P2). Practices identified to *prepare for change* include benchmarking portfolio against other high performance portfolios (P6) and constantly scanning the environment for opportunities and threats even in times of stability (A14,A6,P6).

AS3 Attractor states can change suddenly. Despite their apparent stability, academics warned that a CAS can rapidly transition between attractor states (A3,A11,A6) e.g., thousands of bees swarm in minutes after years of stability (A15). While the experts did not agree on how to predict change, some academics spoke of patterns that *may* act as precursors of major change (e.g. seismic activity before earthquakes) and argued that *agents must seek to identify change as quickly as possible and respond appropriately* (A11, A7,A13). The practitioners also observed abrupt portfolio change (P4, P8, P9, P14) with one practitioner describing an abrupt cultural shift from "helpfulness" to "change fatigue" (P4). Practitioners were more confident than academics that experienced portfolio agents could predict change (P4,P2,P1). Practices identified to *identify and respond to change* include training agents to interpret "weak signals" that indicate change (A13,P7) and regular brainstorming sessions to identify potential responses to change (A11,P4).

AS4 Causes of change are both endogenous and exogenous. The academic experts explained that change can be driven both exogenously (A2, A8) (e.g. invasive species, meteorites) and endogenously (A14,A13,A3,A15) (e.g. fishing fleet switches from competition to co-operation (A3)). The academic experts argued *that agents must seek to both pro-actively create change and respond to it* (A8,A13,A3). The practitioner data supported this. Economic turbulence and regulation drove exogenous change in some portfolios (P6, P4, P1), whereas another practitioner suggested that portfolio agents "just got tired of failure and changed things themselves" (P4). Practices identified to *proactively create change* include ***participating in industry standard setting committees (P8), seeking to disrupt your own portfolio through innovation (P5,A7,A12) and constantly monitoring the environment for threats (A8,A3,P1).***

Resilience (RE)

RE1 Resilience protects the system from external shocks. Experts explained that resilience enables a system cope with shocks and provides coherence in the face of constant disruption (A2,A7,A11,A15) e.g. forests recover quickly from catastrophic fires (A7). However unique systems require different levels of resilience. The academics explained that *a system must build a level of resilience appropriate to its environment* (A11,A15,A7). The practitioners also highlighted importance of matching portfolio resilience to the environment (P9,P1,P11). For example, one portfolio regularly loses up to 50% of revenue but maintains resilience by individual portfolio agents creating new revenue streams (P11), while a stable portfolio focused on developing robust long life projects (P1,P6). Practices identified to *build appropriate portfolio resilience* include modelling the rate of environmental change (P8) and ensuring portfolio has range of projects (P11).

RE2 Resilience arises from agent diversity. According to the academics, variety builds a stronger system (A2,A8,A12). For example, genetic diversity leads to healthier populations. Diversity ensures that potential solutions to problems already exist within the system and that the system has the capacity to adapt to overcome new challenges (A2,A11). The experts argued that *complex systems must have a diverse range of agents to maintain resilience.* The practitioner data also supported the role of diversity in resilience (P11,P7,P9,P2,P4). For example, one practitioner argued that over-specialisation had reduced diversity, impairing the portfolio's ability to survive (P9). Practices identified to *maintain diversity* include recruiting staff from different sources (A11,A1,P2), avoiding overspecialisation through cross training (A11,A2,P9,P14) and increasing skills diversity through rotation and training (A11,P1).

Table 6 Summary of Resilience in Emergent Properties

Finding		*Academic Evidence*	*Practitioner Evidence*	*Practice Derived*	*Operational Examples*	*Code*	*Bin*
RE1	***Resilience protects the system from external shocks***	***Resilience enables a system to cope with shocks e.g. forests recover from catastrophic fires***	***Resilience protects the portfolio from environmenta l disruption***	***Portfolio needs to build level of resilience appropriate to environment***	***Determine required level of resilience by modelling rate of environmental change***	***RE1. 1***	***PM***
					Portfolio has a wide range of projects to cope with external shocks	***RE1. 2***	***PS***
RE2	***Agent diversity contributes to resilience***	***Variety builds a stronger system e.g. a genetically diverse herd of cows is healthier***	***Diverse range of agents and skills creates portfolio resilience***	***Portfolio must maintain a diverse range of agents to maintain resilience***	***Recruit a broad range of staff from a wide variety of sources***	***RE2. 1***	***RM***
					Avoid policies that promote overspecialisation	***RE2. 2***	***RM***
					Build diversity through staff rotation and training	***RE2. 3***	***RM***
RE3	***Trade-off between resilience and performance***	***System must choose between redundancy and***	***There is a trade-off between performance and resilience***	***Portfolio must find appropriate balance between***	***Identify necessary level of resilience***	***RE3. 1***	***PM***
					Portfolio builds resilience into the elements essential	***RE3. 2***	***RM***

		performance e.g. two kidneys but only one brain		***performance and resilience***	***for survival and optimises other parts***		
RE4	***External appearance unchanged despite changes to internal structure***	***Can maintain appearance despite internal change e.g. Species maintains features that deters predators while evolving***	***Portfolio appears resilient to its stakeholders providing appearance remains unchanged***	***Retain resilience by maintaining the same appearance during periods of change***	***Portfolio products maintain consistent user interface during dramatic changes***	***RE4.1***	***PS***

RE3 Trade-off between resilience and performance. Many academics highlighted how resilience can reduce performance (A8,A9,A11,A13,A2). Some experts explained that the redundancy essential for resilience comes at the expense of specialisation which can boost performance (A2,A8). For example, a second kidney increases resilience but reduces efficiency (A15). The experts explained *that complex systems must balance performance and resilience (*A8,A11,A15). This trade-off was echoed in the practitioner data (P9,P6,P8). Practitioners argued that "super-specialisation" came at the expense of general knowledge necessary for resilience (P14) and left the portfolio vulnerable to staff turnover (P6). Practices identified to *balance performance and resilience* include identifying the necessary level of resilience (A11,P8) and focusing on resilience for critical projects and performance for non-critical projects (A15,P9,P1)

RE4 Appearance can remain unchanged despite internal changes. Several academics argued that resilience can be considered in terms of appearance as well as structure (A11,A1). For example, organisms retain an appearance that deters predators while evolving internally. They suggested that agents outside the system don't care what's going on inside providing the system meets their needs e.g. the internet. The academics argued that *complex systems create resilience by maintaining appearance during periods of change* (A11,A1). This was supported by the practitioner data (P9,P8,P5). One practitioner described their portfolio as a "black box" whose stakeholders only care about the interface (P9). Another practitioner argued that stakeholders only cared that goals are met (P5). Practices identified to *maintain portfolio appearance during periods of change* included maintaining consistent user interface across the portfolio during periods of change (P1,P9,P8)

Unpredictable (UE)

Table 7 Summary of Unpredictable Emergent Properties

	Finding	*Academic Evidence*	*Practitioner Evidence*	*Practice Derived*	*Operational Examples*	*Code*	*Bin*
UE1	***Interactions lead to unpredictability***	***System level properties are unpredictable***	***Non-linear interactions between portfolio***	***Agents should be encouraged to***	***Portfolio agents from different areas encouraged to work together on***	***UE1.1***	***PS***

		as they arise from non-linear interactions e.g. flock of birds	***agents create unpredictable portfolio properties***	***experiment with each other and be prepared to adjust strategy to take advantage of opportunities that arise***	***experimental boundary spanning projects***		
					Portfolio prepared to alter strategy in response to unpredictability	***UE1.2***	***SA***
UE2	***There is a leverage point where systems start to behave unpredictability***	***There is a leverage point where systems cease to behave predictably e.g. tipping point in climate change***	***There is a tipping point beyond which the portfolio behaves unpredictably***	***Effective management requires the identification of these leverage points***	***Use models and simulations to identify leverage points in systems***	***UE2.1***	***PM***
					Retention and continuous development of experienced agents who can recognise abrupt transitions	***UE2.2***	***RM***
					Portfolio adjusts strategy to take advantage of abrupt changes	***UE2.3***	***SA***
UE3	***Agents can shape emergence***	***It is possible for agents to prepare and react appropriately e.g. shoal of fish responds to food and predators differently***	***Portfolio agents can take advantage of emergence.***	***Constant refinement of the rules governing interactions in order to encourage what is desirable and seeking to dampen what is undesirable***	***Deep dives to ascertain the actual causes of emergence***	***UE3.1***	***PM***
					Positive feedback is used to reinforce changes that appear desirable e.g. extra resources	***UE3.2***	***PM***
					Negative feedback used to dampen undesirable changes e.g. reduce autonomy	***UE3.3***	***PM***
					Portfolio must build adaptive capacity and autonomy in agents to take advantage of unexpected emergence e	***UE3.4***	***RM***
UE4	***Can result in undesirable outcomes***	***Can be undesirable effects for other agents e.g. racial***	***Portfolio level emergence can be undesirable***	***Portfolio must be continuously monitored with***	***Portfolio performs deep dives to identify the causes of undesirable properties***	***UE4.1***	***PM***

		segregation		***undesirable behaviour being supressed as soon as it starts to emerge***	***Constantly monitor the portfolio for undesirable emergence and highlight the problem through negative feedback***	***UE4.2***	***PM***
					Refine and reinforce the portfolio "rules of behaviour"	***UE4.3***	***RM***

UE1 Interactions drive unpredictability. Several academics explained that emergent properties are unpredictable because of the non-linear nature of interactions in complex systems (A2,A11,A13,A6). For example, a jazz session or the flight of a flock of birds are unpredictable (A1). Interactions are non-linear as agents, informed by flawed assumptions and past experiences, respond inconsistently (A9,A1). However, successful agents regularly experiment with each other and take advantage of opportunities created (A13,A1). The experts argued that *agents should experiment with each other and adjust strategy to take advantage of new opportunities* (A13,A1,A11). The practitioners also provided evidence supporting interactions creating unpredictable portfolio properties (P8,P6,P14). For example, one practitioner described how getting artists, engineers and client-facing staff interacting increased creativity and customer focus across the portfolio (P6). Practices identified to *experiment and adjust* include encouraging agents in different areas to work together on experimental projects (A1,P6), and adjusting strategy to take advantage of unpredicted opportunities (A13,P11,P8).

UE2 Systems behave unpredictably beyond leverage points. Several academics argued that complex systems have leverage points beyond which small changes escalate dramatically (A3,A11). For example, a two-degree increase in global temperatures will lead to unpredictable climate change. Similarly, in IS new technologies allow a cascade of unpredicted innovations (A13). The academic experts suggested that effective management requires *the identification of leverage points* (A7,A11,A3). The practitioner data supports the idea of portfolio leverage points and suggested they are best identified by experienced agents (P8,P9,P2,P14). One practitioner referred to them as pivot points and described how the radical change occurred beyond these points (P8). Practices identified to *identify leverage points* include models and simulations to identify leverage points (A7,A2,P8), the retention and development of experienced agents (A13,P14,P6) and the ability to adjust strategy around leverage points (A13,P8).

UE3 Agents can shape unpredictable emergence. According to the experts, it is possible for agents to influence the emergent properties of a system to suit the environment (A3,A1,A15). For example, a shoal of fish spreads out while feeding but bunches together when under attack. Academics explained that this occurs by *constant refinement of the rules governing interactions in order to encourage what is desirable and to dampen what is undesirable* (A15,A3,A1,A6). The practitioner data also showed how portfolio agents shape emergent properties (P10,P9,P11). They argued that emergence does not arise by chance but is constantly refined and reinforced by agents promoting the behaviours they like (P9,P2). Furthermore, these rules must not become "invisible" (P9). Practices identified to *refine behavioural rules* include "deep dives" to ascertain the causes of project success and failure (A9,P5), positive feedback to reinforce desirable behaviours (A15,A3,P8) and negative feedback to discourage undesirable behaviours (A15,A3,P4).

UE4 Emergence can result in undesirable outcomes. The academics cautioned that emergent properties can be undesirable (A3,A15,A7,A6). For example, the Schelling model shows how racial segregation emerges (A7). Another academic described how repeated attempts to change culture resulted in entrenched cynicism (A15). The academics warned that *the system must be continuously monitored with undesirable behaviour being supressed as soon as it starts to emerge* (A3,A15). The practitioners supported the idea that portfolio level properties can be undesirable (P8,P7,P2). For example, one practitioner described how a culture of "knowledge hoarding" emerged as a result of off-sharing jobs (P8). Other examples included cynicism (P2) and change fatigue (P4,P14). Practices identified to *supress undesirable emergent behaviours* include analysis of causes of undesirable emergence and appropriate adjustment to rules of behaviour (A15,A3,P9,P5) and instant negative feedback to discourage traits such as cynicism (A3,A15,P1,P9,P2).

Path Dependent (PD)

Table 8 Summary of Path Dependence and Emergent Properties

	Finding	Academic Evidence	Practitioner Evidence	Practice Derived	Practices Derived Example	Code	BIN
PD1	***Best practices can't be simply copied***	***Can't copy best practice between systems if initial conditions are different e.g. small changes in initial conditions affect weather***	***Different initial conditions mean best practices can't be transferred from one portfolio to another***	***Must understand how and why practices work in order to adapt them to a new system***	***Portfolio teams adapt agile practices to their own needs rather than implement a standard "best" version***	***PD1.1***	***PM***
					Portfolio teams are evaluated on outcomes as opposed to adherence to standardised practices	***PD1.2***	***PM***
PD2	***Performance is influenced by its history***	***Performance of a system is path dependent e.g. survival against some illnesses dependent on genetic adaptions***	***Portfolio history influences its performance***	***A system must overcome its history by acquiring agents and skills to create future opportunities and overcome weaknesses***	***Consider the future opportunities that projects related skills create***	***PD2.1***	***PS***
					Portfolio can overcome history by recruiting agents with additional skills from outside the portfolio	***PD2.2***	***RM***
					Portfolio must allocate sufficient resources to maintaining legacy projects	***PD2.3***	***RM***
PD3	***Shared memory of***	***System retains a***	***Portfolio memory***	***Systems should build***	***Portfolio seeks to build a shared memory e.g.***	***PD3.1***	***RM***

	success and failure helps decision making	***shared memory of past success and failure, independent of individual agents, which can aid decision making (A5, A6) e.g. cattle new to a herd avoid electric fences tested by others***	***crucial to decision making***	***and retain a memory of past success and failure and utilise it for decision making***	***portfolio uses pair programming and retrospectives***		
					Shared memory is protected during organizational change	***PD3.2***	***RM***
					Forums are used to celebrate success and share knowledge	***PD3.3***	***PM***
					Ensure that the shared portfolio memory is utilised when making difficult decisions	***PD3.4***	***RM***

PD1 Different initial conditions mean "best practices" cannot be simply copied. Many academics warned the path dependence means practices cannot be simply copied between systems without tailoring (A15,A12,A1). Just as tiny changes result in different weather forecasts, small differences between organizations mean practices get different responses in different organizations (A1,A12). Instead the experts argued that *it is necessary to understand how and why practices work in order to adapt them to a new system* (A14,A1). The practitioners also rejected the idea of generalizable best practices (P8, P5, P11) arguing they only work with highly repeatable processes (P8,P5). Practices identified to *adapt practices* included adopting and tailoring "good" practices to specific challenges (A3,A14,P8), understand how and why practices work in specific contexts (A14,A12,P8) and evaluate practices on outcomes (A14,A12,P8)

PD2 Performance is influenced by history. According to the experts, performance is path dependent (A15, A13). For example, inherited genetic adaptions may enable a species exploit a new food source. Systems can acquire skills that may "open doors" in the future (A13). However, if the system is lacking these skills, it cannot take advantage of opportunities (A13,A12,A6). The academic experts suggested that *a system must overcome its history by acquiring skills to create opportunities and overcome weaknesses* (A13,A12,A6). The practitioner data also highlighted the influence of the portfolio history on performance, (P7, P6, P2). For example, one portfolio manager found his team were maintaining obsolete code (P9). Others argued that viable projects were rejected because of previous failures (P4). Practices identified to *overcome portfolio history* include selecting projects that create future opportunities (A13,P8,P3), recruiting agents from outside the portfolio (P2) and constantly reviewing legacy projects (A15,P8,P9)

PD3 Shared memory helps decision making. Several experts argued that systems retain a shared memory, independent of individual agents, of past success and failure which aids decision making (A5,A6) e.g., new cattle avoid fences that older cattle have already tested. While the mechanisms for this are not always understood, humans can act as sages, sharing memories (A2). The experts suggested that *systems should build a memory of past success and failure to aid decision making* ***(A15,A5,A1,A2).***The practitioners also supported the importance of portfolio memory (P8, P2, P1, P6) and advised that it should be invoked whenever possible (P2,P3). However, practitioners warned that the memory is fragile (P6). Practices identified to *build and utilise memory* include pair programming and mentoring (A15,A5,A1,P9,P8,P3), knowledge forums (P5,P2,P5,P1), regularly converting knowledge from tacit to explicit (A2,P2) and adding experienced agents to failing projects (A9,P2)

The practices derived above are summarised in Figure 6