A Conceptual Framework for Tackling Knowable Unknown Unknowns in Project Management

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ABSTRACT

Understanding and dealing with the unknown is a major challenge in project management. An extensive body of knowledge − theory and technique − exists on the “known unknowns,” i.e., uncertainties which can be described probabilistically and addressed through the conventional techniques of risk management. Although some recent studies have addressed projects where the existence of unknown unknowns (unk unks) is readily apparent or may be assumed given the type of project − e.g., new product development or new process implementation − very little work has been reported with respect to projects in general on how a project manager might assess its vulnerability to unk unks. In this paper, we present a conceptual framework to deal with (i.e., recognize and reduce) knowable unk unks in project management. The framework is supported by insights from a variety of theories, case analyses, and experiences. In this framework, we first present a model of the key factors – relating to both project design and behavioral issues – that increase the likelihood of unk unks and a set of propositions linking these factors to unk unks. We then present a set of design and behavioral approaches that project managers could adopt to reduce knowable unk unks. Our framework fills a gap in the project management literature and makes a significant practical contribution: it helps project managers diagnose a project to recognize and reduce the likelihood of unk unks and thus deal more effectively with the otherwise unrecognized risks and opportunities.

Keywords: Unknown Unknowns; Project Management; Project Uncertainty; Complexity; Risk Management

1. INTRODUCTION

On June 4, 1996, the massive *Ariane 5* rocket, launched on its maiden voyage from the European Space Agency's center in French Guiana, exploded 39 seconds into flight, destroying four satellites on board (Lions 1996). How could such an unexpected outcome befall a project that took ten years, $7 billion, and tens of millions of hours of human labor and expertise? In a postmortem analysis, the Agency noted that the problem was due to a malfunction in the rocket's guidance system software, and it acknowledged that the system was not fully analyzed or understood, perhaps because the software had worked successfully with *Ariane 4*. More generally, the disastrous outcome was due to an uncertainty of which the Agency was unaware prior to the launch − an unknown unknown (or "unk unk" in common industry parlance). Yet, was this uncertainty truly unknowable, or was it potentially knowable but just escaped recognition by the project management team? In this paper our basic premise is that just because something is unforeseen does not necessarily mean that it is unforeseeable. Through appropriate analysis, it is possible to recognize and reduce some unk unks which are actually knowable. We examine the factors that drive knowable unk unks in a project and present a conceptual framework to deal with (i.e., recognize and reduce) them in project management. Our framework is based on several key factors – relating to both project (system) design and behavioral (organizational) issues –and a set of propositions linking these factors to the increased likelihood of unk unks. We then present a set of design and behavioral approaches that project managers could adopt to reduce unk unks—i.e., to convert the knowable unk unks to known unknowns.

A project is "a temporary endeavor undertaken to create a unique product, service, or result" (PMI 2013). Two characteristics distinguish projects from operations in general. First, whereas most organizations and operations are ongoing concerns, a project is relatively temporary and finite. Second, projects are by definition "unique," meaning that they are trying to produce a new result that has not been produced before, at least not exactly. The decreased time frame and increased novelty of projects relative to other operations brings heightened challenges with respect to unk unks. The emerging landscape of business management is dominated by new products and services with shorter life cycles, rapid introductions of new technologies, and continuously changing markets, regulations, and security threats, all of which lead to hyper-competition and high-velocity environments (e.g., D'Aveni 1994, Eisenhardt 1989). Such environments, which create unfamiliar and less well-understood uncertainties, are typical for many projects. In contra-distinction, much other organizational decision-making takes place in relatively stable and better-defined environments and is often managed by contingency plans.

A major challenge in project management is dealing with the uncertainties within and surrounding a project that give rise to outcomes that are unknown or known only imprecisely. Uncertainties can have a positive or negative effect on one or more project objectives. Positive or upside outcomes create opportunities while negative or downside outcomes present risks (Hubbard 2009). Successful project management involves risk and opportunity management, which entails identifying, assessing, prioritizing, handling, and monitoring both risks and opportunities effectively (Hillson 2002; PMI 2013). Risks and opportunities are context-specific, depending on the project's objectives and the perspectives of its stakeholders. In this paper, we focus on uncertainties or *unknowns*, which are value-neutral and may lead to both risks and opportunities. Also, we focus on unknowns from the point of view of the project manager (PM), an individual or team responsible for making managerial decisions that affect the outcome of the project. Unknowns exist in the PM's knowledge base. As more information is collected over project time, some of these unknowns become known, whereas others remain hidden. The project's unknowns may be divided into two types:

Known unknowns: Uncertainties of which the PM is aware and to which the techniques of conventional risk and opportunity management can be applied. Examples may include the cost and duration of defined activities, the quality of their outcomes, the availability of planned resources, and the expected possibilities of changes or rework. Known unknowns can be estimated in a *probabilistic* sense.

Unknown Unknowns: Unrecognized uncertainties of which the PM is unaware. When unexpected, surprising outcomes (more often ones with negative or disastrous consequences) are encountered, these are attributed to unk unks. An extreme, catastrophic, or dramatically surprising outcome is *not* an unk unk if it had been envisioned but deemed too unlikely or too costly for which to prepare.

By definition, unk unks are not known. However, the knowledge that unk unks are probably "out there" can motivate the application of appropriate search strategies. Just because something is currently unknown does not mean that it is unknowable. Therefore, we divide unk unks into two sub-categories:

Unknowable unk unks: These unk unks or unexpected surprises cannot be anticipated by the PM. No amount of action by the PM will be able to convert unknowable unk unks to known unknowns. For example, the tsunami in the Indian Ocean in 2004 disrupted many construction projects in India, Indonesia, Thailand, and elsewhere; these projects could not have known to plan for such an extreme event.

Knowable unk unks: These unk unks could be foreseen by the PM but for some reason (e.g., barriers to cognition) are not (yet). Many retrospective studies of project failures suggest that a large amount of unk unks could have been anticipated given due diligence by the PM. For example, the well-publicized problems with the automated baggage-handling system at Denver International Airport in 1995 could have been anticipated but were not until the project was well past its deadline (Montealegre et al. 1996).

From the perspective of a PM, key questions are: *What are the driving factors in a project that increase the likelihood of its encountering unk unks? Where should I invest in uncovering knowable unk unks? What approaches can I take to reduce the likelihood of unk unks*? Answers to these questions can help a PM allocate appropriate resources towards the conversion of knowable unk unks to known unknowns (e.g., risk identification). Our contribution in this paper is to present a conceptual framework to address these questions. We introduce the factors constituting the framework and a set of propositions that enable a PM to *recognize* that unk unks are likely to be lurking in particular aspects of a project, thus providing some guidance on where to look and why. We then discuss a variety of project design and behavioral approaches that a PM may adopt to reduce unk unks in the most promising areas.

Since unk unks are unanticipated outcomes they bear some connection to accidents, safety and reliability, especially in hazardous industries, which have been the subject of prominent sociological theories such as the *normal accident theory* (NAT) and the theory of *high reliability organizations* (HRO). NAT holds that regardless of the intensity of organizational efforts, accidents in complex and tightly-coupled systems (such as nuclear power plants) are inevitable or "normal" as they cannot be foreseen or prevented (Perrow 1984). NAT deals with system accidents (defined as those caused by unanticipated interactions of failures) and offers society the juncture to accept uncertainty (unknowable unk unks) or not use a technology. Thus, NAT is concerned with the unknowable unknowns associated with risky technologies at a macro or societal level. It does not address knowable unk unks at a project level. HRO, on the other hand, asserts that accidents—even in complex organizations that operate hazardous technologies (such as air traffic control and aircraft carriers) —are avoidable by creating appropriate behaviors and attitudes that would increase "heedful interrelations and mindful comprehension" and with emphasis on safety, attention to problems, and learning (Weick and Roberts 1993). HRO theory is based on practices observed in operations with "recognized hazards" and nearly full knowledge of their technical aspects, low levels of uncertainty, and stable technical processes (Roberts 1990). While these broad, sociological theories do not directly tackle the unk unks question in the context of a project as we do, they offer useful insights in developing our framework. For example, since the absence of HRO characteristics might work as barriers to recognizing unk unks, HRO theory motivates some of the sub-factors in our framework. Our paper focuses specifically on PM, and directly addresses unk unks in greater depth. By accounting for several key factors to recognize and reduce knowable unk unks in project management, our framework makes a significant contribution beyond NAT and HRO.

To the best of our knowledge, ours is the first paper to distinguish the *knowable* unk unks from unk unks in general, conceptualize a framework of the driving factors, and thereby provide specific guidance into the areas for recognizing and reducing knowable unk unks in a project. Our framework has significant implications for PM, including the following:

- If a PM knows that unk unks are more likely (and where and why) in a project, then the PM may choose appropriate strategies and investments for uncovering them—i.e., converting them to known unknowns. The emerging trend toward hyper-competition and high-velocity environments in PM underscores the importance of a theory of unk unks (although our proposed framework is not limited to such contexts).
- Some unk unks may be analogous to Taleb's (2010) "black swans"—large events that are both unexpected and highly consequential. An awareness of the likelihood of potential unk unks enables a PM to design project results, processes, organizations, tool sets, and goals that will not fall apart when they encounter black swans, or that might even benefit from these unexpected events (Taleb 2012).
- In some projects (e.g., new product development or new process implementation) the existence of unk unks is readily apparent (e.g., Sommer and Loch 2004; Loch et al. 2008). However, little has been

reported on how a project team might systematically assess its vulnerability to unk unks. Several recent papers in the field of PM (e.g., Perminova et al. 2008; Collyer and Warren 2009) have called for new paradigms and approaches that recognize uncertainty as a complex issue and provide a basis for future research. Our framework to deal with knowable unk unks extends the PM literature by addressing this need.

We note that the process of recognizing the potential existence of unk unks requires an investment of valuable resources. Therefore, although our framework applies to all types of projects, it is particularly useful in high uncertainty projects characterized by hyper-competition and high-velocity environments (which is currently a growing subset of projects). Also, while it is not the focus of this paper, we expect that much of our framework could apply to the broader context of operations management (OM) beyond projects.

II. CONCEPTUAL FRAMEWORK

Based on a synthesis of the information and insights from currently available theories, an in-depth analysis of unanticipated project outcomes, and our own experience, we recognize that the driving factors of unk unks in a project fall into two broad categories: (1) Project (system) design issues and (2) Behavioral issues. We conceptualize a model of the factors that increase the likelihood of unk unks in a project that reflects such categorization. As illustrated in Figure 1, our framework comprises four factors − *complexity*, *complicatedness*, *mindlessness*, and *organizational pathologies*. The first two factors relate to a project's design including intrinsic and perceived characteristics of the project. *Mindlessness* relates to behavioral issues at the level of individuals in the project, and *organizational pathologies* relates to behavioral issues at the level of the project's organization. Table 1 details the extensive sub-factors constituting four of the main factors. In the next section of the paper, we develop each of the factors and sub-factors with supporting theories, literature, and examples. We then develop a parsimonious set of propositions with practical implications in project management to deal with unk unks.

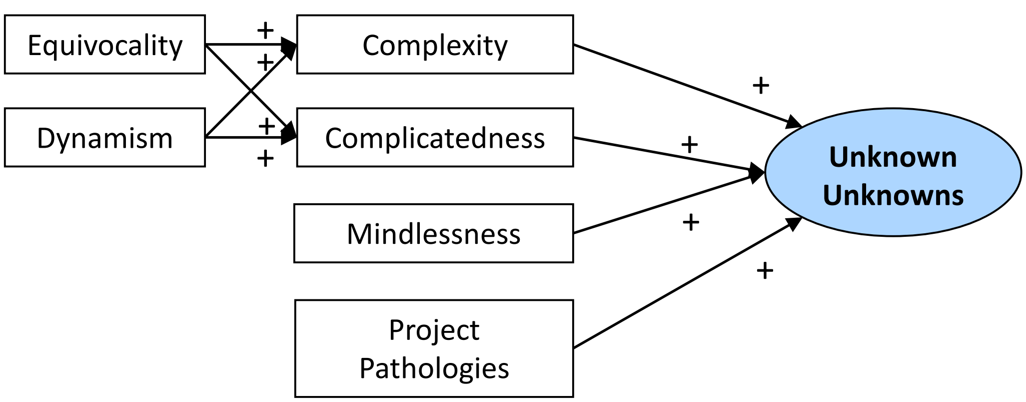

Figure 1: Conceptual framework: Main factors that tend to increase the likelihood of unk unks

Table 1: Sub-factors constituting each of four main factors in the conceptual framework

Complexity *Element complexity*	***Complexity*** *Relationship complexity*	***Complicatedness***	***Mindlessness***	***Project Pathologies***
• *Number of project elements* • *Variety of project elements* • *Internal complexity of project elements* • *Lack of robustness of project elements*	• *Number of relationships among project elements* • *Variety of relationships among project elements* • *Criticality of relationships among project elements* • *Internal complexity of relationships among project elements* • *Externality of relationships*	• *Lack of encapsulated interactions* • *Lack of observer capability* • *Unintuitive system organization* • *Lack of observer experience (novelty)* • *Very large scale-up* • *Divergent viewpoints*	• *Entrapped mindset* • *Pathological intensity* • *Missing weak signals* • *Willful ignorance*	• *Mismatched project subsystems* • *Fragmented expertise* • *Stakeholders' unclear expectations* • *Dysfunctional culture*

In developing our framework, we followed well-established guidelines for conceptual development and theory-building in operations management (e.g., Choi et al. 2001; Handfield and Melnyk 1998; Wacker 1998). We combined insights from a number of related theories in a variety of fields and from many examples from practice. The role of literature search in the research procedure is extremely important since it provides the accepted definitions, applicable domains, previously identified relationships (along with empirical tests), and specific predictions (Wacker 1998). Hence, we conducted an extensive review of the relevant academic and practitioner literature: (i) We searched several major journals closely related to our topic, going back to 1995, focusing on papers that self-identified with the terms "uncertainties" or "unknowns" and "project management"; (ii) We examined the reference lists from selected papers to find relevant papers in related areas such as complexity theory, systems engineering, economic theory, and behavioral psychology; (iii) We performed a general search of the literature—based on the key words "disasters," "technological failures," "knowledge gaps," and "unpredictable surprises"—which led us to broader, relevant literature in fields such as sociology and the behavioral psychology of individuals and groups; (iv) We surveyed a number of books, case studies, and reports on technological failures, major disasters, anomalous outcomes, unexpected surprises, and critical product recalls; (v) We did a Google search on "*unknown unknowns*," which resulted in over 3 million hits. We painstakingly scanned a number of these results and reviewed ones relevant to our research. Iteratively, we sought the sources of unk unks in projects, grouped them into the appropriate categories, and identified their relationships to develop a meaningful and parsimonious set of propositions. Throughout this process, we sought to ensure that our model adequately captured reality by examining the findings from the literature to support (or revise) the categorizations, investigate relationships, and seek explanations as to why the unpredictable outcomes occurred. Helpful feedback from colleagues and reviewers also helped us refine our categorizations and propositions.

III. FRAMEWORK DEVELOPMENT

This section develops our framework of the drivers of knowable unk unks in project management by discussing each of the factors in Figure 1/ Table 1. As a preface to this discussion, we note that a project is a kind of system, "a combination of interacting elements organized to achieve one or more stated purposes"

(INCOSE 2007, p. C5). This system consists of at least five important subsystems: *product*, *process*, *organization*, *tools* and *goals* (Browning et al. 2006). The *product* subsystem represents a project's desired result, be it a new product or service or some other kind of deliverable, and it is itself a system of related components, the decomposition of which can be represented, e.g., with a product breakdown structure (PBS) or indented bill of materials. The *process* subsystem represents all of the work the project does to get the *product*, and it is a system of related activities where a work breakdown structure (WBS) can show the decomposition and an activity network can model the flow relationships. The *organization* subsystem consists of the people and teams doing the activities in the *process*. Its decomposition can be shown with an organizational breakdown structure (OBS) and its lateral relationships as a social network. The *tools* subsystem comprises the tools and technologies, notably software tools, required to accomplish the project's activities. It is also a system of elements (e.g., software tools) that may interact (e.g., through data transfers). The *goals* subsystem includes requirements and objectives for the project's result (*product*), how the result is achieved (*process*), who is involved (*organization*), and the means at their disposal (*tools*). In this paper we italicize each of these five subsystem names only to distinguish from other uses of these terms. Thus, in viewing a project as a system, its elements are components, activities, organizational units, tools, and goals, and interaction occurs through relationships among these elements. Although these five subsystems exist in wider operational contexts beyond projects, that does not diminish their significance within projects. Compared to repetitive operations, a project's *product*s (including services or results) are new and unique (yet to be designed), its *process* (set of activities) is intended to be done once (not repetitively) and may not even be defined entirely at the outset, and its *organization* is temporary. Each of the factors in our conceptual framework can operate through any one or more of these five project subsystems.

3.1 Complexity

Complexity theory provides useful insights on the sources and types of complexity and the behavior of complex systems and helps us understand the phenomenon of the emergence of unanticipated behaviors. The complexity of a system (physical, biological, sociological, etc.) makes it difficult and occasionally impossible to recognize and fully understand all of its variables and all of the relationships among them. Some foundational and synoptic works on complexity theory include those by Simon (1962), Bar-Yam (1997), and Warfield (2000). Baranger (2000) and Homer-Dixon (2000) provided non-technical, managerially appealing elucidations of complexity. Complexity has been discussed and studied in a variety of contexts, and it has been defined and characterized in several different ways in the literature. Recently, Jacobs and Swink (2011) reviewed definitions of complexity in operations management and determined that it is a state manifested by the multiplicity, diversity, and interrelatedness of system elements. Some of the more widely acknowledged notions of system complexity include: its interconnected parts (Simon 1962), its number of components and their relationships (Kauffman and Levin 1987), and the amount of information required to describe it, which depends on its number of distinct possible states (Bar-Yam 1997). All of these depend on intrinsic properties and objective characteristics of the system. In our framework, *complexity* is a construct with two key constituents:

(1) *Element complexity*, determined by the *number*, *variety*, *internal complexity*, and *lack of robustness* of project elements, and

(2) *Relationship complexity*, determined by the *number*, *variety*, *criticality*, *patterns*, *internal complexity*, and *externality* of relationships among the project elements.

Several of these factors have not yet been accounted for in published models of complexity, nor have their effects on the likelihood of unk unks been conceptualized. Each of the factors is supported by logic and evidence from the literature and practice.

3.1.1 (Project) Element Complexity

The link between *element complexity* and uncertainty has been well-documented in the complexity science literature. It is generally recognized that an increase in *element complexity* makes it harder to recognize all possible outcomes and thus leads to a higher likelihood of unknowns. For example, the influence of the *number* and *variety* of elements has been discussed by Kauffman and Levin (1987), Simon (1962), Geraldi et al. (2011), Shenhar (2001), Jacobs and Swink (2011), Baccarini (1996), Bar-Yam (1997), Frizelle (1998), Chu et al. (2003), and Vidal et al. (2011). All else being equal, a project with a greater number and variety of components (*product* subsystem), activities (*process* subsystem), people and teams (*organization* subsystem), resource types (*tools* subsystem), and/or requirements (*goals* subsystem) is more complex and will have a greater potential for unk unks. Moreover, the *internal complexity* of each of these individual elements can also be an important sub-factor, because merely counting the number of elements will be misleading if some of the elements are much more complex (larger and/or containing more internal relationships) than others.

A fourth sub-factor, *lack of* (element) *robustness*, provides new insights to our understanding of unk unks. *Product* components, *process* activities, *organization*al units, particular *tools*, and various *goals* often face pressures to change over the course of a project. Whether or not they must indeed change to accommodate this pressure depends on their robustness, their ability to provide a desired result across a broad range of situations. For example, Clarkson et al. (2004) studied the propagation of engineering changes in product designs, finding that some product components tended to propagate change while others acted as change absorbers—i.e., they could accommodate a wide variety of inputs without much altering their results. The absence of change propagators and the presence of change absorbers make a complex system more resilient and less likely to exhibit unforeseen, emergent behaviors. Similarly, in software development, good design includes making each package of source code robust against spurious inputs. Project tasks that can achieve their desired result despite variations in inputs, resources, and circumstances make plans more predictable. As collections of such elements, particular architectures or designs of the *product*, *process*, and other project subsystems can also be more resilient to perturbations. Buffers, safety margins, and slack help insulate against changes and can contribute to robustness in *product*s and *process*es (Lawson 2001). However, drives towards greater efficiency may remove these protections, making projects brittle and leading to unexpected problems (Browning and Heath 2009; IRGC 2010).

Each of the sub-factors driving *element complexity*, any of which may affect any of the five project subsystems, has the propensity to increase the likelihood of unk unks in a project. This leads to the following proposition:

Proposition 1: *Increased amounts of element complexity—determined by the number, variety, internal complexity, and lack of robustness of a project's elements (product components, process activities, organizational units, tools, or goals/requirements)—will increase the likelihood of encountering unk unks.*

Increased *element complexity* (in any of the five project domains) should cue managers to increase their expectations for the presence of lurking unk unks. Note that this and later propositions do not attempt to express the shape (e.g., linear or non-linear) or strength of the proposed relationships, although some evidence suggests the possibility of a power law (logarithmic) relationship in the case of this factor (Braha and Bar-Yam 2007).

3.1.2 (Project Element) Relationship Complexity

The *number* of relationships that exists among the elements of a system influences its complexity. Systems with more relationships among their elements have an increased chance of propagating causal effects (Kauffman and Levin 1987; Simon 1962). Chu et al. (2003) and Jacobs and Swink (2011) pinpointed connectivity among system elements as a fundamental generator of complexity. Loch et al. (2006, p.75) observed that some unk unks arise from ill-understood interactions among known elements. Furthermore, when the number of relationships reaches a critical value, a system's behavior may change dramatically, such as when highway traffic densities reach 18-20% and the propensity for jams suddenly increases (Choi et al. 2001). A project with more dependencies and constraints among its people, tasks, and tools is more likely to encounter unk unks than one whose various components are relatively independent.

The *variety* of relationships among elements is also important. A system of five elements with the same type of relationship is less complex than a system of five elements with a variety of possible relationships, from which a greater variety of behaviors could emerge. The latter system requires more information to describe (Bar-Yam 1997). For example, a project activity that provides the same report to ten recipients has a less complex job than one having to provide a different, customized report to each of ten recipients. A software tool that must exchange data in different ways with each of six other tools presents a more complex situation than if the interfaces all used the same standard or protocol. A greater variety of relationships requires attention to more details, which increases the possibility that something important might escape notice, thus increasing the possibility of unk unks.

Relationship *criticality*, where some relationships matter more than others, also plays a key role. Not all relationships affect complexity to the same extent. For example, in the project scheduling literature (*process* subsystem), research has shown that a particular type of dependency, "non-redundant arcs," has a greater effect than "redundant arcs" (Browning and Yassine 2010). In the *product* domain, spatial relationships among components are especially important, because other types of relationships, such as data transfer, can be easier to establish over distances (Pimmler and Eppinger 1994). In the *organization* domain, asymmetric communication networks (where information flow tends to be more unilateral) can lead to some organizational units having more valuable information (and more power) than others, which in turn can diminish camaraderie and trust (IRGC 2010). The types of relationships that matter most may very well differ by project domain. Across varied domains, however, Chu et al. (2003) identified non-linear relationships as a particularly salient type. As the number and extent of critical, sophisticated relationships increases, so does the system's complexity, and thus the likelihood of unk unks.

Particular *patterns* of relationships among elements can also significantly affect the complexity and emergent behavior of a system. Thompson (1967) identified three basic types of element relationships: sequential (in which one element's output becomes another's input), parallel (in which each element contributes to a system independently), and coupled (interdependent or cyclical, in which each element's output becomes an input for the other). Of these, coupled relationships are particularly influential (e.g., Geraldi, et al. 2011), because they spawn feedback loops, iterations, or cycles that are often nonlinear and counter-intuitive (Forrester 1971; IRGC 2010) and that compound the propagation of perturbations—e.g., in the *product* (e.g., Clarkson et al. 2004), *process* (Lévárdy and Browning 2009), and *goals* (Vidal et al. 2011) domains. Hirschi and Frey (2002) found that the time required for humans to solve a coupled parameter design problem increased geometrically as coupling size increased linearly. Sosa, Mihm and Browning (2013) found that software components involved in architectural cycles were significantly more likely to contain bugs. Highly interconnected systems are sometimes called *tightly coupled*, meaning that a change in one element can have rapid, multiple effects on others, sometimes causing the system to overreact. For example, as Perrow (1984) pointed out, the response to someone shouting "fire" would be drastically different in a packed stadium versus at a beach. A packed stadium is a tightly coupled system, because the people inside are constrained to leave through a small number of exits, thus forcing many interactions.

Hubs are another relationship pattern that affects a system's complexity and behavior. Unlike random networks in which there no dominant hubs and the number of links at each node is normally distributed around some mean, scale-free networks contain a few dominant hubs with a number of spokes emanating from each hub (Homer-Dixon 2000). The number of links per node in a scale-free network is more likely to follow a power law distribution. Vicious cycles of feedback are known to exacerbate cascading failures in scale-free networks, making them especially vulnerable to potential unk unks (Homer-Dixon 2000). In software development projects, Sosa, Mihm and Browning (2011) found that the presence of hubs in the *product* had a highly significant effect on its likelihood of containing bugs: architectures with more hubs had fewer bugs, up to a point. In the project *organization*, hubs are centralized individuals or teams with significant influence over the network. A project could fail abruptly if a hub person were to be disabled or removed. Cycles, hubs, and any other types of consequential patterns of relationships can engender complexity and thereby increase the likelihood of unk unks in a project.

Relationships among elements may also differ in their *internal complexity*. Although even simple relationships can cause the emergence of unanticipated behaviors in a system (Holland 1998), more complex relationships, such as those in a supply chain or between countries, can amplify the effects of the other factors driving *relationship complexity*. One complex dyad can generate more complex behaviors for a system than several simple relationships. In a project, a complex relationship between two important *product* components, two large teams, or two competing *goals* can result in greater complexity than several simple and more straight-forward interfaces. For example, a multi-faceted, ongoing relationship with a single supplier can cause more project complexity than several simple purchasing arrangements with commodity suppliers. Similarly, many relationships among elements in a project's five subsystems will vary in their internal complexity. The presence of more complex relationships will increase *relationship complexity* and make a project more vulnerable to unk unks.

This is perhaps a good point for a brief sidebar regarding models and complexity measures. It is important to note that the factors commonly accepted as measures of system complexity, such as the numbers of elements and relationships, depend on the chosen model of a system. One modeler might break a system down into ten elements (e.g., a process composed of ten activities), whereas another modeler might choose to represent the same system in terms of only five elements (e.g., five larger activities). These are different maps of the same territory, drawn to different scales. However, when used to operationalize measures of system complexity, the model with ten elements and 20 relationships will yield a different result than the model with five elements and six relationships. Any overly simplistic approach to modeling system complexity (such as one that depends only on the numbers of elements and relationships) would be expected to have low inter-rater reliability. Hence, to adjust for these differences, we account for the internal complexities of both the elements and the relationships. If the second model (with five elements and six relationships) was explicit that each of its elements and relationships was more complex than those in the first model, then both models of the same system would be more likely to yield similar overall measures of complexity.

Finally, since a project's elements often have ties to its external environment, *external relationships* also affect complexity. The greater the number, variety, criticality, and internal complexity of such relationships, the greater is the possibility that the external context will affect the internal elements, thereby amplifying complexity, unpredictability, and the possibility of unk unks. Chu et al. (2003) referred to this situation as "radical openness" and "contextuality," both of which "make the control and prediction of complex systems very difficult." Note that defining the boundary of a complex system is a challenging task. In modeling a complex system, one defines arbitrary boundaries around it, often implicitly by the very act of naming the system. Large, complex projects might contain several segments dispersed across geographical regions, markets, political situations, and regulatory agencies (de Weck and Eckert 2007). The resulting diversity of external interfaces increases complexity in the *organization*, *process*, and *goals* domains. These might result in unanticipated project outcomes, increasing the likelihood of unk unks.

The link between the diversity of external relationships and potential unk unks is further evinced by disastrous failures in projects at three UK companies: Rolls Royce, Virgin, and Northumbrian Water Limited (NWL) (Alderman, McLoughlin, Ivory, Thwaites, and Vaughn 2003). As one illustration, the NWL project involved the design and construction of a sludge treatment center. It was driven by three different goals: a statutory response to the EU's banning of sludge at sea, a sustainability initiative to find a "green" solution to industrial and domestic sludge disposal in the region, and a profit objective to produce a byproduct of commercial value in the form of inert, dried sludge pellets. Management of a range of technologies, many of which were unfamiliar to the firm, and a regulatory process that overlapped two distinct agencies, the UK Government and the EU Authority, contributed further to the external relationship complexity, which in turn led to unforeseen outcomes.

Another example shows the capability of *relationship complexity* to increase unk unks. As part of a major reorganization project in its Sydney, Ohio manufacturing plant, Copeland Corporation sought to achieve facility focus by splitting the plant by product type (Ruwe and Skinner 1987). However, this would require relocating some process "monuments" (large precision-machining equipment such as a 17-station transfer line and a heat treatment facility) that had taken years to adjust to the desired degrees of precision. In recognition of the complexity of the relationships among the production tools and the operating environment as sources of potential unk unks, the project's managers decided to leave the monuments in place.

The factors driving *relationship complexity*, any of which may affect any of the five project subsystems, each have the propensity to increase the likelihood of unk unks in a project. We synthesize these insights into the following proposition:

Proposition 2: *Increased amounts of relationship complexity—determined by the number, variety, criticality, patterns, internal complexity, and externality of the relationships among a project's elements (product, process, organization, tools, or goals)—will increase the likelihood of encountering unk unks.*

3.2 Complicatedness

Complicatedness (or cognitive complexity) is the more subjective, observer-dependent aspect of complexity. Using an example from Tang and Salminen (2001), a car with an automatic transmission is more complex than one with a manual transmission, because the former has more parts and intricate linkages. Yet its complicatedness differs between drivers (to whom the automatic transmission seems less complicated) and mechanics who must fix them (to whom the automatic transmission seems more complicated). Similarly, a software application's complex code may be hidden by a simple and elegant user interface. Or, many of us have known a professor with an office piled with stacks of books and papers. To a visitor, the place looked like a complete mess, but somehow the professor knew exactly where to find everything. He had experience with and aptitude for interacting with a system that he had architected, so he did not perceive it to be complex, while the uninitiated visitor did. Thus, the internal complexity of a system can be more or less well-organized and/or hidden from various observers, who will in turn deem it more or less complicated.

To a PM, a project's complicatedness depends on his or her ability to understand and manage the project. It is influenced by factors such as the intuitiveness of the project's structure, organization, and behavior; the possibility of hiding subsets of information (appropriate abstraction); the ease with which sought elements can be found and cause and effect relationships identified; and the PM's aptitude and experience. Although complexity and complicatedness may correlate and interact, they do not have a generalizable causal relationship. Suh (2001) distinguished "real" and "imaginary" complexity as orthogonal dimensions that correspond to the concepts of intrinsic/objective complexity and perceived/subjective complicatedness. Simon (1956) used the analogy of scissors, where one blade represents the structure of the environment and the other the cognitive limitations of the observer. Complexity can be a desirable property of projects when it increases capability, and it is orthogonal to complicatedness. Because a complex project may present different degrees of complicatedness, separating complicatedness from complexity improves the clarity by which projects can be described and analyzed. Thus, we recognize complicatedness as an orthogonal construct in our framework and derive insights from complicatedness theory to understand and bridge the cognition gaps that result in unk unks in PM.

Here, we are interested in the perceptions of the PM, which again can be examined in the context of each of the project's five subsystems: the *product* (e.g., a product design is unprecedented or unintuitively structured), the *process* (e.g., the project's activities are unusual or grouped unclearly), the *organization* (e.g., the project's participants have not worked together before or are not fluent in the same language), the *tools* (e.g., the project is using a new software tool for the first time), or the *goals* (e.g., the project's requirements are unfamiliar and unclear). As the complicatedness of any of these aspects of a project increases from the point of view of the PM, the likelihood of failing to anticipate significant, emergent outcomes—i.e., of being surprised by unk unks—increases. Our review of theory and empirical results led us to identify six factors driving *complicatedness*: *lack of encapsulated interactions*, *lack of observer capability*, *unintuitive system organization*, *lack of observer experience* (novelty), *very large scale-up*, and *divergent viewpoints*. We examine how each of these six constituents increase the *complicatedness* of a project and thereby the likelihood of unk unks.

Encapsulated interactions occur when a system's inputs and outputs are grouped into a limited number, type, and variety, such as a limited number of knobs, buttons, or options for operating a system or a limited number of states resulting from its use. Encapsulation often implies that the system includes mechanisms for robustly suppressing diverse behaviors into limited classes of output—meaning that it is tougher for a user or observer to "mess it up." (The addition of such mechanisms usually increases the intrinsic complexity of the system, however.) Compared with a manual transmission, an automatic transmission in an automobile is an example of encapsulated interaction. In some large projects, the PM may manage things only at the level of a few major work packages, a few major product subsystems, and a few large teams. The charts and reports provided to the PM for reviews might be "high level" documents with only "big picture" statements. Viewed this way, the project can appear less complicated, whereas exposing more of the details makes it seem more so. Hence, a *lack of encapsulated interactions* increases *complicatedness* and thus the likelihood of unk unks.

Another way to make a system seem simpler to an observer is to organize and present its elements and relationships in an intuitive way. Returning to the example of the professor's messy office, the same number of items (books, papers, etc.), filed and organized by topic, would seem less complicated to a typical observer. Similarly, if the elements and relationships in a project's subsystems seem disorganized, or if the organization scheme does not allow for easy extraction of the information needed to support managerial decisions, then the likelihood of missing a problem will increase. For example, a *process* flowchart with many crossing lines (as opposed to a much cleaner one with the same number of lines, but without any of them crossing) and an *organization* chart with unclear titles and reporting relationships are both examples of system representations that are likely to befuddle an observer. Confused PMs can fail to notice important things. *Unintuitive system organization* can increase *complicatedness* and thus the likelihood of unk unks.

Lack of observer experience (*novelty*) is another subjective, observer-dependent attribute of a project (Brockhoff 2006). As an observer gains experience with a system, he or she develops intuition and learning about its organization and behaviors. The system becomes more familiar. The observer can identify the system's components, relationships, and behaviors and better anticipate cause and effect relationships (Schrader et al. 1993). Novelty represents a lack of such experience and familiarity (Rosenkopf and McGrath 2011). Tatikonda and Rosenthal (2000) pointed out that a higher level of technology novelty leads to greater task uncertainty (*process* subsystem). Sauser et al. (2009) noted that novelty is related to a *product*'s uniqueness in its relation to the market and to the uncertainty in its requirements (*goals*). Novelty also pertains to the relationships in the *organization*—e.g., the classic "storming, forming, and norming" phases (Tuchman 1965). Interestingly, overspecialization (reduced novelty in one area) can also create situations of increased novelty with respect to aspects of a project outside an observer's area of expertise. A project's "observers" may also include external stakeholders, especially customers, who may have desires or needs that they have trouble articulating—or do not even realize that they do not know. Project stakeholders' unk unks may drive unk unks for the PM, especially in the *goals* domain. Thus, increased *novelty* makes a system such as a project seem more complicated, which makes it more likely that something surprising will remain unnoticed.

Furthermore, some observers relate better to some systems than to others. If an observer has a high aptitude to understand a system, and if the system's behaviors seem logical and intuitive, then he or she is in a position to gain more traction from learning about the system. Other variables (such as an observer's relative attention to the system) could also be identified and included, but here we subsume aptitude, attention, and related aspects into the sub-factor *observer capability*. Highly capable managers can more quickly find problems and issues in a project's *product*, *process*, *organization*, *tools*, and *goals*, whereas a *lack of observer capability* increases *complicatedness* and the likelihood of unk unks.

When a system exceeds a certain size, an observer will have difficulty accounting for all of its elements and relationships. The threshold will vary by observer, but it has been noted to occur at about 7±2 elements (Miller 1956). As system size increases, an observer's mental model of the system becomes increasingly abstract and disconnected from the system's details, wherefrom surprising interactions might cause unk unks to emerge. Time scale-ups also pose challenges. For example, feedbacks loops can be especially pernicious when they take a long time to occur, because they inhibit observers from making the connection between causes and effects (Forrester 1971; IRGC 2010). Thus, while a system's *complexity* (element and relationship) can drive unk unks, it can also increase *complicatedness*. Overall, *very large scale-up* increases *complicatedness* and thus the likelihood of unk unks.

As expressed in the famous Asian fable of the blind men and the elephant (Linton 1878, p. 150-152), complex systems are seen and (partially) understood from multiple perspectives, each of which may contain some validity (i.e., equifinality − Beven 2006). Contemporary project organizations often contain many specialists. For example, a product development project may include specialists in reliability, sustainability, usability, safety, supportability, cost, security, quality, supplier selection, production, marketing, etc. The greater the diversity of these viewpoints, the greater will be the *complicatedness* of the project (Jones and Anderson 2005), because discussions among project stakeholders may not confirm and validate an individual's mental model; rather, such discussions may raise additional questions and even create confusion. This situation may be desirable when it serves to dispel ignorance and catch problems, but shepherding project participants and stakeholders towards mutual understanding and eventual agreement takes time and effort. Meetings, conversations, common processes, interactive tools, communication and visualization capabilities, and other integrative mechanisms may all contribute to alignment. Although specialists often develop their own jargon to communicate more efficiently among themselves, it is tedious to develop the common frame of reference needed for multidisciplinary endeavors such as projects, so this effort is often shortchanged. If the diverse viewpoints of the project participants and stakeholders, which can add value initially, fail to converge for the purposes of the project, then these *divergent viewpoints* allow *complicatedness* to fester, thereby increasing the propensity for unk unks.

Examples from the literature corroborate the factors driving *complicatedness* in projects and their propensity to increase unk unks. A project to supply and maintain a fleet of high-speed tilting trains for Virgin Train Operating Company on the UK Rail Network's West Coast Mail Line suffered setbacks due to *novelty* and a *lack of observer capability* (Ivory and Alderman 2005). The aspirations of Virgin for an improved passenger experience created a need to consider new technologies for in-seat entertainment and novel concepts for interior design. However, the diversity of the customers for in-seat entertainment, and the novelty of the interior design concept from the perspective of the railway design engineers, entailed new patterns of outsourcing and an unforeseen increase in the resources required to establish the design details. Another example is the failure of a German start-up company that tried to copy PriceLine's successful reverse-auctioning system (Sommer and Loch 2004). Although the technology was the same, subtle cultural and social differences in the market increased *complicatedness* via a diversity of viewpoints. This rendered the project vulnerable to unk unks: the outcome that the cultural and social differences between German and U.S. consumers could result in the German-consumers' rejection of a technology that had been successful in the U.S. was unforeseen. The 2003 space shuttle *Columbia* disaster (Strange 2007) exhibits *complicatedness* and the emergence of unk unks driven by *very large scale-up*. After an otherwise normal mission, *Columbia* broke up on reentry because parts of the external fuel tank had broken away during launch and struck the wing, damaging the insulating tiles. While *Columbia* was still in orbit, NASA had asked The Boeing Company, the shuttle's contractor, to comment on the probability of the tile damage being severe enough to endanger the craft during reentry. This assessment was an important project, as NASA had two options if the damage had been assessed as life-threatening: (i) a spacewalk by the crew to inspect the damage and perform emergency repairs and (ii) an expeditious launch of another space shuttle which was already in advanced preparations. Based in part on the results of computer simulations of tile strikes, Boeing concluded that the reentry would be safe, yet noted that the "flight condition is significantly outside of the test data base: volume of ramp is 1920 cubic inches versus 3 cubic inches for test." In retrospect, it seems that this scale-up factor of 640 should have alerted NASA to an increased probability of unk unks.

Thus, a *lack of encapsulated interactions*, a *lack of observer capability*, *unintuitive system organization*, a *lack of observer experience* (*novelty*), *very large scale-up*, and *divergent viewpoints* each tend to increase *complicatedness* in a project. These effects can occur via any one or more of a project's subsystem domains—the *product*, the *process*, the *organization*, the *tools*, and the *goals*. We therefore formulate the following proposition:

Proposition 3: *Increased amounts of complicatedness—as determined by a lack of encapsulated interactions, a lack of observer capability, unintuitive system organization, a lack of observer experience (novelty), very large scale-up, and divergent viewpoints regarding a project's elements—will increase the likelihood of encountering unk unks.*

We group these six sub-factors together in Proposition 3 because we expect some amount of confounding among them. For example, a lack of intuitiveness in a system's organization might be confounded with an observer's lack of capability. Further research is needed to develop and refine appropriate measures that seek to disentangle these relationships.

Moreover, at least one of these sub-factors might also have an opposite effect. Greater *encapsulated interactions* might not always imply a reduced likelihood of unk unks. The recognition of a greater amount of complexity than presupposed might draw helpful attention that uncovers unk unks, making them less likely. Some managers are attracted to details; others are repelled by them. A misguided perception of simplicity (a false measure of low *complicatedness*) will increase the likelihood of unk unks. Therefore, as a caveat to Proposition 3, we propose that:

Proposition 4: *Increased amounts of encapsulated interaction of a PM with a project's elements may increase the likelihood of encountering unk unks.*

3.3 Dynamism

Dynamism (volatility or propensity to change) increases *complexity* (see, e.g., Geraldi et al. 2011) and *complicatedness*. Internally, if a project's elements (be they components of a *product*, activities in a *process*, people or teams in an *organization*, *tools* used, or desired *goals*) are changing, then this introduces, eliminates, or varies elements and relationships, potentially spawning new patterns of relationships and emergent behaviors. Externally, aspects such as company-wide politics, other projects competing for the same resources, reorganizations and changes in management, changes in company policies and priorities, mergers and acquisitions, and open-ended contracts with suppliers and sub-contractors may cause changes in a project's *organization*, *goals*, and *tools* subsystems especially. These changes also decrease an observer's experience with and understanding of a project's subsystems: *dynamism* increases *novelty* (*complicatedness*) and disrupts learning.

External changes may affect any of a project's five, internal subsystems, although they are especially likely to affect its *goals*. Regulatory agencies may impose new rules, customers may change their preferences, competitors may change their strategies, or stakeholders may see new technologies or tools as desirable, any of which might prompt a change in a project's *goals*. Of course, changes in *goals* are likely in turn to cause changes in a project's end results (*product*) and its means of achieving them (*process*, *organization*, and *tools*). Internal and external changes might also alter a project's boundary with its environment. Portions of a project might be outsourced; customers or suppliers might become formal partners, etc. These changes adjust the number of components and relationships considered to be "part" of the project, as well as other attributes of *complexity* and *complicatedness*.

Adaptation can be a further source of *dynamism*. The components of some complex systems (such as a project's *organization* subsystem) are agents with the capability to make changes to their attributes, behaviors, and interactions. These changes affect the project and its environment and add to its *dynamism*, essentially making a project a kind of complex adaptive system (e.g., Choi et al. 2001). For example, a project at the liquid carton producer TetraPak sought to design a new production process (Lévárdy and Browning 2009), but the network of activities that would lead to successful completion of this project was unknown at the outset of the project: each step depended on the results of the previous one. The changing nature of the activities and relationships in the *process* subsystem increased project complexity and complicatedness.

Collectively, the effects of *dynamism* lead to the following proposition:

Proposition 5: *Increased amounts of dynamism in a project's elements and their relationships will increase the project's complexity and complicatedness, and thus its likelihood of encountering unk unks*.

Note that we do not propose *dynamism* as a moderator of the relationship between *complexity* or *complicatedness* and the likelihood of unk unks. Rather than altering the nature of those relationships, as a moderator would be expected to do, *dynamism* actually changes the amounts of *complexity* and *complicatedness* themselves—as does the next factor, *equivocality*.

3.4 Equivocality

In most contemporary projects, especially large ones, work is broken down and assigned to various agents, who must then coordinate to achieve mutually satisfactory solutions. This process requires many instances of back-and-forth sharing of information. If this information is not crisp and specific, perhaps because of indecisiveness, ignorance, or poor transmission, then its receiver will not be able to make firm decisions and achieve results with confidence. This situation has been called lack of definition (Kreye et al. 2009) and equivocality (Frishammar et al. 2011). Although the vague qualities of the information itself may be understood for what they are (a known unknown), *equivocality* also increases the *variety of relationships* (e.g., among actors in the project *organization*), thereby increasing *complexity*, as well as *divergent viewpoints* (*complicatedness*). For example, in a large project to develop a new airplane, managers often required a large number of project participants to attend meetings just in case an issue came up that might affect them. An inability to pin down exactly who needed to be at any particular meeting increased scheduling complexity as well as the length of meetings (by having "too many cooks in the kitchen" that often had difficulty understanding each other's issues and perspectives). Thus, by blurring the focus on a system of interest (the project and any of its five subsystems), *equivocality* amplifies *complexity* and *complicatedness*.

Proposition 6: *Increased amounts of equivocality in a project's elements processtoolsgoalsand their relationships will increase the project's complexity and complicatedness, and thus its likelihood of encountering unk unks*.

3.5 Mindlessness

Mindlessness is the antithesis of "mindfulness," a concept originating in the context of the cognitive behavior of individuals. Langer (1989) examined why individuals sometimes act with "mindlessness" and thus fail to recognize key aspects of their situation. Some reasons include: (a) entrapment in mindsets based on past experience or tradition, (b) automatic acting using limited signals from the environment without letting other signals (which may sometimes be weak) penetrate the mind, and (c) acting from a single perspective or as though there were only one set of rules for all situations.

Mindfulness entails an enriched awareness that comes through processes such as (a) active differentiation and refinement of existing categorizations of knowledge, (b) creation of new categories out of a continuous stream of events, (c) more nuanced appreciation of context and alternative ways to deal with it, and (d) reluctance to simplify interpretations. Mindlessness, or lack of mindfulness, constitutes the perceptive barriers to cognition. Inasmuch as unk unks are knowable uncertainties, the mindlessness of the PM and other individuals involved with a project could increase the likelihood of these unk unks remaining unrecognized. We conceptualize *mindlessness* in terms of four key sub-factors: *entrapped mindset*, *pathological intensity*, *missing weak signals*, and *willful ignorance*. Individual mindlessness due to any of these factors can contribute to an overall project's increased susceptibility to unk unks.

Overreliance on past experiences and traditions can lead to an *entrapped mindset*. Tversky and

Kahneman's (1974) work on the heuristics and biases that people use when making judgments under uncertainty provided some insights on cognitive barriers to the perception of reality. Three heuristics—representativeness, availability of instances, and anchoring—lead to systematic and predictable errors yet are commonly employed. Even experienced decision-makers are prone to these errors, yet a better understanding of these heuristics and biases has been shown to improve judgments under uncertainty, and improvement is possible with training (Hubbard 2009). For example, bits and pieces of software are often reused with a mindless expectation that, if they did the job well before, they will do so again in other applications. Software thus tends to accrete over time, almost like alluvial soils deposited in layers; often the inner workings of older software are incompletely understood by programmers using it later. However, software bugs can become deeply embedded, and if left unfixed can have cascading repercussions. But fixing bugs may require tracing out consequences that have metastasized in many directions from the original error. Past experience might not have exposed the error, and using the same apparently successful software is a potential source of unk unks. Every feature that is added and every bug that is fixed adds the possibility of some new and unexpected interaction between parts of the program (Tenner 2001, p. 269.) The case analysis of the unforeseen failure of NASA's Mars Climate Orbiter (MCO) illustrates how entrapment in past experience might impose cognition barriers and lead to unk unks (Sauser et al. 2009). NASA had been successful with several missions to Mars, although no successful mission had been repeated, and each mission had a greater degree of unproven requirements. The navigation system was the MCO's newest component, but its development project used the past successful software, without sufficient attention to the complexities within this component. This may have contributed to one of the unk unks that lead to the loss of the MCO. In another case (Unilever 1980), a project involving a fairly routine installation of a large, replacement chemical reactor illustrates how the use of critical data without physical verification resulted in unk unks with serious consequences. The actual span between the main structural beams was shorter than that indicated on the as-built drawings. Because the diameter of the reactor was larger, it could not be installed without extensive structural modifications involving huge cost and time overruns. Thus, mindless reliance on past data, book inventories, or existing documentation or components instead of physical verification evinces an *entrapped mindset* that may be a source of potential unk unks.

Pathological intensity is a single-minded effort to maximize output through the narrowing of expertise. It is characterized by a never-ending quest for efficiency, speed, and productivity. Citing the examples of modern automobiles and a meltdown in the financial derivatives markets, Homer-Dixon (2000) observed that pathological intensity often contributes to cognition lapses and hence to unk unks. This situation is analogous to the "invisible gorillas" missed by the subjects in the experiments carried out by Simon and Chabris (1999), who demonstrated how failures of cognition and perception of reality could result in what they call "inattentional blindness" due to "selective looking." One of their experiments involved having subjects watch two teams of players pass a basketball around and count the number of times the basketball was passed by players on one particular team. During the experiment a researcher appeared in a gorilla suit amidst the players. At the end of the experiment, nearly 50% of the subjects said they did not notice the gorilla even though the video of the experiment clearly showed the appearance of the gorilla for several minutes and even making attention-grabbing gestures. Chabris and Simon (2010) attributed this to six everyday illusions: attention, memory, confidence, knowledge, cause, and potential. Understanding how these illusions affect one's cognition and perception could improve one's grasp of uncertainties. We find supporting evidence in the case of the *Ariane* 5 rocket project, as mentioned in this paper's Introduction. The rocket exploded 39 seconds into flight because the guidance system malfunctioned when it tried to convert data on the rocket's horizontal velocity from 64- to 16-bit format. Normally, built-in error correction software would handle such problems swiftly, but in this case the software engineers had decided that such protection was not needed because of the success of *Ariane* 4. However, they had not accounted for *Ariane* 5's greater size and speed (Homer-Dixon 2004, p. 179). An intense but misplaced focus or *pathological intensity* can signify *mindlessness* and thereby increase the likelihood of unk unks.

Missing weak signals occurs when individual biases (e.g., selective perception, suppression, and refusal to acknowledge an unpleasant reality) and inappropriate filters keep periphery-dwelling knowledge in the shadows. The signals pointing to such knowledge are usually weak, but failure to recognize them leads to unk unks. Especially on large projects, the project manager's limited "bandwidth" requires filtering out the "noise" of project status while hopefully letting the important "signals" through. However, this filtering is prone to errors in which some important signals, albeit sometimes weakly transmitted, are inappropriately dismissed as noise. For example, findings from post-market studies of a cardiac pacemaker implant device revealed that surprising failures occurred despite state-of-the-art tests and thorough clinical studies during its development project (Stokes 2006). One of the failures, a crush fracture of the pacemaker leads, was later attributed to a weak signal that had gone unrecognized, a seemingly innocuous change in the implant procedure. Whereas the leads had typically been inserted through the cephalic or jugular vein, the change in the implant procedure was to insert the leads via the subclavian vein. However, when placing the leads between bones before entering the subclavian vein, the high pressures could crush the leads. By ignoring this signal, the pacemaker designers continued to rely on preclinical trials using canines, the generally accepted model for such studies, without registering the fact that canines have no clavicles. In another project to develop an advanced, military aircraft, the PM discovered that the production of a test aircraft was several thousand labor hours over budget. Expressing his displeasure at this surprise, he noted that there had been a point when the aircraft had been only a few hundred hours over budget, but no one had brought the situation to his attention then. Lower-level managers had actually tried to weaken the signal to the PM in hopes that they could make up for the overrun and keep it from becoming an issue (which they failed to do). However, by not having contact with lower-level managers and merely relying on inputs from only a few mid-level managers, the PM missed the chance to detect the issue earlier. Our analysis of a variety of cases finds that knowable unk unks are often accompanied by *missed weak signals*, and that a mindless inability to notice them allows the unk unk to remain unknown unnecessarily.

Willful ignorance is the state and practice of ignoring input that is inconvenient or unappealing, in some cases because it appears to contradict the prevailing model of reality. It differs from the standard definition of ignorance (being unaware of something) in that willfully ignorant individuals (or organizations containing them) might be fully aware of facts and sources, or at least suspicious of them, but refuse to recognize them or their implications. It is also different from genuine disagreements between parties about scientific results or worldviews on matters unknown, where both parties have full awareness of the differences. In his seminal work on ignorance and uncertainty, Smithson (1989) identified three sources of willful ignorance: untopicality, where people have intuitions that they refuse to negotiate with others in terms of cognitive relevance; undecidability, where people cannot designate issues as true or false (because they are considered insoluble, or the question of validity or verifiability is not pertinent); and taboos, socially enforced irrelevance (matters that people must not know, deal with, inquire about, or investigate). Although *willful ignorance* has a negative connotation, it is simply a psychological term to explain how people deal with anomalous and cognitively dissonant material and establish defenses against perceived discord. However, *willful ignorance* increases the likelihood of unk unks. In a project management context, *willful ignorance* entails disregarding information, opinions, methods, results, or evidence that does not conform to one's worldview, resulting in complete unresponsiveness to or censorship of information from others. For example, many projects face challenges in getting approval, funding, or selection. Many project managers will therefore suppress negative aspects of their project while accentuating the positive. It is not much of a step further to deliberately disregard uncomfortable information. One place this shows up is in project risk management, where the identification of threats (via any of the five project subsystems, or otherwise) is sometimes limited deliberately so as not to cause a project to be labeled as "too risky." Kutsch and Hall (2010) found *willful ignorance* to be common in information technology projects.

Analysis of internal documents and memos evinces the Space Shuttle *Challenger* disaster to be a poignant example of *willful ignorance* at NASA (PC 1986) that led to an unk unk. *Challenger*'s tenth flight had been scheduled for January 22, 1986, but there had been several technical problems, and by the evening of January 27 the shuttle was still waiting for launch the next morning. NASA was concerned that the forecasted temperature of 26-29ºF was below that of any previous launch. Knowing that there had been blow-by and erosion of the booster rockets' O-rings on several previous flights, NASA asked Morton-Thiokol Inc. (MTI), the lead contractor for the booster program, for a recommendation to launch the next day or not. The MTI engineers' initial assessment was: "O-ring temperature must be ≥ 29ºF at launch." However, MTI and NASA managers relied on sample data from just two previous flights and pointed out that both the coldest (53ºF) and warmest (75ºF) launches had shown O-ring damage. In other words, something other than launch temperature was causing the O-ring damage and the forecasted temperature of 26-29ºF was inconsequential. The original assessment was withdrawn and the Vice President of the Space Booster program at MTI recommended launch—twelve hours before *Challenger* exploded due to O-ring failure (Tufte 1997).

Overall, *mindlessness*—driven by *entrapped mindsets*, *pathological intensity*, *missing weak signals*, and/or *willful ignorance*—increases the chance that important information about a project's *product*, *process*, *organization*, *tools*, and/or *goals* will be missed, and thus that the project could encounter unk unks in any of these areas. Again, it would be reasonable to expect some amount of correlation among these sub-factors and their effects on a project's five subsystems. We therefore state the following proposition:

Proposition 7: *Increased amounts of mindlessness in a project, especially in its PM, will increase the likelihood of encountering unk unks*.

3.6 Project Pathologies

Like a complex organism, a project can suffer from a variety of persistent, subtle or latent abnormalities that increase its likelihood of encountering unk unks. Project decisions are made by people with different backgrounds (experience and knowledge base) and information. In uncertain, ambiguous or contradictory environments, behavior is a function of goals, limits imposed by procedures and incentives, and the connection between the decision-maker's problem space and the task environment. Understanding the prevalence of behaviors that lead to mismatches between the decision-making environment and the choices made by the decision-makers could play a large role in the identification of knowable unk unks. Simon's (1955, 1956) bounded rationality (BR) theory offers practical and insightful perspectives on how people make inferences about unknown aspects of their environment. Although decision-makers are intentionally rational (i.e., they are goal-oriented and adaptive), they may fail at some important points because of the nature of the human cognitive and emotional architecture. In our framework, we propose the factor *project pathologies* to account for the abnormal structural or behavioral conditions which create situations that might lead to unanticipated outcomes. Using the metaphor of an organization as a living organism, *project pathologies* refer to physiological or structural/behavioral aspects of the project as a whole (whereas *mindlessness* refers to psychological or cognitive aspects of the individuals involved with the project). In this sense, the two factors represent independent constructs. We identify four constituents of *project pathologies*: *mismatched project subsystems*, *fragmented expertise*, *stakeholders' unclear expectations*, and *dysfunctional culture*. We examine the effect of each of these sub-factors on the project's propensity to encounter unk unks.

We have considered the effects of factors such as *complexity* and *complicatedness* on the likelihood of unk unks via five project subsystems: *product*, *process*, *organization*, *tools*, and *goals*. Each subsystem is itself complex, and collectively they comprise an even more complex system from which emerges the project's capabilities (Browning 2007). Here, we extend our concerns to the relationships among these five subsystems, such as the assignment of people and teams in the project *organization* to activities in its *process*, and activities to the design of the components of the project's *product*. These relationships are not always identified or formally managed, in which case it becomes more likely that something consequential will be missed, such as an activity without a doer or a supporting tool, or a component without all of its appropriate design, build, and test activities. Recent research (Sosa et al. 2004; Gokpinar et al. 2010) has identified mismatches between the *product* and *organization* domains (i.e., a product component without a corresponding organizational unit or vice-versa) and suggested its negative consequences for projects. Similar effects are expected due to mismatches among any of the five subsystems. Other examples include a project Goal for which no *process* activity or *organization*al unit is responsible, an activity with no supporting Tool or other resources, and a set of activities that are included in a project "because we've always done it that way" yet do not map to any particular project need (Goal). In all of these cases, such *mismatched project subsystems* will make it more likely that the project will run into unpleasant surprises.

Complex projects require a multitude of technologies and management skills that fathom different levels of activities and span the range of tasks at each level. However, this can cause overspecialization and fragmentation of knowledge and reduce the availability of general expertise. Since no single project manager or expert is likely to have expertise that spans the entire depth or breadth of a project, gaps and disconnects in the knowledge base are potential sources of unk unks. This is corroborated by the case analysis of the $10 billion Large Hadron Accelerator (LHA) commissioned in 2008 after over ten years of project management in Strasbourg, France. In 1997, while touring the facility, Homer-Dixon learned from his physicist escort that because of outsourcing to so many partners and suppliers, nobody in the project understood it in its entirety, which prompted him to note: "I felt some discomfort about his answer at that time, but didn't know exactly why" (Homer-Dixon 2000, p.171). Upon starting up in 2008, serious and unforeseen problems emerged with the magnets, and the particle accelerator had to be shut down. This unk unk indicates that joint ventures or outsourcing arrangements to acquire the breadth of knowledge required for managing a project might introduce knowledge segments with gaps among them. Expertise may be fragmented into subspecialties and broad, experiential knowledge may be squeezed out from the project, thereby making the project more vulnerable to unk unks. We call this effect *fragmented expertise*.

A project stakeholder is any individual or group with a vested interest in the project. A project that does not adequately capture the desires of its stakeholders—especially its client, customer, and/or end users—is more likely to discover later rather than sooner that those desires do not match the PM's own expectations in terms of clarity, correctness, and/or comprehensiveness. Improved interaction with stakeholders and efforts to solicit their value propositions could obviate such surprises. Of course, a project in a context of perverse incentives or malicious motives and acts by any stakeholder to sabotage the project is also likely to be unpleasantly surprised (IRGC 2010). It is important to know which stakeholders, both internal and external, are friends and enemies of the project. Overall, *stakeholders' unclear expectations*, if not appropriately captured and addressed, could render a project more vulnerable to unk unks.

Contemporary organizational cultures, including projects, often suffer from a myriad of dysfunctions. As the famous 6th century Chinese philosopher Lao Tsu (1972, sect. 71) observed, "Knowing ignorance is strength. Ignoring knowledge is sickness." For instance, driven by a desire to avoid expending energy and incurring blame, a PM may foster a project culture that emphasizes consensus-building in its decision-making processes. While it is all too easy to treat a lack of any active opposition or divergent insights as positive support for a course of action, it may be illusory because those who harbor doubts may keep quiet to avoid being held accountable for mistakes. The “illusion of consensus” problem is mirrored in the problem of “suppressed dissent,” which occurs when one part of the project (e.g., the marketing activities) has too much power or primacy over other parts (e.g., the production planning activities) (Bazerman and Watkins 2004). In such situations some parts of the project, which may have important information or perspectives to add, may be pushed out of the decision-making process. Also, while emphasizing consensus-building, projects may foster a culture of optimism. Optimism, while desirable, restricts the anticipation of problems and may tend to overlook that “a cogent line of disagreement is as valuable as a reasoned consensus” (Landau and Chisholm 1995). Projects often accept a consensus regarding the basic constituents of their natural, social, or technological systems and the principles by which they manage those systems. They convince themselves that they know enough to manage the systems around them effectively (or at least that there are experts who do), and they are not eager to admit how little they understand the systems they build, live within, and depend upon. Furthermore, information asymmetries (intentional or inadvertent) occur when some stakeholders hold key information (especially about a risk) that is not available to others. In some circumstances such as national security issues, information symmetries may be required, but in most projects this is a pathology that increases the likelihood of unk unks. Other pathological behaviors such as hiding information, shooting down messengers, covering up failures, and discouraging new ideas all prevent latent pathogens from coming to the surface. An excellent example of such a project is the development of the Hubble Space Telescope. Although the telescope’s primary mirror design and adjustment were critical to the project, no single person was charged with responsibility for it. Neither NASA nor its contractor insisted on carrying out all of the necessary tests. Overreliance on a single line of testing, failure to use outside critical resources, and rationalization of anomalies were prevalent. In spite of many indications showing that flaws existed, none were pursued (Westrum and Adamski 2010). A project team’s emphasis on consensus, a lack of information sharing, and a reluctance to invest in preventing a problem that it cannot imagine with great specificity (or that is “someone else’s problem”) thus increases the project’s susceptibility to unk unks. Collectively, these aspects signify a *dysfunctional culture* that tends to increase the likelihood of unk unks.

“Systematic neglect” is a particularly pernicious aspect of a *dysfunctional culture* that could result in unk unks. In the context of a project, systematic neglect involves taking no notice of the changes in the environment or new evidence but continuing to base action on outdated policies and precedencies. Biases such as groupthink, getting locked-up in a certain perspective, and ignoring reality that does not fit with the familiar frame often contribute to systematic neglect. A case study of the Federal Drug Administration’s fast-track 501(k) medical device approval process illustrates this point. This process allows manufacturers to introduce a new medical device without conducting rigorous, pre-market safety testing by showing that it is similar to previously approved devices. Several dangerous and defective products have reached customers via this process, some of which were subsequently recalled after causing deaths and serious injuries. Challoner and Vodra (2011) claimed that these apparently unknown outcomes could have been recognized but were not due to systematic neglect.

Thus, a variety of *project pathologies*—*project subsystem mismatches*, *fragmented expertise*, *stakeholders' unclear expectations*, and *dysfunctional culture*—may contribute to an increased likelihood of unk unks affecting a project.

Proposition 8: *Increased amounts of pathologies in and around a project will increase the likelihood of encountering unk unks.*

IV. IMPLICATIONS FOR PRACTICE: REDUCING UNK-UNKS

Our framework proposes factors and relationships that increase the likelihood of unk unks in projects. By characterizing a project in terms of these factors, a PM can identify specific aspects of a project's *product*, *process*, *organization*, *tools*, and *goals* in which unk unks might be lurking. Once specific areas with likely unk unks have been determined, a PM needs approaches to attack them and convert knowable unk unks to known unknowns. This section briefly presents several approaches in both the project design and behavioral categories to help PMs uncover knowable unk unks. In general, these approaches are orthogonal to the factors in our framework in that they may be used in any area likely to contain unk unks. However, as we will note, some of the approaches are particularly suited to addressing specific factors or areas.

4.1 Project Design Approaches

Project design-related approaches to uncovering knowable unk unks include: decomposing the project, analyzing scenarios, using checklists and predefined categories, scrutinizing project plans and admitting independent oversight, using long interviews, and picking up weak signals. *Decomposing the project* involves breaking it down into elements and their relationships—essential steps towards confronting the project's *complexity*. Hence, the very act of modeling a project in terms of the sub-factors of *complexity* presented in section 3.1 and with respect to each of the five project subsystems can increase project understanding and help uncover unk unks. Project decomposition begins with the natural structure of the overall purpose of the project (the "problem") and then decomposes it by identifying sub-problems relating to key areas (such as customer need, industry readiness, product functionality, cash usage, and the venture team) and complements it with experience and experimentation. Loch et al. (2008) cited the use of such an approach by Escend Technologies, a Silicon Valley start-up company, for the qualitative assessment of a project's vulnerability to unk-unks, and outlined the following steps. First, identify the problem structure: goals, external influences, activities, and causality of activities and effects. Second, break the problem into pieces—e.g., product modules, process activities, and stakeholders. Third, examine (through what could be a highly iterative and gradual process) the complexity and uncertainty of each piece to identify the major risks (known unknowns) that need managing and the knowledge gaps that point to areas of potential unk-

unks. Fourth, consider managing the selected pieces of the project in parallel by using different project management methods—e.g., an “option play” that treats different modes of project activity as options contingent on the outcomes (much like options in the financial securities market).

Scenario planning embodies a set of techniques to deal with uncertainties in a project environment by presenting the decision makers with several, fundamentally different outlooks on the future. It differs fundamentally from forecasting in that it accepts uncertainty, tries to understand it, and makes it a part of the reasoning. Scenarios are not projections, predictions, or preferences; rather they are coherent and credible alternative stories about the future built upon a dynamic sequence of interacting events, conditions, and changes. Cornelius et al. (2005) discussed the application of scenario analysis (combined with real options) in an oil and gas company in the mid-1990s and noted that focusing on the complex interplay of technological, regulatory, environmental, and supply factors through scenario planning could have helped to anticipate an emerging discontinuity in the U.S. natural gas market (p.107). Scenario analysis further benefits from the consideration of “risk cascades”—the indirect effects of direct threats or situations on other stakeholders, competitors, suppliers, and customers—which are often overlooked in basic scenario analysis (Lamarre and Pergler 2010). *Analyzing scenarios* is particularly suited to uncovering unk unks in projects with significant amounts of *complexity*, *complicatedness*, *dynamism*, *equivocality*, and *mindlessness*.

Using checklists and predefined categories of uncertainties represents deliberate efforts to codify learning from past problems to enlighten future planning. For example, instead of asking project planners to begin with a blank page, risk management approaches often provide prompts to address specific topics. Of course, providing such tools will not help if they are viewed as obstacles rather than facilitators of success, so it also matters whether and how such tools are actually used (Slegers et al. 2012). Checklists and categories must be viewed as prompts for thinking, not as substitutes for it.

Scrutinize project plans and admit independent oversight. Project plans represent a hypothesis for successful transformation from the current state to a desired future state. At a minimum, a plan contains information about aspects of the expected work, such as when it should start and finish, its expected costs, its expected results, and particular resources expected to be involved. These expectations should be scrutinized at various levels and to various degrees by the project’s stakeholders. This scrutiny could come in the form of reviews, audits, and even formal verification (checking whether the plan might to lead to success) and validation (checking whether the plan reflects a proper understanding of the success criteria), in terms of not only content but also the techniques by which it was generated (Leleur 2007). Much like a product that is designed and engineered, a project plan may be subjected to some of the techniques of reliability engineering, such as failure mode and effect analysis (FMEA) and robust design. Approaches to uncover more of the unintended consequences of system designs could be applied to projects as well. Just like the insurance of reliable designs may entail some redundancy, project plans may need predefined contingencies. Use of an independent board of overseers composed of experienced experts empowered to obtain all kinds of project data and information is another approach to reduce unk unks due to entrapped mindset and pathological intensity. A lack of such independent verification and validation was touted as a contributing factor to the loss of the Mars Climate Observer in 1992 (MOMFIB 1993).

The *long interview* approach involves (a) digging deeper and wider and asking “out-of-the box” questions of all the project participants and stakeholders at all stages and (b) not letting enthusiasm for the project show through, not focusing on the project team’s ideas, and not asking simple “boxed-in” or “yes or no” questions (Mullins 2007). This approach can help a project develop an understanding of the latent needs that project stakeholders are unable or unlikely to articulate readily. Mullins (2007) described how the long interview technique could have been efficacious in a new product development project at Silverglide Technologies, a company specializing in non-stick electro-surgical instruments for neuro/plastic surgeons. The company came up with what it thought was a novel product, a non-stick surgical probe. Although the surgeons liked the nonstick feature of the new product, the product failed since they were not accustomed to using a probe to operate. Subsequent studies revealed that the surgeons would have greatly liked non-stick forceps rather than probes, a knowable unk unk product design concept. Long interviews are especially helpful for catching *weak signals* and bypassing *pathological intensity* and *entrapped mindsets*.

More generally, potential unk-unks caused by *missing weak signals* may be reduced by looking out specifically for weak signals during planning and execution. Weak signals could come in subtle forms such as a disturbing feeling about the unfathomable complicatedness of a project, a realization that there may not be anyone in the organization who has a complete understanding of the entire project system or any one of its domains, or counterintuitive behaviors or outcomes (as felt by a visitor to the multi-billion dollar Large Hadron Super Collider project) (Homer-Dixon 2000, p.172). A three-stage approach often makes it possible to recognize and interpret weak signals: scanning (e.g., tapping local intelligence, leveraging extended networks, and mobilizing search parties), sense-making (e.g., testing multiple hypotheses, canvassing the wisdom of the crowd, developing diverse scenarios), and probing for further clarity (e.g., confronting reality, encouraging constructive conflict, and trusting seasoned intuition). Note that some of these approaches can overlap in method (such as in the use of scenarios to pick up weak signals) as well as in target area.

4.2 Behavioral Approaches

Behavioral approaches to uncovering knowable unk unks include: communicating frequently and effectively, balancing central control and local autonomy, incentivizing the discovery of unk unks, and cultivating a culture of alertness to unk unks. *Effective and frequent communication* is a valuable tool for anticipating and assessing unk unks driven by *equivocality*. Regularly and systematically reviewing decision-making and communication processes, including any assumptions that are factored into these processes, and seeking to remove information asymmetries, could be effective approaches to anticipate or uncover (and thereby reduce the likelihood of) unk unks. The Ladera Ranch earth-moving project in California (De Meyer et al. 2002) used this approach to uncover and deal with unk unks such as the discovery of prehistoric Indian ruins or rare animal or plant species. The PM and the team met weekly to discuss whether the project or its current plan should change and how. Thus, each project activity was treated as an "option play" requiring frequent and effective communication.

Unk unks driven by the *relationship complexity* and *dynamism* of a project determined by multiple technologies, geographic sites, diversity of interests, and external influences (all of which make the project management team vulnerable to the actions of others such as local teams or subcontractors) may be reduced by *balancing central control and local autonomy*. Granting autonomy to the local nodes of a multi-nodal project through decentralization of control facilitates adaptation and innovation to recognize and reduce unk unks (e.g., the effect of regulatory changes and customer preferences). While decentralization provides a way to compensate for knowledge gaps at the center (i.e., the PM), placement of appropriate levels of trust requires some prior experiences among parties. Complex projects often require controls for governance because autonomous local nodes are less willing to report problems, preferring either to seek a solution from within or even to wait until the problem becomes an issue for another node. To strike a balance between trust and control, project managers may use a mixed, top-down/bottom-up approach which includes (a) local or bottom-up empowerment to correct errors and (b) central or top-down responsiveness to embed learning across the project (Ivory and Alderman 2005).

A key insight from economic reasoning is that the *incentives* faced by individuals should be designed to motivate productive and desirable behaviors. In the present context, desirable behaviors are the ones that enable the PM to uncover and thereby reduce potential unk unks. Examples of such behaviors include timely and honest communication of missteps, errors, anomalous observations, and the inadequacy of one's own technical, social, psychological, or legal competencies to deal with an emerging situation. An effective approach is to develop (and demonstrate through actions) incentives that would convince individuals that it is acceptable to own up to an error or mistake rather than fail to alert upper management in time to do something about it. Conversely, it is also important to eliminate perverse incentives that induce counterproductive or undesirable behaviors, which lead to negative, unintended consequences and to the creation and concealment of emerging risks (IRGC 2010). Examples of perverse incentives in projects include the prevalence of a "check the box" mentality, which makes people strive only to meet pre-set indicators, and encouragement to prioritize short-term over long-term results.

Cultivate a culture of alertness to unk unks as an antidote to *mindlessness* and a *dysfunctional culture*. Some ways to cultivate such a culture include:

(a) *Develop systems thinking*, which includes thinking about limits to what is known about a project. Limits to what can be known imply limits to what can be achieved in an entirely pre-determined, planned way. Systems thinking acknowledges that context recognition is essential yet problematic—i.e., deciding what to do in a complex system is not a simple exercise of repeating what was successful the last time. Further, it emphasizes the use of multiple perspectives to reach a decision, does not expect to be completely right, and accommodates redirection in the face of mounting contrary evidence. Systems thinking helps a PM reduce the likelihood of unk unks driven by *novelty, entrapped mindset*, and *pathological intensity*.

(b) *Build experiential expertise*—i.e., intuitions, subtle understandings, and finely honed reflexes gained through years of intimate interaction with a particular natural, social, or technological system. Ensuring that a wide range of experiential expertise exists in a project is another approach for recognizing and dealing with potential unk unks.

(c) *Become a HRO* by embracing preoccupation with failure, reluctance to simplify, sensitivity to operations, commitment to resilience, and deference to expertise (Weick and Sutcliffe 2001).

(d) *Learn from surprising outcomes*. When analyzing unexpected outcomes, PMs are concerned with coherent explanations, with providing a good story − frequently the rhetoric of justification. However, the very desire for resolution and explanation may preclude the possibility of a deeper understanding of what lies behind the potential for catastrophic failure. Research in sociology suggest looking at the complexity of the contributory cause in accident analysis, the multiplicity of ways in which systems can fail, and perceptual and information difficulties. Narrative approaches (Boje 2001) help to surface issues which are subsumed within the rhetoric of justification and the explanations which follow failure or an outcome unknown *a priori*.

IV. CONCLUSIONS

Diagnosing and dealing with unrecognized but *knowable* uncertainties is of paramount importance in project management. Although a few recent studies have dealt with unk unks in the management of projects − in which the existence of unk unks is readily apparent or may be assumed given the type of project (e.g., new product development or new process implementation) − the project management literature lacks frameworks and models to deal with unk unks. Our paper fills a gap in the project management literature by presenting a framework for recognizing and reducing specific areas in a project likely to contain unk unks. This framework conceptualizes six main factors – relating to both project design and behavioral issues – proposed to increase the likelihood of unk unks in a project: *complexity*, *complicatedness*, *dynamism*, *equivocality*, *mindlessness*, and *project pathologies*. This framework is both parsimonious and meaningful. We develop eight propositions, each of which covers five important subsystems (*product*, *process*, *organization*, *tools*, and *goals*) through which unk unks can emerge in a project.

Besides filling a gap in the project management literature, our paper makes a practical contribution by helping a PM to diagnose, recognize, and reduce the likelihood of unk unks in specific aspects of a project and thence deal effectively with the otherwise unrecognized risks and opportunities. If it is known that unk unks are more likely because of particular project characteristics, then it enables the PM to choose appropriate risk management strategies, such as aggressive approaches for the exploitation of upside surprises (opportunities) and conservative approaches for the mitigation of downside threats (risks). Also, some unk unks may be large events that are both unexpected and highly consequential. Awareness of an increased potential for unk unks enables a PM to allocate resources more appropriately and create an organization that will not fall apart as easily when unk unks occur − and that might even benefit from them. Since many unk unks result from failures of recognition, a systematic diagnosis of the characteristics of a project and its operating environment, facilitated by a framework such as ours, will enable PMs to develop at least a *qualitative* knowledge about the likely presence of lurking unk unks. By putting this insight to use, a PM has a much better shot at converting knowable unk unks into known unknowns.

Our framework represents an important first step toward understanding the drivers of unk unks in project management. We visualize several avenues for furthering this research. Future research could explore the shape (e.g., linear or non-linear) and relative strength of the proposed relationships. It could also explore key questions such as: How much effort should a project manager put into discovering unk unks? What constitutes due diligence for a given project? How can stakeholders be led to agree on this? What solutions—cognitive, managerial, and organizational capability-based approaches—would be most appropriate for resolving the impact of each of the causal factors? In some ways, these questions are analogous to challenges in other areas, such as how much effort (and where) an automotive company should put into making a safe car. Clearly some amount of prudent design and testing is required, and some additional amount could provide a competitive differentiation for the risk averse, but it is also clear that many cars could be safer than they are if designers and customers were willing to give up other attributes. A similar argument can be made regarding projects: all project stakeholders may not have the same appetite for risk and surprises, so what constitutes due diligence in uncertainty management will differ across projects. Coming to such a decision will require the best possible estimates of the likelihood of a project to encounter unk unks. This is where we hope this paper and the future research it enables will improve our knowledge and capabilities. Finally, since all types of operations, not just projects, can be characterized by the factors in our framework and have products, processes, organizations, tools, and goals, we are optimistic that many insights from this research could be generalized beyond projects.

V. REFERENCES

Alderman, N., I.P. McLoughlin, C.J. Ivory, A.T. Thwaites, and R. Vaughn (2003) “Trains, cranes, and drains: Customer requirements in long-term engineering projects as a knowledge management problem,” in von Zedtwitz, M., et al. (Eds.) *Management of Technology*. Pergamon Press. Oxford, UK, pp. 331-348.

Baccarini, D. (1996) “The concept of project complexity—a review,” *Int J of Project Mgmt*, 14(4), 201-204

Baranger, M (2000) “Chaos, Complexity, and Entropy” A physics talk for non-physicists, MIT-CTP-3112, Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, MA.

Bar-Yam, Y. (1997) *Dynamics of Complex Systems*, Addison-Wesley, Reading, MA

Bazerman, M.H., and M.D. Watkins (2004) *Predictable Surprises*, Harvard Business School Press, Boston, MA

Boje, D. (2001) “*Narrative Methods for Organizational and Communications Research*”, Sage Publications, London, UK

Braha, Dan and Yaneer Bar-Yam (2007) "The Statistical Mechanics of Complex Product Development: Empirical and Analytical Results," *Management Science*, **53**(7): 1127-1145.

Brockhoff, K. (2006) “On the Novelty Dimension in Project Management,” *Project Management Journal*, 37(3), p. 26

Browning, T.R. and A.A. Yassine (2010) "A Random Generator of Resource-Constrained Multi-Project Network Problems," *Journal of Scheduling*, **13**(2): 143-161.

Browning, T.R. (2007) "Program Architecture and Adaptation," *Proc. of the Symposium on Complex Systems Eng.*, Santa Monica, CA, Jan. 11-12.

Browning, T.R. and R.D. Heath (2009) "Reconceptualizing the Effects of Lean on Production Costs with Evidence from the F-22 Program," *Journal of Operations Management*, **27**(1): 23-44.

Browning, T.R., E. Fricke and H. Negele (2006) "Key Concepts in Modeling Product Development Processes," *Systems Engineering*, **9**(2): 104-128.

Beven, K. (2006) "A Manifesto for the Equifinality Thesis," Journal of Hydrology, 320: 18-36

Chabris, C.F. and Simon, D.J. (2010) *Invisible Gorillas*, Crown: New York, NY.

Challoner, D.R. and W.W. Vodra (2011) "Medical Devices and Health – Creating a New Regulatory Framework for Moderate-Risk Devices" *New England Journal of Medicine*, 365 (11): 977-979

Choi, T.Y., K.J. Dooley and M. Rungtusanatham (2001) "Supply Networks and Complex Adaptive Systems: Control versus Emergence," *Journal of Operations Management*, **19**: 351-366.

Chu, D., R. Strand and R. Fjelland (2003) "Theories of Complexity: Common Denominators of Complex Systems," *Complexity*, **8**(3): 19-30.

Clarkson, P.J., C. Simons and C. Eckert (2004) "Predicting Change Propagation in Complex Design," *Journal of Mechanical Design*, **126**:788-797

Collyer, S. and C.M.J. Warren (2009) "Project management approaches for dynamic environments," *International Journal of Project Management*, 27, 355-364.

Cornelius, P., A. Van de Putte and M. Romani (2005) "Three Decades of Scenario Planning in Shell," *California Management Review*, **48**(1): 92-109.

D'Aveni, R. (1994) *Hypercompetition*. New York, Free Press.

De Meyer, A., C.H. Loch, and M.T. Pich (2002) "Managing Project Uncertainty: From Variation to Chaos," *MIT Sloan Management Review*, Winter: 60-67.

de Weck, O. and C. Eckert (2007) "A Classification of Uncertainty for Early Product and System Design," Massachusetts Institute of Technology, Engineering Systems Division, Working Paper ESD-WP-2007-10.

Dooley, K.J. and A.H. Van de Ven (1999) "Explaining Complex Organizational Dynamics," *Organization Science*, **10**(3): 358-372.

Eisenhardt, K.M. (1989) "Making fast strategic decisions in high-velocity environments." *Academy of Management Journal*, 32, 543-576.

Forrester, J.W. (1971) "Counterintuitive Behavior of Social Systems," *Technology Review*, **73**(3)

Frishammar, J., H. Florén and J. Wincent (2011) "Beyond Managing Uncertainty: Insights From Studying Equivocality in the Fuzzy Front End of Product and Process Innovation Projects," *IEEE Transactions on Engineering Management*, **58**(3): 551-563.

Frizelle, G. (1998) *The Management of Complexity in Manufacturing*, London, UK: Business Intelligence Limited.

Geraldi, J., H. Maylor and T. Williams (2011) "Now, Let's Make It Really Complex (Complicated): A Systematic Review of the Complexities of Projects," *Int Journal of Operations & Production Management*, **31**(9): 966-990.

Gokpinar, B., W.J. Hopp and S.M.R. Iravani (2010) "The Impact of Misalignment of Organizational Structure and Product Architecture on Quality in Complex Product Development," *Management Science*, **56**(3): 468-484.

Handfield, R.B. and S.A. Melnyk (1998) "The Scientific Theory-Building Process: A Primer using the Case of TQM," *Journal of Operations Management*, **16**(4): 321-339.

Hillson, D. (2002) "What is risk? Towards a common definition," *InfoRM, Journal of the UK Institute of Risk Management*, April 2002, p. 11-12.

Hirschi, N.W. and D.D. Frey (2002) "Cognition and Complexity: An Experiment on the Effect of Coupling in Engineering Design," *Research in Engineering Design*, **13**(3): 123-131.

Holland, J.H. (1998) *Emergence*, Reading, MA: Helix (Addison-Wesley).

Homer-Dixon, T. (2000) *The Ingenuity Gap*, Alfred A. Knopf, New York, NY.

Hubbard, Douglas W. (2009) *The Failure of Risk Management*, Wiley, New York, NY.

INCOSE (2007) *Systems Engineering Handbook*, Version 3.1, International Council on Systems Engineering.

IRGC (2010) "The Emergence of Risks: Contributing Factors," Report of the International Risk Governance Council, Geneva, 2010.

Ivory, C and N. Alderman (2005) "Can Project Management Learn Anything from Studies of Failure in Complex Systems?" *Project Management Journal*, 36(3): 5-16.

Jacobs, M. A. and M. Swink (2011) "Product portfolio Architectural Complexity and Operational Performance: Incorporating the Roles of Learning and Fixed Assets," *Journal of Operations Management*, **29**(7-8): 677-691.

Jones, B.S. and P. Anderson (2005) "Diversity as a Determinant of System Complexity," Digital Design Studio, Glasgow School of Art, GIST Technical Report 2005-1

Kauffman, S.A. and S. Levin (1987) "Towards a general theory of adaptive walks on rugged landscapes," *Journal of*

Theoretical Biology, **128**, 11-45.
Kreye, M.E., Y.M. Goh, and L.B. Newnes (2009) "Uncertainty in through life costing within the concept of product service systems: a game theoretic approach," *Proc of the 17th Int Conf on Eng Design*, Stanford, CA, Aug 24-27.
Kutsch, E. and M. Hall (2010) "Deliberate Ignorance in Project Risk Management," *International Journal of Project Management*, **28**(3): 245-255.
Lamarre, E. and M. Pergler (2010) "Risk: Seeing Around the Corners," *McKinsey Quarterly* (1): 102-106.
Lampel, J., J. Shamsie, and Z. Shapira (2009) "Experiencing the Improbable: Rare Events and Organizational Learning," *Organizational Science*, **20**(5): 835-845.
Landau, M. and D. Chisholm (1995) "The Arrogance of Optimism: Notes on Failure-Avoidance Management," *Journal of Contingencies and Crisis Management* **3**(2): 67-80.
Langer, E. (1989) *Mindfulness*, Harvard Business School Press, Boston, MA
Lao Tsu. *Tao Te Ching*. Vintage Books, New York, 1972.
Lawson, M.B. (2001) "In Praise of Slack: Time Is of the Essence," *Academy of Management Executive*, **15**(3).
Leleur, S. (2007) "Systemic Planning: Dealing with Complexity by a Wider Approach to Planning," *Emergence: Complexity & Organization*, **9**(1-2): 2-10.
Lévárdy, V. and T.R. Browning (2009) "An Adaptive Process Model to Support Product Development Project Management," *IEEE Transactions on Engineering Management*, **56**(4): 600-620.
Linton, W.J. (1878) *Poetry of America*, London, UK: William Clowes and Sons.
Lions, J. L. (1996) "Ariane 5: Flight 501 Failure," Report by the Inquiry Board, Paris: European Space Agency, available at www.esrin.esa.it/tidc/Press/Press96/ariene5rep.html
Loch, C.H., A. De Meyer and M.T. Pich (2006) *Managing the Unknown.* Hoboken, NJ: Wiley.
Loch, C.H., M.E. Solt and E.M. Bailey (2008) "Diagnosing Unforeseeable Uncertainty in a New Venture," *Journal of Product Innovation Management*, **25**(1): 28-46.
Miles, M.B. and A.M. Huberman (1984) *Qualitative Data Analysis*, Beverly Hills, CA: Sage.
Miller, G.A. (1956) "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information," *Psychological Review*, **63**(2): 81-97.
Mintzberg, H. (1979) "An Emerging Strategy of 'Direct' Research," *Administrative Science Quarterly*, **24**(4): 582-589.
MOMFIB (1993) "Report of the Mars Observer Mission Failure Investigation Board," Mars Observer Mission Failure Investigation Board, Report, Dec 31.
Montealegre, R., H.J. Nelson, C.I. Knoop and L.M. Applegate (1996) "BAE Automated Systems (A): Denver International Airport Baggage-Handling System," Harvard Business School, Teaching Case 9-396-311, Nov 6.
Mullins, J.W. (2007) "Discovering 'Unk unks': How Innovators Identify the Critical Things They Don't Even Know that They Don't Know," *MIT Sloan Management Review*, **48**(4): 17-21.
PC (1986) "Investigation of the Challenger Accident" Report of the Presidential Commission, House Report No. 99-1016, available at http://www.gpo.gov/fdsys/pkg/GPO-CRPT-99hrpt1016/pdf
Perminova, O., M. Gustafsson and K. Wikström (2008) "Defining Uncertainty in Projects - A New Perspective," *International Journal of Project Management*, **26**(1): 73-79.
Perrow, C. (1984) *Normal Accidents: Living with High-Risk Technologies*. New York, NY: Basic Books.
Pimmler, T.U. and S.D. Eppinger (1994) "Integration Analysis of Product Decompositions," *Proc. of the ASME Int. Design Eng. Tech. Confs. (Design Theory & Methodology Conf.)*, Minneapolis, Sep.
PMI (2013) *A Guide to the Project Management Body of Knowledge*, 5th Edition, Newtown Square, PA: Project Management Institute.
Roberts, K. H. (1990) "Some characteristics of one type of high reliability organization," *Organization Science*, 1(2), p. 160-176
Rosenkopf, L. and P. McGrath (2011) "Advancing the Conceptualization and Operationalization of Novelty in Organizational Research," *Organization Science*, 22(5): 1297-1311.
Ruwe, D. and Skinner, W. (1987) "Reviving a Rust Belt Factory," *Harvard Business Review*, May-June, p. 70-76.
Sauser, B.J., R.R. Reilly and A.J. Shenhar (2009) "Why Projects Fail? How Contingency Theory Can Provide New Insights - A Comparative Analysis of NASA's Mars Climate Orbiter Loss," *International Journal of Project Management*, **27**(7): 665-679.
Schrader, S., W.M. Riggs, and R.P. Smith (1993) "Choice over uncertainty and ambiguity in technical problem solving," *J. of Engineering Technology Management*, **10**: 73-79
Shenhar, A. (2001) "One Size Does Not Fit All Projects: Exploring Classical Contingency Domains," *Management Science*, **47**(3): 394-414.
Simon, D. J. and Chabris, C. F. (1999) "Gorillas in our midst: sustained inattentional blindness for dynamic events," *Perception*, vol. 28, 1059-1074.
Simon, H. A. (1955) "A Behavioral Model of Rational Choice," *Quarterly J. of Economics*, 69(1): 99-118.
Simon, H. A. (1956) "Rational Choice and the Structure of the Environment," *Psychological Review*, 63, p. 129-138.

Simon, H. A. (1962) “The Architecture of Complexity,” *Proceedings of the American Philosophical Society*, **106**(6): 467-482.

Slegers, N.J., R.T. Kadish, G.E. Payton, J. Thomas, M.D. Griffin and D. Dumbacher (2012) “Learning from Failure in Systems Engineering: A Panel Discussion,” *Systems Engineering,* **15**(1): 74-82.

Smithson, M. (1989) *Ignorance and Uncertainty,* Springer-Verlag, New York, NY

Sommer, S.C. and C.H. Loch (2004) “Selectionism and Learning in Projects with Complexity and Unforeseeable Uncertainty,” *Management Science*, **50**(10):1334-1347.

Sosa, M.E., S.D. Eppinger and C.M. Rowles (2004) "The Misalignment of Product Architecture and Organizational Structure in Complex Product Development," *Management Sci.*, **50**(12): 1674-1689.

Sosa, M.E., J. Mihm and T.R. Browning (2011) "Degree Distribution and Quality in Complex Engineered Systems," *J. of Mechanical Design,* **133**(10).

Sosa, M.E., J. Mihm and T.R. Browning (2013) "Linking Cyclicality and Product Quality," *Manufacturing & Service Operations Management,* **15**(3): 473-491.

Stokes, K. (2006) “Polyurethane Pacemaker Leads: The contribution of clinical expertise to the elucidation of failure modes and biodegradation mechanisms” in *Clinical Evaluation of Medical Devices*, 2nd ed., KM Becker and JJ Whyte, Human Press Inc., Totowa, NJ, p. 285-304.

Strange, N. (2007) Smokes and Mirrors, A&C Black, London, UK

Suh, N.P (2001) *Axiomatic Design*, Oxford University Press, New York, NY

Taleb, N.N. (2010) *The Black Swan,* Random House Publishing, New York, NY.

Taleb, N. N. (2012) “Learning to love volatility”, *Wall Street Journal*, November 17, 2012, p. C1

Tang, V. and V. Salminen (2001) “Towards a Theory of Complicatedness: Framework for Complex Systems Analysis and Design,” *Proc. of the 13th International Conference on Engineering Design (ICED)*, Glasgow, Scotland, Aug.

Tatikonda, M.V. and S.R. Rosenthal (2000) “Technology Novelty, Project Uncertainty, and Product Development Execution Success,” *IEEE Transactions on Engineering Management*, **47**(1): 74-87

Tenner, E. (2001) “When Systems Fracture: On the tendency of advanced technology to promote self-deception,” *Harvard Magazine*, November-December 2001, p 26-29.

Thompson, J.D. (1967) *Organizations in Action*, New York: McGraw-Hill.

Tuchman, B.W. (1965) “Developmental sequence in small groups,” *Psychological Bulletin*, **63**(6): 384-399.

Tufte, E.R. (1997) “Visual Explanations,” Graphics Press, Cheshire, CT, USA

Tversky, A. and D. Kahneman (1974) “Judgment under Uncertainty: Heuristics and Biases,” *Science,* 185(4157), p. 1124-1131, September.

Unilever (1980) “Installation of a New 6-ton Glycerin Evaporator in Bombay Factory,” Technical Report-HLL-SF-1980, Bombay, India

Vidal, L., F. Marle and J. Bocquet (2011) “Measuring Project Complexity using the Analytic Hierarchy Process,” *International Journal of Project Management*, **29**(6): 718-727.

Wacker, J.G. (1998) “A definition of theory: research guidelines for different theory-building research methods in operations management,” *Journal of Operations Management*, **16**, 361-385.

Warfield, John N. (2000) *A Structure-Based Science of Complexity*, Amsterdam: Kluwer.

Weick, K. E. and K. H. Roberts (1993) “Collective mind in organizations: Heedful interrelating on flight decks,” *Administrative Science Quarterly*, 38(3): 357–381.

Weick, K. E. and K.M Sutcliffe (2001) “Mindfulness and the quality of organizational attention,” *Organizational Science*, 17(4) 514-524.

Weick, Karl E., K. Sutcliffe, and D. Obstfeld (1999) “Organizing for high reliability: processes of collective mindfulness,” In B.M. Staw and L.L. Cummings (Eds.), *Research in Organizational Behavior*, 21: 81–123, Greenwich, CT: Jai Press.

Westrum, R. and A.J. Adamski (2010) “Organizational Factors Associated with Safety and Mission Success in Aviation Environments,” in Wise, John A. *et al.*, Eds., *Handbook of Aviation Human Factors,* Boca Raton, FL: CRC Press, pp. 5-1 - 5-37.