White Paper

Living on the Edge

Managing Project Complexity

Kathleen B. Hass, PMP

Project Management and Business Analysis Practice Leader

Management Concepts

Introduction

Complexity is one of those words that is difficult to define. Some say *complexity* is the opposite of *simplicity*; others say *complicated* is the opposite of *simple*, while *complex* is the opposite of *independent*. Complexity exists in systems because a large number of variables are present, or in situations where cause and effect are subtle. A complex structure is said to use interwoven components that introduce mutual dependencies and produce more than the sum of their parts. In today's systems, this is the difference between a myriad of connecting "stovepipes" and an effective set of "integrated" solutions (Lissack and Roos, 2002). A complex system can also be described as one in which there are multiple interactions between many different components (Rind, 1999). In the context of a design that is difficult to understand or implement, complexity is the quality of being intricate and compounded (Alawneh, *et al.*, 2006).

In the twenty-first century, business processes have become more complex—that is, more interconnected, interdependent, and interrelated than ever before. Businesses today are rejecting traditional management structures to create complex organizational communities comprised of alliances with strategic suppliers, networks of customers, and partnerships with key political groups, regulatory entities, and even competitors. Through these alliances, organizations are addressing the pressures of unprecedented change, global competition, time-to-market compression, rapidly changing technologies, and yes, increasing complexity. Twenty-first century solutions deal with behaviors arising from the interdependence of users, technology, and context often referred to as "wicked" problems (Vandergriff, 2006). As a result, business systems are significantly more complex than in the past. It follows that the effort to manage the projects that implement these complex business systems presents new challenges. The huge cost and schedule overruns that have been commonplace in the past are no longer acceptable. To reap the rewards of significant, large-scale business/technology change initiatives, designed to not only keep organizations in the game but make them a major player, we must find new ways to manage project complexity.

MANAGEMENTCONCEPTS

This paper explores how the principles of complexity thinking can be used to find new creative ways to think about and manage twenty-first century projects. Creativity manifests itself in spontaneous emergence; *emergence* is at the focus of complexity thinking. Emergence happens when the intricate interplay of dynamics, forces, and energies are present. Creativity emerges in systems that are constantly evolving, reorganizing into dynamic structures, or dissolving in chaos. The genius of complexity thinking is that it nourishes and masters creativity, never trying to lock it into systems, subsystems, or parts (Dimitroy, 2007).

Scientists originally thought the world to be linear, explained by simple cause and effect relationships. They theorized that if we could break down natural systems into their component parts, we could learn how to predict and control them. Gradually, complexity theory emerged. Complexity theory is based on relationships, emergence, patterns, and iterations. It maintains that the universe is full of systems (weather systems, immune systems, social systems) that are complex and constantly adapting to their environment; hence the term *complex adaptive systems* (Fryer, 2007). Our challenge is to learn how to employ complex thinking to building solutions for the twenty-first century.

The Project Complexity Model

There are many different ways projects can become both complicated and complex: the business problem might be difficult to define; the solution may be elusive and difficult to determine, describe, or grasp; the business boundaries might be unclear; and the business process relationships are likely to be non-linear and contain multiple feedback loops. Today's complex business systems will change over time, and therefore need to be dynamic, adaptive, and flexible. Some business systems are nested—that is, the *components* of the system may themselves be complex. There are a number of *dimensions of project complexity* that will be discussed, including: team size, diversity and composition, project duration, schedule, cost and scope flexibility, clarity of the problem and solution, stability of requirements, strategic importance of the initiative, the level of organizational change, inter-project dependencies, political sensitivity, and unproven technology.

The **Project Complexity Model** presented here is used to evaluate project size, complexity, and risk, and determine the specific dimensions of complexity that are present on a project. The project complexity model describes the project characteristics in terms of complexity dimensions for projects that are: (1) small, independent, and low risk; (2) medium-sized with moderate complexity and risk; and (3) large, with high complexity and risk. (Refer to Figure 1: Project Complexity Model)

Directions for Using the Project Complexity Model

To use the model to diagnose the size, complexity, and risk of a particular project, shade the boxes that describe the project and apply the complexity formula below. Note that a project which is small in size may be moderately or even highly complex based on the existence of other complexity dimensions. (Refer to Figure 2: Project Complexity Formula)

When to Apply Complexity Thinking to Projects

Apply complexity thinking to help manage complex projects during many phases of the project life cycle. Take your project leadership team through the analysis recommended in the remaining sections of this paper to apply complexity thinking to the major decisions you make about your project. Specifically, adopt the project complexity management approaches outlined here when you are:

- Managing projects
  - Conducting enterprise analysis during the study phase of a project
  - Conducting feasibility studies to determine the optimal business solution
  - Preparing the business case for a new project proposal

Figure 1: Project Complexity Model

Complexity Dimensions	Project Profile		
	Independent	**Moderately Complex**	**Highly Complex**
Time and Cost	< 3 months < $250K	3–6 months $250K–$750K	> 6 months > $750K
Team Size	3–4 team members	5–10 team members	> 10 team members
Team Composition and Performance	• Strong project leadership • Team staffed internally, has worked together in the past, and has a track record of reliable estimates. • Formal, proven PM, BA, SE methodology with QA and QC process defined and operational	• Competent project leadership • Team staffed with internal and external resources; internal staff has worked together in the past and has a track record of reliable estimates • Contract for external resources is straightforward; contractor performance is known • Semi-formal methodology with QA and QC processes defined.	• Inexperienced project leadership • Complex team structure of varying competencies (e.g., contractor teams, virtual teams, culturally diverse teams, outsourced teams) • Complex contracts; contract performance is unknown • Diverse methodologies.
Urgency and Flexibility of Cost, Time, and Scope	• Minimized scope • Small milestones • Schedule, budget, and scope are flexible	• Schedule, budget, and scope can undergo minor variations, but deadlines are firm • Achievable scope and milestones	• Over-ambitious schedule and scope • Large, extended milestones • Deadline is aggressive, fixed, and cannot be changed • Budget, scope, and quality have no room for flexibility
Problem and Opportunity Clarity	• Clear business objectives • Easily understood problem or opportunity	• Defined business objectives • Problem or opportunity is undefined	• Unclear business objectives • Problem or opportunity is ambiguous and undefined
Solution Clarity and Level of IT Complexity	• Solution is readily achievable using existing, well-understood technologies • IT complexity low	• Solution is difficult to achieve or the technology is proven but new to the organization • Moderate IT complexity and legacy integration	• Solution requires ground-breaking innovation • Solution is likely to be using immature, unproven, or complex technologies provided by outside vendors • IT complexity and legacy integration high
Requirements Stability and Risk	• Strong customer and user support • Basic requirements understood, straightforward, and stable	• Adequate customer and user support • Basic requirements understood, but are expected to change • Moderately complex functionality requirement	• Inadequate customer and user support • Requirements are poorly understood and largely undefined • Highly complex functionality requirement
Strategic Importance, Political Implications, and Multiple Stakeholders	• Strong executive support • No political implications • Straightforward communications	• Adequate executive support • Some direct mission impact • Minor political implications • 2–3 stakeholder groups • Challenging communication and coordination effort	• Inadequate executive support • Affects core mission • Major political implications • Visible at highest levels of the organization • Multiple stakeholder groups with conflicting expectations
Level of Organizational Change	• Impacts a single business unit, one familiar business process, and one IT system	• Impacts 2–3 somewhat familiar business units, processes, and IT systems	• Large-scale organizational change that impacts the enterprise • Spans functional groups or agencies • Shifts or transforms the organization • Impacts many business processes and IT systems
Level of Commercial Change	• Minor changes to existing commercial approach	• Enhancements to existing commercial practices	• Ground-breaking commercial practices
Risk, External Constraints, and Dependencies	• Considered low risk • Some external influences on project • No challenging integration issues • No new or unfamiliar regulatory requirements • No punitive exposure	• Considered moderate risk • Some project objectives dependent on external factors • Challenging integration effort • Some regulatory requirements • Acceptable exposure	• Considered high risk • Overall project success depends largely on external factors • Significant integration required • Highly regulated or novel sector • Significant exposure

Figure 2: Project Complexity Formula

Highly Complex	Moderately Complex	Independent
Level of change = large-scale enterprise impacts OR Both problem and solution are difficult to define or understand, and the solution is difficult to achieve; solution likely to be using unproven technologies OR Four or more dimensions in the "Highly Complex" column	Four or more categories in the "Moderately Complex" column OR One category in "Highly Complex" column and three or more in the "Moderately Complex" column	Remaining Combinations

- Conceptualizing and architecting the business solution
- Initiating and planning a new project
- Initiating and planning a new major phase of a project
- Recovering a troubled project

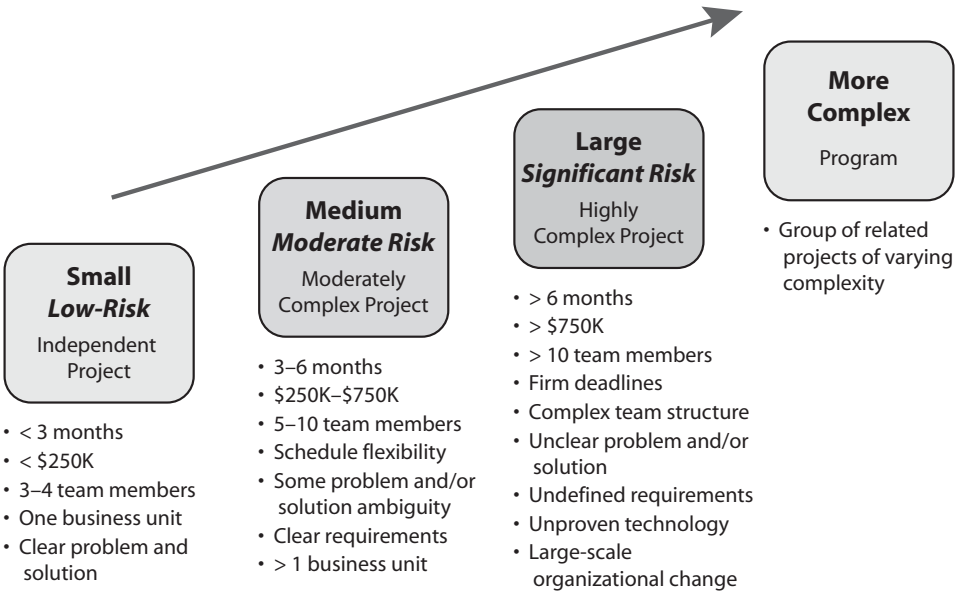
- Managing programs that consist of groups of related projects of varying complexity
  - Initiating and planning a new program
  - Recovering troubled projects within a program

Refer to Figure 3 for another view of the Project Complexity Model for Programs. This view incorporates the concept of *program management*. As you diagnose the complexity of each project within the program, it is wise to focus on the high-risk, highly complex projects first to ensure the risks and complexities can be managed, before investing time and resources on the less complex projects.

Applying Complexity Thinking to Manage Projects

Applying complexity thinking to projects involves selecting methods and techniques, and assigning project leadership based on the *project profile* and

Figure 3: Project Complexity Model for Programs



the *complexity dimensions* that are present. There are four steps in the process:

1. Select the project cycle based on the project profile

   The project team first determines the appropriate project cycle to use based on the project profile. All projects have a cycle—a sequence of stages through which the project passes. Typical cycles have a series of periods and phases, each with a defined output that guides research, development, construction, and/or acquisition of goods and services (Mooz, *et al*., 2003). As projects have become more complex, project cycles have evolved to address the various levels of complexity.

2. Select appropriate management techniques based on complexity dimensions

   Projects sometimes fail because good methods and techniques are misapplied. Applying complexity thinking to determine the appropriate techniques to use based on the complexity dimensions present is the key to success when managing complex projects. Successful managers of complex projects use *situational project leadership* by adapting not only their leadership style, but also the project management, systems engineering, and business analysis techniques to manage the complexity dimensions that exist.

3. Assign project leaders based on the project profile

   Projects sometimes fail because of an inappropriate assignment of project leaders. The project manager, business analyst, business visionary, and systems/software engineer are critical project leadership positions. Once the project cycle is selected, and project complexity dimensions have been identified, organizations should also apply complexity thinking to project leadership assignments.

4. Build complex, adaptive business solutions

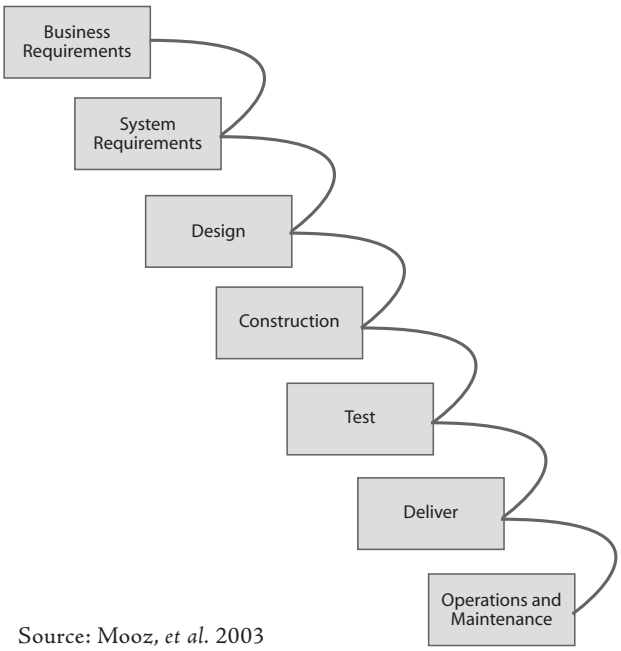
   The 21st century challenge we face is to become capable of building complex business solutions that meet today's business needs and that can adapt, self-adjust, or be easily changed as the business strategy and/or the competitive environment changes. As we learn how to manage project complexities, we must also become adept at building complex, adaptive business solutions.

Step 1: Applying Complexity Thinking to Select the Project Cycle

Applying Complexity Thinking to Small, Independent, Low-Risk Projects

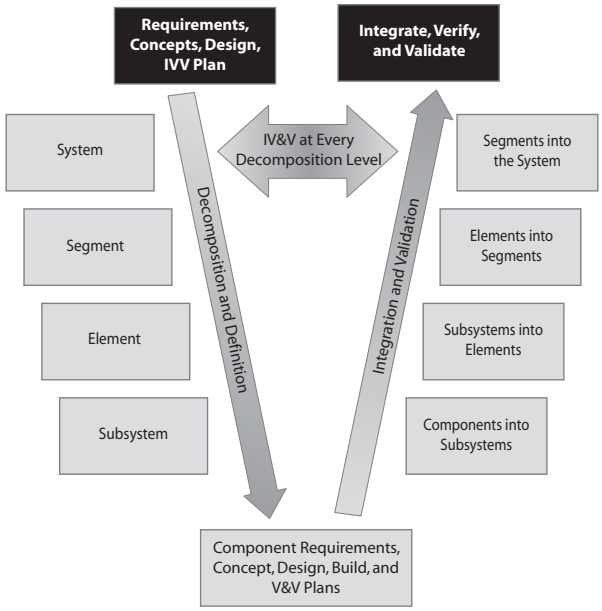
The *Waterfall Model* is a highly effective project cycle for short-duration, well-understood projects with stable requirements and few or no dependencies. This is the classic systems development lifecycle. It is essentially a linear ordering of activities that presumes requirements are fully developed and approved. It also assumes that events affect-

Figure 4: Waterfall Model



Source: Mooz, *et al.* 2003

Figure 5: Vee Model



Source: Mooz, *et al.*, 2003

ing the project are predictable, tools and activities are well-understood, and as a rule, once a phase has been completed, it will not be revisited. The strengths of this approach are that it lays out the steps for development and stresses the importance of requirements. The limitations are that projects rarely follow the sequential flow, and clients usually find it difficult to completely state all requirements early in the project. Figure 4 depicts the classic Waterfall Model.

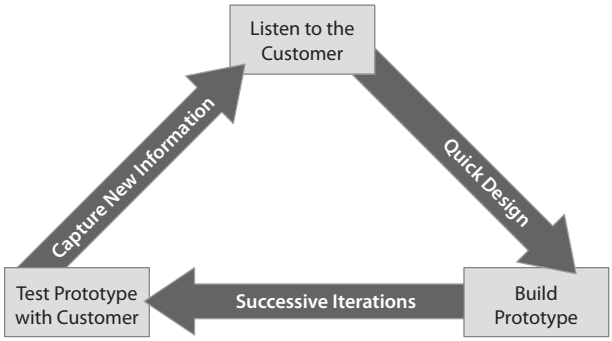
Applying Complexity Thinking to Medium-Sized, Moderately Complex Projects

As projects become more complicated and more dependencies exist, it is wise to break the work down into manageable components or sub-projects developed and, if possible, delivered incrementally. The challenge is to ensure that the increments can be integrated into a fully functioning solution that meets project objectives. The *"Vee" Model*, authored by NASA to manage project complexity, is often used for moderate-risk projects because it includes the relationship between decomposition and integration, and the concept of incremental delivery. The Vee Model involves progressively elaborating requirements (the left side of the "V"), while defining the approach to integration, verification, and validation (the right side of the "V") at every decomposition level. It assumes that the requirements and testing processes, elicited through various business analysis techniques, are known before building begins. In essence, the Vee Model adds the vertical dimension to the Waterfall Model, altering the Waterfall shape into a "V." At the base of the Vee is the component build. Components of the system are developed in increments, and each component produces a partial implementation; functionality is gradually added in subsequent increments. Figure 5 depicts the classic Vee Model.

Applying Complexity Thinking to Large, Highly Complex Projects

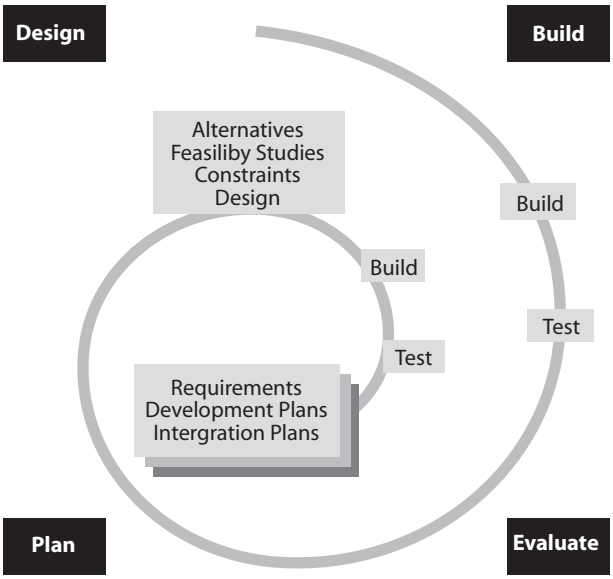
Since complex projects are by their very nature less predictable, it is important for the project team to keep their options open, and moreover, to build options into the project approach. This "keep-our-options-open" approach requires a considerable amount of time spent on researching and studying the business problem or opportunity; conducting competitive, technological, and benchmark studies; defining dependencies and interrelationships; and, identifying all potential options to meet the business need or solve the business problem. In addition, the team analyzes the economic, technical, operational, cultural, and legal feasibility of each

Figure 6: Rapid Prototyping Model



Source: Pressman, 2005

Figure 7: Spiral Model



Source: Bechtold, 1999

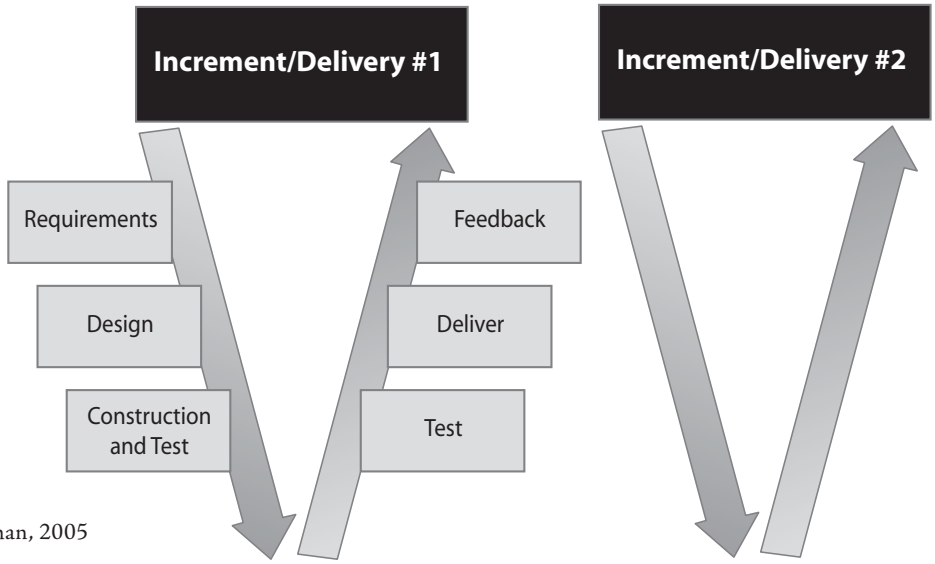
solution option until it is clear which option has a higher probability of success. This approach often involves rapid prototyping (refer to Figure 6)—a fast build of a solution component to prove an idea is feasible—typically used for high-risk components, requirements understanding, or for a proof of concept. The model that applies in this situation is the *Spiral Model*, described as an iterative waterfall approach. Figure 7 depicts the Spiral Model. In addition, the *Evolutionary Development Model* can be used, which allows for the implementation of the solution incrementally, based on experience and learning results from prior versions. Solution functions are prioritized based on business value, and once high-risk areas are resolved, the highest value components are delivered first. Figure 8 depicts the Evolutionary Development Model.

Finally, if requirements are ambiguous and poorly understood, the *Agile Model* (refer to Figure 9) is appropriate for analysis and development. Agile analysis is a highly evolutionary and collaborative process where developers and project stakeholders actively work together to understand the domain, to identify what needs to be built, and to estimate and prioritize functionality.

Step 2: Applying Complexity Thinking to Manage Project Complexity Dimensions

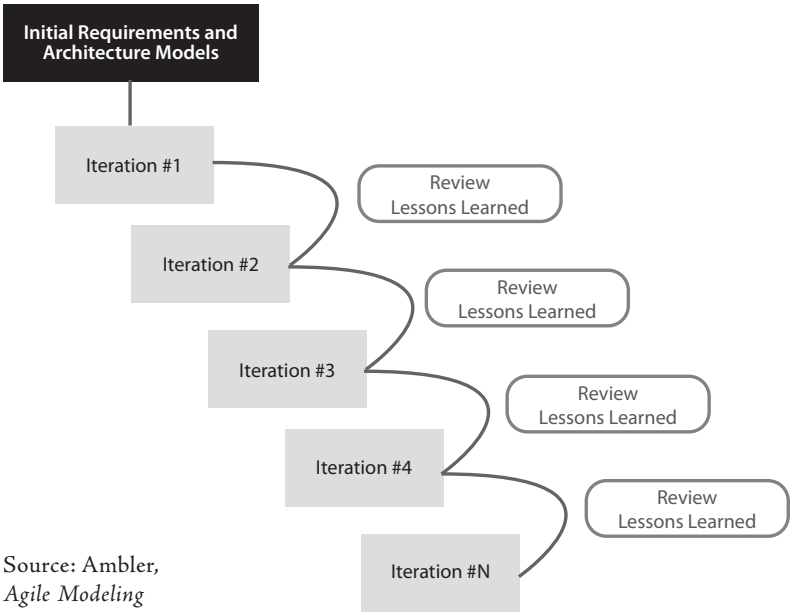
Traditional reductionist project management, systems engineering, and business analysis practices are often insufficient when applied to complex projects that behave dynamically. In the case of

Figure 8: Evolutionary Development Model



Source: Pressman, 2005

Figure 9: Agile Development Model



Source: Ambler, *Agile Modeling*

complex projects, *leadership versus control is* ***the*** *critical component* that can make the difference. Just as pilots adapt to ever-changing conditions, project leaders must learn to manage projects through flexibility, trade-off analysis, and agility. Just as planes are very sensitive to the environment and easily maneuverable, business solutions must be able to sense change and adapt to it appropriately (Vandergriff, 2006).

The next section presents practical techniques for project leaders faced with challenging complex initiatives. Management Concepts estimates that putting these techniques into practice can reduce project rework by 30–50 percent, thus eliminating excessive time and cost overruns. For each complexity dimension, the project team has an array of complexity management techniques from which to choose. Steps to manage project complexity dimensions include: (1) identifying the dimensions that make your project complex, (2) selecting the techniques that will best manage each complexity dimension that is present, and (3) tailoring techniques to best manage the unique characteristics of the complexity dimension.

Applying Complexity Thinking to Long-Duration Projects

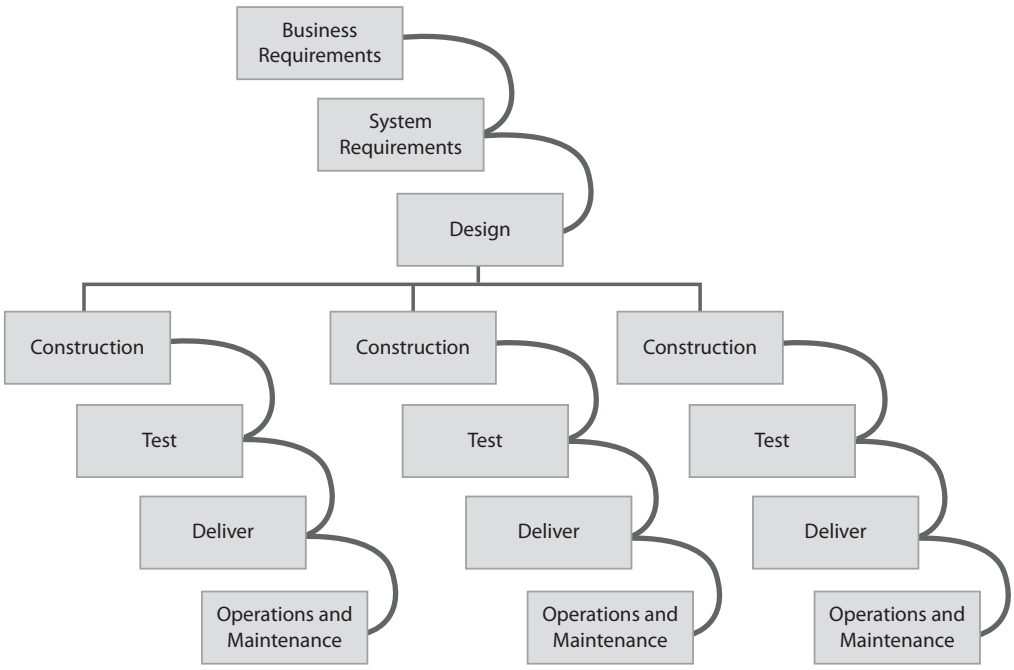
The biggest problem with long-term projects is that so many unforeseeable things can happen. Not only is the business landscape constantly changing, but all the other organizations and technology solutions in the enterprise are altering as well (Vandergriff, 2006). Long-duration projects run the risk of working to achieve a business objective that has changed during the course of the project. Consequently, the new business solution may no longer meet current business needs. Dependencies that have been identified and managed may disappear, but new ones often emerge. In addition, project teams fatigue over time, losing interest in the project. Long-duration projects typically cause a lack of confidence in time and cost estimates. Complexity management techniques to reduce risk include:

- **Appropriate management approach** – Conducting rigorous enterprise analysis during the pre-project study phase clarifies the high-level management issues and helps the customer, architect, and project manager make the appropriate management choices for what appears to be a long-duration project. Determine the specific nature of the business problem and appropriate project management approach and structure (e.g., Is this really a program? Is it a series of modestly scoped, small projects? Something else? Must the project or program deliver a product line, a system of systems? Can the solution be delivered in components?). Whether the project is long- or short-duration, success depends on selecting the management approach that will deal with the problem/solution complexities. The project leadership team needs to: (1) recognize the nature of the problem/solution; (2) understand that the

conventional, reductionist systems/software engineering, and project management approaches may not work; and then (3) make the right choice of management approaches that ensure user satisfaction through early and often customer/end-user evaluation and feedback that ensure developers deliver what is needed, not what was originally proposed (Vandergriff, 2006).

- **Evolutionary development** – Developing, and if possible, delivering the solution in increments, applying lessons learned from each increment into the next iteration, and constantly testing for alignment with business objectives. This technique involves iterations of a cycle that builds, refines, and reviews, so that the correct solution gradually emerges. This technique can be difficult to control, but it is very useful when properly applied.
- **Time and cost management** – Delivering on schedule is one of the main challenges for a long-duration project due to the enormous amount of work involved. Implement a rigorous process to track progress and control delivery. Manage the interdependencies among time, cost, scope, quality, and risk by establishing a project support team to update and maintain the schedule and budget baselines, and escalate issues to your attention in a timely manner.
- **Rapid Application Development (RAD)** – If requirements are understood and scope is contained, RAD can greatly abbreviate the development timeline. This component-based approach allows for incremental testing and defect repair, and a significantly reduced risk compared to single, comprehensive delivery. RAD can be costly if requirements are not well-defined (high risk of requirement defects), or if the design is not sound (high risk of integration issues). (Refer to Exhibit 10)
- **Progressive elaboration and rolling wave planning** – Instead of trying to plan the entire project, start by defining just the requirements and conceptual design activities in detail, and define the remaining phases at a summary level. After requirements are understood and there is an idea of what the solution will be, develop a release plan and define the design,

Figure 10: RAD Model



construction, and test activities in detail; this makes it possible to request the resources needed in increments rather than all at once.

- **Multiple estimating methods** – Build a work breakdown structure (WBS) and estimate the time and cost associated with the lowest-level activities for near-term project phases (bottom-up estimating). It is difficult to know what out-phases will require, so the WBS cannot be used for bottom-up estimating; therefore, other estimating approaches are needed. Use expert judgment and historical information from similar projects to help devise and verify estimates. Industry guidelines may also be helpful for creating estimates.

- **Attention to team composition and process** – As the project drags on and fatigue sets in, project managers should look at both team composition and team processes to maintain continued motivation among members. Celebrate and reward successes at key milestones rather than waiting until the end of a long project. Continually capturing lessons learned about how well the team is working together and implementing suggested improvements will help to build your expertise in leading high-performing teams.

- **Lean development and analysis techniques** – Although the project duration adds complexity, do not be tempted to apply more rigor than necessary. Limit producing documents and conducting meetings only to those that add value to the project. Continually verify that the project is building the minimal viable solution. Use the motto: "Barely sufficient is enough to move forward."

- **Control gate reviews; stage-gate management** – After completing each major project phase, conduct quality reviews of deliverables and determine lessons learned. Update the project cost, schedule, and scope baselines for the remaining project phases, incorporating lessons learned in the plans. At the same time, re-examine the business case to make sure the investment is still sound.

- **Real risk management** – In practice, few projects perform adequate risk management techniques. For long-duration projects, it is essential to identify risks every month and re-examine risk responses to ensure the management of known risks and the identification of new ones.

Applying Complexity Thinking to Large, Dispersed, Culturally Diverse Project Teams

Complex projects almost always involve multiple layers and types of teams. Geographic diversity and dependency on technology dramatically magnify the levels of organizational complexity. Outsourcing all or part of the solution also adds a significant level of complexity. Applying the appropriate practices, tools, and techniques to multiple parties at the right time is a complex endeavor. The role of the project manager is more about team leadership than project management. Techniques include:

- **Great teams…you need one** – When structuring the project, establish a small *core leadership team*, and multiple core sub-project teams. These core teams will augment their efforts by bringing in subject matter experts and forming sub-teams as needed. Sub-project teams should be small (four to six people), dedicated full-time to the project, co-located (preferably in a workroom), highly trained, and multi-skilled. Select team members not only because of their knowledge and skills, but also because they are passionate and love to work in a challenging, collaborative environment. Create and use a team operating agreement. Develop team-leadership skills, and dedicate efforts to transitioning these groups into high-performing teams with common values, beliefs, and a cultural foundation upon which to flourish.

- **Team leadership** – Project managers of complex teams need to learn how to delegate and decide what roles and responsibilities to keep since they are now managing through others. In addition, the project manager needs to determine what procedures to standardize across

sub-teams and what to allow others to tailor. For example, the overall project/program may follow one project cycle while allowing other teams to differ. The program may use a variant of the Waterfall Model with highly structured phases and decision gates, but allow individual projects to use agile techniques to achieve their individual objectives.

- **Contractor team management** – Management of contractor teams is challenging because the contractor organization has its own set of methods, practices, and tools. To avoid problems during project execution, determine how you would like the contractor team to operate prior to finalizing the contract. When drafting the outsourcing contract, include terms that will later ensure your ability to manage the contractor team (e.g., joint planning sessions, integrated project schedules, EVM, control gate reviews, award fees, and penalties). Document and communicate expectations and establish clear evaluation criteria. Develop and use a team operating agreement. Conduct regular progress evaluations and periodic reviews of contract terms and conditions.

- **Virtual team management** – For complex projects involving virtual team members distributed globally, communication and collaboration are critical. Methods, frequency, and manners of communication are crucial factors in determining the success or failure of virtual teams, so develop a communication strategy early in the project. There is no substitute for face-to-face sessions when the team is in early formative stages or when the team is in crisis; however, in today's electronically borderless world, technology is an enabler to keep in close touch, manage interdependencies, and resolve issues. Audio conferencing, web meetings, and e-mail are the rule of the day for progress reporting and quick decision making. Paper-based communication takes on enormous importance when virtual teams are involved. Learn the art of keeping an adequate amount of documentation, without overburdening the team with too much. Formal procedures and processes are necessary to set and maintain expectations. Virtual teams can be more productive than traditional teams when managed well, so use them as a strategic advantage.

- **Collaboration** – Involve all core team members in the project planning process and seek feedback often to continually improve the performance of the team. Secure best-in-class software tools to enable collaboration and document sharing, as well as personal communication and telecommunication tools. Enforce the use of standard procedures, practices, and tools.

Applying Complexity Thinking to Fixed Deadlines and Inflexible Competing Demands

Fixed deadlines almost always add risk to projects because of the complex interdependency among time and other competing demands, including project scope, risk, quality, and cost. For years, economists have warned that success in a global marketplace is contingent upon our capability to produce small batches of tailored products on a tight schedule to meet growing demands in emerging markets. The same is true of projects delivering new business solutions: it is necessary to deliver value to the organization faster, cheaper, and better. Techniques include:

- **Flexible high-performing team members** – High-performing team members must have the skills, information, and motivation to adapt to change quickly. Team members must be able to move freely from project to project as priorities change. Consistent but flexible project management, business analysis, and systems engineering procedures and tools, along with a project sponsor who is available in real time, all combine to provide the foundation for this flexibility.

- **Time-boxed schedule** – While we all hate fixed deadlines, a time-boxed schedule increases the level of urgency felt by the project

team and forces decisions to be made quickly and efficiently.

- **Fierce scope management** – Eliminate all "nice-to-haves" and unnecessary features. Deliver the minimal viable solution.
- **Stage-gate or milestone management** – Structure the schedule into a series of milestones marked by the completion of a major deliverable. Conduct control-gate reviews at each milestone to ensure the quality of the deliverables and to move quickly into the next stage. Milestone management allows the team to focus on the work needed to get to the next milestone only.

Applying Complexity Thinking to Ambiguous Business Problems, Opportunities, and Solutions

Complex projects frequently involve a significant level of uncertainty and ambiguity. When the business problem or opportunity is unclear and ill-structured, it is difficult to identify stakeholders, define business benefits, determine interdependencies, and establish project boundaries. Likewise, when the solution is ambiguous, it is likely to be difficult to assess the feasibility of the concept or estimate costs with any degree of certainty. In this situation, all options must remain on the table and an implementation project should not be funded until the team is certain that they understand both the business problem and/or opportunity, and that the recommended solution is optimal in terms of cost, time, value, and risk. Techniques include:

- **Business analysis** – Professional business analysis is an emerging discipline (see www.theiiba.org). Embrace practices that use business models and requirements-understanding models to clarify the current and target states of the business. Spend ample time researching and studying the business problem or opportunity; conducting competitive, technological, and benchmark studies; defining dependencies and interrelationships; and, identifying all potential options to meet the business need or solve the business problem.
- **Decision analysis** – Decision analysis is applied during the enterprise analysis and architecture effort preceding project launch, and subsequently as needed. Analyze the economic, technical, operational, cultural, and legal feasibility of each solution option until it is clear which option has a higher probability of success. Develop initial solution designs to demonstrate the ability to manage solution dependencies and interrelationships. Determine answers to questions such as:
  - Is this effort unprecedented? Have we, or anyone else, faced it before?
  - Is the technology that is likely to be needed advanced (not commercially available) or even nonexistent?
  - Do we understand the phenomena involved? That is, the scientific phenomena, if there are any involved.
  - Is the problem within our business competence to solve? To understand?
  - Is the problem/solution environment clear?
- **Value-chain analysis** – Describe processes within the organization and evaluate the value each activity contributes to the organization's product or services. The goal is to establish the ability to perform particular activities, and to manage the interrelationships between the activities that result in a source of competitive advantage. The linkages can be flows of information, goods, and services, as well as systems and processes (Porter, 1985).
- **Root-cause analysis** – Conduct rigorous root cause analysis to determine the underlying business problem.
- **Feasibility studies** – Brainstorm to identify all potential solution options and conduct feasibility analyses (analyze technical, operational, economic, cultural, and legal feasibility) for

each solution option to determine the highest-value alternative.

- **Complex project risk management** – Conduct meticulous risk assessments and risk response planning. Focus on identifying and managing interdependencies with external projects, groups, organizations, and application systems.
- **Vendor partnerships** – If the technology planned for use is unproven, establish a partnership with the technology vendor that assigns them a significant part of the risk. Use techniques mentioned above for contractor management. Use award fees for quality and early delivery. Insist that part of the vendor's responsibility is to provide adequate knowledge to your technology team so they will be able to operate and maintain the solution.
- **Rapid prototyping** – Quickly build the riskiest components of a solution first to prove that the idea is feasible. This is typically used to better understand requirements or to prove a concept. (Refer to Exhibit 6.)
- **Feature-driven development** – Used when the solution can be delivered incrementally. The goal is to provide value early, implement the highest value features first, and continually improve based on the learning from the prior increment.
- **Edge-of-chaos management** – Systems exist on a spectrum ranging from equilibrium to chaos, where equilibrium equals paralysis and death, and chaos means an inability to function. The most productive state to be in is at *the edge of chaos*, where there is a maximum variety and creativity, leading to new possibilities. In some circumstances, when a project seems to be operating on the edge of chaos, the team is still brainstorming, creating, studying, examining ideas, and evaluating complexity and dependencies in order to select the most valuable and least complex solution. Encourage lots of experimentation and prototyping to bring the solution into focus. In rare cases, project teams design and develop more than one solution in order to prove which one is truly the optimal approach. When this "tiger-team" approach is used, the outcome can be more innovative and creative then ever imagined. So, if your team seems to be operating on the edge of chaos, it might be just the right approach! Researchers have identified distinguishing features and associated behaviors present when teams are operating on the edge of chaos that are important for project leaders to understand and promote (Vandergriff, 2006, citing Wheatley, 1999; Rosenhead, 1998; Stacey, 1993):
  - Long-term prediction and control are impossible
  - Knowing the future is not necessary to be prepared for it
  - Diversity enables survival and creativity
  - Learning is essential to organizational survival
  - Present concerns with a pragmatic approach
  - The longer problems go unchecked, the more extensive their effect
  - As effects are observed, unknown interdependencies become apparent
  - Cause and effect are impossible to track and assigning blame is fruitless
  - Use Cases provide insight but not predictability
  - Current modeling techniques are often insufficient to foster solution understanding and may impose unnecessary limits on potential solutions

Applying Complexity Thinking to Volatile Requirements

A significant percentage of project failures occur because of poor requirements. Defining requirements is hard—very hard. Individual requirements are not complex; it is the relationships and interdependencies among them that result in complexity.

In addition, requirements are dynamic, changing as the business changes and as they are progressively elaborated. Techniques include:

- **Interdependency management** – Set up a requirements integration team to manage requirements relationships and dependencies. Identify boundaries and ensure each team knows its area of responsibility and areas of overlap. Trace requirements throughout design, construction, and test work products.
- **Professional business analysts** – Critical complex projects need a full-time, senior business analyst (BA), and will likely need a BA team to elicit, analyze, specify, validate, and manage requirements.
- **Enterprise analysis** - Be sure to complete thorough stakeholder and purpose analyses, problem structuring, behavior modeling, value modeling, solution structuring, concept development and selection, and architecture description during the pre-project study phase. Then, although the requirement definition that is completed after project initiation is still hard, it will be significantly easier and less risky.
- **Agile development** – The agile movement is flourishing because requirements are so volatile. Agile analysis is a highly iterative and incremental process in which developers and project stakeholders actively work together to understand the domain, identify what needs to be built, and prioritize functionality (Ambler, 2007). Use agile methods when the following conditions are present: the project value is clear; the customer participates throughout the project; the customer, designers, and developers are co-located; incremental feature-driven development is possible; and, visual documentation (cards on the wall vs. formal documentation) is acceptable. (Refer to Exhibit 10)
- **Test-driven requirements development** - Build the test case before or concurrent with documenting requirements. Sometimes building the test case clarifies the requirement, or even changes it.
- **Effective scope change management** – Avoid spending too much time up front. Uncover 80 percent of requirements in 20 percent of the time. Expect, plan for, and welcome changes that add value. Reduce the cost of change by using incremental development methods. Do requirements and early design concurrently and collaboratively.
- **Iteration** – Iteration is the best defense against unpredictability. Use iterative approaches when defining requirements and building systems to manage changes to requirements throughout the life of the project. Determine lessons learned after each iteration with two goals: (1) to drive down the cost of change, and (2) to increase innovation.
- **Visualization and communication** – Visualize and communicate requirements in the right way to the right audience. Create a blueprint (a view or conceptual model, a rich picture) of what the solution will cover. It is the starting point for defining the phasing of critical and non-critical functionality. Build prototypes and "a-day-in-the-life" scenarios. Use technology to share information (e.g., video recordings of current user operations, web casts of business vision and rationale for change, and live, interactive usability testing).
- **Appropriate level of detail** – Know what needs to be defined at the front end, and what can be defined at a summary level initially. When using purchased components, establish the goal of using the current system functionality, versus developing requirements without taking system functionality into account.

Applying Complexity Thinking to High-Visibility Strategic Projects with Multiple Stakeholder Groups

Strategic projects are by their very nature politically sensitive. Every organization has undefined political processes and ever-present power struggles. Political maneuvers can be stifling and overwhelming to a project, and can even lead to project failure.

Strategies can shift, causing virtually every aspect of the project to change. Project stakeholders often have conflicting expectations. Executive stakeholder interrelationships cause complexity, as do unspoken management expectations. Techniques include:

- **Executive sponsorship** – A project cannot exist successfully without a project sponsor. If a project does not have a sponsor, it is important to find one. Build a trusting, collaborative relationship with the sponsor, seeking mentoring and coaching.
- **Executive oversight** – Establish a governance committee consisting of the project sponsor and key members of management who are impacted by the project. Build a framework for effective decision-making and project oversight, focused on realizing the project benefits, achieving strategic goals, addressing risks, managing change, and setting expectations.
- **Political management strategy** – Identify key stakeholder groups and individuals, internal or external to the project. Conduct an analysis to determine those who can influence the project, and whether they feel positively or negatively about the project. Identify the goals of the key stakeholders. Assess the political environment. Define problems, solutions, and action plans to take advantage of positive influences, and to neutralize negative ones.
- **Public relations** – Find ways to promote yourself. To do so, you must be genuine, competent, and credible. Also, promote your project as central to, and important for, organizational goals and strategies.
- **Benefits management** – Continually assess the value and organizational impact of the project benefits. Ensure expected benefits are specific, measurable, agreed to, realistic, and time-bound. Make certain the project has a business sponsor who is responsible and accountable for the actual benefits expected from the project. Move from a cost reduction to a revenue generating focus; concentrate on value, innovation, and risk reduction.
- **Virtual alliance management** – Strategic projects involve alliances with suppliers, customers, key political groups, regulatory entities, and even competitors. When seeking out partners, look for the *best-in-class* competencies to build high-quality, specific products or services in the shortest period of time.

Applying Complexity Thinking to Large-Scale Organizational Change Initiatives

Large-scale organizational change typically involves new technologies, mergers and acquisitions, restructurings, new strategies, cultural transformations, globalization, new partnerships, and/or e-business. Handling change well can mean the difference between the success and failure of a project, and consequently, of an organization. Techniques include (Kotter, 2002):

- **A sense of urgency** – After identifying key stakeholders and developing a political management strategy (see above), work with stakeholder groups to reduce complacency, fear, and anger over the change, and to increase their sense of urgency.
- **The guiding team** – Using some of the same techniques mentioned above, build a team of supporters who have the credibility, skills, connections, reputations, and formal authority to provide necessary leadership.
- **The vision** – Use the guiding team to develop a clear, simple, compelling vision, and set of strategies to achieve the vision.
- **Communication for buy-in** – Execute a simple, straight-forward communication plan using forceful and convincing messages sent through many channels. Use the guiding team to promote the vision whenever possible.
- **Empowerment for action** – Use the guiding team to remove barriers to change, including disempowering management styles, antiquated business processes, and inadequate information.

- **Short-term wins** – Wins create enthusiasm and momentum. Plan the delivery to achieve early successes.
- **Cross-project dependency management** – When the project is dependent on major deliverables from other projects currently underway within the organization, the core project team should identify and manage such deliverables. Assign someone from a core program team as the *dependency owner*, to liaise with the team creating the deliverable. A best practice is for dependency owners to attend team meetings of the dependent project, so as to demonstrate the importance of the dependency and to hear status updates first hand.

Step 3: Applying Complexity Thinking to Project Leader Assignments

Staffing surveys reveal an increasing demand for senior project managers and business analysts. As these project leaders are assigned to complex projects, it is essential that they are prepared for the challenge. Presented here is the information needed to make appropriate project leadership assignments by applying complexity thinking.

Project Leader Knowledge and Skill Requirements

The knowledge and skills required to manage complex projects is considerable. Figure 11 describes the array of competencies required to lead complex projects. This list was derived from a survey of job descriptions appearing on the Internet.

Project Leader Career Path

As organizations depend more and more on project outcomes to achieve their strategic goals, they are developing career paths for their project managers and business analysts. Refer to Figure 12, which presents a generic project manager/business analyst career path.

Project Leader Assignments Mapped to Project Complexity

To apply complexity thinking to project leadership assignments, project complexity must be considered. Refer to Figure 13 which maps career levels with the project profiles contained within the Project Complexity Model (Figure 1). As you can see by the *Business Analyst and Project Manager Organizational Maturity Model* in Figure 13, in addition to large, highly complex projects, strategic level project managers and business analysts manage programs (a group of projects managed in a coordinated way to obtain greater benefits) and portfolios (a collection of projects or programs managed together to achieve strategic goals).

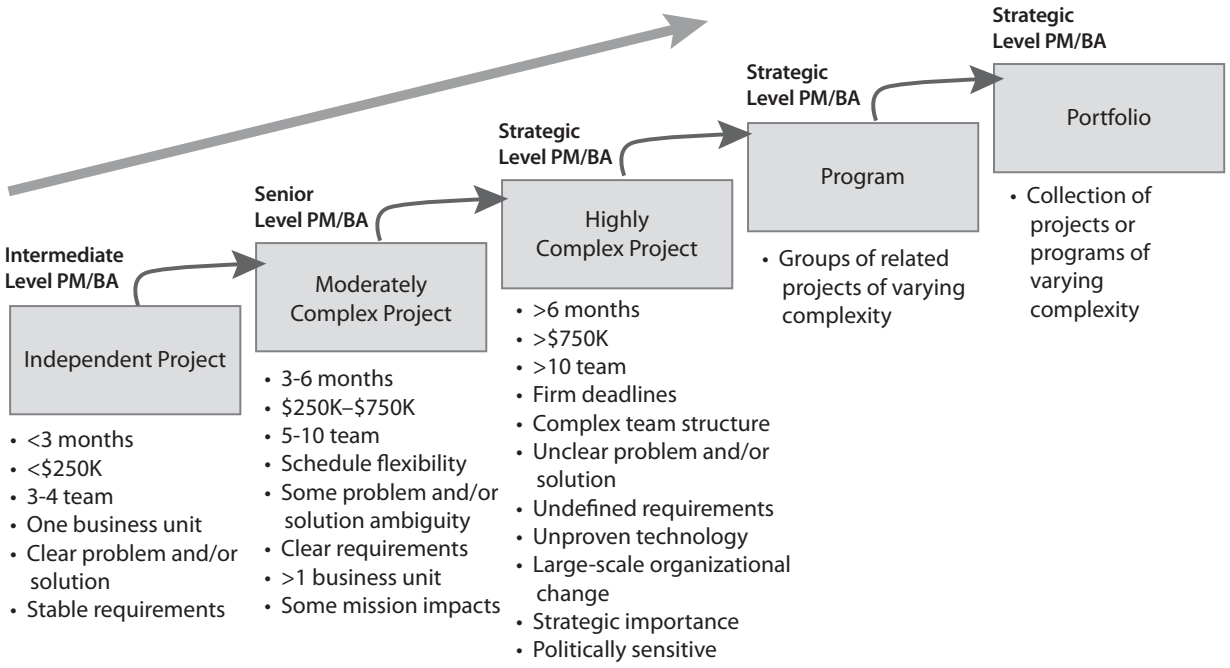
Figure 11: Skill Requirements for Senior Project Manager and Business Analyst

Technical	Analytical	Business	Leadership
Use of technology to support business objectives	Use of project life cycles to deliver valuable solutions quickly	Strategic planning, goal setting, and measurement	Customer relationship management
Systems engineering concepts and principles	Business analysis	Business process improvement and reengineering	Project, program, and portfolio management
Powerful modeling techniques	Ability to conceptualize and think creatively	Business planning	Capacity to articulate vision
Communication of technical concepts to non-technical audiences	Techniques to plan, elicit, analyze, specify, validate, trace, and manage requirements	Communication of business concepts to technical audiences	Organizational change management; management of power and politics
Testing, verification, and validation	Requirements risk assessment and management	Business outcome thinking	Problem solving, negotiation, and decision-making
Technical writing	Administrative, analytical, and reporting skills	Business writing	Team management, leadership, mentoring, facilitation, and meeting management
Rapid prototyping	Cost/benefit analysis	Business case development	Authenticity, ethics, and integrity
Technical domain knowledge	Time and cost management and personal organization	Business domain knowledge	Project benefits management

Exhibit 12: Project Manager and Business Analyst Career Path

Level	Proficiency	Responsibilities	Competencies
Strategic	Ability to perform strategic tasks with minimal direction	Lead large, highly complex projects	• Business and IT strategy • Program and portfolio management • Systems engineering, business process reengineering (BPR), Six Sigma • Enterprise architecture • Business case development
Senior	Ability to perform complex tasks with minimal coaching	Lead moderately complex projects	• Business and IT domains • Advanced project management and business analysis • Systems engineering, BPR, Six Sigma • Requirements engineering
Intermediate	Ability to perform simple-to-moderately complex tasks with minimal assistance	Lead small, independent projects	• Business and/or IT domain • Fundamentals of project management and business analysis • Quality management • Facilitation and meeting management • Basic requirements modeling
Associate	Ability to perform simple tasks with assistance	Support intermediate and senior PM/BAs	• PM/BA Principles • BPR, Six Sigma Principles • Business Writing

Figure 13: Project Manager and Business Analyst Organizational Maturity Model



Step 4: Build Complex, Adaptive Business Solutions

To design, build, and maintain complex adaptive business solutions, which are almost always comprised of highly complex IT systems, we must understand and account for the business strategies as they evolve, as well as the system interrelationships and interdependencies. In addition, we must be able to build and support nested systems within systems, complex business rules, and intricate feedback loops. While engineering complex adaptive systems is a field in and of its own, we offer just a few techniques for your consideration:

- **Reduce solution component dependencies** – When the technical solution is complex, it is prudent to divide the development into a core system (the operative part of the system) and special components (separate from the core, adding functionality in components). Further divide the core system into extension levels, building the foundation level first and then extending system capabilities incrementally. As the core system is developed and implemented, different technical teams work on specialized functional components. The goal is to build the specialized components with only a one-way dependency to the core system; therefore, specialized components are independent of each other and can be created in any order or even in parallel (Lippert, et al. 2002).
- **Manage IT complexity** – World-class organizations follow these simple rules to manage IT complexity (Briody, 2007):
  - Standardize and consolidate data and applications
  - Focus on high-return opportunities
  - Do not minimize costs indiscriminately
  - Maximize value of information assets
  - Outsource selectively for effectiveness (not efficiency)
  - Use portfolio management processes to prioritize and therefore, reduce complexity of IT portfolio of projects

- **Transform IT** – IT organizations everywhere are reinventing themselves to ensure they are adding value to their organizations. Strive to transform your IT group to:
  - Use information as a competitive asset as opposed to a utility for running the business
  - Change the focus of IT improvements from reducing costs to generating value
  - Implement ITSM (IT Service Management) to ensure IT/Business alignment, and to transition from a technology focus to a service orientation; many IT groups are embracing ITIL, (IT Infrastructure Library), an internationally recognized best practice framework for the delivery of quality IT Services. ITIL focuses on continuous improvements to IT processes to optimize service quality
- **Design IT systems using new complexity reduction strategies** – One such method is Service Oriented Architecture (SOA). SOA is a breakthrough software design technique that allows the development of smaller "services" (groups of software components that perform business processes). The services are then hooked together with other services to perform larger tasks. The services are loosely coupled, have an independent interface to the core system, and are reusable. Web services, one of the important strategies to increase business and reduce transaction costs, are an example of SOA. SOA represents a transformation in how businesses and IT develop business solutions. It is an effort to drive down the total cost of ownership of IT systems, thus freeing scarce resources to develop innovative IT applications and infrastructures (Davis 2007).

Final Words

Organizations depend on successful projects to sustain or seize competitive advantage, and ultimately achieve their strategies. Managing projects in highly competitive and changing circumstances requires us to understand complexity thinking and put it into practice. Traditional project management and solution engineering techniques are based on our desire to decompose work into simple, easily managed components. Yet sometimes, more creative solutions emerge from teams operating on the edge of chaos. The trick is to know when to apply traditional project management techniques, and when to live on the edge. Complexity thinking enables project managers and business analysts to learn to diagnose the dimensions of complexity present in a project, and then, to apply appropriate management techniques.

> "Fools ignore complexity. Pragmatists suffer it. Some can avoid it. Geniuses remove it."
>
> – Alan Perlis,
> American Computer Scientist

References

Alawneh, Luay, Jarraya Debbabi, Soeanu Yosr, Hassayne Andrei, and Fawzi Hassayne. *A Unified Approach for Verification and Validation of Systems and Software Engineering Models*. 13th Annual IEEE International Symposium and Workshop on Engineering of Computer-Based Systems (ECBS '06) 409–418.

Ambler, Scott W. *Agile Analysis*. www.agilemodeling.com/essays/agileanalysis.htm.

Bechtold, Richard, Ph.D. *Essentials of Software Project Management*. Management Concepts, 1999.

Briody, Dan. 2007. *Making IT Complexity Work for You*. Ziff Davis Enterprise, Inc. (September 4, 2007). www.ca-itmanagement.com

Davis, Mark Frederick. *SOA: Providing Flexibility for the Health and Science Industry*. July 2006. Retrieved from the Internet on 29 March 2007. http://h20245.www2.hpt.com/publicsector/downloads/Technology_Davis_VB.pdf.

Dimitroy, Vladimir. *Complexity, Chaos and Creativity: A Journey Beyond Systems Thinking*. www.zulenet.com/VladimirDimitroy/pages/complexthink.html.

Fryer, Peter. *A Brief Description of Complex Adaptive Systems and Complexity Theory*. www.trojanmice.com/articles/copmlexadaptivesystems.htm

Kotter, John P. .2002. *Getting to the Heart of How to Make Change Happen*. Boston, MA: Harvard Business School Press.

Lippert, M., S. Roock, H. Wolf, and H. Züllighoven. *XP in Complex Project Settings: Some Extensions*. Informatik/Informatique. Schweizerischer Verband der Informatikorganisationen (April 2, 2002).

Lissack, Michael R., and Johan Roos. 2002. *The Next Common Sense, The e-Manager's Guide to Mastering Complexity*. London, UK: Nicholas Brealey Publishing.

Mooz, Hal, Kevin Forsberg, and Howard Cotterman. 2003. *Communicating Project Management*, Hoboken, New Jersey: John Wiley & Sons.

Porter, Michael. 1985. *Competitive Advantage: Creating and Sustaining Superior Performance*. New York, NY: Simon and Shuster Inc.

Pressman, Roger S. 2005. *Software Engineering: A Practitioner's Approach*. Sixth Edition. McGraw-Hill: New York.

Rind, D. 1999. "Complexity and Climate," Science Magazine: Complex Systems Special Issue, 284, no. 5411 (April 2, 1999):105–107.

Rosenhead, Jonathan. 1998. *Complexity Theory and Management Practice*. www.human-nature.com/science-as-culture/rosenhead.html.

Stacey, R. D. 1993. *Strategic Management and Organizational Dynamics*. London, UK:Pitman.

Vandergriff, Linda J. *Complex Venture Acquisition. Complexity Conference White Paper*, 2006.

Wheatly, Margaret J. 1999. *When Complex Systems Fail: New Roles for Leaders*. Leader to Leader, 11 Winter. 28-34. http//leadertoleader.org/lederbooks/L2L/winter99/wheatley.html.