Project Management Theory and the Management of Large Complex Projects

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Abstract

The normal condition of a project is "failure" and this is no more true than in the world of large complex projects where two out of three projects "fail". Current project management theory does not provide a framework for success. In this article, the current theoretical framework for management of large complex projects is considered in light of the continuing evolution of general management theory and the theories of management and projects explored. Characteristics of large complex projects are reviewed and changed management perspectives suggested.

The purpose of this article is to move beyond the author's previous question of "Is it time to rethink project management theory" to suggesting some of the essential perspective and focal changes that such a rethink will likely include. Just as theory in physics moved from a purely classical view to a classical and relativistic (or neo-classical view) view, each with their own scalar domains, so too must the universe of large complex projects be better underpinned.

The large complex projects contemplated in this article are large, complex engineering and construction projects but others may judge its conclusions to apply equally in other domains.

Extensive footnoting is intended to both support the author's views as well as provide readers with avenues for additional reading and insight.

1. Introduction

Those of you that have discussed with me my various writings over the years have heard me describe these writings as how I think. Writing drives a discipline of organizing thoughts and concepts and as a minimum positing premises that become refined as the result of comments, debate and even refutal. This paper has been a long time in the making, reflecting my continuing work on and thinking about large complex projects.

In this paper I continue to build on my questioning of the adequacy of current project management theory to serve the needs of large complex projects. This questioning is driven by a simple reality - large projects fail two thirds of the time[1] [2]

This fundamentally must be the result of:

- Poor conceptualization of what the project really was
- Inherent weaknesses in the plan or planning process
- Weak or inadequate execution – processes, people, technology
- Inadequate control recognizing the changing internal capabilities and constraints and ever evolving externalities.

Underpinning our approach to the management of large projects are two central theoretical constructs[3]:

- Theory of Management
- Theory of Projects

Results suggest that both may warrant examination and likely modification of their respective frameworks. As we examine each, we must remain cognizant of broader management thinking and the evolution of new theories of management.

2. Where the Theory of Management Stands Today

In order to assess the current state and adequacy of project management theory, especially as it relates to the universe of large engineering and construction projects, it is helpful to first review the evolution of broader management theory. The objective of such a review is to test whether current project management theory has evolved along

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[1] As large projects are increasingly a fundamental management technique in the management of large organizations, getting failure rates down to acceptable levels is essential for good organizational governance
[2] Is it Time to Rethink Project Management Theory?; Bob Prieto; PM World Journal; 2015 provides a summary of project failure rates reported by others.
[3] The Theory of Project management: Explanation to Novel Methods; Lauri Koskela, Greg Howell

similar lines or whether there are insights that may yet be gleamed from the broader field of management.

In many instances large, semi-permanent project organizations have lifetimes longer than the organizations served by general management theory.

3. A Short History of Management Theory

The management of various endeavors ranging from the creation of ancient works to warfare has existed for thousands of years but it was only on the heels of Adam Smith's[4] magnus opus, The Wealth of Nations[5], that attention shifted to how to best organize tasks and labor. In The Wealth of Nations, Smith highlights the importance of **division of labor**, breaking down of large jobs into many tiny components, a concept which has pervaded management theory since. In many ways this was the first identifiable management theory and one which was focused on the ***approach to execution of work***.

The concept that the organization and coordination of labor of labor could be taught emerged with the transition from entrepreneurial capitalism of the 19th century, where owners used their own money and were daily engaged in the business, to managerial capitalism in the 20th century, with larger organizations with capital provided by others not directly engaged in the day to day business. This led to an explosion in management thought that continues to today.

Management theory at this stage can be described as **classical theory** comprising at least two major schools of thought:

- **Scientific management**
- **Administrative theories**

Scientific management theory is underpinned by the work of Taylor[6], an American engineer, focused on improving the efficiency of growing industrial production. Administrative theories can be segregated for this discussion into two subsets:

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[4] Adam Smith was a Scottish moral philosopher, pioneer of political economy, and key Scottish Enlightenment figure. Smith is best known for two classic works: The Theory of Moral Sentiments (1759), and An Inquiry into the Nature and Causes of the Wealth of Nations (1776). The latter, usually abbreviated as The Wealth of Nations, is considered his the first modern work of economics. Smith is cited as the "father of modern economics" and is still among the most influential thinkers in the field of economics today.

[5] An Inquiry into the Nature and Causes of the Wealth of Nations, generally referred to as The Wealth of Nations, published in 1776 is a fundamental work in classical economics. The book touches upon such broad topics as the division of labor, productivity, and free markets.

[6] Frederick Winslow Taylor was an American mechanical engineer who sought to improve industrial efficiency. He was one of the first management consultants. Taylor is regarded as the father of scientific management.

- **Bureaucracy**
- **Administration and management**

Bureaucracy was based on a set of principles developed by Weber[7], a founding father of modern social sciences, while administration and management theory was developed by Fayol[8], a mining engineer.

Each of these theories focused on the ***approach to management of execution*** of work. The following table (Table 1) compares some of the key ideas of each of these classical management theories.

Table 1
Classical Management Theories

School	**Scientific Management**	**Administrative Theories**	
Theory	Scientific Management	Bureaucracy	Administration
Thought Leaders	Frederick Winslow Taylor	Max Weber	Henri Fayol
Defining Work	The Principles of Scientific Management[9]	Die Protestantische Ethik und der Geist des Kapitalismus[10] (The Protestant Ethic and the Spirit of Capitalism)	"Administration industrielle et générale"[11] (General and industrial administration)

[7] Karl Emil Maximilian "Max" Weber was a German sociologist, philosopher, and political economist who has influenced social theory and research. Weber is often cited, with Émile Durkheim and Karl Marx, as among the three founders of sociology. Max Weber's Bureaucratic theory or model is sometimes also known as the "Legal-Rational" model. The model tries to explain bureaucracy from a rational point of view via nine principles.
[8] Henri Fayol was a French mining engineer and director of mines who developed a general theory of business administration that is often called Fayolism. His theory was developed independently of scientific management but contemporaneously. He is acknowledged as a founder of modern management methods.
[9] The Principles of Scientific Management; Frederick Winslow Taylor; Monograph; Harper & Brothers; 1911
[10] Die protestantische Ethik und der Geist des Kapitalismus (The Protestant Ethic and the Spirit of Capitalism); Karl Emil Maximilian "Max" Weber; 1905 (German); 1930 (English)
[11] "Administration Industrielle et Générale" (General and industrial administration); Henri Fayol; 1916 (French); 1930 (English)

Key Principles	Science for each element work, replaces rule-of-thumb method	Distinct/separate areas of competence, set out in law/regulation	Forecast and plan
	Scientifically select, train, teach, and develop workers	Hierarchy of office	Organize
	Cooperation to ensure work done in accordance with the science	Decisions based on written documents and written rules	Command/direct
	Division of the work/responsibility between management and workers. Management undertakes work for which they are better trained than the workers	Relationships and decisions are impersonal	Coordinate
		Officials have extensive education in area of competence	Control
		Employment based on expertise and is full time	
		Fixed salaries	

Classical theories of management were soon complemented by theories with basis in the human relations movement. Behavioral Theory focused on the people aspects of organizations and management, recognizing that management is an ongoing, dynamic process and that employees must be active participants, with "buy-in" of decisions. Early work by Follet[12] and Barnard[13], who she greatly influenced, was reinforced by Mayo's[14] Hawthorne[15] studies. Follet might be regarded as the mother of modern management with her ***consideration of human aspects***.

Their work was later extended by Maslow[16] with his Theory of Motivation and McGregor[17] with his perspectives on so-called Theory X and Theory Y managers. The manager's toolbox was bigger but so was his job. The following table (Table 2) summarizes some of the elements of Behavioral Theory.

Table 2
Behavioral Theory

Theory	Behavioral Theory	Theory of Motivation	Theory X/Theory Y
Thought Leaders	Follet; Barnard	Maslow	McGregor

[12] Mary Parker Follett was an American social worker, management consultant and pioneer in the fields of organizational theory and organizational behavior. Mary Parker Follett was one of the great women management gurus in the early days of classical management theory

[13] Chester Irving Barnard was an American business executive, public administrator, and the author of pioneering work in management theory and organizational studies. His work sets out a theory of organization and of the functions of executives in organizations.

[14] George Elton Mayo (1880–1949) was an Australian born psychologist, industrial researcher, and organizational theorist. Mayo made significant contributions to business management, industrial sociology, philosophy, and social psychology. His field research in industry had a significant impact on industrial and organizational psychology and is known for scientific study of organizational behavior. His work helped to lay the foundation for the human relations movement which emphasized that along with the formal organization there exists an informal organizational structure as well.

[15] Hawthorne Works (a Western Electric factory outside Chicago). The Hawthorne Works commissioned a study to see if workers became more productive in higher or lower levels of light. Productivity improved when changes were made, and slumped when the study ended. It was suggested that the productivity gain occurred as a result of the motivational effect on the workers of the interest being shown in them.

[16] Abraham Harold Maslow was an American psychologist known for creating Maslow's hierarchy of needs, a theory predicated on fulfilling innate human needs in priority, culminating in self-actualization

[17] Douglas Murray McGregor was a management professor at the MIT Sloan School of Management and president of Antioch College. He was a contemporary of Abraham Maslow and contributed to the development of the management and motivational theory. He is best known for his Theory X and Theory Y which proposed that manager's individual assumptions about human nature and behavior determined how individual manages their employees.

Defining Work	The New State[18] (Follett); The Functions of the Executive[19] (Barnard)	A Theory of Human Motivation[20]	The Human Side of Enterprise[21]
Key Principles	Management is a dynamic process	Hierarchy of needs	Managers create situations where employees confirm manager's expectations (self-fulfilling prophecy)
	Workers should be involved in decisions	Needs never completely satisfied	People work for inner satisfaction not materialistic rewards (drives performance)
	Noncoercive power sharing (managers need buy-in of employees; "power with" vs. "power over")	Behavior motivated by need for satisfaction	
	Employees motivated by social needs	Needs encompass physiological; safety; belonging; esteem; and self-actualization.	
	Reciprocal relationships (peer forces are strong)		

[18] The new state : group organization the solution of popular government; Mary Parker Follett ; Longmans; 1918
[19] The Functions of the Executive; Chester I. Barnard; Harvard University Press; 1938
[20] A Theory of Human Motivation; Abraham H. Maslow; Psychological Review, 50, 370-396; 1943
[21] The Human Side of Enterprise; Douglas Murray McGregor; 1960

	Win-win philosophy (employees respond to managers who help them satisfy needs)		
	Managers coordinate work fairly to improve efficiency		
	Authority of expertise (leads to matrix organization)		
	Conflict as opportunity to develop integrated solutions vs. compromising		
	Critical role of soft factors and informal processes		
	Relevance of theory is underpinned by the "scientific" Hawthorne studies		

Post World War II we saw development of a concerted study of systems theory as it might be applied to each area of scientific endeavor. This surge in systems interests was driven by the recognition that recent advances in science called us to question all classical assumptions. Management theory was not spared this reexamination. The early work of Bertalanffy[22] was foundational and an agreed to ontology for systems theory is lacking but could be thought to be more **biological**. The suggested systems ontology in this paper is for convenience and may be described as follows:

- **Static** – highly encapsulated with limited or no exchange with its environment (more akin to what Taylor envisioned)

- **Dynamic** – exchange of information with environment can be reasonably well characterized with behaviors that may be either:
    - **Deterministic** – exchanges with environment can be modeled (system is more closed in nature) and sensitivity to initial conditions will support either:
        - **Stable** systems – inputs well known or limited sensitivity (This is the realm of ***Systems Theory*** in management)
        - **Chaotic** systems – high sensitivity to initial conditions (This special case of systems theory is often characterized as ***Chaos Theory***)
    - **Non-deterministic** – exchanges with environment cannot be reasonably modeled and the potential for "global cascade"[23] exists as various agents in the system interact with and adapt to each other over time[24]. This more **evolutionary** description is best associated with:
        - **Complex** systems – that can be further characterized by their resilience[25] or sensitivity of complex systems to catastrophic failure from a minor change in input (fragile or resilient); or their anti-fragility or ability to grow stronger with disorder[26]. We will characterize this as ***Complexity Theory***.

Attributes of these various systems theories are described in the following table (Table 3).

[22] Karl Ludwig von Bertalanffy was an Austrian-born biologist known as one of the founders of general systems theory. General systems theory describes systems with interacting components, applicable to biology, cybernetics, and other fields. Bertalanffy proposed that the classical laws of thermodynamics applied to closed systems, but not necessarily to "open systems," such as living things.
[23] Network wide domino effect in a dynamic network
[24] Social systems are acted upon and influenced by interventions by various agents whose behavior is not readily predictable at the individual level. Human agents alter the very structures and associated parameters of social systems present both within organizations and in interactions and interface with external stakeholders.
[25] Characterized by their flexibility, adaptability and responsiveness. Strong self-organization (delegation of relevant decision-making to lower organizational levels closer to the workface) is a feature of resilient systems.
[26] Antifragile: Things That Gain from Disorder; Nassim Taleb

Table 3
System Theory

	Static	Dynamic		
		Deterministic		Non-deterministic
Theory	Systems Theory (special case more similar to industrial setting envisioned by Taylor)	Systems Theory	Chaos Theory	Complexity Theory
Thought Leaders	Bertalanffy	Bertalanffy	Wheatley[27]	Kauffman[28]; Morin[29]; Cilliers[30] (others)
Defining Work	General System Theory: Foundations, Development, Applications[31]	General System Theory: Foundations, Development, Applications	Leadership and the New Science[32]	'The Origins of Order: Self-organization and Selection in Evolution (Kauffman)[33]; From the concept of system to the

[27] Margaret J. Wheatley (Meg Wheatley) is an American management consultant who studies organizational behavior. Her approach includes systems thinking, theories of change, chaos theory, leadership and the learning organization: particularly its capacity to self-organize. She describes her work as opposing "highly controlled mechanistic systems that only create robotic behaviors."

[28] Stuart Alan Kauffman (born September 28, 1939) is an American medical doctor, theoretical biologist, and complex systems researcher who studies the origin of life on Earth. Kauffman rose to prominence through his association with the Santa Fe Institute (a non-profit research institute dedicated to the study of complex systems). Kauffman is best known for arguing that the complexity of biological systems and organisms might result from self-organization and far-from-equilibrium dynamics

[29] Edgar Morin is a French philosopher and sociologist known for the transdisciplinarity of his works. Edgar Morin has concentrated on developing a method that can meet the challenge of the complexity.

[30] Friedrich Paul Cilliers was a South-African philosopher, complexity researcher, and Professor in Complexity and Philosophy at the Stellenbosch University known for his contributions in the field of complex systems

[31] General System Theory: Foundations, Development, Applications; Ludwig Von Bertalanffy; George Braziller; 1968

[32] Leadership and the New Science: Discovering Order in a Chaotic World; Margaret J. Wheatley; Berrett-Koehler Publishers, Inc.; 1996

[33] Kauffman, S (1993), 'The Origins of Order: Self-organisation and Selection in Evolution', Oxford University Press, Oxford.

				paradigm of complexity (Morin)[34]; Complexity and postmodernism. Understanding complex systems (Cilliers)[35]
Key Principles	Encapsulated	Encapsulated	Encapsulated	More permeable boundary
	Bounded in time and space	Bounded in time and space	Bounded in time and space	Bounded in time and space
	Exchanges information/material with environment – limited and controlled	Exchanges information/material with environment – limited and less controlled	Exchanges information/material with environment – measurable and least controlled	Exchanges information/material with environment – unknown and uncontrolled
	Processes that transform inputs to outputs	Processes that transform inputs to outputs	Processes that transform inputs to outputs	Emergent outcomes
	Dynamic	Dynamic	Dynamic	Dynamic
	Self-correcting through feedback	Self-correcting through feedback	Self-correcting through feedback	Self-creating through feedback and interaction
	Seeks equilibrium but can oscillate	Seeks equilibrium but can oscillate	Seeks equilibrium but can oscillate	Adaptive
	Exhibit multifinality and equifinality	Exhibit multifinality and equifinality	Exhibit multifinality and equifinality	Exhibit multifinality and equifinality

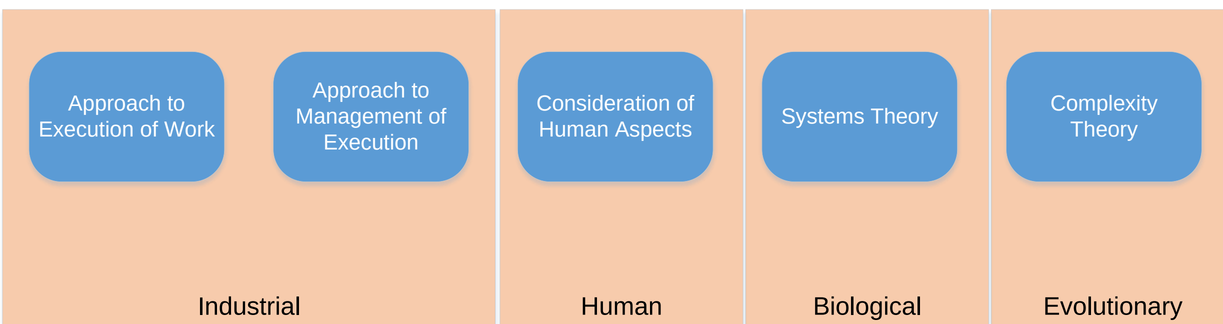
[34] Morin, E. 1992. From the concept of system to the paradigm of complexity. Journal of Social and Evolutionary Systems 15 (4):371–385. http://dx.doi.org/10.1016/1061-7361(92)90024-8
[35] Cilliers, P. 1998. Complexity and postmodernism. Understanding complex systems. Routledge, London, UK.

	View as industrial machine (Taylor)	View as biological system	View as living organism	View as evolving organism
	Well defined processes	Well defined processes with focus on controlling and managing change	Self-organizing (role of managers changes)	Self-adapting
	Division of labor limits required knowledge	Communities of practice share "relevant" information	Everyone has access to all information needed to do their job (Knowledge Management; continuously educated workforce)	New information is continuously created and shared. (Knowledge Management challenges increase; knowledge is increasingly contextual and temporal)
			Everyone has access to anyone they need to do their job	Discovery of newly emergent actors impacting delivery of outcomes
			Strong organization or purpose linkage (requires employee involvement)	Strong outcome centric focus and multi-stakeholder commitment to outcomes
	Top down information flows	Matrix information flows (hierarchical and authority of expertise)	Open information flows (changed communication methods)	Strong information flows across all boundaries

	Predictable (statistical variance)	Predictable; Statistical variance or Patterned	Unpredictable; Patterned	Unpredictable; Random

We may view the evolution of management theory to have moved through four broad schools of thought:

- **Industrial** – encompassing Smith's division of labor as an approach to execution of work and scientific and administrative approaches to the management of execution
- **Human** – encompassing consideration of human aspects as part of organizational behavior
- **Biological** – representing much of systems theory and encompassing static and dynamic systems which exhibit more deterministic characteristics including chaotic systems
- **Evolutionary** – representing non-deterministic complex systems



4. A (Very) Short History of Project Management Theory

The roots of project management theory go very much back to the work of Taylor on scientific method and explicitly to two of his "students", Henry Gantt[36] (who worked with Taylor) and Henry Fayol. Gantt is readily recognized for his so-called Gantt charts, a modernized version of which we find in the 1950's conceived PERT[37] with its stochastic

[36] Henry Laurence Gantt was an American mechanical engineer and management consultant who is best known for developing the Gantt chart in the 1910s. Gantt charts were employed on major infrastructure projects including the Hoover Dam and Interstate highway system and continue to be an important tool in project management and program management. In 1887 he joined Frederick W. Taylor in applying scientific management principles to the work at Midvale Steel and Bethlehem Steel, working there with Taylor until 1893.

[37] The program (or project) evaluation and review technique, commonly abbreviated PERT, is a statistical tool, used in project management. Commonly used in conjunction with the critical path method (CPM). It was able to

(uncertain) activity times. Fayol's administrative theories with his defined five management functions represent the core of the project management body of knowledge.

Fayol's Functions of Management

- To forecast and plan
- To organize
- To command or direct
- To coordinate
- To control

So at its roots, project management has an industrial focus similar to the beginnings of modern management theory. Work breakdown structures (divisions of work) and resource allocation approaches flow directly from the work of Taylor, Gantt and Fayol.

In the post war period we see project management make further advances through the introduction of CPM[38], with its deterministic activity periods and PERT, a modernization of Gantt's work, with the previously mentioned stochastic activity times.

This traditional project management approach is codified with the 1969 issuance of PMBOK, the Project Management Body of Knowledge, which was intended to provide a management framework for ***most projects, most of the time***[39]. We may have lost some visibility of this important qualification, especially as projects have grown in scale, duration and complexity.

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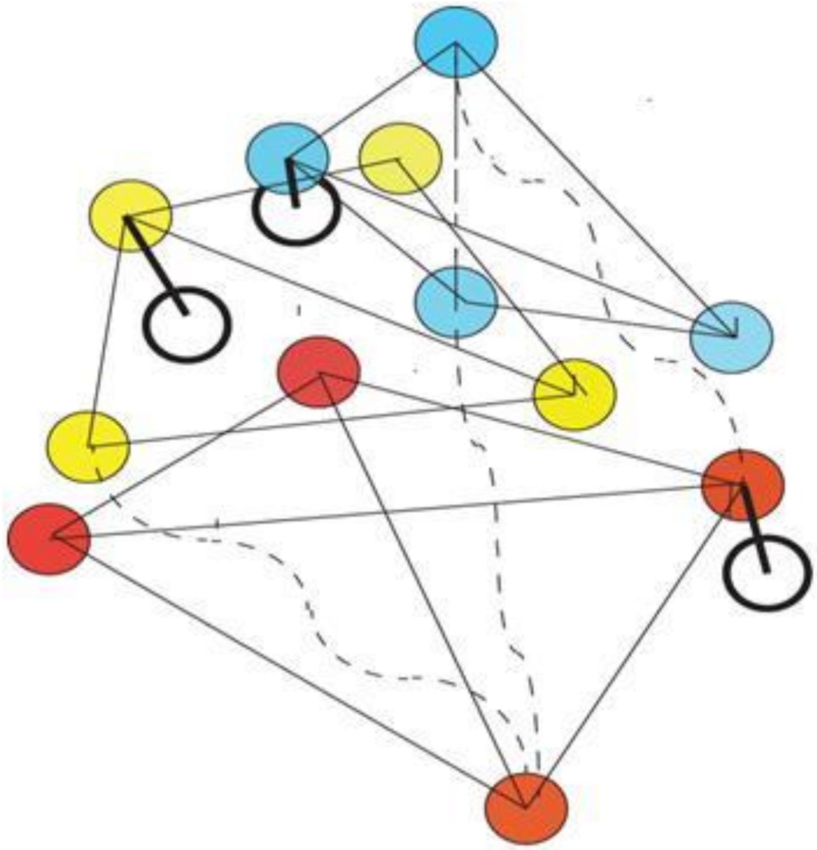
incorporate uncertainty by making it possible to schedule a project while not knowing precisely the details and durations of all the activities. It is more of an event-oriented technique rather than start- and completion-oriented. This project model was the first of its kind, a revival for scientific management, founded by Frederick Taylor.

[38] The critical path method (CPM) is a project modeling technique developed by Morgan R. Walker of DuPont and James E. Kelley, Jr. of Remington Rand. Kelley attributed the term "critical path" to the developers of the Program Evaluation and Review Technique (PERT) which was developed at about the same time by Booz Allen Hamilton and the U.S. Navy. The precursors of CPM contributed to the success of the Manhattan Project

[39] Hatfield in The Coming Sea-Change in Project Management Science: Advances in Project Management; PM World Journal; 2013 notes that "Organizations embracing the whole of the project management body of knowledge, as documented by the Project Management Institute, could not demonstrate a consistent competitive advantage over those organizations that choose to only implement certain aspects of PM, or even none at all."



Further refinement of traditional PM theory comes with the introduction of Prince2 and CCPM. Prince2[40] is a generic process driven PM methodology with an output orientation and a strong quality focus. PRINCE2 is based on seven principles (continued business justification, learn from experience, defined roles and responsibilities, manage by stages, manage by exception, focus on products and tailored to suit the project environment), seven themes (business case, organization, quality, plans, risk, change and progress) and seven processes (starting up a project, initiating a project, directing a project, controlling a stage, managing stage boundaries, managing product delivery, and closing a project) .

[40] PRojects IN Controlled Environments, version 2.

Process Based Management[41], another amplification of the traditional model, is driven by the use of maturity models such as CCMI[42] (Capability Maturity Model Integration) and its sixteen core process.

Agile[43] moves us beyond traditional PM theory with considerations of iterative human interactions. Agile relies on a series of small, discrete tasks conceived and executed to conclusion as required. Task execution is contingent, executed as required and in an adaptive manner rather than executing a pre-planned process. Key to successful use is active client involvement and real-time decision making.

Lean[44] begins the integration of traditional methods and human characteristics, focusing on individual and team performance in addition to the more traditional task elements and processes. The human dimension and commitment to mission, vision and objectives is now a core management feature and a key system's element. System "flows" replace pure input/output measures in more traditional project management. Lean project management provides flexibility in responding to dynamic systems, moving beyond the more static constructs of traditional PM theory but potentially introducing risks as capabilities and capacities are narrowed to reduce waste and internal variability.

Critical Chain Project Management [45](CCPM) addresses uncertainty and resource constraints. Critical chain project management is based on methods and algorithms derived from Theory of Constraints and include resource leveling and use of buffers. All activities converge to a final deliverable. As such, to protect the project, there must be internal buffers to protect synchronization points and a final project buffer to protect the overall project. CCPM builds on PERT and CPM as well as system dynamics thinking. CCPM moves into the world of dynamic systems.

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[41] Process-based management is a management approach that views a business as a collection of processes. Vision, mission and core value are three crucial factors to manage an organization from a process perspective.

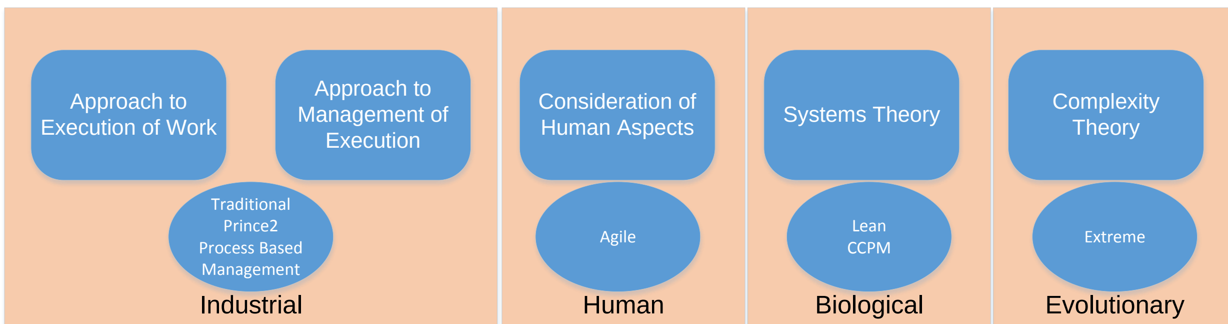
[42] Capability Maturity Model Integration (CMMI) is a process improvement training and appraisal program. CMMI models provide guidance for developing or improving processes that meet the business goals of an organization.

[43] Agile project management is an iterative and incremental method of managing the design and build activities projects in a highly flexible and interactive manner. It relies on capable individuals from the relevant business, with supplier and customer input.

[44] The main principle of lean project management is delivering more value with less waste. Lean project management has many techniques including standardization, blame-free employee involvement and the need for a strong facilitator.

[45] Critical chain project management (CCPM) is a method of planning and managing projects that emphasizes the resources required; strives to keep resources levelly loaded, but requires that start times be flexible; and quickly switches between tasks.

The emergence of extreme project management[46] moves project management theory into the world of dynamic, non-deterministic systems. The control point is focused on how you respond to the reality that you have no (or at least limited) control. The theoretical constructs of extreme project management are as different from traditional PM theories as Newtonian physics is from Einstein's theory of relativity. Each is reasonable within their respective scales. This is a key point; extreme project management has applicability only in the world of dynamic, non-deterministic projects with the properties of scale, uncertainty and emergence[47].



The following table (Table 4) provides a brief comparison of the major classes of PM theory[48].

Table 4
Comparison of Classes of PM Theories

Class	Industrial	Human	Biological	Evolutionary
Theories	❖ Traditional Approach ❖ Prince2 ❖ Process	Agile	❖ Lean ❖ CCPM	Extreme Project Management

[46] Extreme project management (XPM) refers to a method of managing very complex and very uncertain projects. It utilizes an open, elastic and non-deterministic approach. The focus is on the human side of project management (managing stakeholders), rather than on intricate scheduling and formal processes and methods.

[47] Emergence is a process whereby larger entities, patterns, and regularities arise through interactions among smaller or simpler entities that themselves do not exhibit such properties. Emergence is a central element in complexity theories. Emergence is described by economist Jeffrey Goldstein as "the arising of novel and coherent structures, patterns and properties during the process of self-organization in complex systems".

[48] In general, the various project management theories are not seen as management of projects, including all the strategic contextual factors that this would entail, but rather as the delivery of a project on time, in budget and to scope.

	Based Manageme nt ❖			
Thought Leaders	Taylor; Gantt; Fayol		Goldratt[49]	
Focus	Input/Process	Process/Adaptive Human	Inputs (waste)	Stakeholders
Control Point	Output	Output	Deterministic output/outcome	Emergent outcomes
Key Principles	Work Breakdown Structure	Interactive human interaction	Traditional methods	Open approach
	Resource allocation	Contingent task execution	Individual performance	Focus on response not control
	Quality focus	Adaptive execution	Team performance	Stakeholder management
	Output orientation	Active client involvement	Dynamic system	Dynamic non-deterministic systems
	Maturity models	Real time decision making	System flows	Large scale
			Flexibility in response	High uncertainty
			Uncertainty	Emergence

[49] Eliyahu Moshe Goldratt was an Israeli physicist who became a business management guru. He was the originator of the Optimized Production Technique, the Theory of Constraints (TOC), the Thinking Processes, Drum-Buffer-Rope, Critical Chain Project Management (CCPM) and other TOC derived tools. Processes are typically modeled as resource flows. The constraints typically represent limits on flows.

			Resource constraints	
			Waste minimization	

5. Extension of Management Theory to the Theory of Project Management

Each of the prior sections attempts to lay out the evolution of respective theories of management in both a general context as well as one more specific to the world of projects. The absence of broad acceptance in either theory set of one theory of management suggests that each theory may have limited utility, not being universally applicable across all management settings.

These limitations in and of themselves are not troubling as long as we clearly understand the likely boundary conditions with respect to relevance and applicability. This is a particular weakness in the world of project management.

Having established the principle that one size does not fit all, it is useful to identify theoretical constructs from general management theories that have not received broader awareness or acceptance in the world of project management. These under recognized elements may be found in particular in two distinct general management systems theories related to chaos and complexity. Specifically elements related to special cases of dynamic systems theory, one deterministic (Chaos Theory) and the other non-deterministic (Complexity Theory) in nature. Both of these special cases have been contemplated in the context of Project Management Theory but elements of each have been under recognized in my view, at least as they may apply to the special case of large complicated projects.

These differentiating (and under recognized) elements (shown in bold) are summarized in the following table(Table 5) retaining the chaos and complexity construct, but in the world of large complex projects the non-deterministic attributes are of particular interest.

Table 5
Key Principles from General Management Theory not Comprehensively Addressed in Project Management Theory
(Shown in Bold)

System Type	**Deterministic**	**Non-deterministic**
Theory	***Chaos Theory***	***Complexity Theory***
Key Principles	Encapsulated	**More permeable boundary**
	Bounded in time and space	Bounded in time and space
	Exchanges information/material with environment – measurable and least controlled	**Exchanges information/material with environment – unknown and uncontrolled**
	Processes that transform inputs to outputs	Emergent outcomes
	Dynamic	Dynamic
	Self-correcting through feedback	**Self-creating through feedback and interaction**
	Seeks equilibrium but can oscillate	**Adaptive**
	Exhibit multifinality and equifinality	**Exhibit multifinality and equifinality**
	View as living organism	View as evolving organism
	Self-organizing (role of managers changes)	Self-adapting

	Everyone has access to all information needed to do their job (Knowledge Management; continuously educated workforce)	**New information is continuously created and shared. (Knowledge Management challenges increase; knowledge is increasingly contextual and temporal)**
	Everyone has access to anyone they need to do their job	**Discovery of newly emergent actors impacting delivery of outcomes**
	Strong organization or purpose linkage (requires employee involvement)	**Strong outcome centric focus and multi-stakeholder commitment to outcomes**
	Open information flows (changed communication methods)	Strong information flows across all boundaries
	Unpredictable; Patterned	Unpredictable; Random

Subsequent sections will discuss the ramifications of deeper consideration of these highlighted features in the management of large projects but for now let's look a bit more closely at the Theory of Projects and how this theory may be modified in the world of large complex projects.

6. Theory of Projects

The Project Management Institute defines a project as a temporary endeavor undertaken to create a unique product or service.[50] Howell[51] describes the prevailing view of a project as the transformation of inputs to outputs and captures the key

[50] Project management Institute; 2000
[51] New Theory of Project Management; Howell

assumptions associated with that view. We will look at how these and other assumptions related to the Theory of Projects break down in the world of large projects.

Table 6 **Assumptions Related to the Current Transformative View of Projects**[52]
Tasks are independent, except sequential relationships
Tasks are discrete and bounded
Uncertainty as to requirements and tasks is low
All work is captured by top-down decomposition of the total transformation
Requirements exist at the outset and they can be decomposed along with work

Other definitions of a project exist. A project is a collaborative enterprise that is carefully planned to achieve a particular aim.[53] Projects are temporary rather than permanent systems constituted by teams within or across organizations to accomplish particular tasks under time constraints.[54]

The classical theories of projects have a set of precepts, assumptions and even some implied principles that breakdown or inadequately serve the world of large complex projects. These attributes are summarized in the following table and alternative attributes associated with a so-called neo-classical perspective outlined.

Let's look first at the precepts that underpin the current theory of projects.

First, and foremost, projects are viewed as temporary endeavors. This precept extends across the prevailing theory of projects as dealing with **transformation** of inputs into outputs as well as extensions of this theory that view operations as focused on **flow** or

[52] New Theory of Project Management; Howell
[53] Adapted from Oxford English dictionary
[54] Embedding projects in multiple contexts – a structuration perspective; Stephan Manning; International Journal of Project Management 26 (2008) 30–37

value generation. Later we will see that in neo-classical theory as suggested in this paper, the perspective of time horizon is altered.

In the prevailing theory of projects, total transformation can be decomposed into manageable tasks, while extensions for operations as flow would refine this notion to say that transformation flows are distinct from task operations. Executing each task in an optimal manner and in an optimal sequence optimizes overall project execution according to prevailing theory while flow theory would somewhat modify this to say optimal task execution must include optimal process flows in order to optimize overall project execution. In this important extension to the prevailing theory of projects, lining up a series of tasks is not enough. The "influencing vectors" are now separate, distinct and equally important. We will return to this concept of "influencing vectors" in our discussion of neo-classical theory.

The prevailing theory of projects rests on a bedrock of key assumptions that include independence of discrete and bounded tasks (except for sequential relationships), with high certainty of the requirements to be met and how the task is to be performed. The totality of work to be performed can be described by top down decomposition of the total transformation effort. Comprehensive sets of requirements are assumed to exist at the outset of project and can be decomposed together with the work to be executed.

Flow and value creation extensions to the classical theory of projects add additional framework elements such as a focus on reducing lead times and process and flow time variability and the notion of the customer as a singular reference point for value determination.

We will see that this foundational set of assumptions are not adequate in the world of large complex projects and that some of the implied principles[55] from flow and value creation take on greater importance in the world of large projects.

7. Attributes of Large Complex Projects

Large projects fail two thirds of the time. In essence failure is the expected condition of large projects when we apply current project management theory to the conception, initiation and execution of these projects. Either the execution of these projects, founded on the Theory of Management, or the foundational concept of a project, especially a large project, founded on the classical Theory of Project is flawed. In an earlier section of this paper we looked at weaknesses in current project management thinking. In the prior section we looked at project attributes from a classical Theory of Projects.

[55] Implied principles include minimization of steps, parts and linkages; increased flexibility; increased transparency

In this section we will look at a few of the project attributes that we observe in large complex projects and suggest they may serve as a basis for a neo-classical Theory of Large Complex Projects.

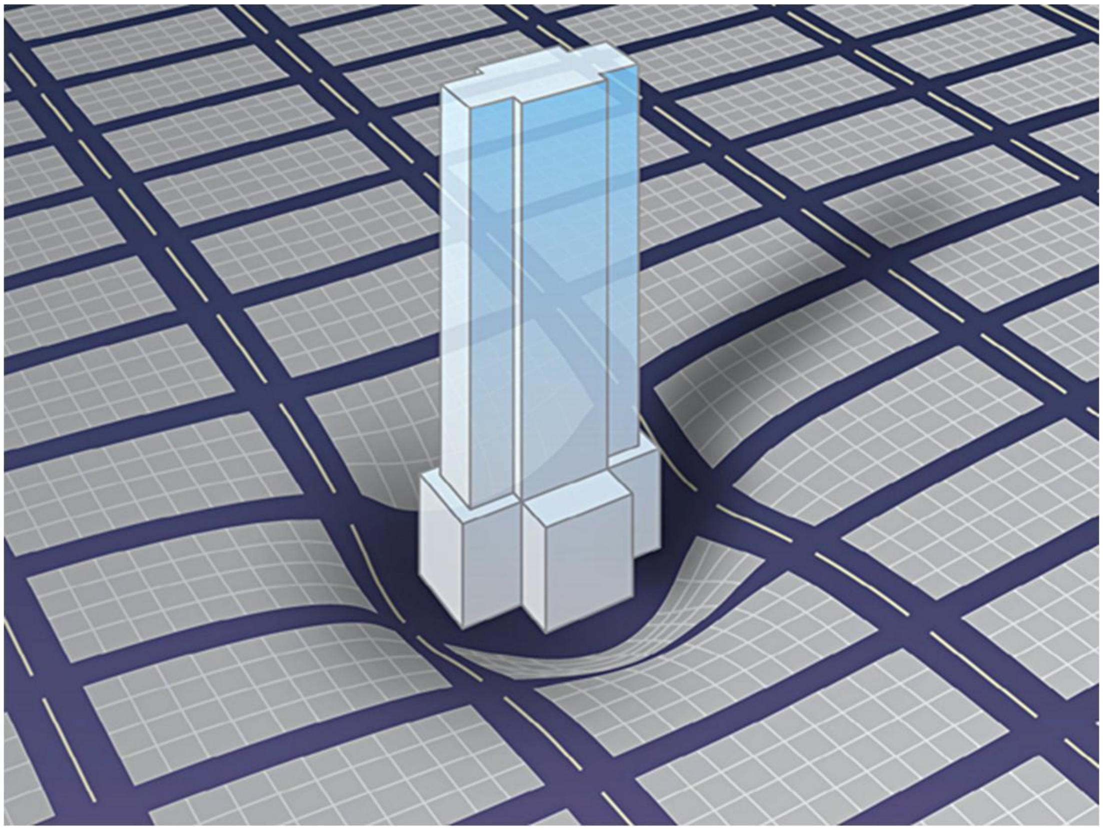
Large complex projects differ from those that comprise the traditional domain of projects as defined and served by the Project Management Institute and its Project Management Body of Knowledge (PMBOK). Remember its admonishment that PMBOK provides a management framework for ***most projects, most of the time.*** Large complex projects appear to live outside these boundary conditions.

So what are some of the precepts and attributes of large complex projects and how do they differ from projects better served by the classical theory of Projects?

Large complex projects, unlike their more normative cousins, range from semi-permanent endeavors to life cycle provision of services. The absolute durations often encountered in initial delivery and growing use of increasingly life cycle relationships drives these project organizations to have life spans often longer than most corporations. The growing use of joint ventures both on the client side as well as for the principle service provider often results in new organizations with cultural and operating regimes very different than either of the respective parents. The readiness of both the owner's[56] organization and respective joint ventures[57] warrants particular attention[58].

Influencing flows shape the transformative flows we have come to know in classical PM Theory and may arise from flows crossing semi-permeable project boundaries as well as the interaction between two or more transformative flows present within the project context. This is a key point, large projects are not easily isolated and just as they are susceptible to changing externalities, they too act to change the external environment that they affect. I have wrestled with whether to describe these boundaries as fully permeable or semi-permeable and have opted for the later since certain governance regimes will likely limit full permeability as it relates to these externalities.

[56] Owner's Readiness Index; Bob Prieto; PM World Journal Vol. III, Issue 1 – January 2014
[57] A Look at Joint Ventures; Bob Prieto; PM World Journal; Vol. II, Issue III – March 2013
[58] Chaotic and complex systems are sensitive to initial conditions. Even if readiness of a particular project is close to an ideal condition it will none-the-less take a different trajectory. Investment and diligence on achieving a high level of Owner and JV readiness is essential to good project outcomes.



These so called influencing flows may change the nature of tasks to be undertaken as well as how the various process flows define, interact with and drive forward the transformation process. This is significantly different than classical theory's execution of each task in an optimal manner with optimal process flows.

Tasks are no longer independent but rather are increasingly interdependent, coupled by constraints and "white space" risks. "Influencing vectors" arise from process flows, influencing flows, and new flows created from the interaction of two or more of these "influencing vectors". Tasks may become coupled and entangled and task limits may change and at times become open ended. They are no longer discrete and bounded.

Requirements may emerge in the course of project execution and susceptibility to the "planning fallacy" grows in large complex projects. Tasks may arise as a result of these emergent requirements, "influencing vectors" and flow-to-flow[59] interactions.

[59] Otherwise independent transformative flows in a large project may find themselves indirectly coupled through hidden constraints or common susceptibility to risks that lie between major project elements or flows that have been referred to as "white space" risks

Totality of work is influenced by semi-permeable project boundaries, emergent requirements, and “influencing vectors”. Initial decomposition of the initial transformation effort may not define the ultimate totality of transformation.

Strategic Business Objectives (SBO) become more important than requirements and in some instances projects may be faced with emergent SBOs especially when “influencing vectors” cross the semi-permeable project boundary over an extended timeframe

Requirements must not only address emergent factors but also uncertainty over time as large complex projects often have extended project delivery times and significant considerations of life cycle factors and needs. Assumptions that might otherwise be considered fixed in a more normative project may now migrate in these longer durations often associated with large complex projects.

The objective of reduced lead times and process and flow variability is carried further through an expanded basis of design together with tight supply chain linkages that place a strong emphasis on the value of time. Increased emphasis on standardization, fabrication and modularization is the new norm as large projects seek to accrue productivity advantages more typically associated with manufacturing opportunities. Strengthened work face planning and greater knowledge enablement represent the new norms that large complex projects must strive for.

A key difference that large complex projects face is that an exclusive focus on satisfying the client may not result in project success. Value is now determined through a multi-stakeholder lenses that strives to provide increased benefits for a broad set of stakeholders.

The implied principles in flow and value creation extensions to classical PM Theory become essential in the world of large complex projects. Standardization of systems, structures, components and work processes and de-coupling of activities that can be undertaken independently is essential. Precedence’s must be reduced and work plans must facilitate contingent execution.

Stakeholder engagement, not just management, is a core activity and knowledge sharing is a core execution principle.

The following table (Table 7) provides a comparison of the attributes of these respective theories of project’s attributes.

Table 7
Theory of Project Attributes

	Classical Theory of Projects		**Neo-classical Theory**
	Prevailing Theory of Project (Transformation)	**Extension of Prevailing Theory for Operations as Flow[60] and Value Generation[61]**	**Theory of Large Complex Projects[62]**
Precepts	Project is a temporary endeavor	Project is a temporary endeavor	Large complex projects range from semi-permanent endeavors[63] to life cycle provision of services
	Total transformation can be decomposed into manageable tasks	Transformation flows are distinct from task operations	Influencing flows shape transformative flows and may arise from flows crossing semi-permeable project boundaries as well as the interaction

[60] Shingo (1988)
[61] Levitt (1960) and Drucker (1989)
[62] Large projects have many of the same characteristics of large programs and no distinguishment is made here. See Strategic Program Management, Prieto for a discuss of management challenges associated with large programs.
[63] Many large projects have delivery lifetimes that exceed average lifetimes of corporations. Increasingly projects may be procured on a DBOM (design, build, operate, maintain) basis or a DBOMF or PPP basis, where finance is an added service component

			between two or more transformative flows present within the project context.
	Executing each task in an optimal manner and in an optimal sequence optimizes overall project execution	Executing each task in an optimal manner and with optimal process flows optimizes overall project execution	Influencing flows may change the nature of tasks to be undertaken as well as how the various process flows define, interact with and drive forward the transformation process.
Assumptions	Tasks are independent, except for sequential relationships	Tasks are independent but connected by "influencing vectors"	Tasks are increasingly interdependent, coupled by constraints and "white space" risks[64]. "Influencing vectors" arise from process flows, influencing flows, and new flows created from the

[64] These are risks that lie in the white space between the various projects that comprise a program or the various tasks that comprise a large complex project and which are not readily identified through the first order interfaces which are typically identified and tracked as part of the overall project management effort. White space risks are not obvious from the risk methodologies routinely employed because they either address unobvious constraint coupling, of both the first and second order, or are related to contextual risks such as stakeholder trust. White space risks are systemic in nature and are potentially present within both the internal as well as the external context in which the project operates.

			interaction of two or more of these "influencing vectors"
	Tasks are discrete and bounded	Tasks are discrete and bounded	Tasks may become coupled and entangled and task limits may change and at times become open ended
	Uncertainty of requirement is low	Uncertainty of requirement is low	Requirements may emerge in the course of project execution; susceptibility to the "planning fallacy"[65]
	Uncertainty of tasks to be performed is low	Uncertainty of tasks to be performed is low	Tasks may arise as the result of emergent requirements, "influencing vectors" and flow-to-flow interactions
	The totality of work to be performed can be described by top down decomposition of the total transformation effort	The totality of work to be performed can be described by top down decomposition of the total transformation effort	Totality of work is influenced by semi-permeable project boundaries, emergent requirements, and "influencing

[65] Daniel Kahneman and Amos Tversky (1979)

			vectors". Initial decomposition of the initial transformation effort may not define the ultimate totality of transformation.
	Requirements exist at outset of project	Requirements exist at outset of project	Strategic Business Objectives (SBO)[66] become more important than requirements and in some instances projects may be faced with emergent SBOs especially when "influencing vectors" cross the semi-permeable project boundary over an extended timeframe
	Requirements can be decomposed together with the work to be executed	Requirements can be decomposed together with the work to be executed	Requirements must not only address emergent factors but also uncertainty over time as large complex projects often have extended project delivery times and significant

[66] Strategic Program Management; Bob Prieto; Construction Management Association of America (CMAA); 2008

			considerations of life cycle factors and needs.
Extensions		Reduce lead time (flow concept of production)	An expanded basis of design together with tight supply chain linkages and a strong emphasis on the value of time[67] is essential
		Reduce process time variability (flow concept of production)	Increased emphasis on standardization, fabrication, modularization
		Reduce flow time variability (flow concept of production)	Strengthen work face planning; enable with knowledge assemblies; RFI reduction through an expanded basis of design[68,69]
		Value determined only in reference to	Value determined through multi-

[67] Perspective on the Cost of Delayed Decision Making in Large Project Execution; Bob Prieto; PM World Journal Vol. III, Issue II – February 2014

[68] BOD^X – Expanded basis of design, collectively incorporating the traditional engineering basis of design (BOD), new construction basis of design (CBOD) and a new operating and maintenance basis of design (O&MBOD). BOD^X is driven by construction and O&M considerations while meeting the performance and functional requirements typically detailed in the owner's project requirements (OPR).
[69] Addressing Project Capital Efficiency through a Business Basis of Design; Bob Prieto; PM World Journal; Vol. III, Issue IV – April 2014

		customer (value generation concept of production)	stakeholder lenses; increased benefits focus
Implied Principles		Minimize steps, parts, linkages	Standardization of systems, structures, components and work processes; de-coupling of activities that can be undertaken independently
		Increase flexibility	Precedence's reduced and work plan allows for contingent execution
		Increase transparency	Stakeholder engagement as core activity; knowledge sharing as execution principle

8. It's Complicated!

We have looked at the evolution of general management theory as well as project management theory as part of our examination of the Theory of Management. We have identified some elements of general management theory not yet fully incorporated into project management theory that may be useful in dealing with the world of large complex projects. Subsequently we have considered the Theory of Projects, looking at classical project theory and some of the recent extensions to it. We have identified attributes of large complex projects that we do not find in the classical theory of projects but which are core to describing the various aspects we encounter on these projects. The following figure summarizes these various aspects of large projects and provides a foundation to consider what a new Theory of Project Management for large complex projects may look like.

Table 8
Aspects of Large Complex Projects

Aspect	**Management**	**Project**
Project Time Scale		Large complex projects range from semi-permanent endeavors to life cycle provision of services
Outcomes	Self-creating through feedback and interaction	Strategic Business Objectives (SBO), perhaps better termed “Strategic Business Outcomes”, become more important than requirements and in some instances projects may be faced with emergent SBOs especially when “influencing vectors” cross the semi-permeable project boundary over an extended timeframe
	Strong outcome centric focus and multi-stakeholder commitment to outcomes	Value determined through multi-stakeholder lenses; increased benefits focus

	Exhibit multifinality and equifinality	Multifinality influenced by stakeholder interests
Stakeholder Role	Discovery of newly emergent actors impacting delivery of outcomes	Stakeholder engagement as core activity
Boundary	More permeable boundary	Semi-permeable
Flows Across Boundary	Exchanges information/material with environment – unknown and uncontrolled	Influencing flows shape transformative flows and may arise from flows crossing semi-permeable project boundaries as well as the interaction between two or more transformative flows present within the project context.
Flows		Influencing flows may change the nature of tasks to be undertaken as well as how the various process flows define, interact with and drive forward the transformation process.
		New “induced” flows created
		De-coupling of activities that can be undertaken independently
		Precedence’s reduced

		and work plan allows for contingent execution
Requirements		Requirements may emerge in the course of project execution; susceptibility to the "planning fallacy"
		Requirements must not only address emergent factors but also uncertainty over time as large complex projects often have extended project delivery times and significant considerations of life cycle factors and needs.
Scope		Totality of work is influenced by semi-permeable project boundaries, emergent requirements, and "influencing vectors". Initial decomposition of the initial transformation effort may not define the ultimate totality of transformation.
Tasks		Tasks are increasingly interdependent, coupled by constraints and "white space" risks. "Influencing vectors" arise from process flows, influencing flows,

		and new flows created from the interaction of two or more of these "influencing vectors"
		Tasks may become coupled and entangled and task limits may change and at times become open ended
		Tasks may arise as the result of emergent requirements, "influencing vectors" and flow-to-flow interactions
Project Organization	Adaptive	Flexible, adaptive, responsive (Concept of F-A-R ness may represent a measure or organizational capabilities and capacities)
	Self-organizing (role of managers changes) and adapting	Greater emphasis on "workface" planning and execution
Knowledge Management	Everyone has access to all information needed to do their job (Knowledge Management; continuously educated workforce)	Knowledge sharing as central execution principle
	New information is continuously created and shared. (Knowledge	

	Management challenges increase; knowledge is increasingly contextual and temporal)	
Execution Focus		Standardization of systems, structures, components and work processes; de-coupling of activities that can be undertaken independently
		Expanded basis of design together with tight supply chain linkages and a strong emphasis on the value of time
		Increased emphasis on standardization, fabrication, modularization
		Strong work face planning enabled with knowledge assemblies; RFI reduction through an expanded basis of design

The various aspects detailed are intended to be illustrative of key attributes of a Theory of Large Complex Project Management. They focus on some key differentiators and are incomplete without select elements associated with both chaotic and complex projects, especially those that focus on the non-deterministic nature of complex projects.

Let's explore the highlighted differences further to lay the theoretical foundations for large complex projects, covering each aspect in turn:

- Project time scale
- Outcomes
- Stakeholder role
- Boundary
- Flow across boundary
- Flows
- Requirements
- Scope
- Tasks
- Project organization
- Knowledge management
- Execution focus

8.1 Project Time Scale

Large complex projects are often characterized by significantly longer gestation and approval times than more traditional projects. These longer gestation and approval times are driven not only by the projects complexity but a myriad of other factors including increased environmental scans; expanded internal and often external stakeholders that must be consulted with even before more rigorous stakeholder engagement efforts are initiated; increased use of more rigorous stagegate processes prior to full sanctioning of the project; and often a discrete project financing period.

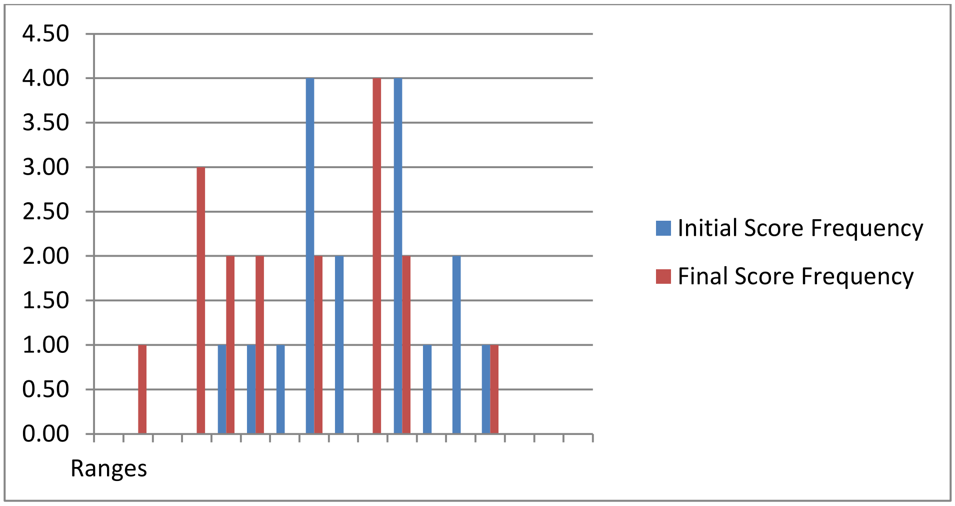
These projects often have longer engineering and construction durations driven by their scale; expanded permitting and approval processes; extended stakeholder engagement periods; greater inherent schedule risks and increased exposure to the effects of disruption; increased risks associated with greater risk exposure times; and the nature of many such projects that transitions them to a multi-phase program. In addition many of these projects may incorporate a period of maintenance by the original contractors, effectively extending the warranty period. Some of these extended periods may represent significant fractions of overall facility lifetimes.

These extended gestation, initiation, execution and effective contract timeframes often result in project organizations for large complex projects that range from semi-permanent endeavors to life cycle provision of services. This changed management context is suggestive of the need to adopt general management practices that are associated with complex endeavors. These practices differ from more traditional project management practices but become critical as we move into the world of large complex projects.

8.2 Outcomes

Large complex projects require a strong outcomes focus not just an outputs focus as suggested by more traditional management practice. This outcomes focus is critical since large complex projects often are associated with ultimate project outputs which are to some extent self-defining and self-creating through extensive feedback mechanisms which are driven by a multiplicity of actors over relatively longer timeframes.

A characteristic of underperforming large projects is often a failure by the owner's senior most management to articulate these strategic business outcomes that they are seeking to achieve. Even in those instances where they have been articulated two other factors are equally important and often not fully addressed. SBOs must be agreed to and continuously communicated. As a minimum this must encompass the entirety of the owner's ecosphere which includes not only responsible line and project execution organizations but also supporting staff elements such as treasury, contracts and accounts payable; owner's board and involved investors and financing organizations; and as we shall soon discuss, other significant external stakeholders. This internal institutional alignment is a key aspect of owner readiness, a critical requirement when undertaking large complex projects.



Survey of 17 Large Complex Project Managers on Owner Readiness. Initial scores were assigned on a 100% basis prior to a review of the necessary ingredients of owner readiness and are shown distributed over the 100% range. Following a review they reassessed the same project's readiness. Average scores dropped from 62.8 to 51.9.

A strong outcomes centric focus and multi-stakeholder commitment to these outcomes is essential in large complex projects. Satisfying these outcomes sets may be achieved through a range of possible outputs (multifinality) which are influenced through stakeholder interactions over time as well as evolution and changes within the project organization and more importantly, externally.

Strategic Business Outcomes (SBO) become more important than requirements in achieving ultimate success. In some instances projects may be faced with emergent SBOs especially when "influencing flows" cross what is in reality a semi-permeable project boundary over an extended project timeframe. These influencing flows are discussed later but are an important characteristic when we consider large complex projects and their management.

Value in large complex projects is determined through multi-stakeholder lenses and an increased benefits focus.

8.3 Stakeholder Role

Large complex projects by their very nature require the project design and outcomes to satisfy not just the outcomes desired by the owner (a key and driving stakeholder but not the exclusive stakeholder required for project success) but also many of the outcomes desired by a network of enabling and blocking stakeholders[70]. This multi-stakeholder context is a simple reality of large complex project delivery. Stakeholders in many instances have an ability to determine the success or failure of a project and in many extractive industries a social license to operate may carry more value than many other project strategies and optimizations[71]. Stakeholder engagement is a core activity and can serve to reduce opportunistic delays from emergent actors. It is important that we have identified and characterized potential stakeholders at an early stage, always cognizant of possible new actors. The following table (Table 9) provides a construct for stakeholder identification and strategy alignment must consider the stakeholder type in addition to the specific issues and concerns raised.

Table 9
ESPRIT Framework of Stakeholder Types

Stakeholder Type	**Examples**
Economic	Owner; investors; directly affected economic interests
Social	Local populations; various "bound and aligned" subgroups
Political	Partisan interests; local, national, global interests seeking to leverage project circumstances for otherwise independent agenda
Religious/Cultural	Gender; community; denominational interests
Ideas Driven	Ideas driven organizations ranging from NIMBY to global agenda such as "Save the Planet"

[70] Stakeholder Management in Large Engineering & Construction Programs; Bob Prieto; PM World Today; 2011
[71] Spinning Gold: The Financial returns to Stakeholder Engagement; Witold Henisz; Sinziana Dorobantu; Lite Nartey; Strategic Management Journal; 2014

Technical	Technical preferences or technology denial (anti-fracking)

Stakeholder's desires and context in turn are influenced by the project itself, which acts to shape and deform the context in which it is set. In addition, stakeholder-stakeholder interactions become important and it is not unusual to find competing or even diametrically opposed stakeholder interests among the web of stakeholders that may influence the project.

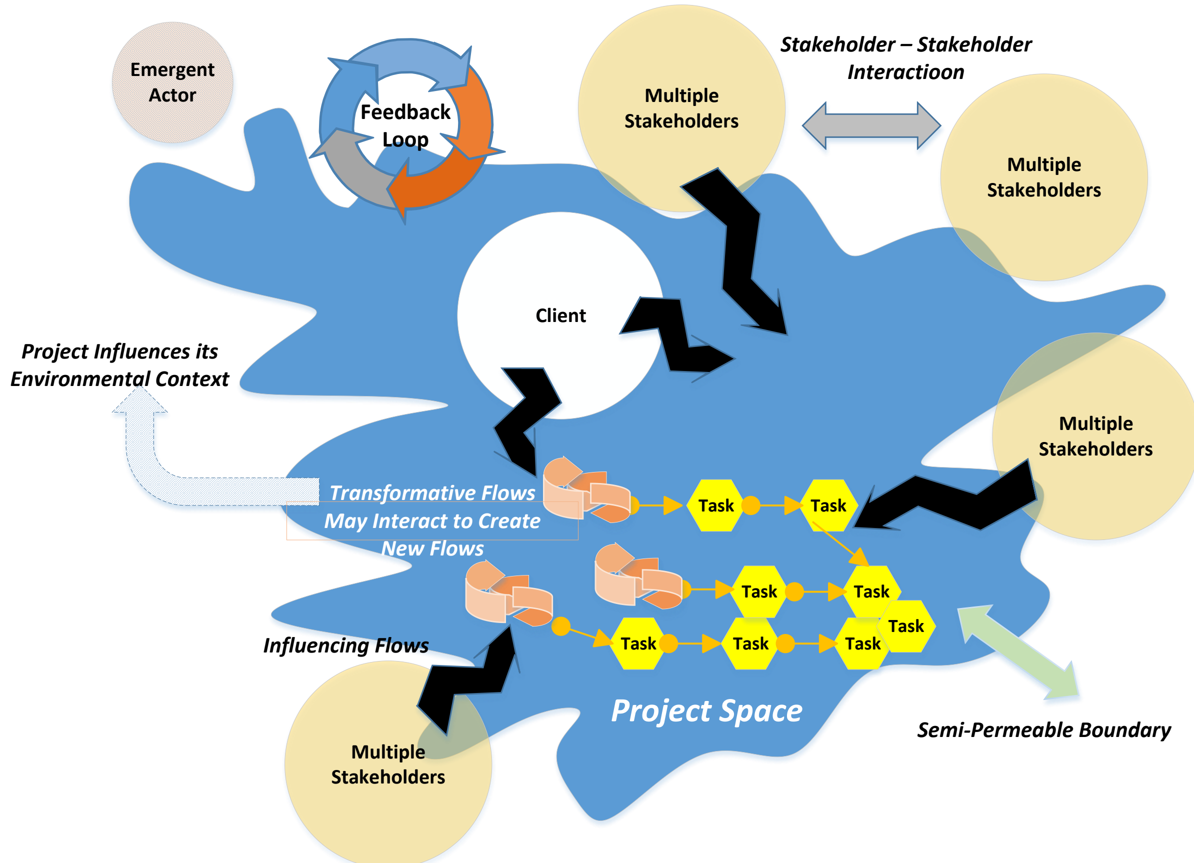
As the project proceeds and new issues arise or as context becomes fixed through engagement and agreement with one or more influencing stakeholders, we may see new actors emerge, further impacting delivery of outcomes. This concept of emergence is commonplace on large complex projects and may be regarded as both a core characteristic as well as a central management challenge.

The following figure illustrates the multi-stakeholder context; associated influencing flows; and stakeholder-stakeholder interaction.

8.4 Boundary

Large complex projects are not well bounded. Large stakeholder influences; emergence of new outcomes and stakeholders over extended delivery timeframes and lifetimes; and the sheer number of ex-project inputs and assumption drivers, all act to create a semi-permeable boundary across which there are many informational and influencing flows. This porous project limit combined with the self-defining and emergent nature of the project characterizes the non-deterministic system which best describes large complex projects.

This emerging or evolving project is depicted in the following figure.



Large Complex Projects Don't Follow Classical Transformation Models

8.5 Flow Across Boundary

The semi-permeable boundaries of large complex projects represent an important management frontier to be posted with sentries on the lookout, giving visibility to flows across this boundary and identifying emergent outcomes.[72] Many good things happen at this frontier including exchange of information and knowledge as we engage stakeholders and valuable insights on outcome affecting factors. But not all things crossing this frontier are necessarily reinforcing of the desired project outcomes or the efficiency and effectiveness of the various sets of ongoing transformational flows ongoing in the project.

Flows crossing this frontier may influence, sometimes significantly, the project's well planned transformation processes. These flows and the other exchanges across the project frontier may be unknown and uncontrolled.

[72] See A complex systems theory perspective on lean production; Saurin, Rooke, Koskela; International Journal of Production Research; 2013 for a good description of complex systems.

Influencing flows, such as those described, act to shape transformative flows and may arise not only from flows crossing this semi-permeable project boundary but also as a result of the interaction between two or more transformative flows present within the project context.

8.6 Flows

The influencing flows arising from a multiplicity of stakeholders was shown in the preceding figure and the eddies they create in the planned transformative flows are also shown together with a new flow which arises from this interaction between flows.

Influencing flows may change the nature of tasks to be undertaken as well as how the various process flows define, interact with and drive forward the transformation process. This leads to an important recognition that planning activities must address two key elements:

- Tasks, including the work flows within those tasks
- Flows, including transformative (or systems) flows between tasks as well as new flows induced by these influencing flows

Table 10
Flows Acting on Large Complex Projects

Transformative Flows inside a Task	Influenced by systems level Transformative flows from task to task which may act to change task timing and sequencing as well as modify system flow outputs required from the task operation
Transformative Flows between Tasks	System level Transformative flows influenced by the overall system state. Transformative flows between tasks may be modified by Task level performance; impacts of Influencing flows directly on the planned Transformative flow; impacts of Influencing flows on other Transformative flows which are directly or indirectly coupled (through constraints); impacts from Induced flows

Induced Flows	Created by the interaction of one or more Influencing flows on various system elements (Task; Transformative Flows) or the interaction of Transformative flows with each other as a result of the effects of Influencing flows.
Influencing Flows	Flows across semi-permeable project boundaries that arise from external stakeholders or changed project environment.

Task level planning will involve a more classical approach focused on transforming inputs to outputs. Management information however must now include information on how the output of a preceding task will flow to the subsequent task and how outputs will flow onwards. These flows have characteristics with respect whether they are planned or contingent; when they will actually occur and whether there are any buffering mechanisms to optimize overall project flows. The nature and timing of these flows will be shaped increasingly on a dynamic basis and as such project execution must include a contingent capability to redirect and retime various flows or act to restore already influenced flows to an optimal state, recognizing this may be significantly different than the original transformative plan.

This contingent execution requires increased awareness of actual or potential direct or indirect coupling such as what can happen when flows are coupled by second or third order constraints.

A key strategy to manage this inherent complexity is through a systematic de-coupling of activities that can be undertaken independently. On one large complex project, overall schedule was improved by 20% through a conscious decoupling of major elements of work that had previously been bundled to “simplify” project execution. The law of unintended consequences was clearly evident.

This decoupling of major elements should also consider careful elimination of precedence’s to increase the opportunity for contingent execution which is a reality of large project execution.

8.7 Requirements

An owner's project requirements (OPR) are often memorialized directly in contract documents or scopes of work shaped by earlier conducted planning studies. In large complex projects these requirements documents subsequently prove to be optimistic or incomplete. There are three principal causes each of which requires special attention in the world of large projects:

- Owner's Project Requirements (OPR) are too narrowly defined and often drive optimization around the wrong criteria
- Planning fallacy leads to an optimistic view of an uncertain future
- Emergence of new requirements during project execution, which is a characteristic of long duration complex systems

Let's look at each of these in turn.

Owner's project requirements, OPR, are often developed by engineering organizations to define the technical characteristics of the final desired facility. These are subsequently converted into a basis of design by engineering elements of the implementing contractor resulting in what in reality is simply an engineering basis of design. Described differently, it is the output of the last task of the CAPEX phase of a project. But as we have seen earlier, large complex projects require us to focus not only on task inputs and outputs, but importantly, on the transformative flows between tasks. During the CAPEX phase of a project these flows are representative of the construction process itself and selected means and methods. To improve overall execution in the CAPEX phase, therefore, it is necessary to expand our basis of design (BOD) to include not only the traditional engineering basis of design but also what we may call a construction basis of design (CBOD).

But in the world of large complex projects, traditional time boundaries associated with initial delivery, may be extended to include initial or even life cycle operation and maintenance. In these instances we must extend our basis of design even further, incorporating an O&M basis of design (O&MBOD) element. Taken together we have now created an expanded basis of design[73] or BOD^X.

It is important to highlight that incorporation of CBOD and O&MBOD at the outset is fundamentally different than conducting constructability or maintainability reviews at a later design stage. The former shapes what is to be designed and acts to expand the requirements as defined in the OPR, while the later merely confirms or improves at the margin what has already been designed to some level.

[73] Addressing Project Capital Efficiency through a Business Basis of Design; Bob Prieto; PM World Journal; 2014

Generalizing, in large complex projects, project requirements must reflect not just final "task" states but also the coupling transformative flows. Additionally, the more unbounded timeframes of large complex projects, requires a more life cycle consciousness than we often experience in more traditional projects.

Turning now to the planning fallacy which large complex projects appear to be particularly susceptible to[74], we are drawn to the work of Kahnemann and Tversky[75] which defined the planning fallacy as the tendency of people and organizations to underestimate how long a task will take even when they have experience of similar tasks overrunning.

Perhaps the poster children for the planning fallacy are large scale public works projects. In a 2006 paper in the Project Management Journal[76], Bent Flyvbjerg describes transportation projects "inaccuracy in cost forecasts in constant prices is on average 44.7% for rail, 33.8% for bridges and tunnels, and 20.4% for roads."

Work by Kahneman, Tversky, Flyvbjerg and others shows that errors of judgment are:

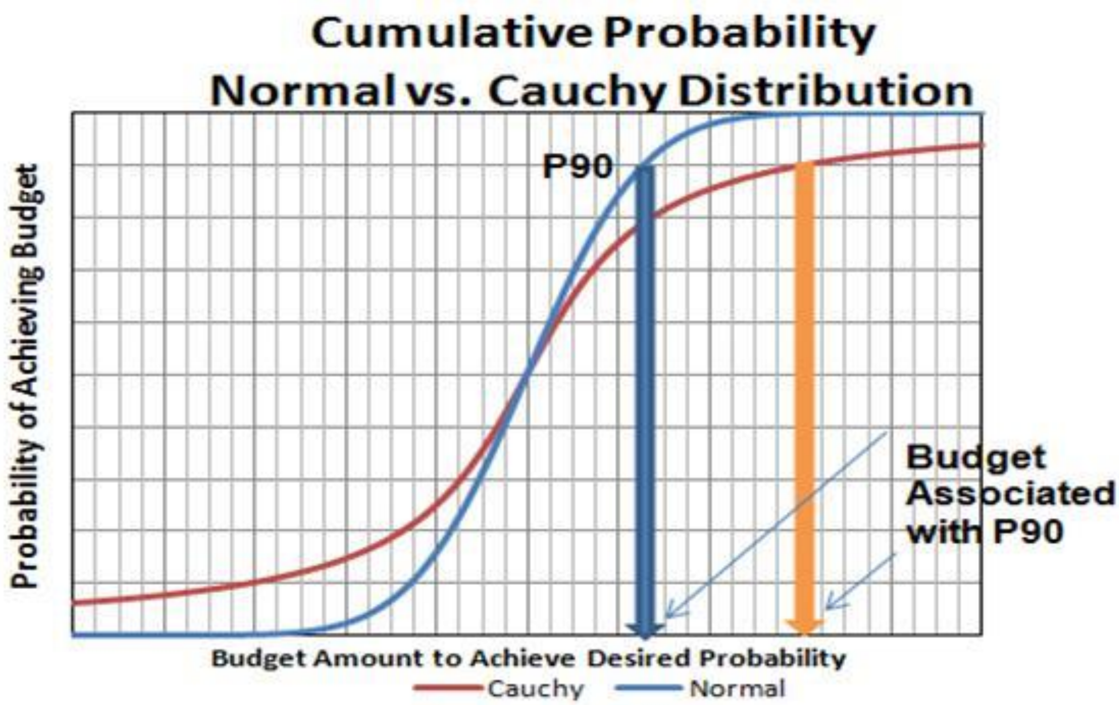
- systematic and predictable
- reflect bias
- persist even when we are aware of, and
- require corrective measures that reflect recognition of this bias

These natural tendencies are further exacerbated when "motivated" individuals, which may include both internal and external stakeholders, frame questions in such a way as to constrain the range of possible answers.

Large complex projects demand extra care in dealing with the planning fallacy. First is to test initial assumption reasonableness employing techniques such as reference class forecasting and conducting a thorough review of modeled confidence levels (P50 vs P80) and of the distributions employed in the models themselves[77]. A diversity of perspectives further aids this step. Second, given the long term nature of many of these projects, periodically reconfirm the assumptions used in the planning basis. Assumption migration[78] is a key challenge in the world of large complex projects.

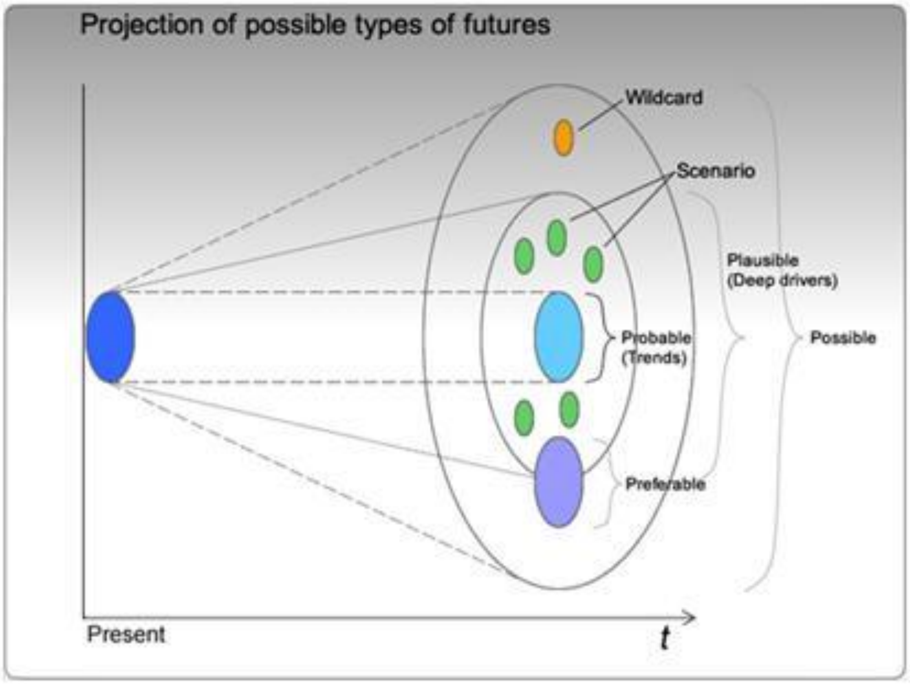
[74] Managing the Planning Fallacy in Large, Complex Infrastructure Programs; Bob Prieto; PM World Journal; 2013
[75] "Prospect theory: An analysis of decisions under risk". Econometrica; Kahneman and Tversky; 1979
[76] From Nobel Prize To Project Management: Getting Risks Right; Bent Flyvbjerg; Aalborg University, Denmark; Project Management Journal; August, 2006.
[77] Improbability of Large Project Success; Bob Prieto; PM World Journal; 2015
[78] Is it Time to Rethink Project Management Theory?; Bob Prieto; PM World Journal; 2015

Large complex projects move into the ranges of non-linear behavior and traditional project estimation may not adequately account for this factor.[79] Traditional project management theory falls short and perhaps our high project "failure" rates are more reflective of fundamental planning and estimation shortfalls and not merely execution difficulties[80].



Finally, requirements must not only address emergent factors but also uncertainty over time as large complex projects often have extended project delivery times and significant considerations of life cycle factors and needs.

[79] Reflections on the functional relationship between project efforts and its complexity; Pavel Barseghyan
[80] The figure compares normal and a Cauchy fat tailed distribution. Other distributions may be more appropriate and the intermediate distribution in Liu et. al.(2012) warrants consideration.



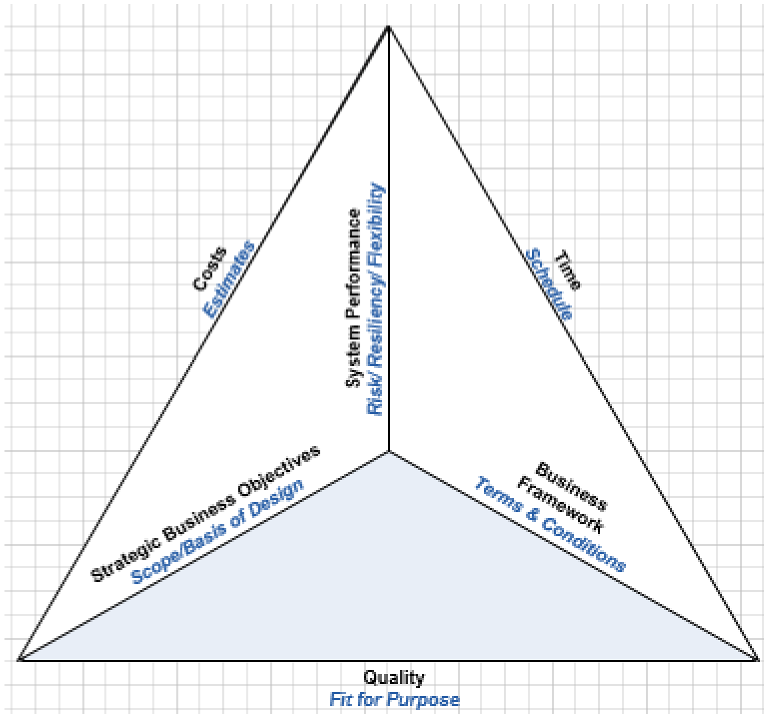
8.8 Scope

The scope of a large complex project defines the nature of the facility asset, its intended purpose and use, and the business context within which it is intended to operate. In large complex projects scope must go beyond just the project's technical requirements and explicitly include a:

- broader set of owner's requirements, including the strategic business outcomes the owner is trying to achieve
- mandatory and quasi-mandatory requirements from external stakeholders

The totality of work is influenced by the interplay with cost and time dimensions and the traditional project triangle becomes much more of a project tetrahedron[81] [82]when looking at large complex projects.

[81] The "Program Tetrahedron": A Changed Baseline Control Basis under Strategic Program Management; Bob Prieto; PM World Journal; 2012
[82] Program Tetrahedron – Further Developing the Concept; Bob Prieto; PM World Journal; 2013



Other factors influencing project scope and contributing to the non-deterministic nature of many large projects include the semi-permeable project boundaries inherent in large complex projects; emergent requirements; and "influencing vectors".

Initial decomposition of the initial transformation effort may not define the ultimate totality of transformation.

8.9 Tasks

Tasks are increasingly interdependent, coupled by constraints[83] and "white space" risks. "Influencing vectors" arise from process flows, influencing flows, and new flows created from the interaction of two or more of these "influencing vectors"

Tasks may become coupled and entangled and task limits may change and at times become open ended

Tasks may arise as the result of emergent requirements, "influencing vectors" and flow-to-flow interactions as previously discussed. As a result task inputs and outputs must consider and pass along information related to transformational flows from one task to the other.

[83] Improbability of Large Project Success; Bob Prieto; PM World Journal; 2015

Coupled Constraints

Consider the situation where an activity not on the critical path begins late but near enough to the original plan to stay off the critical path.

No problem?

It will be, if that key resource it uses doesn't arrive on time for a critical path activity.

The complexity of large projects masks a raft of hidden, coupled constraints that can then cascade throughout the project. Near enough is not good enough and the complexity of large projects needs to consider the probability of disruption where previously the Law of Near Enough (*The Improbability Principle; David J. Hand*) seemed to govern project risk assessments.

8.10 Project Organization

Large complex projects require an organizational design that reflects the complexity of the tasks at hand; the dynamic environment in which the project is set[84], subject to both a multiplicity of influencing flows and extended project timeframes; and the emergent nature of project outcomes in such project types. These organizations must be adaptive, flexible, self-renewing, resilient and learning. They must be capable of responding intelligently to change, recognizing that change is the only project constant.

These adaptive project organizations must see change as an organizing force not a disruptive one. Experimentation and progressive innovation must be core characteristics. The rules of connection within the project organization must be simple in order to have the flexibility to respond to complexity. Organizational behavior and response is determined not so much by the tasks to be undertaken as they are by information on current flows acting on and within the project.

Project organizations in the world of large complex projects rely on a strong sense of identity built upon the common understanding of the owner's strategic business outcomes that serve as the initial rational for the project. Information flows reflecting process and influencing flows is essential for strong organizational performance. Finally, relationships based on process not task alignment becomes key and add to organizational intelligence. Identity, information and relationships[85] trump processes and structures and awareness of the overall state of the "system" becomes even more important than task status.

[84] This dynamic environment introduces variability
[85] The Irresistible Future of Organizing; Margaret Wheatley, Myron Rogers; 1996

While large complex project organizations require many of the attributes of self-organization we see in agile project management, more is required because of the emergence these projects experience.

Table 11
Adaptive Project Organization Framework[86]

Organizational Capacity	Practices	Requisite Skills
Identity	Strategic Business Outcomes; Vision & Mission	Strategic thinking; Visioning
	Goals; Scope; Requirements	Mobilization of resources (people; systems; processes)
	Planning	Scenario based evaluation; Risk identification and modeling; Contingency planning and strategy
	Evaluation (Management & Control)	Big analytics; Pattern recognition; Root cause analysis
	Change Management	Organizational change management; Dealing with disruption
Information	Flow monitoring and assessment; Assumption tracking; Coupling and interfaces	Data analytics; technology
	Decision making	Communication

[86] Adapted from "Generating Self-Organizing Capacity: Leadership Practices and Training Needs in Non-Profits; Allen and Morton; Journal of Extension; 2006

	(Management)	
Relationships	Trust; Connectedness	Team building
	Communities of Practice	Partnering; Collaboration
	Stakeholder networks	Partnering; Collaboration; Conflict management
	Disputes & distrust	Conflict management and resolution

8.11 Knowledge Management

The importance of information flows has been previously discussed. Throughout the project information is transformed into actionable knowledge which provides a bedrock for adaptation by the project team to the emergent natures of the project. But this knowledge bedrock and organizational adaptability requires that everyone has access to all information needed to do their job. Filters that may have served well in smaller, less complex projects in static contexts have no place in the world of large complex projects. Knowledge management supports a continuously educated and adaptive workforce. Knowledge sharing is a central execution principle

Influencing flows and continuous improvement create new information to be shared. In turn, the knowledge management challenges increase and knowledge is increasingly contextual and temporal. Similarly, the extent of available knowledge demands the use of self-assembling knowledge assemblies[87] focused on the various tasks and flows of the project.

8.12 Execution Focus

Execution challenges grow in large complex projects and simplification and flexibility become core features of efficient and effective execution. Many execution aspects have been touched upon earlier in this section but to these we can add:

- Standardization of systems, structures, components and task level work processes

[87] Knowledge assets are combined based on the user and what they are working on into Knowledge Assemblies

- De-coupling of activities that can be undertaken independently
- Expanded basis of design
- Tight supply chain linkages
- Strong emphasis on the value of time
- Increased emphasis on standardization, fabrication, modularization
- Strong work face planning enabled with knowledge assemblies
- RFI reduction through an expanded basis of design

9. Theory of Large Complex Project Management

Dalcher asks "Is there a universal theory of project management?"[88] To this I would respond that while a grand unifying theory of project management may exist, it is not the subject of this paper. Rather as I have highlighted in the "Physics of Projects"[89] classical and neo-classical theories of physics were both focused on the same problem. If the state of a dynamic system is known initially and something is done to it, how will the state of the system change with time in response?

This is analogous to what we are trying to determine in project management.

In the world of physics, classical theory breaks down at scale[90]. Conventional project management theory similarly seems to break down at scale. The theoretical construct I have been building to in this paper and summarize in the following table is very much focused on this project realm where scale and complexity rule.

In developing this theoretical construct I have essentially considered three simple hypotheses, the first of which is:

- **Large complex projects are not well served by conventional project management theory and practice.**

This hypothesis was demonstrated at the outset of this paper and the differential behavior between large and traditionally scaled projects has been previously noted.[91]

[88] Advances in Project management Series; Is there a universal theory of project management?; Darren Dalcher; PM World journal; 2013
[89] Physics of Projects; Bob Prieto; PM World Journal; 2015
[90] Although not explored in this paper, classical physics also breaks down at extremely small scales and it may be worthwhile exploring how classical PM Theory behaves on a similarly small scale. The fundamental forces at play here may be those of human interactions.
[91] Large projects "fail" 2 out of 3 times while more traditional projects fail 1 out of 3 times. This later fact would suggest that further refinement of traditional theory, perhaps drawing from the observations and lessons which underpin the theory suggested in this paper for large complex projects is warranted.

The second hypothesis considered relates to the Theory of Management as applied to the management of projects. In simplest terms this hypothesis says:

- **The Theory of Project Management does not draw fully on the richness of the Theory of Management**

This hypothesis is demonstrated as we explored the extensions of the Theory of Management to address chaos and complexity and the more limited extensions of project management theory.

The third and final hypothesis we considered focused on the Theory of Projects, positing:

- **Large complex projects have significantly different attributes than the more traditional projects which comprise the basis for classical project management theory**

These attributes and their differences from classical projects have been previously laid out in a comparative table.

In constructing a Theory of Large Complex Project Management we build on the premise that these three hypotheses have been adequately demonstrated. We must now define the nature of the theory[92] proposed. Here we may consider theory from two perspectives:

- **Scientific theory** – supported by a well-substantiated explanation tested and confirmed through observation; describes the causal elements responsible for observations and useful to explain and predict aspects of the area of inquiry (large complex projects)
- **Management theory** - collection of ideas which set forth general rules on how to manage an endeavor

The following table (Table 12) outlines a possible construct for a Theory of Large Complex Projects considering each of these perspectives and further disaggregating this overall theory into three principle theories that comprise it:

- Organizational
- Cultural
- Professional Identity

[92] See Project Management Philosophy: Incremental improvement of project management through the use of research; Van der Merwe; PM World Journal; 2012 for a discussion of the concept of "theory"

Table 12 Possible Construct for Theory of Large Complex Projects					
Principle Theories Comprising Overall Theory of Large Complex Projects	**Theoretical Element**	**Core Attributes**	**Defining Characteristics**	**Actions and Effects**	**Theoretical Perspective[93]**
Organizational	Identity	Core organizational behavior (internal)	Competency and capability	Ability to respond and adapt emphasized over fixed plans	M[94]
			Systems focus	Monitor system properties (patterns) to assure outcomes achievement	S[95]
			Dynamic management	Flow driven responsivenes	S, M[96]

[93] S = Scientific Theory perspective; M = Management Theory perspective
[94] Presently this responsive approach is found more in large contingent operations such as those found post-disaster or in support of ongoing military operations. The emergent nature of each situation benefits from inherent capabilities and capacities as formal plans often don't survive their drafting.
[95] Various approaches to pattern recognition have been tested and deployed to gain earlier assessment of project trajectories
[96] We see attributes of this in Agile project management but what is suggested here includes assessment of higher order derivates of these flows as well as insights into the driving functions and chages in boundaries and boundary conditions.

				s	
			Contingent management	Timely application of competencies and capabilities in response to influencing flows and emergent behaviors and requirements	M
			Expected lifetime	Semi-permanent to lifecycle	S[97]
		Core organizational behavior (external)	Confirming	Assessing continued validity of assumptions[98]	M
			Monitoring	Environmental scan for emergence or change in systemic forces and flows acting on project (influencing flows)	M[99]

[97] Durations of large complex projects are often characterized by longer project durations, in part due to longer project initiation phase activities; in part due to longer engineering, procurement and construction durations; and in part due to inclusion of more life cycle elements (up to full life cycle) in project definitions

[98] Assumption migration is primarily a function of longer project durations but can also arise from inherent complexity and interaction of two or more of the various flows a project experiences

[99] Presently, environmental scans such as contemplated here are done on an irregular basis at best, often triggered by the occurrence of an impacting changed condition.

				Identification of potential emergent actors	M
			Engaging	Stakeholder engagement vs. management	S
				Multi-party engagement and solutions set	S
			Influencing	Shaping the project environment through project flows across a semi-permeable boundary	S[100]
			Evolving	Modifying project in all dimensions to anticipate and respond to emerging externalities	M
		Core organizational structures	Management focus	Response to change vs. control	M[101]

[100] Economic, social and environmental impacts of large complex projects are both anticipated and assessed on a continuing basis. Examples include labor and logistical impacts and pricing on locally and regionally sourced materials of construction.
[101] This represents a core change associated with the suggested theory

		(internal)			
			Governance [102]	Enabling and direction and objective communicating vs. directing and controlling	M
		Core organizational structures (external)	Frontier	Continuous monitoring of project frontier (boundary changes over time; flows across the boundary (two way flows); reconfirmation of assumptions; monitoring of existing and emerging influencing flows)	M
			Scouting	Identification of changed and changing externalities; identification of changes in stakeholder map; identification of emergent	S

[102] Organizational enablers for project governance and governmentality in project-based organizations; Muller, Pemsel, Shao; International Journal of Project Management; 2014

				actors	
			Ambassadors	Engagement with stakeholders	S
	Institutions	Formation and institution of discourses (internal)	Conception and initiation	Strategic business outcomes articulation	S
				Owner readiness	S
				Strategic business outcomes agreement (internal)	S[103]
				Continuous communication of SBOs	S
				Emergent SBOs	M[104]
				Project readiness	S[105]
				Internal team alignment	S[106]
		Formation	External	Outcomes	M

[103] The author has identified the absence of articulation, agreement to, and continuous communication of SBOs as a principle cause in the underperformance of large complex projects and has observed the project improvement possible when this factor has been thoroughly addressed
[104] This is new, significant concept and presents special challenges for large complex projects
[105] This practice is well documented by the Construction Industry Institute (CII)
[106] This practice is well documented by the Construction Industry Institute (CII)

		and institution of discourses (external)	stakeholder engagement (more than management)	must satisfy owner and key stakeholders (multifinality); Owner not single reference point	
				Awareness of stakeholder – stakeholder interactions	S
			Emergent Actors		M[107]
Cultural	Culture	Dimensions	Time	Strong valuation of time	S
				Semi-permanent to lifecycle	S
				Importance of timing (flows focus)	S[108]
				Temporal decoupling	S[109]

[107] Early identification through continuous environmental scans is especially important in large complex projects
[108] This is particularly evident in logistical and manufacturing flows
[109] In recent large project examples, attempts to "simplify" management of the project resulted in the coupling of major activities that benefited from being kept separate. Consider one infrastructure example where civils, systems and architectural elements were combined into a single procurement. Architectural approvals were extended, complicated and the pacing element for construction work to begin. Separating out architectural work allowed civil's work to proceed while architectural approvals continued in parallel. Subsequent segregation of the systems work was in recognition of the lag time between start of civil work and start of systems work. By separating and delaying the systems piece one generation later technology could be obtained for the project. In this particular example a two year schedule reduction with later technology was possible without shortening and of the task durations.

			Action orientation	Flexible	M
	Practices	Social structures	Trust	Transparency	S
			Communication	Continuous; two-way; flat	S
			Knowledge	Valued	S
				Emergent	M[110]
				Contextual	M
				Temporal	M
				Shared – available to all	S, M[111]
		Identity formation	Outcomes alignment	SBOs clearly articulated, agreed to, continuously communicated	S
			Boundary conditions	Semi-permeable boundary	M
		Cultural resources	Outcomes alignment and commitment		S

[110] While the emergent, contextual and temporal nature of knowledge is recognized, it is not presently an explicit management basis
[111] Knowledge as power still limits full project wide sharing. In addition sharing between organizations is not typically well addressed in contracts and when addressed is usually mono-directional in nature

			Trust		S
			Teamwork		S
			Knowledge		S
			Communication		S
Professional Identity	Self-definition	Role definition	Team based	Self-organizing (workface planning)	S, M[112]
	Work practices	Organization	Tasks	Minimize precedences (supply chain design)	S, M
				De-coupling of tasks - standardization; fabrication	S
				Risks in "white space" between tasks (expanded basis of design reduces white space)	S[113]
				Constraint coupling of	S, M

[112] Self organization is often witnessed at lowest task levels such as discrete construction activities at the workface. Enablement of self organization is essential for flexibility and responsiveness to emergent factors of all types. Traditional barriers to efficient workface activities include waiting for information (knowledge); direction/decisions (importance of the value of time not clearly established; and materials and other resources including completion of couples tasks (highlights importance of de-coupling)

[113] Addressing Project Capital Efficiency through a Business Basis of Design; Bob Prieto; PM World Journal; 2014

				tasks	
				Knowledge enabled (knowledge assemblies)	S, M
			Flows	Principle management focus	S, M
				Focus on flow perturbations	M[114]
				Transformational flows (within tasks)	S
				Transformational flows (task to task)	S
				Influencing flows (including induced constraints)	M[115]
				Induced flows (emergent flows)	M[116]

[114] Generalized Analysis of Value Behavior over Time as a Project Performance Predictor; Bob Prieto; PM World Journal; 2012

[115] Influencing flows are envisioned to have crossed the project's semi-permeable boundary and arise from outside the project's direct context. Influencing flows may act to block (slow down), reinforce (speed up) or modify (change trajectories or otherwise "entangle") transformational flows within the project. Influencing flows may act differently at different times on different transformational flows.

[116] Induced or emergent flows are not traces directly back across the project's semi-permeable boundary but rather arise as a result of the interaction of one or more flows within the project (transformational, influencing, or other induced flows). Induced flows are often temporary in nature, analogous to eddies that may form when two streams interact. Induced flows may also be thought of being chaotic in nature, unpredictable but ultimately exhibiting convergence around a recognizable pattern.

		Contingency	Impact on Environment	Modifies environmental setting and context (two way flows across semi-permeable boundary)	S, M
			Environments Impact on Project	Modifies project and context (two way flows across semi-permeable boundary)	S, M
	Boundary conditions	Outcomes	Emergent		M[117]
		Tasks	Unbounded	Emergent tasks (project not necessarily decomposable in its entirety as originally conceived)	M
				Changed sequencing	S, M
		Flows	Not discrete	Entangled and induced flows	M
		Timeframe	Non deterministic	Not well bounded	M

[117] The potential for new outcomes to emerge reflects the state altering nature of large projects and is associated with the non-deterministic nature of these systems.

The management theory aspects highlighted in the above table are still to be tested and confirmed but observationally seem suggestive. Those delimited as being the result of a scientific method are based on author's experience and various data reviews over his career but would benefit from further testing and confirmation.

The decomposition of an overall theory of management of large complex projects into three separate but complementary and reinforcing theories related to organizational, cultural and professional identity leaves the door open for a broader consideration beyond the author's work on projects in the engineering and construction sector.

Core Organizational Behaviors with Respect to the External Environment

- Confirming
- Monitoring
- Engaging
- Influencing
- Evolving

The organizational theory laid out addresses both identity and institutions. Core organizational behaviors and structures are considered both internal to the project and how it relates to its external, ever changing environment.[118] Key characteristics that are addressed by this organizational theory include the competencies and capabilities that the project team requires. These include but go well beyond the traditional skill sets called for by traditional PM theories. Unlike the implementation of decomposed plans called for by PMBOK and others, the emphasis in large complex projects is on adaptability and an ability to respond. These competencies and capabilities are more akin to what we find in contingent organizations such as those associated with disaster response and war fighting.

The organizational theory laid out in the preceding table very much has a systems focus but as we might expect to see it manifested in non-deterministic system behavior over an extended timeframe.

Fayol's plan, organize, direct, coordinate and control are now expanded to include confirming, monitoring, engaging, influencing and evolving.

[118] Environment as used throughout this paper describes the broader contextual ecosystem in which the project is set and is not limited to the physical environment which would represent only a partial description of this broader ecosystem.

Large complex project's are not easily bounded, rather their boundaries, such as they are semi-permeable in nature, limited by law, regulation and dominant social constructs.

Project boundaries become **frontiers** to be monitored and awareness requires continued **scouting**. Large complex projects require the services of **ambassadors** to the external stakeholders to assess and influence intentions and actions.

Project boundaries now become frontiers to be monitored and awareness requires continued probing such as we may find in the various scouting and intelligence operations of a well organized military operation. Other interests lie across these ill defined boundaries and large complex project require the services of ambassadors to the external stakeholders to assess and influence intentions and actions. These external stakeholders must also be satisfied at some level for us to be successful.

Institutional constructs now place a heavy burden on all of the strategic thinking, alignment and preparations that precede the more tradition project activities encompassed by FEL – 1, 2 and 3. These might conveniently be referred to as FEL – 0, but I have avoided this terminology to underscore the differences from traditional project management approaches. I have written extensively on SBOs in the past but as used in this paper they should be viewed as Strategic Business Outcomes and not Strategic Business Objectives as I have previously used the term. This difference is not insignificant as it underscores the non-deterministic and multi-finality aspects of large complex projects. The potential for emergence of new SBOs over the project's lifetime reflects the realities of time and changing circumstances which large complex projects are prone to. This potential for

These might conveniently be referred to as FEL–0, but I have avoided this terminology to underscore the differences from traditional project management approaches.

emergent SBOs is not to suggest that any such change should be easily adopted. The converse is true, SBOs must be clearly articulated, including their strategic rationale; agreed to by the relevant internal and external stakeholders; and clearly and continuously communicated.

The cultural theory summarized in the preceding table addresses both culture and the defining and reinforcing practices associated with it. Differentiating cultural dimensions that we experience in the world of large complex projects encompass strong emphasis on time and action. Time is no longer just a pacing and synchronization point. It is now something that is increasingly valued; extended beyond what we may encounter in more traditional projects; and a tool to gauge and control the various flows the project experiences. Temporal coupling now represents a new risk point given the various influencing flows that a large complex project faces.

Cultural practices encompass important social structures; identity formation in the broader organization (supports team alignment and personal commitment); and the cultural resources available to the project organization. Trust (driven by transparency); communication, knowledge and teamwork are defining characteristics of large complex projects.

Professional identity theory as used herein, speaks more directly to many of the execution approaches that we would expect from classical project management theories but as modified to address large complex projects. Role definition, work practices and boundary conditions must all be addressed. Increased emphasis on self-organizing[119] [120]and cross functional teams places an increased focus on work face planning and execution. Embedment in a multi-stakeholder context further influences team composition and focus in non-deterministic ways. [121]Tasks, the heart and soul of work breakdown structures, must change in numerous ways. Precedences must be minimized, or at the very least limited and clearly understood. Tasks must be increasingly decoupled[122] to support contingent execution driven by influencing flows, utilizing techniques such as increased standardization (at the component and work process level) and more extensive and comprehensive fabrication.

[119] "…managerial diseconomies or scale, which arise when contractors integrate more activities…"; The impact of complexity and managerial diseconomies on hierarchical governance; Brahm, Tarzijan; Journal of Economic Behavior & Organization; 2012

[120] See Wheatley's work of self-organizing systems such as The Unplanned Organization: Learning From Nature's Emergent Creativity; Margaret Wheatley; Noetic Sciences Review #37; 1996

[121] Manning (2008) identifies that a great number of multi-stakeholder projects cannot easily be 'embedded' in any given context nor can project participants always refer to past experiences when assigning tasks, structuring times and assembling teams

[122] In tightly coupled systems slack must be designed in while it is intrinsic in loosely coupled systems (Orton, Weick (1990); Perrow (1984)

Risks which previously fell in the "white space" between tasks now offer greater opportunities of appearing as task flows are stretched, compressed, twisted and reconfigured. Hidden constraints now offer greater opportunities for "spooky action" at distance as work execution patterns change in initially unplanned ways.

Task execution now needs to be performed when and where appropriate, based on the latest available knowledge, carrying requisite contextual and temporal significance. This leads to a conception of knowledge assemblies similar in some constructs to the assemblies one would expect from fabrication activities but much more self-assembling in nature.

Flows now become essential focal points in large complex projects with increased emphasis on perturbations (and potential points of perturbation). Flows are no longer limited to the transformational flows within and between tasks. Influencing flows, across the project's semi-permeable boundary, and the induced flows[123] they may create take on significant importance.

The project acts equally on its environment as the environment acts on the project. We must be cognizant of feedback loops that translate an internal project action to a new or modified induced flow. Labor represents one such feedback loop we must be sensitive to.

Finally, as described throughout this paper, boundary conditions are non-deterministic.

10. Core Concepts

We have seen a construct for the management of large complex projects laid out in the previous section. In this section we will simply lay out some of the main concepts and considerations for a practitioner. Each of these can be more extensively developed but for purposes of this paper we will limit additional discussion to the focus on managing emergent patterns which is covered in the next section.

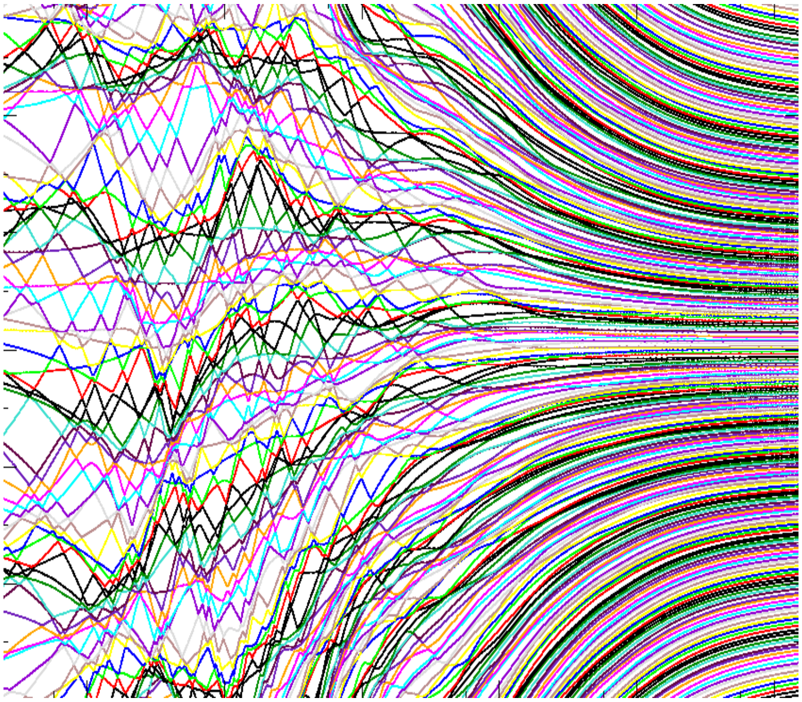
Table 13 **Core Concepts**	
Provide clarity and rationale for desired outcomes	*Supports emotional and transcending engagement and a shared frame of reference. Ensure owner readiness.*

[123] One manifestation of induced flows may be the emergence of informal work practices

Engage the environment	*Stakeholders have a real seat at the table*
Shine a bright light on planning bias	*Bias limits the environmental scans we will undertake and the contingencies we plan for*
Know your assumptions and their current condition	*Monitor, test, confirm, repeat*
Be transparent	*Builds trust; promotes two-way communication; enables knowledge sharing; communication is essential to managing complex systems and projects; reinforces strong values system*
Manage flows	*Anticipate, respond, assess, correct; dynamic environment drives flows*
Manage risk	*Not just (inadequately) provide for it*
Value time	*Flow management demands it*
Simplify	*Tasks and coupling between tasks*[124]
Focus on emergent patterns	*Project is adapting to its immediate environment which in turn is itself adapting to broader forces; evolving rules; emerging and interacting agents*

[124] Added compliance requirements often associated with large complex projects may provide an unintended coupling of various management and other tasks with the unintended consequence of adding to project complexity.

11. Principles of an Evolving Project



The theoretical construct laid out for the management of large complex projects has as a central tenet the notion of emergence or more specifically an evolving project. This evolution is driven by various flows across the semi-permeable boundary of the project and the effect of those flows on outcomes definition; task sequencing and timing; execution strategies; required competencies and capabilities; risk exposures and management strategies.

Evolving systems can be viewed from the perspectives of interdependence, diversity drawn from different contexts, modes of interaction, and self-organization[125]. "Decision or action by any agent (individual, group, institution etc.) may affect related individuals and systems[126]."[127] In classical PM theory we had always recognized this human relations dimension within the context of the bounded project but tended to deal with external stakeholders as transactions to be managed. In the context suggested here for large complex projects, the multiplicity of stakeholders now have a seat at the table[128] and project optimization and execution occurs within an expanded outcomes set. Solution sets are no longer singularly solved but now have a multifinality as previously described. The non-linear dynamics of the complex processes and relationships which define this class of projects means that the links between cause and effect may be almost impossible to detect.

[125] "Management commits to guiding the evolution of behaviors that emerge from the interaction of independent agents instead of specifying in advance what effective behavior is." The Biology of Business; Philip Anderson

[126] Complex systems and evolutionary perspectives on organizations: the application of complexity theory to organizations; Mitleton-Kelly; 2003

[127] Social Complex Evolving Systems: Implications For Organizational Learning; Elena Antonacopoulou and Ricardo Chiva; OKLC 2005 Conference

[128] In some instances other stakeholders may bear the same degree of responsibility in advancing the project as the project's owner. We see this in particular in major economic development projects.

Fayol's plan, organize, direct, coordinate and control are now expanded to include confirming, monitoring, engaging, influencing and evolving.

Interrelationships between stakeholders and project actors provide coupling and reinforcing mechanism that warrant increased attention and monitoring. These interrelationships influence the existence and strength of interdependences but can also be exploited for the resolution of coupling constraints.

Importantly, context matters. Project actors (multiple project team elements; stakeholders; regulators and others who limit permeability of the project boundary; emergent actors) each view the project from different contexts and each acts from the basis of different contextual perceptions. Project management on large complex projects requires not just awareness but a deep understanding of each of these contexts, seeking to reflect their perspectives in project strategies and actions and importantly seeking to bring what would otherwise be a fairly chaotic state into some semblance of alignment and order. As these different contexts are considered it is essential that recognition be maintained on their very nature which itself is temporal, being influenced by this multiplicity of actors and others in the world beyond the immediate project environment.

A key attribute of an evolving system is that the way in which it interacts with and responds to its environment changes over time. Said another way, large complex projects learn and adapt to the realities that they encounter. Efficient learning and adaptation are characteristics of successful projects while underperforming projects have neither learned nor adapted as efficiently. This underscores the importance of knowledge as a currency for project success. Knowledge must be continuously gathered, contextually and temporally; shared broadly; and then readily deployed to drive project adaptation. "Hierarchical structures do not facilitate the knowledge specialization and development needed to execute complex activities"[129]

[129] The impact of complexity and managerial diseconomies on hierarchical governance; Brahm, Tarzijan; Journal of Economic Behavior & Organization; 2012

In a broader sense, the world of large complex projects benefits when this knowledge is shared beyond the project's boundaries, establishing better planning bases, competencies and capabilities for subsequent projects[130]. Previously we have talked about decoupling in a different context but in the context of learning, project teams and the broader organizations require an ability to decouple current practices from their historical context in the face of new learnings. The phrase, "we have always done it this way" has somewhat limited value in many large complex projects.

The concept of self-organization reflects a simple reality of large complex projects – central direction by a management team is no longer practical. Rather project management must create context, capacities and capabilities recognizing the delicate balance between formal and informal systems that are essential to avoid chaos on large complex projects. The project co-evolves with its environment[131] and the tools of the project manager include a combination of positive and negative feedback loops to guide the project to its final state. Proper application of these loops rely not just on traditional command and control strategies and metrics but also knowledge gained from a learning organization and the careful monitoring of project frontiers (flows; assumption migration), environmental scouting (new flow drivers; emerging flows; emerging actors) and engagement of stakeholders through almost ambassadorial activities. There is a need "to look for patterns and for points of change which can trigger off new patterns."[132]

The concept of a project as an unbounded, open system challenges the project manager and the project management team. They "must deal with uncertainties and ambiguities and must be concerned with adapting the organization to new and changing requirements"[133]. Initial conditions matter and the projects temporal beginnings must extend all the way back to identification of organizational outcomes to be satisfied by implementation of the project. Not only must projects and project teams be ready and aligned but so to must the owner's organization. The importance of these strong owner foundations in achieving project success have been well documented.

[130] Research has emphasized the difficulties project-based organizations face when attempting to capture the learning built during project execution and when disseminating this knowledge to the overall organization. See "The project-based organisation: An ideal form for managing complex products and systems?"; Hobday; Research Policy ; 2000 and "The management of operations in the project-based organization"; Turner & Keegan; Journal of Change Management; 2000

[131] Evolutionary systems seek to align with the deeper meta-patterns which exist in the environment within which the project is set but also in the much broader environment. These meta-patterns may be more discernible in the broadest context, at least suggesting directionality of those more immediately experienced by the project.

[132] A lateral view of organizational complexity; Part 2: Non-linear dynamics – informal coalitions; Chris Rodgers; 2008

[133] The Contributions of Management Theory and Practice to Emergency Management; John C. Pine

Management processes span the multitude of flows – transformational, influencing and induced. Management seeks to align people, processes and systems for efficient execution while reducing uncertainty and increasing flexibility. It seeks to do this within a context that is "dynamic, inherently uncertain, and frequently ambiguous. Management is placed in a network of mutually dependent relationships. Management endeavors to introduce regularity in a world that will never allow that to happen."[134]

Large complex projects require different leadership constructs and behaviors. Training must go well beyond traditional skills training and include simulations and consistent use of cross functional teams and developed "challenge" approaches[135] to open up team based communication. The following table (Table 14) highlights some of the leadership changes that must occur.

[134] ibid
[135] A variety of approaches exist including random or rotating selection of individuals to continuously challenge assumptions and proposals to ensure group think or deferral to the strongest or most senior personality doesn't drive decision making.

Table 14
Management of Large Complex Projects
Require Changed Leadership Behaviors

New Leadership Behaviors		***Traditional Leadership Behaviors***
Group leadership	vs.	Individual leadership
Motivation and movement	vs.	Control and order
Transformative leadership	vs.	Scientific management
Shared outcomes focus	vs.	Outputs focus
Agreement and acceptance of goals	vs.	Assignment and directive
Flat communication and information structures	vs.	Hierarchial and siloed
Questioning (assumption, process, outputs)	vs.	Acceptance of normative
Collaboration and information sharing with stakeholders	vs.	Adversarial or transactional approach
Management of flows	vs.	Management of tasks[136]
Engaged and decentralized decision making	vs.	Centralized decision making

[136136] As indicated in Saurin et. al. (2013)"prescriptive procedures on how to do a task are insufficient in a complex system"

12. Beyond Complexity

Complexity Theory provides a good starting construct for many of the aspects of what I have described as a Theory of Large Complex Projects but I can't help but feel that large complex projects force us to go even further. Unlike complexity theory, this class of projects may be effectively unbounded in both time and space. Project readiness must be underpinned by owner readiness and clear outcomes to be achieved, recognizing that even these are subject to emergence. Flows that we define in complexity theory are complemented by stronger stakeholder derived influencing flows and importantly a new construct of induced flows. Stakeholder influences[137] now define a surrounding and interacting ecosystem that includes stakeholder-stakeholder interactions[138] but also one which the project acts on and can influence through so-called "ambassadors". While not predictable, perturbations in flows become signatures of the direction of likely system emergence. Our predictive project efforts employing big analytics may be better aimed at flow patterns, especially those crossing the semi-permeable project boundary, and the broader externalities driving and shaping them.

Strong and often unseen coupling within the project system offers us a chance to understand where indirect coupling should be made direct (because we can witness improvements in outcomes as we strengthen select links; an example might be tighter integration of supply chains) and importantly where we should seek to decouple transformative activities which do not require to be linked.

Emergence is not limited to outcomes as complexity theory would suggest but also includes emergent actors, flows and tasks, the former being a notable addition. Management is not only self-organizing (out of necessity, recognizing the limits of centralized control) but heavily driven by the creation and refinement of capacities, capabilities and knowledge flows throughout the project's lifetime. In some ways these may represent some of the most predictive project metrics.

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[137] According to Lesard, Sakhrani, Miller (2014) "new literature argues that the institutions within which a project is embedded and interacts also should be taken into account, thereby refining or extending traditional contingency models" (Scott, 2012). What is proposed here is even more definitive but also considers stakeholder – stakeholder interactions in order to understand the complexity of the surrounding ecosystem.

[138] Lessard et al (2014) notes the dominant importance of what is referred to as "institutional complexity". In the outlined construct in this paper, institutional complexity includes stakeholder – stakeholder relationships but also the owner's own institutional complexity and readiness.

Table 15 **Extended Focus of the Theory of Large Complex Projects**	
Extended Focus	**Classical Focus**
Owner readiness	Project Readiness
Emergent outcomes (Multifinality)	Output Focus
Flows including emergent influencing and induced flows	Tasks and transformative flows
Stakeholder engagement (partners in success)	Stakeholder Management
Confirm, monitor, engage, influence, evolve	Organize, direct, coordinate and control

13. Conclusion

In this paper I have tried to address the realities of project management performance as it relates to large complex projects. The normal condition that current theory supports is one of failure. A new theoretical construct is required and directs us to revisit the theories of management and projects at least as they apply to large complex projects.

This paper begins by looking at the evolution of general management theory and later suggests that project management theory would benefit by strongly drawing on its evolutionary progress. Project theory is considered largely from the aspect of various systems theories and elements of both Chaos Theory and Complexity Theory are seen to provide valuable insights. But a bit more seems to be required and these elements are laid out near the end of the paper.

The importance of getting the core of the project well prepared is highlighted (strategic business outcomes; owner readiness; stress testing baselines to avoid planning fallacies; and modeling for non-normal behavior). Flows rise in importance as contrasted with tasks and new flows (beyond transformational flows) are introduced (influencing and induced). Finally, the rise of stakeholders as flow drivers (influencing flows) and determinants of final outcomes (multifinality) is stressed.

Each of these changes where our efforts should be directed on large complex projects and the boundaries of the project itself is redefined both in its extent and temporal nature.

The author does not view this paper as either fully definitive or complete but rather as a continuation of thinking focused on addressing the question previously raised of "Is It Time to Rethink Project Management Theory?"[139] Many of the concepts are supported by scientific theory while other elements merely represent management theory. The views represent the author's own evolving perspectives on what it will take to improve execution and delivery of large complex projects.

[139] Is it Time to Rethink Project Management Theory?; Bob Prieto; PM World Journal; 2015

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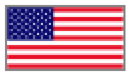

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