Quantum Project Management[1]

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Abstract

Quantum Project Management or QPM as described and developed in this paper focuses on drawing a strong analogous framework from both relativistic theory and quantum theory recognizing their departures from classical physics. The goal is to lay out a comprehensive theory to replace conventional project management theory when applied to large complex projects (LCP). As described in this paper QPM seeks to move beyond a pure metaphorical framework and provide a robust framework for conceiving, planning and executing LCP.

QPM is a new management paradigm that replaces Taylorism's Scientific Management paradigm upon which classical project management is founded.

Relativistic behaviors, influenced by Einstein's theory of relativity, involve effects like time dilation and length contraction, highlighting the interplay between space and time. Similarly, large complex projects often experience time dilation as schedules may extend, and the perception of progress varies based on perspectives. Additionally, just as objects with mass affect the fabric of spacetime in relativity, key components or challenges within large projects can significantly influence their overall trajectory, creating a dynamic and interconnected environment.

Both quantum systems and large complex projects exhibit a level of unpredictability. In quantum systems, particles can exist in multiple states simultaneously until measured, reflecting uncertainty. Similarly, large projects involve various factors, making outcomes unpredictable until completion. Additionally, the interconnected nature of quantum entanglement parallels the interdependence of tasks in complex projects, where changes in one area can impact the entire system. However, unlike the deterministic classical world, both quantum systems and large projects introduce an element of probabilistic behavior.

Quantum project management draws inspiration from quantum mechanics, emphasizing adaptability and flexibility. Like the uncertainty principle in quantum physics, it acknowledges the inherent unpredictability of projects. Teams in quantum project management embrace ambiguity, allowing for simultaneous exploration of multiple solutions until a clearer path emerges. This approach encourages rapid adaptation to changing conditions, resembling the

[1] How to cite this paper: Prieto, R. (2024). Quantum Project Management, *PM World Journal*, Vol. XII, Issue I, January 2024.

behavior of particles in superposition. The goal is to navigate complex projects with a mindset that accommodates uncertainty, leveraging agility and creative problem-solving[2].

This paper, while comprehensive, is not intended to be the final word on quantum project management. It draws parallels between modern physics and large complex projects and importantly provides us with a path forward that is unlocked from conventional project management. It seeks to encourage debate, help us ask the right questions, decoupled from a theory which has fallen short for large complex projects, and explore a new framework more analogous to what we see in other complex systems. It is not the final word on this new framework but rather a framework to see more, know more, and importantly, do better.

QPM illustrated by Dall-e

[2] Prieto, R. (2021). Large Complex Project Success: Have we institutionalized the wrong lessons; *PM World Journal* (ISSN: 2330-4480); Vol. X, Issue I, January - https://pmworldlibrary.net/wp-content/uploads/2021/01/pmwj101-Jan2021-Prieto-Large-Complex-Project-Success.pdf

Quantum Project Management

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Part A. Quantum Project Management

Preface

Quantum Project Management introduces a new management paradigm to replace classical project management as applied to large complex projects. QPM draws a strong analogous framework from both relativistic theory and quantum theory, providing a robust framework for conceiving, planning, and executing large complex projects.

This paper provides a comprehensive exploration of Quantum Project Management (QPM). The content is organized into sections, covering various aspects of QPM, including its theoretical foundations, the shortcomings of classical project management in the context of large complex projects, and the sources of uncertainty in project management.

This document effectively presents the key concepts, principles, and analogies related to QPM, making it accessible for readers interested in understanding the application of quantum and relativistic theories to project management. Additionally, the inclusion of tables and appendices is intended to enhance the clarity and organization of the content, providing valuable insights into the complexities of large complex projects and the need for a more adaptive and probabilistic approach to project management.

QPM illustrated by Dall-e

Introduction

In the early 20th century, classical physics shortcomings were becoming more apparent. At the turn of that century quantum theory (QT) was first posited but initially not strongly adopted. Early proponents of that theory included Einstein who abandoned it in favor of his Theory of Relativity (RT). These two theories speak to both complex processes (QT) and systems at scale (RT). Both theories are viewed as incomplete[i] but each provide valuable insights into the observable universe in which we live. Importantly, classical physics was not invalidated by these new theories but rather represents special cases in each.

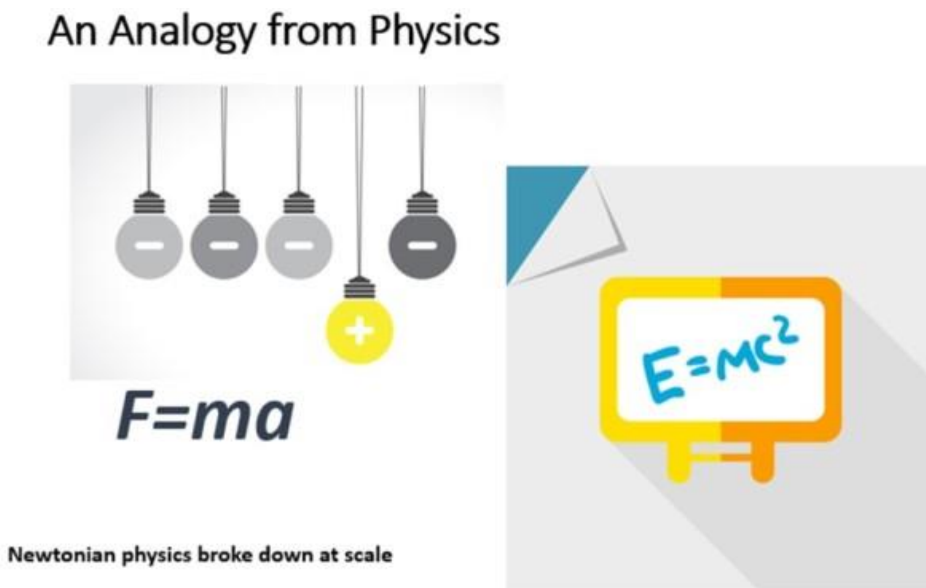
The importance of challenging identified weaknesses in classical theory cannot be overstated. This willingness to challenge opened the aperture for new insights and new advances in our understanding and manipulation of now unveiled fundamental properties of nature. Key insights we have gained from each theory are reflected in Table A-1 and underscore the value created by challenging the established physics dogma at the time.

Table A-1
Key Insights Gained Post Classical Theory

Quantum Theory (QT)	**Relativity Theory (RT)**
Quantum chemistry	Behavior of objects in space and time,
Quantum optics	Predicts things such as the existence of black holes, light bending due to gravity, the behavior of planets in their orbits, neutron stars, gravitational waves
Quantum computing (qubit)	Magnetism and electromagnetic effects
Superconducting magnets	Pinpoint accuracy required for GPS (time dilation)
Light-emitting diodes	Nuclear power
The optical amplifier and the laser	Distortion of space-time
The transistor and semiconductors such as the microprocessor	Precession of orbits due to the presence of a large mass
Medical and research imaging such as magnetic resonance imaging and electron microscopy	Expansion of the universe
Quantum teleportation (entanglement/correlation)	
Emergence	
Probabilistic uncertainty	
Quantum decoherence	

Classical Physics as an Analog for Classical Project Management

Classical physics for a long time adequately described the world we encountered in our normal daily lives. But by 1900 there were identified shortcomings[ii] in the theory and these were further exacerbated by Einstein's attempt to apply them at scale (universe). This is analogous to where project management finds itself today with unacceptable project performance[iii].



As we move through this paper, we will identify some of the insights from both RT and QT that seem to be relevant analogs for the challenges we see in the current application of classical project management theory to large complex projects (LCP). At the conclusion of this paper, we will suggest some theoretical frameworks of a new theory of project management which we will refer to as Quantum Project Management or QPM. QPM is a new management paradigm that replaces Taylorism's traditional Scientific Management paradigm upon which classical project management is founded.

Just as Newtonian physics underpinned the first scientific revolution and the management and project management thinking needed for the industrial revolution which followed, relativistic and quantum science has given birth to a second scientific revolution. This revolution calls for us to rethink how we lead and manage society, our companies and of particular relevance here, our projects.

It is important to note that the "quantum" reference is not intended to indicate only analogs from QT but more broadly from Quantum Field Theory (QFT)[iv] [3] that subsumes QT, RT and classical physics.

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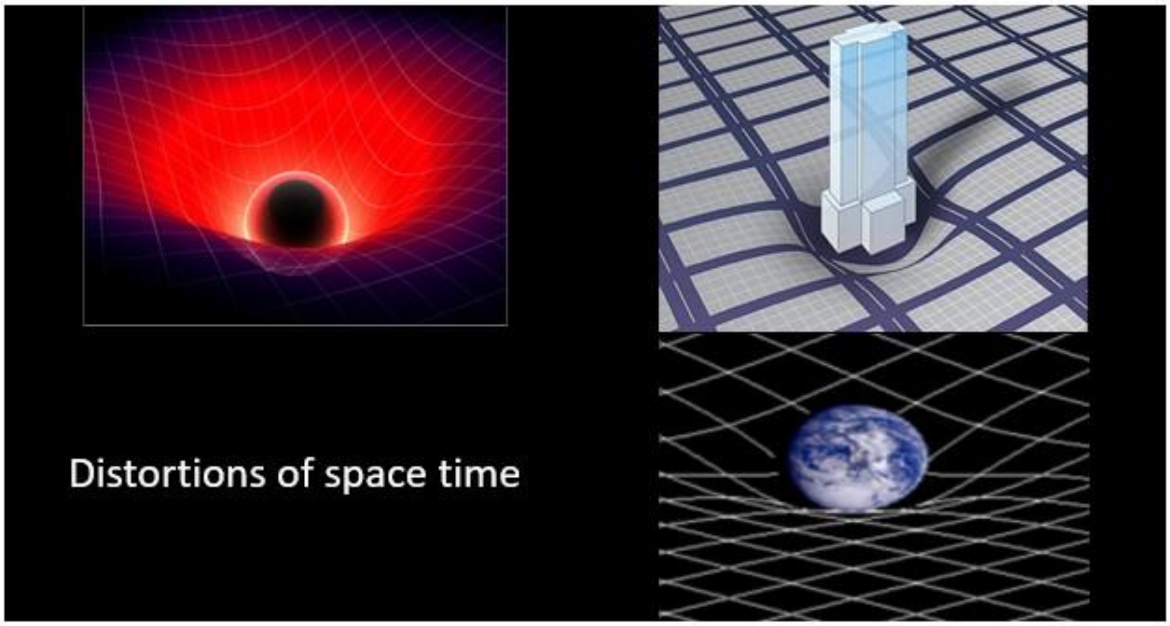
[3] Studies have been conducted on the relationship between quantum entanglement and spacetime and envision a universe fabricated by entangled spacetime. Quantum entanglement can be a result of complex spacetime geometry. "Study on the Relationship between Quantum Entanglement and Spacetime;" Peiyu Zhu; ICMMAP 2021 Journal of Physics: Conference Series (2012)

Analogs from RT

RT predicts the distortion of spacetime in the presence of large masses or energy[v]. We see this often described by the heavy ball on a stretched rubber sheet and the distortions created by the deformation of the sheet.



This is like the effects that LCPs have on their surrounding ecosystems of stakeholders, supply chains and informational and other flows that both interact with the LCP or are locally or more broadly influenced by them. These ecosystems are complex and adaptive.

RT also predicts an expanding universe or stated another way a "stretching" of spacetime. But while masses may move further apart the total dark energy in the universe grows. In LCPs, the context in which our project happens grows more challenging with time. The stretching of LCP spacetime often manifests as extended project durations and objectives seem ever farther away. The expanding universe is analogous to the totality of ecosystems acting directly and indirectly on our project, with growing dark energy in an overall systems context. Delayed projects become more susceptible to the effects of dark energy on their behavior, manifesting changes in the broader stakeholder ecosystem.

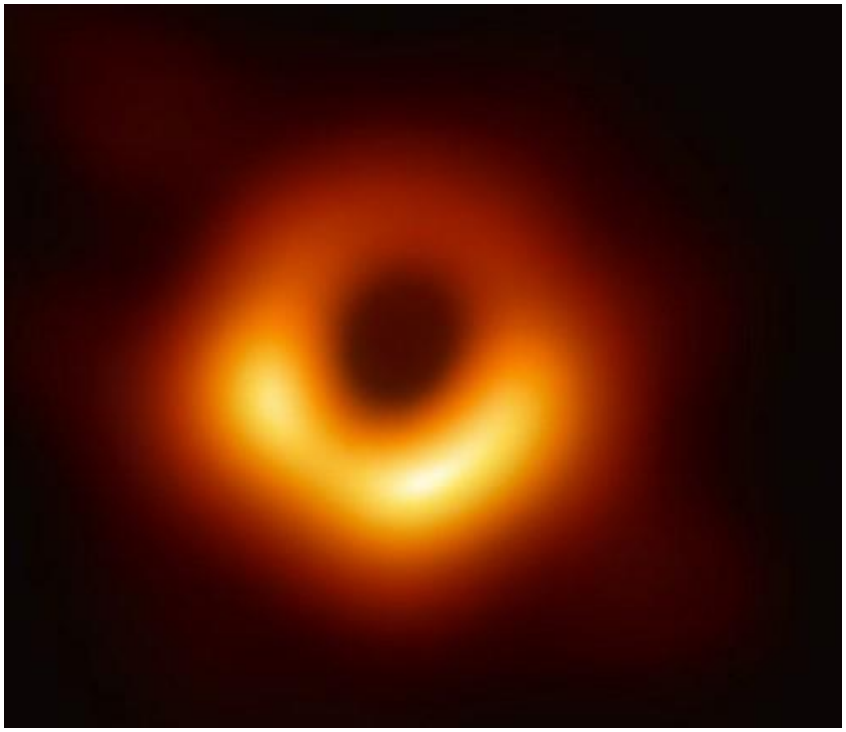
RT's gravitation waves which affect the very fabric of spacetime as they ripple through the universe as the result of a significant event can be seen in LCPs as "black swan" type disruptions that broadly impact the universe of projects. The impacts of these "events of scale" are significant and more frequent than we might wish. Table A-2 illustrates some of the events of scale which impacted the broader universe of projects and society more generally.

Table A-2
Some Events of Scale with Global Effects

Oil Crises (1973 and 1979)	Fukushima Daiichi nuclear disaster (2011)
Iranian Revolution (1979)	Arab Spring (2010-2012)
Black Monday (1987)	Syrian Civil War (2011-present)
Fall of the Berlin Wall (1989) and the Collapse of the Soviet Union (1991)	Ukraine Crisis (2014-present)
End of Apartheid in South Africa (1994)	Brexit (2016)
HIV/AIDS Pandemic (1980s-present)	COVID-19 Pandemic (2019-present)
Asian Financial Crisis (1997)	Climate change (Paris Agreement in 2015)
Dot-com Bubble (2000)	Rise of China and South China Sea Disputes
9/11 Attacks (2001)	Refugee and Migration Crisis
European Union Enlargement (2004 and 2007)	Commercialization of space
Global Financial Crisis (2008)	Generative AI
European Debt Crisis (2010-2012)	

RT identifies bending of light by sizable masses in spacetime as an inevitable and documented outcome that changes the very path light flows take. These flows take longer because of time dilation arising from the distortions (gravity) arising from the mass-spacetime interaction.

We see similar effects in LCPs as various flows, informational and other, are now slowed down both by the local effects of the LCP-spacetime interaction but also by other LCPs in the neighborhood or more generally along the flows required by the LCP. This underscores that the source of flows, while important, may not be as important as the path the flows take.



RT predicted black holes, super massive distortion of space time from which nothing practically can escape once crossing the event horizon. This is analogous to LCPs which continue to grow in scale as want after want is added to the detriment of meeting initial project strategic business outcomes/objectives (SBO). Ultimately, these LCPs collapse under their own weight. Table A-3 illustrates just a few.

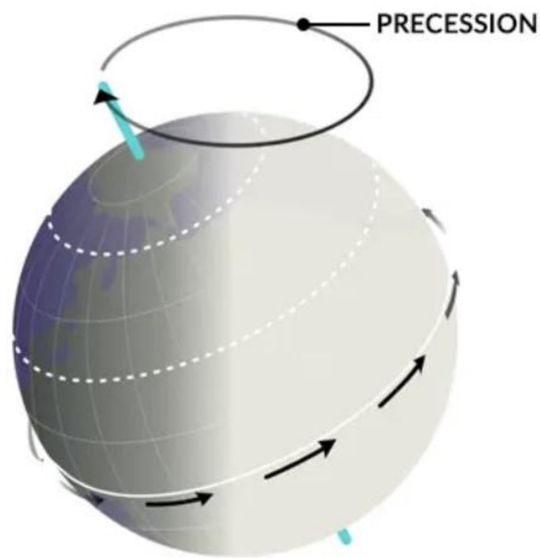
Table A-3 LCP Collapses of Note	
1976 Montreal Olympics Stadium Tower	The Montreal Olympic Stadium, known as the "Big O," was constructed for the 1976 Summer Olympics. While the stadium itself was completed, the retractable roof project was abandoned due to financial problems and engineering challenges.
Chicago Spire	The Chicago Spire was a proposed 2,000-foot-tall (610-meter) skyscraper that was supposed to become the tallest building in the Western Hemisphere. The project was halted in 2008 during the global financial crisis, and the site remained undeveloped for many years.

Table A-3
LCP Collapses of Note

London's Garden Bridge	The Garden Bridge was a proposed pedestrian bridge in London, featuring trees, plants, and shrubs. It was canceled in 2017 due to financial difficulties and concerns about its viability.
Aladdin Hotel and Casino (Las Vegas)	The Aladdin Hotel and Casino in Las Vegas faced financial difficulties during its construction in the early 2000s. It filed for bankruptcy, leading to its takeover by Planet Hollywood Resort and Casino.
Denver International Airport Automated Baggage System	The baggage handling system at Denver International Airport experienced significant problems during its construction, leading to its cancellation in the mid-1990s. The airport reverted to a manual baggage handling system. Problems cost $1.1 million per day until the project abandoned after a cost of $ 3 billion
Doha World Trade Center, Qatar	This ambitious project was canceled in 2013 due to financial and contractual disputes, leading to a halt in construction despite the significant progress made.
Fukushima Ice Wall, Japan	Following the Fukushima Daiichi nuclear disaster in 2011, a project was initiated to build an underground ice wall to prevent groundwater from seeping into the reactor buildings. However, the effectiveness of the wall was questioned, leading to debates about its long-term viability and efficiency.
HS2 Northern Leg	The decision to cancel the northern leg of the HS2 railway ended the UK's ambition to build a high speed line linking northern and southern cities along the spine of the country. The economic case had been "massively weakened" by changes to business travel patterns following the pandemic.
National Health Service IT Project	Largest civilian IT project in the world at the time canceled after a decade.
US Census Bureau Decennial Automation Project	Canceled after $3 billion overrun.
US Airforce Logistics Management Program	Canceled after spending $ 1.2 billion.
Boeing 787 Dreamliner	Cost overrun of $ 12 billion.

RT has as a core concept "frames of reference." It is essential for understanding how physical laws and observations depend on the relative motion of observers and the presence of gravitational fields. In LCPs we often fail to adequately consider the respective frames of reference associated with it. For example, initial planning is usually undertaken from a static observer's perspective but the execution team's frame of reference when the project is in motion will look very different and behave very differently. The "gravity" of the project challenge changes when execution begins (mass/kinetic energy of the project grows). One's frame of reference influences behaviors and decision-making.

The LCP frames of reference also extend into the inevitable operating phase.



RT identifies precession, such as that of planetary orbits, as the rotation on the axis of spin, in the presence of a large mass, the sun in an immediate case. In LCPs we see a precession in alignment and performance in nearby bodies (suppliers, labor base, regulators and arguably stakeholders, more broadly). The results of this nearby precession may manifest as either increased axial alignment with the LCP (its SBOs mark the alignment point of its axis) or complete unalignment with the LCP SBOs.

The earth itself experiences precession over a relatively stable 26,000 year period. LCPs require relative stability as well and any outside forces that act to change the SBO alignment will have unplanned impacts on the LCP and its suppliers, labor base and stakeholders.

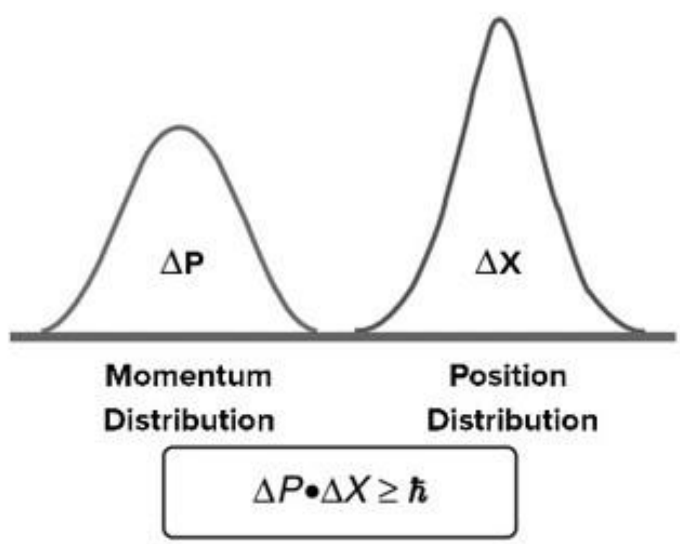
Analogs from QT

QT's development preceded the development of RT, but both benefited from a set of renowned physicists who contributed to the development of both. Among them was Einstein who later shifted his focus to the development of RT.

QT in the realm of physics describes the behavior of nature at the scale of atoms or subatomic particles. It has been demonstrated to hold for complex molecules with thousands of atoms. Its strength lies in addressing complexity and complex systems and recognizing that inherent uncertainties may lead to a range of possible outcomes. The complexity we observe in QT is akin to the complexity we find in LCPs and the microscopic focus of QT can be thought of as analogous to the behaviors of all the independent actors and actions and the uncertainty inherent in their behaviors.

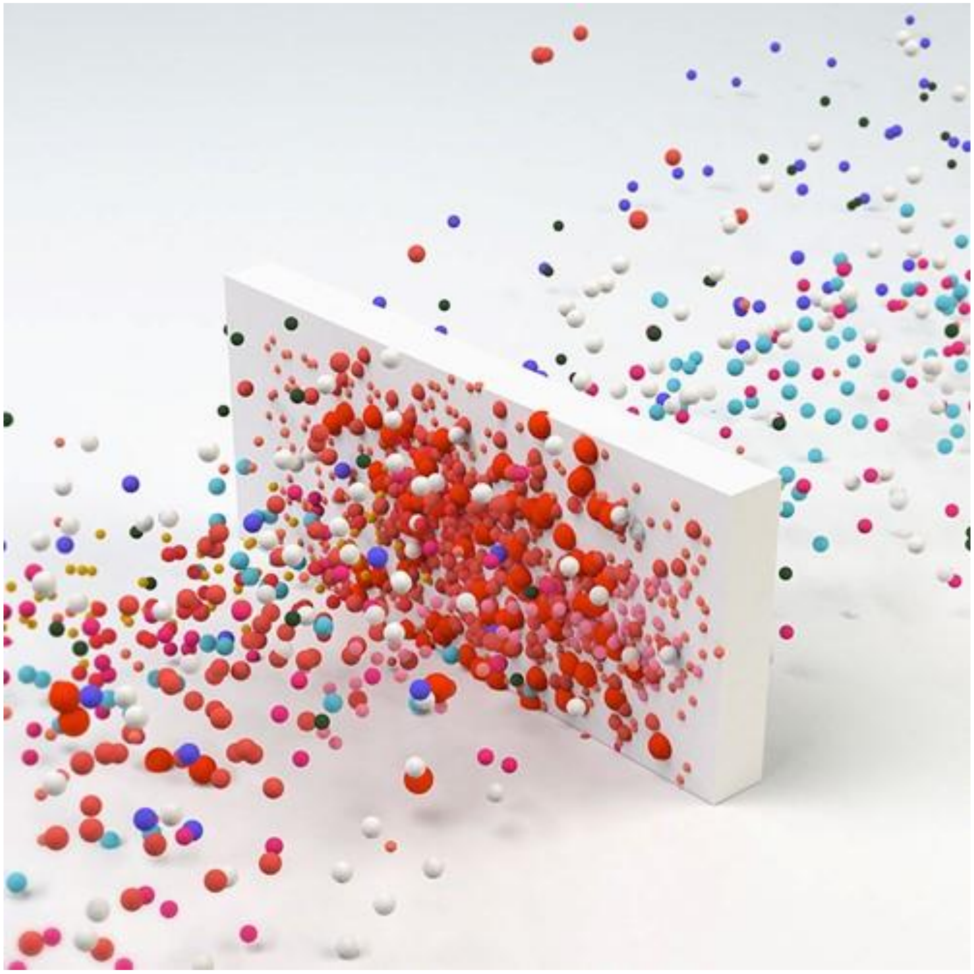
A fundamental feature of the theory is that it usually cannot predict with certainty what will happen, but only give probabilities. We see this probabilistic outcome in the collective performance of LCPs. Like QT, LCP behavior is influenced by structure, interactions, feedback loops, and external influences. It is important to remember that LCPs include both a complexity element as well as a scalar one. In that sense it is more like the world around us!

In QT this gives rise to the uncertainty principle which says that no matter how careful we are in preparing and performing our experiment, it is impossible to have a precise prediction for a measurement of position and at the same time for a measurement of momentum.



This is analogous to predicting the project's progress and productivity precisely no matter how well we have planned and executed our plan. Position/progress in each system is described by a probability distribution function, often ignored in the management of LCPs that adopt a more deterministic outlook based on a classical PM approach.

Quantum tunneling in QT allows particles to cross barriers that they do not have the energy to. This inability to completely isolate a system enables radioactive decay and has been applied in scanning tunnel microscopy.



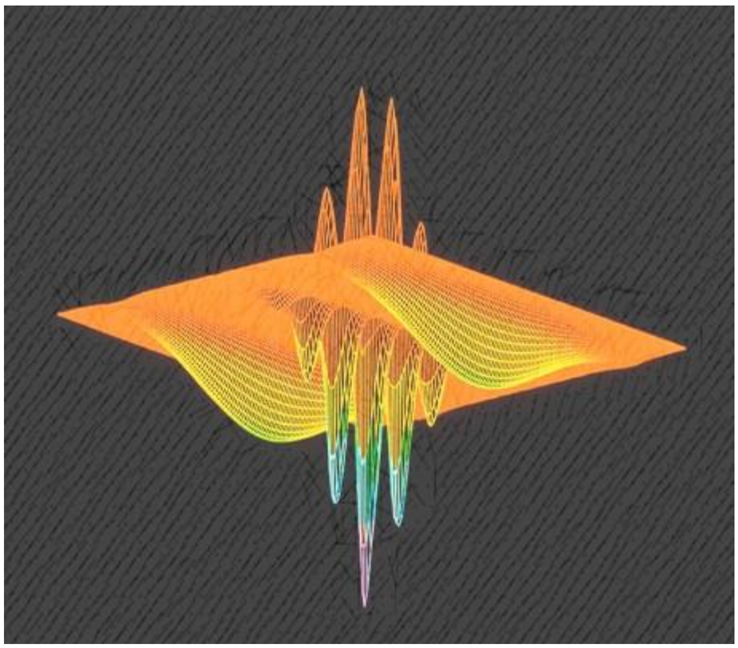
In LCPs we recognize that project boundaries are semi-porous (the result of tunneling both into and out of an LCP) and not well bounded as assumed in classical PM theory. The insight that even actions with low energy may cross project boundaries and impact our project system[4] is an important one and one which contributes to the uncertainty of outcomes and likely even to performance probability distribution. Project performance decays over extended time frames as the project becomes less isolated and more susceptible to changes in the surrounding ecosystem.

LCPs are comprised of a collection of complex systems rather than just a singular system. These systems may include subparts of the LCP or physical, natural, human and informational systems. QT says that when quantum systems interact, the result can be the creation of quantum entanglement. Their properties become so intertwined that a description of the whole solely in terms of the individual parts is no longer possible. This is where classical PM theory's premise on decomposition of projects falls short.

[4] Think of these as persistent small changes in project perceptions that impact both decisions and decision making. Individually they do not rise to a significant concern but cumulatively their impacts can be even greater.

QT involves emergent properties as a crucial part of their explanation of outcomes for entangled systems. The system exhibits properties and behaviors not reducible to the intrinsic properties of its spatially local parts. We witness this emergent behavior both directly within the context of the LCP as well as in adjacent, interacting stakeholder systems.

Finally, QT importantly recognizes decoherence, the loss of information from a system into the environment since every system is loosely coupled with the "energetic" state of its surroundings. The more energetic the surrounding environment the faster and greater the loss of coherence. Analogously in LCPs, the energy present in the surrounding stakeholder environment can contribute to decoherence of an LCP's execution.



Transitioning to a New Theory of Project Management

RT and QT both seek to answer the question 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 try to do in project management. And like in RT we see that performance is overpredicted and that scaling leads to lower performance.

Classical PM theory does not adequately recognize that frames of reference are relative and change over the project lifetime…. not just the project delivery lifetime. Probability and uncertainty take on greater importance in LCPs and classical modeling breaks down.

The migration from classical physics to quantum and relativistic physics recognized many of the same shortcomings that drive us to move on from classical PM theory to QPM.

- Scale matters

- Scale reveals presence of complexities not otherwise seen
- Multiple changing frames of reference must be considered
- Probabilities provide for extreme behaviors
- Uncertainty opens door to multiple paths/outcomes
- Time (and timing) is an integral property of everything

As we formulate QPM we must address:

- ♦ Uncertainty, in what we know and measure; what we do; what externalities exist; and the variabilities of human nature and performance
- ♦ Governance models that:
  - Reflect complexity and changing nature of large projects
  - Achieve strong and sustained stakeholder alignment
  - Support owner and project readiness
- ♦ Planning Biases influenced by frames of reference[vi]
- ♦ Probability & Improbability as complex projects do not behave "normally" but rather catastrophically
- ♦ Complexity
- ♦ Extended time frames

Illustrated by Dall-e

QPM

QPM seeks to draw on the insights from RT and QT and importantly the transition in thinking which took place from classical theory. These core insights, embedded in QPM Include:

- **LCP represent open systems that influence and are influenced by their contextual setting and its behaviors over time**
    - Quantum systems (QT) are not closed but open, meaning that there are dissipation (tunneling and decoherence) and re-feeding mechanisms that play a role when correctly describing a physical system
    - RT predicts the distortion of spacetime in the presence of large masses or energy

- **LCP, by their very scale and complexity, are imbued with uncertainty and have a propensity to fundamental indeterminism characterized by emergent behaviors and outcomes**
    - We cannot predict, with certainty, the project's progress (QT position) and productivity (QT momentum) precisely no matter how well we have planned and executed
    - QT systems exhibits properties and behaviors not reducible to the intrinsic properties of its parts
    - Scale reveals presence of complexities not otherwise seen
    - Probabilistic outcomes are a fundamental feature of QT. Probabilities provide for extreme behaviors.

- **Traditional decomposition of projects (breaking project into smaller pieces/tasks) does not fully describe an LCP. LCP are complex entangled systems where the whole is greater than the sum of its parts.**
    - LCP are a collection of complex systems – physical, natural, human, informational. QT says when complex systems interact entanglement is created. Complex projects do not behave "normally" but rather catastrophically

- **LCP are strongly influenced by the totality of all surrounding ecosystems, stakeholders, forces and flows and in turn influence and interact and shape them.**
    - The open system nature of QT and the RT interaction of mass/energy (QPM scale and inherent complexity) with spacetime underscore the importance of a system of systems perspective

- **Neither the LCP nor its surrounding universe are static. Disruptive events, especially significant ones, ripple through the broader system of systems changing each. The potential for significant impacts grows with time as the LCP context is stretched.**
    - RT gravitational waves ripple through spacetime which is stretched by the passage of time growing the potential energy (dark energy) of the universe

- **Flows arise from disruptions and disturbances in the surrounding ecosystem impacting the LCP and changing its context. Some flows may take longer to emerge or be more persistent as the LCP and its surrounding universe change.**
    - RT time dilation is an example arising from the distortions of gravity arising from the mass-spacetime interaction

- **Strategic Business Outcomes (SBO) clarity and alignment requires continuous alignment to address the natural precession associated with LCP. It is essential to ensure that the addition of "wants" do not contribute to the LCP collapsing under its own weight.**
    - In RT, precession is the rotation of the axis of spin in the presence of a large mass.
    - Black holes are supermassive distortions of space that grow with the addition of more and more mass.
    - SBO clarity, agreement and communication are essential for LCP success, remembering though that LCP outcomes are heavily influenced by one's frame of reference as well as the uncertainty inherent in complex adaptive systems.

- **Frames of reference in an LCP are rarely aligned and require continuous attention to understanding their interplay.**
    - In RT, observers in different frames of reference might perceive events differently. This is particularly important with respect to time dilation where the path taken becomes important.
    - Frames of reference in LCP include owner, workforce, regulators, funders, stakeholders.
    - Planning biases are influenced by frames of reference

These core insights have been restated and reordered into a set of fundamental precepts associated with QPM and are shown in Table A-4.

Table A-4 QPM Precepts		
	**1.**	**Strategic Business Outcomes (SBO) requires continuous alignment**
	**2.**	**Frames of reference, of all project participants, require continuous attention**
	**3.**	**LCP are dynamic open systems influenced by their setting**
	**4.**	**LCP are imbued with uncertainty and characterized by emergent behaviors and outcomes**
	**5.**	**Traditional decomposition of projects does not describe an LCP. LCP are complex entangled systems**
	**6.**	**LCP are strongly influenced by surrounding ecosystems, stakeholders, forces and flows**
	**7.**	**Flows arise from the surrounding ecosystem impacting the LCP**
	**8.**	**Neither the LCP nor the surrounding universe are static. Potential for significant impacts grows with time**

Part B. Precepts of Quantum Project Management

Developing the Precepts

The sections that follow develop each of the precepts further and provide guidance on how they should be considered in the management of an LCP. Theoretical foundations are complemented by practical advice to better manage an LCP.

The sections have been numbered to correspond to the precept numbering contained in Table A-4. Each section had been developed to stand on its own so any repetition from section to section is designed to support that objective.

The sections include:

1. Strategic Business Outcomes (SBO) requires continuous alignment
2. Frames of reference, of all project participants, require continuous attention
3. LCP are dynamic open systems influenced by their setting
4. LCP are imbued with uncertainty and characterized by emergent behaviors and outcomes
5. Traditional decomposition of projects does not describe an LCP. LCP are complex entangled systems
6. LCP are strongly influenced by surrounding ecosystems, stakeholders, forces and flows
7. Flows arise from the surrounding ecosystem impacting the LCP
8. Neither the LCP nor the surrounding universe are static. Potential for significant impacts grows with time

Extensive reference is made to prior papers by the author to further reinforce the respective sections.

Precept 1. Strategic Business Outcomes (SBO) require continuous alignment

In discussing this precept, I will consider two aspects. The first is the tendency of alignment around SBOs to migrate similar to the precession we see in RT. The second is the potential for the project to become a Black Hole as more and more wants are added to the project's mass, growing it in scale until it collapses under its own weight.

Illustrated by Dall-e

1.1 Continuous Alignment Imperative

As projects are initiated and various elements (physical, informational, etc.) of what can be described as the project's mass grow, there is a natural tendency for these elements to coalesce and develop and align around a primary axis. This primary axis represents the project's alignment which ideally aligns with a projects SBO. During the project's formational phase, the momentum of the various elements can either aid in the project's progress or act to hinder forward progress. This is why effective project startup[5] is essential and initial alignment around SBOs so significant[6].

Alignment of project participants, especially during the pre-project planning phase is a recognized key to project success. Alignment activities within a project context are focused on defining, understanding and meeting project objectives by the various project participants. LCP are better

[5] Project Kick-Off for Large Complex Projects; National Academy of Construction Executive Insights https://www.naocon.org/wp-content/uploads/Project-Kick-Off-for-Large-Complex-Projects.pdf

[6] The Importance or Strategic Business Objectives; National Academy of Construction Executive Insights https://www.naocon.org/wp-content/uploads/The-Importance-of-Strategic-Business-Objectives.pdf

described as programs, comprised of multiple large scale projects. In this sense a broader view of alignment is suggested.[7]

Continuous alignment requires that:

- SBOs are clearly articulated
- Agreed to
- Continuously communicated

Recognizing the important relationship between LCP performance and the universe surrounding it we find that alignment in LCP around SBOs is not confined to internal stakeholders even though these objectives represent organizational goals. Key external stakeholders will need to be engaged to ensure that these top level SBOs are achievable. Agreement is both an internal as well as external imperative. Just as the accretion of mass in RT leads to the spin of a planet, its ultimate condition is greatly influenced by its surrounding ecosystem.

Examples of key external stakeholders can include:

- Major investors including founding shareholders, large institutional investors, pension funds
- Bond holders
- Institutional lenders or others who will provide capital to achieve the program's objectives
- Executive Branch leadership for governmental programs
- Legislature, in general, and appropriating committees, in particular, for government funded or subsidized projects
- Regulatory authorities for objectives requiring significant regulatory support.

But even the best efforts at continuous alignment must recognize that LCPs will see a natural tendency for its SBO alignment to precess as it moves through its execution path, especially as the mass of the project grows and the surrounding spacetime is stretched. In RT, precession is the rotation of the axis of spin in the presence of a large mass. This natural tendency toward precession must be recognized and accounted for in the project execution journey. Additionally, sustaining the project's momentum is essential, lest frictional forces create a "wobble" in project alignment much like what we see when a spinning top experiences friction, ultimately falling over.

This requires the project organization to exhibit "change-agility"[8] especially in an environment characterized by volatility, uncertainty, complexity, and ambiguity (VUCA). Alignment requires continuous effort and attention as the project and its environment, especially for an LCP,

[7] Prieto, R. (2011). Continuous Alignment in Engineering & Construction Programs Utilizing a Program Management Approach, Second Edition, *PM World Journal*, Vol. X, Issue VIII, August 2021. Originally published in *PM World Today*, April 2011. pmwj108-Aug2021-Prieto-continuous-alignment-in-engineering-and-construction-programs-2nd-ed-2010.pdf (pmworldlibrary.net)
[8] The Science of Organizational Change; Paul Gibbons; 2019 Edition

undergoes significant changes. Organizational transformation[9] is best carried out through a series of smaller transformation efforts creating an organization that has an ability to change and adapt as a core capability. The project team is always change ready, an essential element required to deliver an LCP. The project team and by extension the project is not just agile but also anti-fragile[10]. Project operations are dynamic, adaptable and nimble but also focused on continuous alignment even as the project progresses through its execution.

Keeping the project soundly on an axis of alignment stops a "wobble" in project execution from developing, potentially resulting in a catastrophic outcome. The importance of maintaining alignment with strategic business objectives cannot be overstated. Failing to do so is the #1 reason LCP fail in the author's experience.

Assessing the various project communications utilizing the pattern recognition capabilities of open AI, as applied to large language models, represents a potential methodology to assess project alignment in near real time.

1.2 The Tendency to Becoming a Black Hole

Let us turn now to a characteristic predicted by the General Theory of Relativity[11], black holes. In physics these represent regions in space-time where extreme densities so distort space-time that no energy or information can escape. Their gravity is so strong that they effectively create a hole in normal space-time. In large projects we experience two different types of black holes. The first is at the foundational center of our project and the second is at a distance, containing a great potential for catastrophic action that while remote should not be ignored.

Let us look at the first type, those present in the foundational cores of our project universe.

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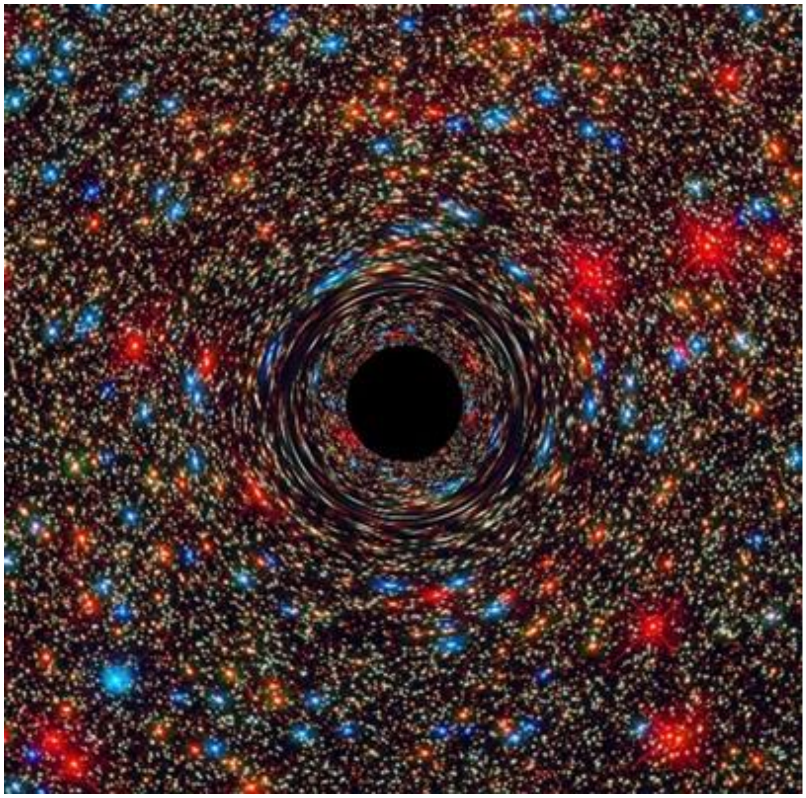
[9] The GIGA Factor; Program Management in the Engineering & Construction Industry; CMAA; ISBN 978-1-938014-99-4; 2011
[10] Taleb, Nassim Nicholas. Antifragile. Penguin Books, 2013
[11] General relativity is a theory of gravitation developed by Albert Einstein between 1907 and 1915. The theory of general relativity says that the observed gravitational effect between masses results from their warping of spacetime.



In physics, a black hole is a region of space-time where gravity prevents anything including light from escaping. In the universe of projects, the analogous region is one which prevents a strongly founded project from being initiated[12]. These black holes may manifest themselves as weak or absent project definition processes, with well-defined stage gates that ensure a well-founded project. Alternately, they may be masked by the perception of a well-founded project only to discover later that the fundamental assumptions underpinning the project suffer from optimism or other heuristic biases affecting project selection (Appendix 3) or underestimating the true nature of risk[13].

Potential bias in assumptions may be identified by looking at the disparate impact of project model outcomes across different assumption subsets. Artificial intelligence tools designed to detect AI and human bias can aid in detecting bias in fundamental LCP assumptions.

The second type of black hole becomes important when we consider the project universe equivalent of gravitational waves.

[12] Project Selection in Large Engineering Construction Programs ; PM World Journal V Vol. II, Issue 12 – December 2013 (Second Edition); Originally published PM World Today – June 2011 (Vol. XIII, Issue VI) pmwj17-dec2013-prieto-project-selection-large-engineering-construction-programs-Jun2011-SecondEdition.pdf (pmworldlibrary.net)
[13] Foundations for Success; National Academy of Construction Executive Insight; https://www.naocon.org/insights/

Before moving onto gravitational waves, a final thought on black holes is in order. Quantum field theory in the curved space-time which is characteristic of black holes says that the horizon of the black hole has entropy[14] [15]. In our project universe this may represent a possible means to detect and assess the impact of these black holes (before they hatch into Black Swans) remembering that the entropy is related to its area. Three examples of events of scale and the growth in entropy that arises can be seen in Table 1.2–1.

Tools such as Shannon's entropy formula[16] [17] applied in AI assessment of data may be applied to broader scans of our project universe.

Natural Disaster	Table 1.2-1 Entropy Increase
Earthquake	Energy stored in the earth's crust is released, leading to a more disordered state.
Hurricane	Heat transfer from the warm ocean surface to the cooler atmosphere increases entropy.
Forest Fire	Rapid release and dispersion of potential energy stored in trees increases entropy.

The smaller black holes at the center of our project foundations may be harder to detect.

[14] Black holes are spheres of maximum entropy.
[15] Hawkings radiation provides a direct linkage between RT and QT.
[16] Shannon Entropy is a measure of the information content of data, where information content refers more to what the data could contain, as opposed to what it does contain. In this context, information content is really about quantifying predictability, or conversely, randomness. Shannon Entropy decreases when order is imposed on a system and increases when the system is more random. Entropy is maximized (and predictability minimized) when all outcomes are equally likely.
[17] Santamaría-Bonfil G, Gershenson C and Fernández N (2017) A Package for Measuring Emergence, Self-organization, and Complexity Based on Shannon Entropy. Front. Robot. AI 4:10. doi: 10.3389/frobt.2017.00010

Precept 2. Frames of reference, of all project participants, require continuous attention.

Perceptions and perspectives matter. We see this from the earliest conceptual stages of SBO and project formulation and articulation. How an LCP and its challenges are viewed is very much dependent on the observer's frame of reference. This is what we see in RT, where observers in different frames of reference might perceive events differently. The importance of frames of reference is particularly important with respect to time dilation where the path taken becomes important.

In this precept we will look at the:

- Varying frames of reference which include owner, workforce, regulators, funders, stakeholders.
- Influence of frames of reference on planning biases
- Concept of time dilation as it relates to LCP

Illustrated by Dall-e

2.1 Varying frames of reference

Perception is in the eye of the beholder or perhaps from a physics perspective, his frame of reference. The owner's perceptions of the degree of difficulty of a project, the challenges it will face, the risks involved and importantly, its cost and schedule come from a perspective of requiring a defined level of performance and outcome.

This perspective will differ significantly from a workforce which daily uncovers the uncertainties in the project and its plans as well as the tugs on surrounding spacetime from regulators and other stakeholders whose own frames of reference may not be aligned with that of the owner or particularly sensitive to the realities that the workforce faces as its local setting literally changes by the minute.

Just as good risk assessment requires us to adopt multiple different perspectives to fully see the elephant in the room, so does our understanding, planning and execution of an LCP require alignment of the varying perspectives of each frame of reference.

In LCP, perceptions quickly become reality.

Table 2.1-1 **Typical Frames of Reference to be Considered in LCP**
Owner Executive Management (including Board)
Owner General Management with Project Responsibility
Financiers (Stockholders; Bond Holders; Rate Payers)
Regulators
Project Manager
Workforce (Design; Construction)
Supply Chain
Stakeholders (Direct)
Stakeholders (Indirect but acting on Direct Stakeholders)
Operations & Maintenance

2.2 Influence of frames of reference on planning biases[18]

The planning fallacy is the tendency of people and organizations to underestimate how long a task will take even when they have experience of similar tasks over running. 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. QPM would ascribe this consistent and inaccurate behavior to the adoption of a common proponent frame of reference. Arguably the biases that we witness on close examination are part of the very framework of that frame of reference and the concept of "framing questions"[19] flows directly from the frame of reference.

When we employ techniques such as reference class forecasting, we seek to broaden our perspective by considering the project from another frame of reference. Reference class forecasting is one method to unlock from a proponent's frame of reference and adopt a more critical evaluation of the project at hand. It addresses the natural proponent tendency to

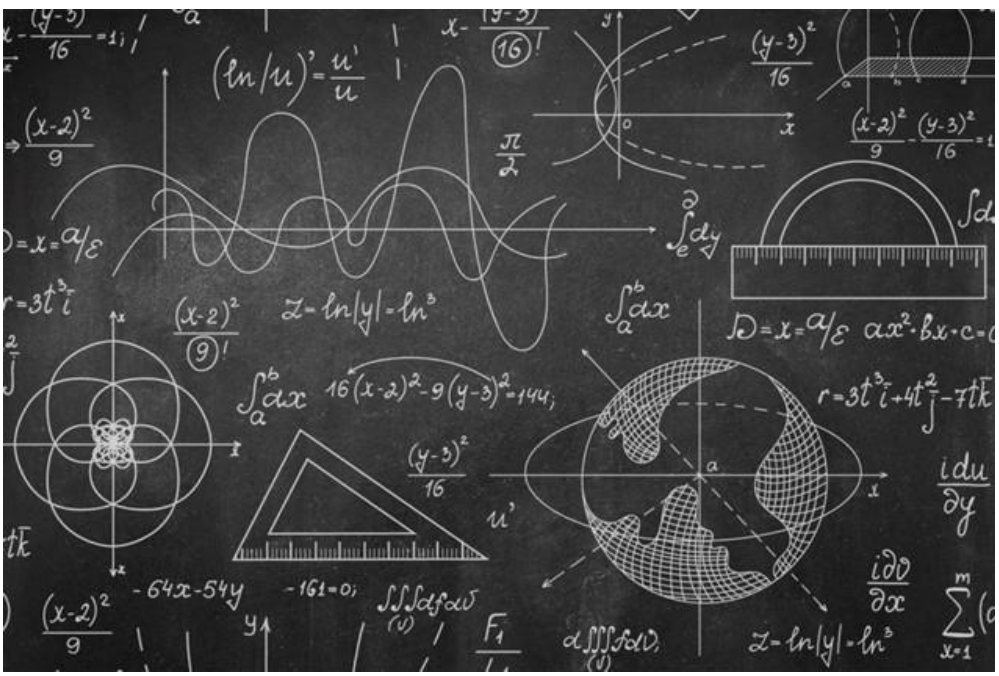
[18] Managing the Planning Fallacy in Large, Complex Infrastructure Programs; PM World Today; Vol. II, Issue VIII – August 2013 pmwj13-aug2013-Prieto-Managing-the-Planning-Fallacy-FeaturedPaper.pdf (pmworldlibrary.net)
[19] Kahneman, Daniel, Thinking, Fast and Slow. New York: Farrar, Straus and Giroux, 2011

underestimate costs, completion times and risks while at the same time overestimating benefits. It squeezes out many biases while considering the inevitable "improbable" risks that all projects face. AI enabled tools[vii] aid in the selection of reference class data.

While this improves the likely outcomes it all too often falls short in large part from the failure to consider a more holistic set of frames of reference that collectively help expose other latent planning biases[20]. These other frames of reference should include the various economic, social, political, cultural, and technological forces that may influence the project's trajectory.

2.3 LCP time dilation

One of the predictions of General Relativity relates to the passage of time as experienced by two observers. In physics, if one observer is moving very fast, time takes longer to pass as compared to what the other outside observer sees. This is called time dilation[viii]. This same time dilation occurs in the presence of strong gravitational fields such as those caused by large masses in space-time.



Analogously, in large complex projects, project time passes more slowly than it would for an outside observer (real world time). Now, this is not as if all project clocks run slow but rather the larger and more complex a project the harder and slower it is to make progress. The mass of the project and the strength of its distortion on local space-time create a degree of difficulty not experienced with smaller projects.

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[20] Human Factors in Large Complex Projects; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Human-Factors-in-Large-Complex-Projects.pdf

There is a tendency to underestimate the real-world time required for an LCP. Part C looks at the math related to time dilation.

3. LCP are dynamic open systems influenced by their setting

The interaction of an LCP and the surrounding ecosystem is a fundamental characteristic of LCP and a central precept of QPM. In discussing this precept, we will look at three aspects of the LCP as a dynamic open system:

- The nature of open systems in general
- Quantum systems, using QT as an analogy, considering properties related to dissipation (tunneling and decoherence) and re-feeding mechanisms that play a role when correctly describing a physical system
- The distortion of spacetime, using RT as analogy, in the presence of large masses or energy

Illustrated by Dall-e

3.1 General nature of open systems

QPM looks at LCP from a systems perspective recognizing that such projects are not as well bounded as classical project management theory, as espoused by Taylor, Gantt and Fayol[21], would have us believe. Rather, they behave in both independent and interconnected ways in a dynamic systems environment.

They demonstrate the evolutionary nature of all complex systems. They face uncertainty and emergence that comes with human actions and interactions.

[21] See R. Prieto, Theory of Management of Large Complex Projects; Construction Management Association of America (2015); ISBN 580-0-111776-07-9

LCP struggle from insufficient situational awareness, treating the project to be more well-bounded than reality would suggest and using simplified models to understand the complexity inherent in execution. Best practices from project management were typically not derived from such environments and, worse, have fallen short on other large complex programs. The pattern recognition capabilities of AI may be applied to the large information sets that describe the broader project ecosystem. The potential for detecting disruptive flows arising from the surrounding project ecosystem is enhanced.

LCP are characterized by boundaries that change in response to changing environments; emphasize coping with challenges and change; go beyond uncertainty and require a change in perspective; face a high level of unknown unknowns and unclear/incompatible stakeholder needs.

Systems theory represents a different way of seeing, thinking and acting[22]

Systems are viewed as greater than the sum of their parts. A system's holistic properties can never be completely known. Different perspectives will provide different views that may overlap and not be completely compatible.

Complexity of systems may exist at multiple levels – component, sub-system, system and system of systems. Complex systems can exhibit a wide range of behaviors, including both stable and catastrophic ones. See Table 3.1-1 for a full range of potential complex system behaviors.

Table 3.1-1
Complex System Behaviors

Stable Behavior	Many complex systems exhibit stable and predictable behavior under normal conditions for an extended period without any catastrophic failures.
Critical Behavior	Some complex systems can display critical or near-critical behavior, where they are sensitive to changes in certain parameters. A complex system can be stable under typical conditions but become fragile and prone to failure if a critical parameter suddenly changes.
Catastrophic Behavior	In certain situations, complex systems can exhibit catastrophic behavior, leading to large-scale failures or disasters. An example is a financial market crash.
Chaotic Behavior	Complex systems can exhibit chaotic behavior, which is highly sensitive to initial conditions and can be difficult to predict over long time scales.
Emergent Behavior	Complex systems often exhibit emergent behavior, where the system's overall behavior cannot be easily deduced from the behavior of its individual components. The result is surprising and unpredictable outcomes.
Resilient Behavior	Well-engineered complex systems may be resilient and capable of withstanding shocks and disruptions without exhibiting catastrophic failures.

[22] De Rosnay, Macroscope: A New World Scientific System, 1975

The behavior of a complex system often depends on a multitude of factors, such as its structure, interactions, feedback loops, and external influences. Flexibility, adaptability and responsiveness provide resilience in complex systems and redundancy of information flows and critical resources are essential characteristics in well performing systems. Time must be managed to accommodate disruptions and disturbances and provide adequate time for the system to recover.

Systems methodologies are characterized as either hard or soft systems methodologies.

Hard systems methodologies sometimes referred to as operations research do not deal as effectively with complex human conflictual problems as soft systems methodologies. The latter consider the broader environment including human and sociological elements. Soft systems methodologies are often iterative, learning at each stage.

The focus of QPM is on open systems which are analogous to LCP.

LCP inhabit the open system world. The adoption of a systems approach to the management of LCP carries with it a requirement to think strategically.

Table 3.1-2 compares traditional PM theory and QPM from a systems perspective.

Table 3.1-2
Comparison of Traditional and QPM Theory from a Systems Perspective

	Traditional PM Theory	**QPM Theory**
Predominant Project Type	Traditional	LCP
Foundational Thoughts	Taylor; Fayol; Gantt	von Bentalanffy[23]
Nature of Projects	"Newtonian"[24]; mechanistic; deterministic (Descartes)	Relativistic (RT) and Quantum (QT); they represent change, not just are changed
Nature of PM	Control	Synthesis
Thinking	Reductionist	Anti-reductionist, holistic
Project Boundary	Well bounded; closed systems do not interact with their environment	Open exchange with environment; open systems have an ongoing relationship with their environment; part of a larger System of Systems (SoS)

[23] Karl Ludwig von Bertalanffy (19 September 1901 – 12 June 1972) was an Austrian biologist known as one of the founders of general systems theory (GST), an interdisciplinary practice that describes systems with interacting components.
[24] Newtonian view held that the Universe was made up of closed systems.

Table 3.1-2 Comparison of Traditional and QPM Theory from a Systems Perspective		
	Traditional PM Theory	**QPM Theory**
View of project	Well-bounded	Embedded in and interacting with other systems (SoS)
Feedback loops	Defined to support positive control (negative feedback loop)	Emergent; positive and negative feedback; reactions to changes in environment (also change environment)
Properties	Defined; fixed; derived from sum of the parts (components)	Emergent; systemic[25]
Organizations (individuals, groups, departments)	Machine like closed systems; mechanistic structures (highly specialized, compartmentalized, strict rules, well defined and rigid hierarchy; well defined formal tasks)	Flexible organismic structures (decentralized, self-organizing (ongoing process of order-disorder interaction), distributed leadership, extensive interdependence, high individual discretion, informal tasks, 360°communication)
Planning basis	Environment is "knowable;" predictable; limited impact on strategy and execution	Continuous stakeholder engagement
Stability	More stable closed system; in equilibrium with no exchange with their environment	Less stable open system; potential disequilibrium (bad = disruption; good = change, creativity, innovation); stabilized by flows Structural stability relative as it is transferred by exchanges with environment
Emergence	Non-emergent	Emergence of novelty
Strategic Business Objectives; goals	Fixed	Exist in continuous interaction with environment
Complexity	Reductionist approaches do not handle well; complexities	Complexities considered in context of broader ecosystem;

[25] Metaphysics (Aristotle) recognized that…many things have a plurality of parts and are not merely a complete aggregate but instead some kind of whole beyond its parts…"

Table 3.1-2
Comparison of Traditional and QPM Theory from a Systems Perspective

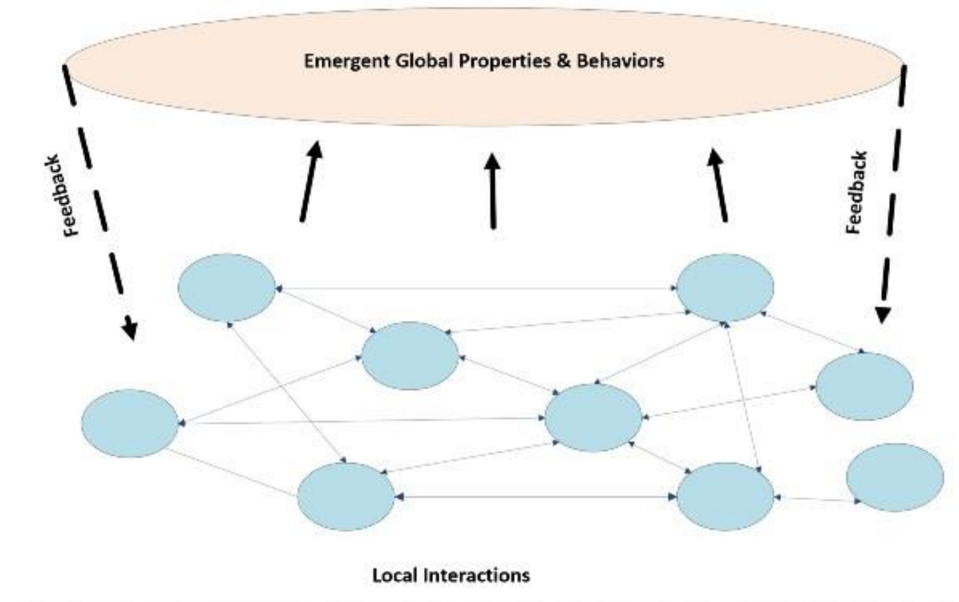
	Traditional PM Theory	**QPM Theory**
	considered in isolation from their environment	arises from inclusion of relationships as a dynamic property at various levels starting with components and activities
Most valuable contributor	Specialist	Generalist
Project execution	Master schedule; recovery to the plan	Equifinality[26] recognized; provision for contingent execution
Predictability	Predictable (order); outcome determined by initial conditions	Unpredictable (shifting balance of order and disorder); outcomes influenced through interaction with environment; continual evolution
Logic	Binary; evaluation separates behavior (inside) from environment/context (outside)	Spectrum of possibilities; relational context matters
Nature of Flows	Steady, laminar; clear information	Turbulent; information amidst the noise

Core building blocks in systems thinking[27] include:

Understanding interconnections — This must begin with a recognition that people(human system) and systems (engineered systems and ecosystems) are interconnected and that actions in one system influence the outcomes in another system. A comprehensive understanding of these interconnections requires us to identify them[28] and then to look at potential second or third

[26] Equifinality is way systems can reach the same goal through different paths.
[27] Systems Thinking in the Construction Industry; National Academy of Construction Executive Insight Member-Viewpoint-Systems-Thinking-For-the-Construction-Industry.pdf (naocon.org)
[28] Coupling in complex systems can be analyzed by using two different approaches: parametric and non-parametric. The parametric approach can be called the model-based approach: It assumes some à priori knowledge about the physical mechanisms of the underlying complex phenomena and their interactions.
It is assumed that the observed phenomena can be reliably modelled. The physical theory and mathematical equations describing the dynamics of such coupling can be used to derive methods for extracting information about coupling properties from data recorded from systems having the assumed properties.

order interconnections, including hidden coupling through constraints. A model-free data-driven framework[29] consisting of deep neural networks[30] to reveal and analyze the hidden interactions in complex systems from observed data alone offers one possibility.



We must develop a broadened solution set that moves thinking from simply linear solutions to circular solutions that are more holistic and life-cycle oriented.

- **Understanding the concept of emergence** — This is particularly important as it relates to large complex systems, which are the domain of the greatest engineering problems now being faced: global climate change, natural and engineered resilience, and re-envisioned

The other approach, nonparametric, is a model-independent approach which uses general, statistical measures of dependence. Only properties of the analyzed data and their probability distributions are considered, not the physical bases of the underlying systems. There is, however, one property of the underlying systems and their interactions and, consequently which is important—linearity or nonlinearity of the studied dynamics.
Linear approaches to time-series analysis, in particular, frequency-specific causality analysis, are well developed and have found numerous applications even in systems with inherently nonlinear dynamics. On the other hand, failures of the linear methods applied to nonlinear systems have been demonstrated, and therefore many nonlinear approaches to study coupling and causality in nonlinear systems have been proposed, including measures of nonlinear dependence developed in information theory.
See Paluš M. 2019 Coupling in complex systems as information transfer across time scales. Phil. Trans. R. Soc. A 377: 20190094. http://dx.doi.org/10.1098/rsta.2019.0094

[29] Unraveling hidden interactions in complex systems with deep learning; Seungwoong Ha1 & Hawoong Jeong; Nature Portfolio Scientific Reports | (2021) 11:12804 | https://doi.org/10.1038/s41598-021-91878-w

[30] Deep Neural Networks are best described by considering their evolution from AI to Machine Learning to Artificial Neural Networks to Deep Neural Networks. It is a model-free data-driven framework to reveal and analyze the hidden interactions in complex systems from observed data alone.

cities. Emergence shapes both the problems to be addressed and the outcome set that may result. It results from interactions of parts of a system as well as system-to-system interactions. Emergence is a force that results in new, more innovative solutions that are not possible with traditional design thinking. Various tools for measuring the potential for emergence are applied across various fields.

- **Lateral synthesis** — This requires a more granular look at cross-domain factors and knowledge. It is characterized by combining well-established ways in a broadened domain set to achieve a new solution and gain added information for even deeper insights. This is an element of QPM.

- **Importance and nature of flows** — Many of the complex systems challenges engineers/constructors face are living systems, where various flows within and into the system shape the success of short-term solutions and longer-term outcomes. Engineers must move beyond solving problems through decomposition linked by transformative flows. Instead, broader systems environments must be recognized, such as influencing flows from stakeholders and other systems as well as induced flows and attendant feedback loops that are created.

- **Coupling and causality** — Systems contain myriad couplings of several types and strengths. These couplings can contribute to perturbations and changes in system behaviors, both forward and backward. Cause and effect are no longer simply obvious but require the systems thinker to understand both direct and indirect influences.

3.2 Properties of quantum systems

LCP, like quantum systems, exhibit several unique properties that distinguish them from classical systems. These include:

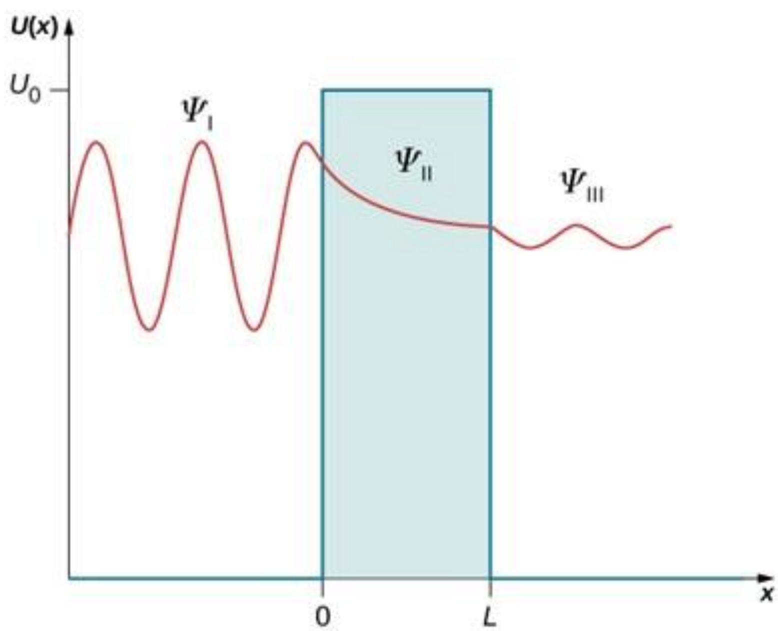
Entanglement: Entanglement is a phenomenon where the properties of two or more particles become correlated in such a way that the state of one particle cannot be described independently of the state of the other(s). Changes to one entangled particle will instantaneously affect the others, regardless of the distance between them. We witness this correlation at scale in LCP and often observe, in hindsight, the deleterious effects of second and third order coupling[31]. Entanglement is discussed further in Precept 5.

Quantum Uncertainty: The Heisenberg Uncertainty Principle states that certain pairs of properties, like position and momentum, cannot be precisely known simultaneously. The more

[31] Coupling in Large Complex Projects; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Coupling-in-Large-Complex-Projects.pdf

accurately you know one property, the less accurately you can know the other. We see analogous examples of this uncertainty in LCP, and this is discussed in Precept 4.

Quantum Tunneling: Quantum tunneling allows particles to pass through energy barriers that would be insurmountable in classical physics. This phenomenon is crucial in various applications, such as in the operation of transistors and certain types of microscopy. We see similar tunneling behaviors in LCP as discussed in the section on QT. It is important to underscore that tunneling into an LCP from the surrounding ecosystem in effect creates porous LCP boundaries. Conversely, LCP behavior and performance have probability density functions that reflect tunneling like behaviors.



Other quantum properties include:

- Superposition: The famous example is Schrödinger's cat, which can be both alive and dead until observed.
- Quantization
- Wave-Particle Duality
- Quantum Interference
- Quantum Measurement Problem

These properties collectively contribute to the complex and often counterintuitive nature of quantum systems, and by analogy LCP, making them significantly different from classical systems.

3.3 LCP and Spacetime[32]

Let us return now to one of Einstein's central concepts, namely space-time. For Einstein, the two parameters were linked and inseparable. Importantly, they are shaped by the presence of mass (m) but also the passing of energy through it. The latter is most notable in the form of gravitational waves that transmit gravitational radiation, distorting local space-time as they transit it.

In large complex projects we progressively change the local nature of a project's "space-time" in several ways. Initially, we impact the project setting through the introduction of a significant amount of "potential energy" defining the proposed project and its implications and ramifications. This "potential energy" (one component of relativistic energy) has not yet been made tangible by transformation into kinetic energy and ultimately the mass of the project itself. But the concentrated presence of this relativistic energy component will have the effect of beginning to shape space-time. We see this in the induced responses in space-time by the introduction of this local distortion. Stakeholder concerns emerge as the space-time they have previously experienced is gradually distorted by the introduction of this significant potential. In a sense space-time is the ecosystem of stakeholders and importantly their relationships, ideas and priorities[33]. It is important to baseline stakeholder sentiment[34] prior to the introduction of this distorting potential energy and then to monitor those sentiments as project formation and execution occurs.

Second, as we undertake the execution of the project, converting "potential energy" into "kinetic energy" and ultimately into the resultant project "mass" we draw into the local project setting mass from outside of the local region. Remember, in the large complex project setting mass represents the tangible form of some work (kinetic energy) times a conversion factor. Think of the formation of the planets as they progressively drew other nearby masses together in their formation. As this transformation process is happening these logistical flows are themselves distorting local regions of space-time, sometimes at great distance. This transformational period for the project creates a growing and unpredictable distortion in spacetime as more and more flows enter the project, sometimes interfering with each other or even transforming one another[35]. The interaction between the project and its local space-time is not deterministic but rather emergent as are the distortions in space-time that the project creates.

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[32] Prieto, R. (2020). A Deeper Look at the Physics of Large Complex Projects: A Neo-classical Project Management Theory is Required; *PM World Journal*, Vol. IX, Issue VIII, August. pmwj96-Aug2020-Prieto-Deeper-Look-at-the-Physics-of-Large-Projects.pdf (pmworldlibrary.net)

[33] I have referred to this as the project's ecosystem and also as the stakeholder ecosystem in other contexts. My current thinking suggests that this broader space-time concept are these and more.

[34] Sentiment analysis with AI involves a combination of linguistic analysis, machine learning techniques, and computational algorithms to discern and quantify emotions within text data. It is a powerful tool for understanding public opinion.

[35] Flows in Large Complex Projects; National Academy of Construction Executive Insight; Flows-in-Large-Complex-Projects.pdf (naocon.org)

Finally, the project is complete or perhaps said another way it is now stable with a well-defined and steady (distortional) relationship with its local space-time. It may be perturbed later but that is not of interest here. While the project has now reached a stable phase the transformation phase has had far reaching effects. Relationships with nearby stakeholders have been reframed (space-time has been distorted), with the potential for longer lasting perturbations in this project-stakeholder system. Logistical chains have been significantly modified often with very different pre and post-project trajectories. This may impact subsequent project transformations even at a distance.

Our large project is transformed into an expanding dynamic system that is changing overall even as we seek to create a local region of stability.

Let us look at our project's space-time setting a little closer. It is not just distorted by the introduction of the relativistic energy of the project, but it is itself turbulent, akin to what quantum mechanics might suggest. New issues pop in and out of existence and the extent to which they define or modify the local setting, local region of space-time, is uncertain. Space-time is endowed with properties. It is defined by its relationship to different objects. Space-time itself is emergent.

The project setting and its interaction with space-time both locally and at a distance behaves very much as an open system. As a result, our project has a relatively open scope for possibilities, certainly not what classical project management theory with its closed systems view would suggest. Our large complex project, like all open systems, tends toward differentiation, growth in complexity and networking with other systems, such as the supply chains which feed it but also many more.

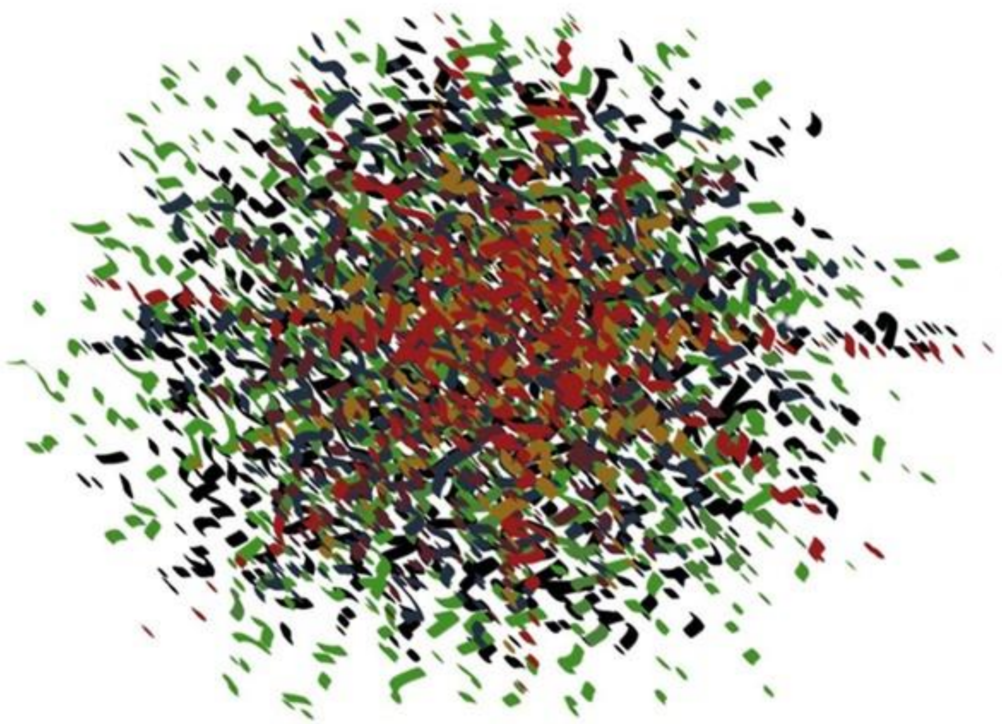
Precept 4. **LCP are imbued with uncertainty and characterized by emergent behaviors and outcomes.**

Illustrated by Dall-e

We cannot predict, with certainty, the project's progress (QT position) and instantaneous productivity (QT momentum) precisely no matter how well we have planned and executed. As the installed work grows and with it the "mass" of the project, so too does the difficulty in accelerating the project. Scale reveals the presence of complexities, not easily seen in more traditional size projects, but also present.

LCP systems exhibit properties and behaviors not reducible to the intrinsic properties of its parts. We see this in QT systems. The whole is greater than the sum of its parts. This point is discussed further in Precept 5.

Finally, the uncertainty embedded in LCP give rise to probabilistic outcomes that are also a fundamental feature of QT. These probabilities provide for extreme behaviors.



In this precept we will look at:

- Project prediction/forecasting
- Challenge of LCP acceleration
- Probabilistic outcomes
- Uncertainty
- Emergence

4.1 Project prediction/forecasting

Quantum probability distributions, as described by the principles of quantum mechanics, are fundamentally different from classical probability distributions. In quantum mechanics, the behavior of particles is described by wavefunctions, and the probability of finding a particle in a particular state is given by the squared magnitude of the wavefunction. This is known as the Born rule[ix]. LCP performance exhibit analogous behavior with variability of potential project states driven by the project's complexity and inherent uncertainty.

Quantum probability distributions do not exhibit "fat tails" in the same way that classical probability distributions might. In classical statistics, a fat-tailed distribution refers to a distribution with heavy tails, meaning that extreme events are more likely to occur than in a normal (Gaussian) distribution.

The behavior of quantum systems is inherently probabilistic and can be quite different from classical systems, but while the concept of fat tails in the traditional sense is not directly applicable neither is the concept of a normal distribution. Quantum wave functions are not typically described by normal distributions. The probability distribution associated with a quantum wave function is given by the square of its absolute value, often referred to as the probability density function. This probability density function is a fundamental concept in quantum mechanics and is usually represented by the wave function, symbolized as Ψ, squared, or Ψ^2 .

The probability density function gives the probability of finding a particle in a particular region of space. The shape of this distribution is determined by the specific form of the wave function for a given quantum system. An analogous distribution for LCP would assign a probability to the project's performance being at a particular level but would require insight into the wave function for a particular LCP or family of LCP.

Given the absence of such a wave function we are driven to approximate a behavior that allows for extremes higher than what a normal distribution might suggest. So, while fat tailed distributions do not fully describe the behavior of an LCP, they provide a better first order approximation. This is described further in section 4.3.

4.2 Challenge of LCP acceleration

Mass represented the conversion of relativistic energy such that energy (E) times a conversion factor ($1/c^2$ in the case of special relativity) was equal to the mass resulting from the conversion of energy to a more tangible form. In the universe of large complex projects, it is convenient to think of energy as related to the work done by one person unit of work. The resultant output is the "frozen energy" of people if you will. Mass represents the tangible form of some units of work times a conversion factor. The conversion factor will more likely be analogous to Einstein's more general form found in General Relativity

In General Relativity the more familiar form of $E=mc^2$ is replaced with $E=\lambda mc^2$, where $\lambda= 1/ (\surd(1-v^2/c^2)$ [36]. At rest, the rest energy for a given mass is mc^2. As we accelerate this mass the kinetic energy of an object moving at relativistic speeds is equal to $(\lambda- 1)\ mc^2$. As we accelerate a given mass to higher energy levels significantly more energy is required, and no mass can ever be accelerated to the speed of light.

In the universe of projects as we seek to increase the resultant outputs (mass) the increase in human activity (energy) is non-linear, growing either with total project size or accelerated mass deployment (shorter schedule). Assuming a relationship like what we see in relativistic physics, increasing the "velocity" of the project from 89 to 90% of a theoretical maximum would require

[36] √square root

4.6% more energy while increasing it from 93 to 94% would require 7.7% more energy. Project acceleration faces the same energy challenges as mass acceleration[37].

4.3 Probabilistic outcomes

LCP are complicated and often sophisticated endeavors, and we seek to improve the quality of our time and cost estimates by accounting for certain quantitative uncertainties in our estimates. Clearly a step in the right direction, but as the results of large project performance would suggest, not good enough. Perhaps we are unwitting victims to some of the Laws of Improbability[38], and maybe even the Law of Selection[39] impacts our best efforts to address the uncertainty of estimates in our own risk analysis.

Consider a given estimated value, where we have assumed a normal distribution around a mean value. Have we selected the data set for calculating the mean in such a way as to dismiss so called "outliers"[40]? Or potentially more common, have we utilized a distribution around a mean that dismisses these outliers without any direct action on our part other than the selection of the probability distribution itself? One place where these distribution assumptions come together with direct impact on our perception of likely vs. actual project performance is in our project risk analysis.

Now consider the very typical case where a Monte Carlo analysis is run utilizing a normal distribution. Implicit is an assumption that extreme outliers are so improbable as to be impossible.

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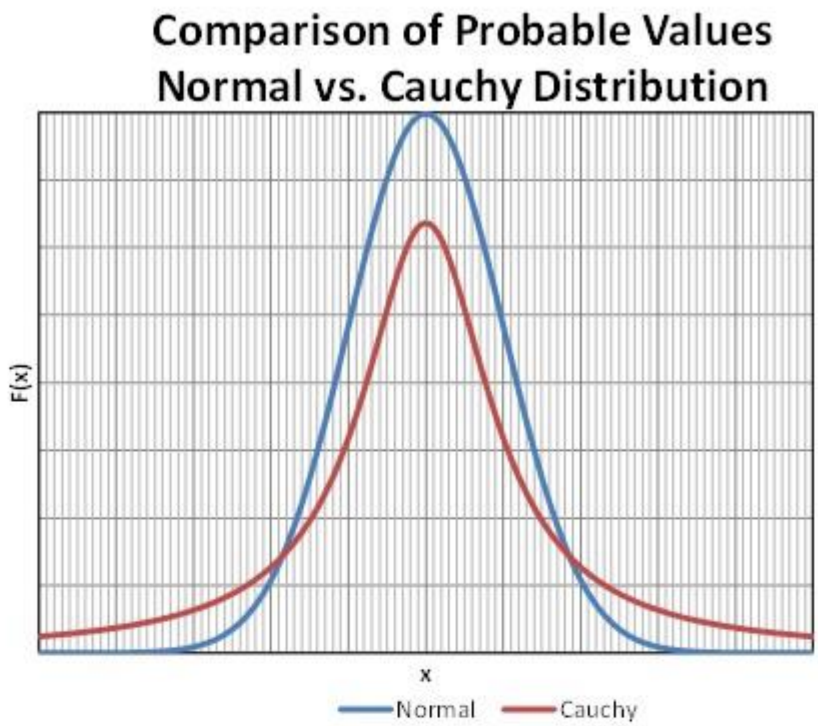
[37] More generally, barriers to productivity grow as we seek to accelerate a project. These barriers are discussed in Barriers to Productivity – An Overview ; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Barriers-to-Productivity.pdf and Factors Affecting Productivity; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Factors-Affecting-Productivity.pdf

[38] Laws of Improbability; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Laws-of-Improbability.pdf

[39] The Law of Selection says one can make probabilities as high (or low) as desirable if one chooses after the event. Large projects are characterized by tens of thousands of assumptions, most never written down. Many of these assumptions are based on perceptions of values or their trajectory.

[40] Borel's Law states sufficiently unlikely events are impossible. But in evaluating the risks on LCP, events that appear sufficiently unlikely are ignored, treating them as Borel would, as impossible. Are these ignored events truly as unlikely as perceived?



We see the normal distribution's characteristic "thin tails" as contrasted with the thicker, "fat tails"[41] associated with the Cauchy distribution[42]. It is in these fat tails that we might expect to see "Black Swans" or even less exotic but extremely significant "off normal" events that combine for project failure in large projects.[43]

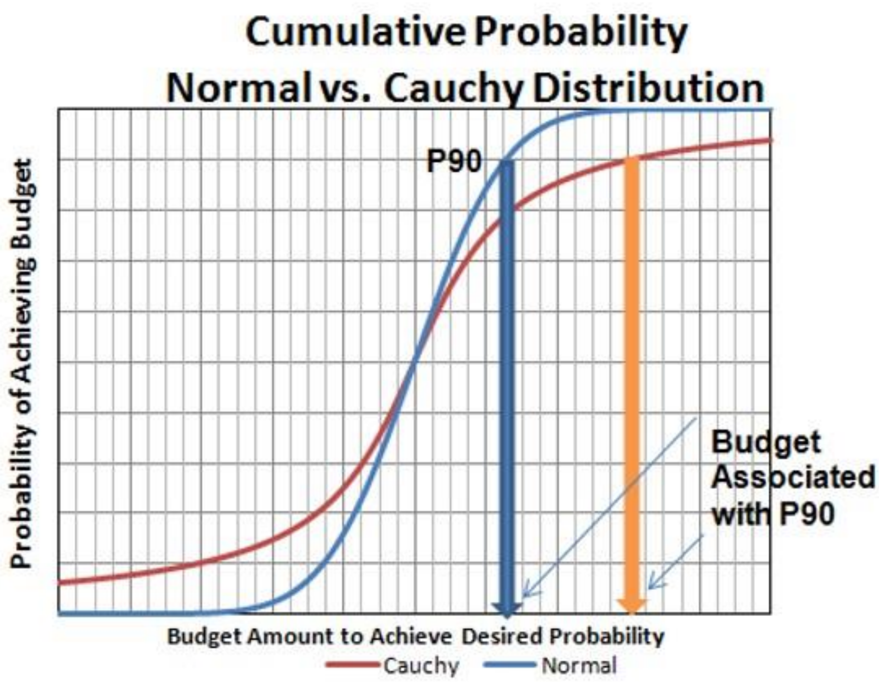
Let us consider these distributions from a slightly different perspective by looking at the cumulative probabilities.

We can see that to achieve higher confidence levels (say P90), the Cauchy distribution and its inherent inclusion of the possibility of off normal events would have us include a significantly higher budget amount.

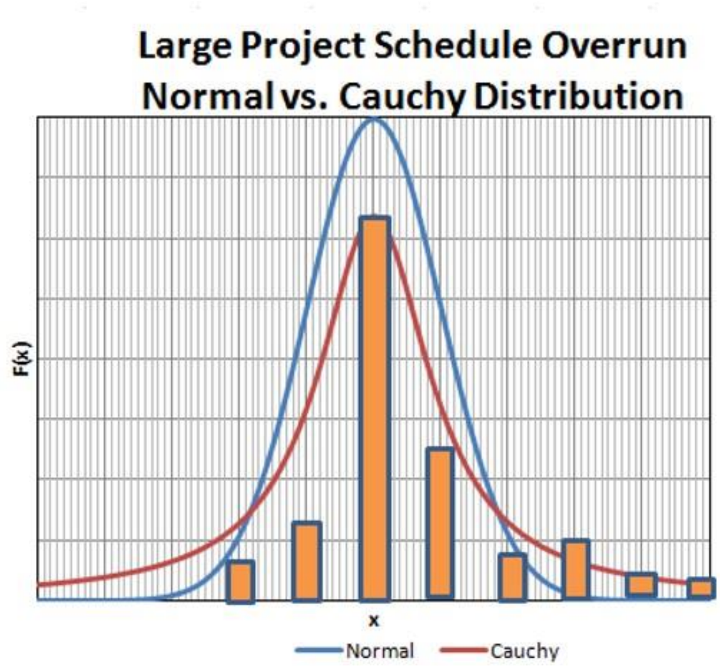
[41] Fat Tails; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Fat-Tails.pdf

[42] Also known as the Lorentz distribution, where it is the distribution of the energy of an unable state in quantum mechanics.

[43] In our later discussion in this paper we will see that the probability density function for quantum wave behavior is a more accurate and consistent description but in certain instances may be approximated by the Cauchy distribution.



The following figure shows the distribution of project schedule overruns for a sample of large industry projects. Note the better fit of the Cauchy distribution for overruns larger than the mean overrun. The fatter overrun tail better describes the "failed" project performance we see in large projects.



The stark difference in the views of the two distributions as it relates to improbable events should cause us to reconsider the choice of distributions for select parameters in our overall Monte Carlo risk assessments or, at the very least, confirm the parameters we are modeling vary as the normal (or other assumed) distribution would suggest. Said another way, the behavior of LCP is neither "normal" nor as well bounded as classical project management theory might lead us to believe.

In QT, these fat tails are associated with the uncertainties of both the complex system itself and its interaction with the surrounding broad ecosystem. While more accurately described by a wave function, specifically its probability distribution function, Ψ^2, fat tails move us away from a normal distribution.

This is discussed further in Part C. where we find a mathematical analogy between the Cauchy distribution and a certain type of wave function related to tunneling.

Table 4.3-1 shows the probability of the improbable.

Table 4.3-1
Probability of the Improbable

	Normal	Cauchy
5 sigma event	1 in 3.5 million	1 in 16
10 sigma event	1 in 1.3 x 10^{23}	1 in 32
20 sigma event	1 in 3.6 x 10^{88}	1 in 63
30 sigma event	1 in 2.0 x 10^{197}	1 in 94

4.4 Uncertainty[44]

Uncertainty in projects is often conflated with risk and the two terms used interchangeably. All too often uncertainty is then treated in the same way as risk, or worse ignored. In LCP large pools of uncertainty may exist, associated with project complexity.

Uncertainty is an inability to foretell consequences or outcomes because there is a lack of knowledge or basis on which to make any predictions.

While the quantification of risks (event uncertainty) and risk values (estimate uncertainty) may have varying levels of uncertainty associated with them, risk is different from uncertainty. Project level uncertainty is where the content and results of future actions and activities are uncertain as are the conditions and circumstance under which they will take place.

[44] Uncertainty in Large Complex Projects; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Uncertainty-in-Large-Complex-Projects.pdf

Uncertainty falls along a spectrum ranging from known knows to unknown unknowns. Unknown knowns are characterized by our inability to assign objective probabilities but for which we have a historical context. Known unknowns are possibilities but we do not know when, where or how they will occur. Finally, unknown unknowns lead us to the unexpected, the uncertainty which is a characteristic of QT and LCP.

The best way to understand the differences between risk and uncertainty is a side-by-side comparison as shown in Table 4.4-1. We often fail to give uncertainty sufficient attention, assuming we know more about the future than we have any right to assume. Once we understand the differences between risk and uncertainty, we open the door to multiple potential futures limited only by the way we think about the world.

Similarly, we each think about risk and uncertainty differently[45], and even more differently than others, which is why group efforts around identifying each and associated management strategies is so important.

Table 4.4-1
Contrasting Risk and Uncertainty

Risk	**Uncertainty**
Risk is measurable uncertainty	Uncertainty is immeasurable risk
Risk describes a situation in which there is a chance or a loss or danger	Uncertainty refers to a condition where you are not sure about the future outcomes
Risk: We do not know what is going to happen next, but we do know what the distribution looks like.	Uncertainty: We do not know what is going to happen next, and we do not know what the possible distribution looks like
Risk is unknown outcome with well-defined possibilities.	Uncertainty occurs when we have no idea of what the possible outcome might be
Risk can be measured and quantified; risk taker can take steps to protect himself from.	Uncertainty does not allow someone to protect themselves since no one can foretell the future
Risk may be taken or not	Uncertainty is a circumstance that must be faced
Taking a risk may result in either a gain or a loss because the probable outcomes are known	Uncertainty comes with unknown probabilities.
A risk is a discrete event with a probability of occurrence. The risk effect (impact) is only felt if / when the event occurs.	There is no probability of occurrence with an uncertainty – you know that you do not know the actual value of the input variable
Can be measured	Cannot be measured
Controllable	Uncontrollable

45 Note the biological differences described in Table 4.4-1

Table 4.4-1 Contrasting Risk and Uncertainty	
Risk	**Uncertainty**
Probability of winning or losing something of worth is known as risk	Uncertainty implies a situation where future events are not known
Chances of outcomes are known	The outcome is unknown
Risk is an outcome which can be calculated through measuring probabilities	Uncertainty concerns the unknown future
Probabilities can be assigned	Probabilities cannot be assigned
Multiple alternatives resulting in a specific outcome where the probability of the outcome is known	Multiple alternatives resulting in a specific outcome where the probability of the outcome is not certain and may be unknowable
Measured in quantitative terms	Cannot be measured in quantitative terms as the probabilities are unknown
Risk can be minimized by taking necessary precautions	Uncertainty cannot be minimized
Risk, in principle, is calculable, and predictions can be expressed statistically or mathematically determined probabilities	Uncertainty is characterized by events in the future that are unknown and/or their consequences cannot be estimated/quantified
Risk recruits the orbitofrontal cortex, striatum, insula, and posterior parietal cortex[46]	Uncertainty recruits the amygdala and parts of the frontal cortex such as the inferior frontal gyrus, and the dorsal lateral prefrontal cortex
Risk is the product of events regarded as having known outcomes	Uncertainty exists in events with unknown probabilities and outcomes

Uncertainty is a lack of precise knowledge about what the truth is, either qualitatively or quantitatively. This lack of knowledge can reflect a current gap with respect to the present or near future or more likely a later period[47]. There is often a reluctance to qualify or quantify uncertainty for fear it will impact confidence in our risk assessments. This undermines the central goal of good risk management to produce the best possible assessment of project outcomes and strategies to

[46] Disentangling Risk and Uncertainty: When Risk-Taking Measures Are Not About Risk; Kristel De Groot; Front. Psychol., 15 November 2018; Sec. Decision Neuroscience https://doi.org/10.3389/fpsyg.2018.02194
[47] The effects of uncertainty over time grow exponentially so if you plot the impact of uncertainty on a log scale you will get a straight line. If you think of a parameter's value as V(t) where t is time, then you can write it as V(t) = V(0)*EXP (kt), where V(0) is your value at time of estimate or contract and k is a positive constant related to the particular parameter. In the case of an unmodified contract, k=0, and the contract value if you will is unchanged over time. Now think of a parameter such as labor cost where a higher labor escalation rate is realized throughout the project period. Here k would be equal to the delta between the labor rate growth assumed in the contract and the actual realized rate. The slope of that log plot would be k.

assure their achievement. What matters for decision making is not whether particular indicators have become more or less variable or dispersed per se, but rather whether the project has become more or less predictable; that is, less or more uncertain.

Table 4.4-2 outlines some sources of uncertainty on projects. They have been segregated into sources within the project context and external to it.

Table 4.4-2
Sources of uncertainty in projects

Project Team	**Project Environment**
Complexity of selected project design, technology or execution approach	Incomplete information; inadequate time to gain better information and knowledge
Complex organizational relationships and diversity of personalities and behaviors	Stakeholders, changing, competing and conflicting demands
Lack of clear organizational culture	Governmental and institutional decisions and decision making process
Information overload; ambiguous information	Political influences
Turbulence of project objectives, facts and decisions	Geopolitical forces
Randomness of project changes	Regulatory landscape in turmoil or transition
Lack of understanding of key project issues	Industry, market and supply chain capabilities and capacities
Relationship between cause and effect in various aspects of the project not understood	Number of stakeholders
Inadequate or untimely decision making in project	Industry capability to deliver project
Uncertain or ever-changing project scope	Project team capabilities
Scale of project	Maturity of project processes
Actual or perceived complexity of the project	Availability and capability of required resources
Extended project timeframes	Inappropriate or inadequate contractual frameworks

When we act like everything is a risk, we increase the chance of failure. When we act like everything is unknowable, uncertainty gets blamed for inaction.

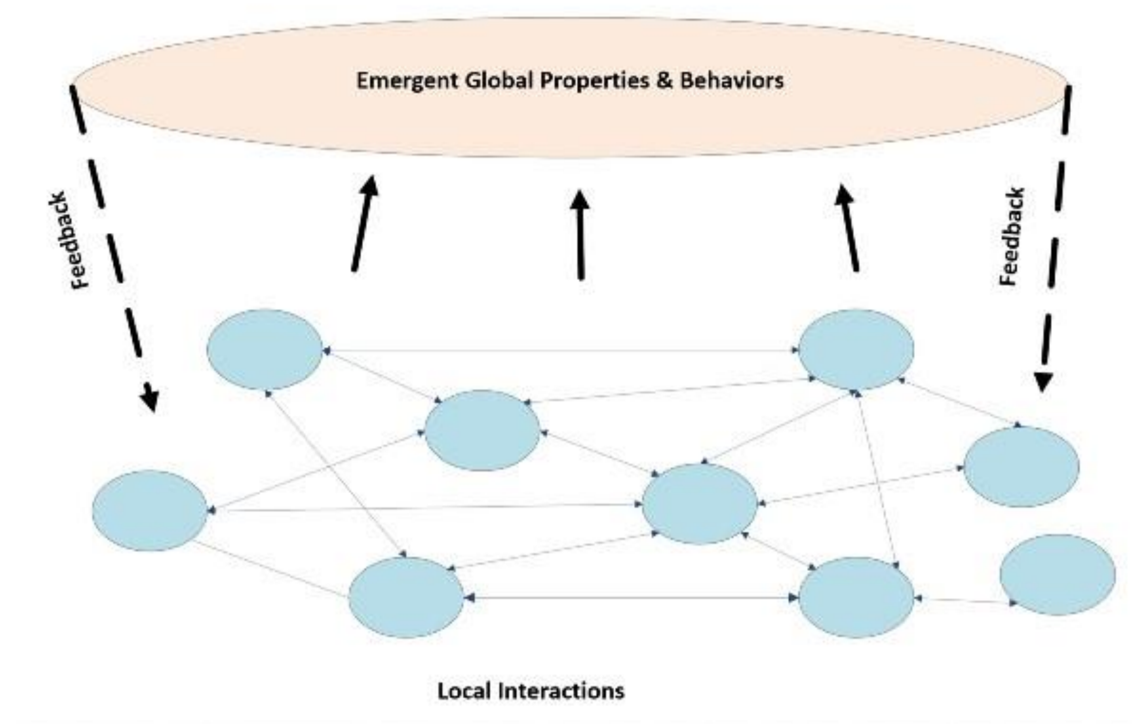
We cannot use not knowing as an excuse not to act. We never know. We either suppress uncertainty, and act overconfidently, or we overemphasize uncertainty, and do not act at all. Both are bad outcomes.

Table 4.4-3 summarizes some strategies for managing project uncertainty.

Table 4.4-3 **Managing project uncertainty**	
Strategic business outcomes clearly articulated, agreed to and communicated	Strong stakeholder engagement, including client, around project uncertainties
Robust and complete scope of facilities	Transparency and communication
Robust and complete scope of services	Looking ahead and over the horizon more than the rear-view mirror
Expanded basis of design	Structured approach to continuous re-orientation - Brainstorming, scenario and sensitivity analysis, horizon scanning
Well-developed project baselines (scope, schedule, estimate/budget, risk)	Seeking external advice and identifying project or situational analogs
Gated review processes	Piloting and small-scale trials to understand uncertainties and test solutions
Steering reviews to ensure strategic business outcomes being achieved	Contingent execution planning and authorities
Risk processes that keep areas of uncertainty front and center	Project contingencies that reflect levels and extent of uncertainties the project may face
Uncertainty appropriate team based behaviors - Flexibility, optimism, valuing time/decisive, focus on changing areas of uncertainty	

4.5 Emergence

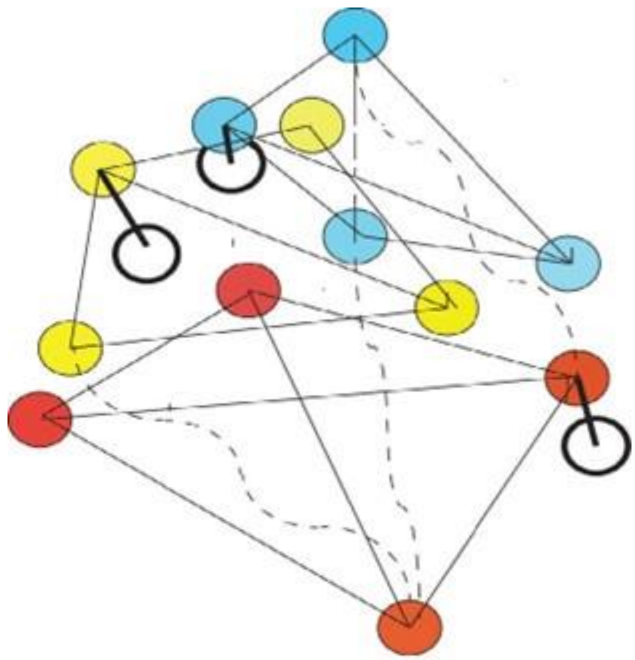
Emergence is when LCP exhibit properties and behaviors which are attributed to the whole, not to its various tasks. Emergent behavior in LCP is a result of the interactions and relationships between project elements and tasks rather than the behavior of individual elements. It emerges from a combination of the behavior and properties of the project elements and the project structure, both physical and execution process, and the potential interactions between them. We observe emergence in both the problem set to be addressed and the available solution set.



Emergence stems from complexity (See Appendix 2 for a non-quantum analogy) like what we see in QT. Complex systems consist of multiple interacting subsystems, whose nonlinear interactions can result in unanticipated (emergent) system events. Extant systems analysis approaches fail to detect such emergent properties, since they analyze each subsystem separately and arrive at decisions typically through linear aggregations of individual analysis results. Various detection and management approaches for emergence have been researched including a framework[48] to detect emergent properties given observations of its subsystems. This framework, based on a probabilistic graphical model called Bayesian Knowledge Bases (BKBs), learns individual subsystem dynamics from data, probabilistically and structurally fuses said dynamics into a single complex system dynamic, and detects emergent properties. Fusion is the central element of the approach to account for situations when a common variable may have different probabilistic distributions in different subsystems.

Vulnerabilities enter large programs, project organizations and other human-designed systems as they grow more complex. Increasingly, these systems and their myriad of relationships, including hidden relationships, are so complex that they defy a thorough understanding.

[48] Automatic Emergence Detection in Complex Systems; Hindawi Complexity Volume 2017, Article ID 3460919; Eugene Santos Jr. and Yan Zhao



As complexity grows, insufficient attention is often paid to the introduction and proliferation of new links with new risks. As a result, many LCP in the execution phase continually implement workarounds and "fixes," without fully understanding the impacts and unintended consequences. In many cases, these ultimately add to the total life-cycle cost and often sow the seeds of new risks and new failures.

Today, the risk relationships in singular projects are more easily identified and risk relationships are clearer to define. Even then, we have the occasional surprise. As we move to an LCP environment complexity grows.

These new risk linkages are not always readily apparent; the complexity of an LCP masks them; and traditional risk management approaches do not adequately help us discover as many of them as we can. This complex and highly interlocked environment is mirrored in execution plans which often provide a false sense of security. Within this complexity, we have created new breeding and nesting grounds for "Black Swans."[49]

To exacerbate matters, the possibility of random failure rises as the number of combinations of things that can impact the program grows. This is non-linear. The enormous complexity of LCP means that even tiny risks and attendant failures can cascade to catastrophic proportions.

Severe impacts from Black Swans are almost guaranteed to occur in some complex programs, especially those with strong externalities or of a long duration. The statistics of events in

[49] Black Swan Risks; PM World Journal Vol. IV, Issue III – March 2015 pmwj32-mar2015-Prieto-black-swan-risks-second-edition.pdf (pmworldlibrary.net)

manmade systems are starting to resemble that of natural phenomena like earthquakes; they are bound to happen.

Table 4.5-1 provides some examples of sources of complexity in an LCP.

Table 4.5-1
Sources of Complexity in Large Engineering & Construction Programs

Strategic Business Objectives (SBO)	• Ambiguity; visibility; lack of alignment • SBO migration over time • Conflicting SBOs • Competitive landscape changes • Market migration • Economic susceptibility (local; global) • Owner complexity (JV; alliance; state owned enterprise) • Scope/reach of defined outcomes
Organizational	• Shared understanding of program management inadequate • Clarity of roles and responsibilities inadequate • Resistance to change • Value destroying processes and procedures • Lack of sense of urgency • Stress level; team fatigue • Silos that impact communication and knowledge sharing • Cultural issues • Number of locations • Distance of program from day-to-day business • Workshare systems and process experience and effectiveness inadequate • Duplication of efforts (Owner/PMC) • Duplication of efforts (PMC/suppliers) • Risk aversion vs. risk management
Political	• Degree of political sensitivity (project or key supply locations) • Political stability (number of relevant political players; number of election cycles or other anticipated changes of government) • Role in power struggles • Sustainability of political will • Role of supply chain in international relations (enabler or held hostage)

Table 4.5-1 **Sources of Complexity in Large Engineering & Construction Programs**	
	• Extent of capacity building and feedback role
Project Portfolio	• Number of projects • Precedences and interdependencies • Uncertainties of assumptions and data • Sophistication of modeling and analysis • Assumption migration • Definition of "white space" • Number of constraints
Program Execution	• Cyclomatic complexity • Structural complexity of program plan, WBS, and schedule • Degree of shared constraints (first; second; third order) • Degree of constraint coupling (direct and indirect) • Number of changes • Supply chain resiliency; extent of common failure modes (common sub-tier sourcing) • Depth of labor pool (total and critical skills) • Labor predictability (labor action; productivity) • Physical complexity of projects comprising the program (footprint; degree of temporary construction; duration of discrete work activities (duration of transition phases)) • Specialized equipment availability and lead times • Permitting and regulatory complexity; timeliness • Logistical congestion and chokepoints • Flexibility of sequencing • Financial and financing constraints • Regulatory constraints • Management tools and systems not adequately integrated • Shallow risk management • Extent of feedback mechanisms • Distance of projects and key supply locations from day-to-day operations
Technological	• New process • New tools • Technical design basis not fixed • Prototyping, planning, and analysis inadequate

Table 4.5-1 **Sources of Complexity in Large Engineering & Construction Programs**	
	• Specialized materials or skills • Limited number of suppliers • IT complexity • Systems integration extent
Environmental	• Extent of regulatory processes • Number of significant issues • Effective footprint • Duration of impacts

Dependencies and correlations[50] can significantly affect program performance, and any analysis must consider covariance among the input variables. Long-term LCP are susceptible to strengthening or weakening of dependencies or correlations over time as well as the emergence of new dependencies or correlations over a long-lived program. We must test the sensitivity of the results to a range of assumed dependencies. This testing further identifies risk drivers, correlations, assumptions, or constraints to be tracked.

[50] An Overview of Correlation; National Academy of Construction Executive Insights https://www.naocon.org/wp-content/uploads/An-Overview-of-Correlation.pdf

Precept 5. Traditional decomposition of projects does not describe an LCP. LCP are complex entangled systems.

The view of classical PM that projects may be decomposed into smaller and smaller parts, linked by transformational flows does not describe what we observe or experience on LCP. LCP are:

- Complex
- Entangled

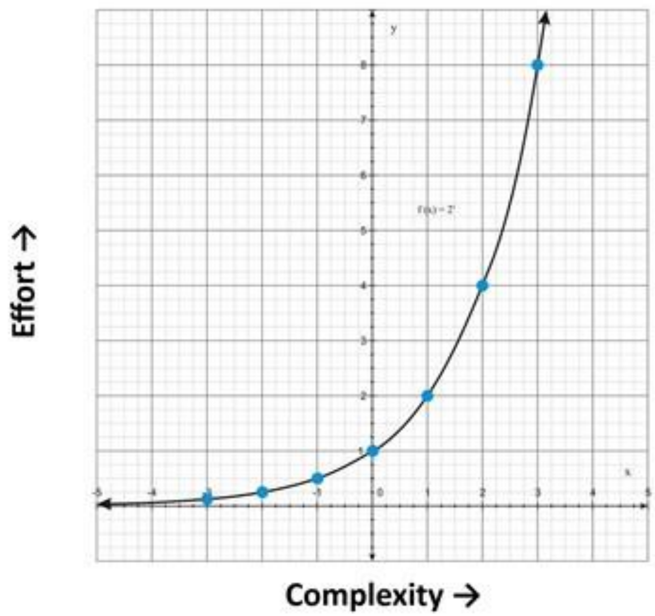
Illustrated by Dall-e 1

In practical terms this means that tasks may become coupled and entangled and task limits may change and at times become open ended. This contrasts with classical PM where tasks are discrete and bounded. This entanglement can extend beyond the proper boundaries of the LCP itself, encompassing elements of the surrounding ecosystem.

The whole of the LCP can no longer be described just by the sum of its parts. Importantly, the LCP must be looked at in a broader system of systems context, where the effects of entanglement become even more significant. System of Systems (SOS) problem sets have no singular deterministic solution. Currently, systems of systems is a critical research discipline for which frames of reference, thought processes, quantitative analysis, tools, and design methods are incomplete.

5.1 Impacts and Sources of Complexity

If the complexity of a LCP increases towards a point at which the LCP would become unfeasible the effort required to make measurable progress increases sharply as errors, iterations and rework grow. Required project effort grows exponentially with complexity.



The non-linear portion of this relationship is where LCP reside. Traditional project estimation does not sufficiently reflect this impact of complexity on project performance.

Table 5.1-1 describes some sources of complexity in LCP.

Table 5.1-1 Sources of Complexity in LCP	
Strategic Business Objectives (SBO)	Ambiguity; Visibility; Alignment
	SBO Migration Over Time
	Conflicting SBOs
	Competitive Landscape Changes
	Market Migration
	Economic Susceptibility (Local; Global)
	Owner Complexity (JV; Alliance; State Owned Enterprise)
	Scope/Reach of Defined Outcomes
Organizational	Shared Understanding of Program Management Inadequate
	Clarity of Roles and Responsibilities Inadequate
	Resistance to Change
	Value Destroying Processes and Procedures
	Lack of Sense of Urgency

Table 5.1-1 Sources of Complexity in LCP	
	Stress Level; Team Fatigue
	Silos that Impact Communication and Knowledge Sharing
	Cultural Issues
	Number of Locations
	Distance of Program from Day-to-Day Business
	Workshare Systems and Process Experience and Effectiveness Inadequate
	Duplication of Efforts (Owner/PMC)
	Duplication of Efforts (PMC/Suppliers)
	Risk Aversion vs. Risk Management
Stakeholders	Number, Types, Importance
	Conflicting Stakeholder Interests
	Timing & Duration of Stakeholder Processes
	Number & Types of Stakeholder Issues
	Ex-Process Interventions (lawsuits; protests; labor actions)
	Extent of Commitments
Political	Degree of Political Sensitivity (Project of Key Supply Locations)
	Political Stability (Number of Relevant Political Players; Number of Election Cycles or Other Anticipated Changes of Government)
	Role in Power Struggles
	Sustainability of Political Will
	Role of Supply Chain in International Relations (Enabler or Held Hostage)
	Extent of Capacity Building and Feedback Role
Project Portfolio	Number of Projects
	Precedence's and Interdependencies
	Uncertainties of Assumptions and Data
	Sophistication of Modeling and Analysis
	Assumption Migration
	Definition of "White Space"
	Number of Constraints

Table 5.1-1 Sources of Complexity in LCP	
Program Execution	Cyclomatic complexity
	Structural Complexity of Program Plan, WBS and Schedule
	Degree of Shared Constraints (First; Second; Third Order)
	Degree of Constraint Coupling (Direct and Indirect)
	Number of Changes
	Supply Chain Resiliency; Extent of Common Failure Modes (Common Sub-tier Sourcing)
	Depth of Labor Pool (Total & Critical Skills)
	Labor Predictability (Labor Action; Productivity)
	Physical Complexity of Projects Comprising the Program (Footprint; Degree of Temporary Construction; Duration of Discrete Work Activities (Duration of Transition Phases))
	Specialized Equipment Availability and Lead Times
	Permitting and Regulatory Complexity; Timeliness
	Logistical Congestion and Chokepoints
	Flexibility of Sequencing
	Financial and Financing Constraints
	Regulatory Constraints
	Management Tools and Systems Not Adequately Integrated
	Shallow Risk Management
	Extent of Feedback Mechanisms
	Distance of Projects and Key Supply Locations from Day to Day Operations
Technological	New Process
	New Tools
	Technical Design Basis Not Fixed
	Prototyping, Planning and Analysis Inadequate
	Specialized Materials or Skills
	Limited Number of Suppliers
	IT Complexity
	Systems Integration Extent
Environmental	Extent of Regulatory Processes
	Number of Significant Issues

Table 5.1-1 Sources of Complexity in LCP	
	Effective Footprint
	Duration of Impacts

5.2 Measuring Complexity

Various measurement tools exist for assessing complexity in projects. These include the Global Alliance for Project Performance Standards[51] which developed a project manager standard in 2007 with a comprehensive project management complexity measurement tool called CIFTER (Crawford-Ishikura Factor Table for Evaluating Roles). Another developed a method[52] to measure the complexity level of a project uses the Delphi and Analytic Hierarchy Process (AHP) methods. The authors have identified seventy possible complexity factors. Then, using the Delphi method, eighteen (18) essential factors were selected as the most influential factors on project complexity. The tool provides a seven-factor model on which the project management complexity of projects can be assessed. More recently, the PCAM tool[53] was developed on the basis of a complexity measurement matrix comprising of the complexity indicators that have been proven significant to project complexity. The measures of complexity were developed based on the data set collected from the historical projects[54]. The importance of each complexity factor on the overall complexity level of a project was allocated based on the expert ranking results. A project team can use PCAM Tool to assess the current complexity level of project at a particular point in the project life cycle. The tool can be used for different phases of a project.

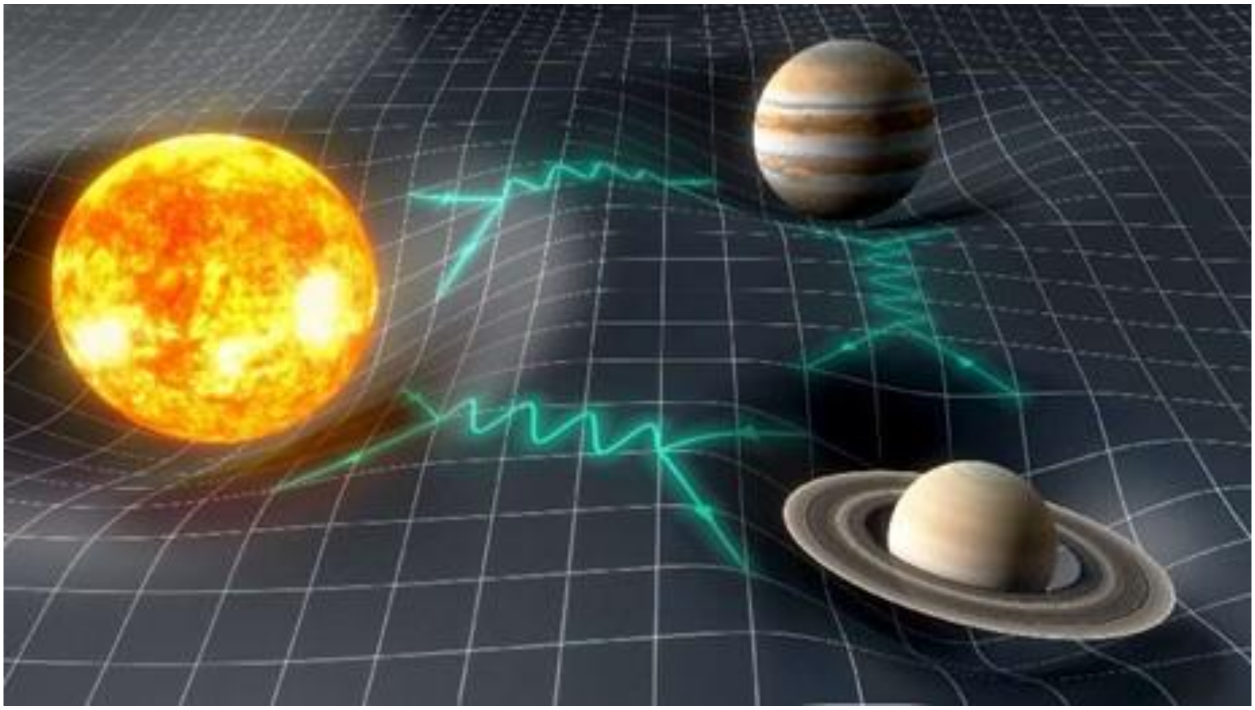
More important than any absolute measurement of complexity is its relative measure[55] to either another project or execution option or to a prior (or future) point in project execution.

Precept 6. LCP are strongly influenced by surrounding ecosystems, stakeholders, forces and flows.

[51] GAPPS. 2007. A Framework for performance-based competency standards for global level 1 and 2 project managers Sydney: Global Alliance for Project Performance Standards.
[52] Vidal, L. A., Marle, F., and Bocquet, J. C. 2011. Measuring project complexity using the Analytic Hierarchy Process. International Journal of Project Management, 29(6): 718-727.
[53] Project complexity assessment and management tool; International Conference on Sustainable Design, Engineering and Construction, Procedia Engineering 145 (2016) 491 – 496; Bac Dao, Sharareh Kermanshachi, Jennifer Shane, Stuart Anderson
[54] Supported by the Construction Industry Institute (CII RT 305 Research Project)
[55] Complexity in Large Engineering & Construction Programs; PM World Journal Vol. VI, Issue XI – November 2017 pmwj64-Nov2017-Prieto-complexity-in-large-engineering-construction-programs.pdf (pmworldlibrary.net)

Illustrated by Dall-e

In RT, spacetime is influenced by the presence of large masses distorting its very fabric. In our planning and development of an LCP we exhibit a planning bias that places the LCP at the center of our universe, underestimating the effects of other masses present in a broader view of spacetime. These other masses that are present include a range of stakeholders, forces and other flows all of which are tugging on the very fabric of our narrow view of the centrality of our LCP. These surrounding masses are dynamic, with shifting positions relative to our LCP, with effects that grow stronger or weaker over time. Yet we persist in our belief that projects remain well-bounded.



Effective LCP planning and execution must thoroughly account for these first order effects from the surrounding ecosystem, stakeholders and the other forces and flows present in and rippling through our project's local spacetime.

The stakeholder environment of which the project is a part can be characterized as[56]:

- **Including the project itself as an equal actor in this complex ecosystem.** This is a key point as the project de facto commands no higher position than any other potential stakeholder. The illusion of preeminence or priority has degraded stakeholder relationships on many large complex projects with corresponding poorer outcomes.

- **Comprised of a web of stakeholder-stakeholder relationships** which are affected not only by changing binary wants, needs and relationships but also by the multiplicity of "tugs" from other parts of this complex web. Large complex projects which focus on their binary stakeholder relationships only are apt to be surprised when these relationships and

[56] Stakeholder Management in Large Engineering & Construction Programs; PM World Journal Vol. X, Issue VII – July 2021 pmwj107-Jul2021-Prieto-stakeholder-management-in-large-engineering-construction-programs.pdf (pmworldlibrary.net)

agreements are "tugged" by other parts of this complex web. Even the best stakeholder maps need to recognize that "the map is not the territory"[57]

- **Complex, turbulent and emergent in nature**. The very multiplicity of direct and indirect stakeholders associated with large complex projects is in itself daunting at first glance but becomes even more so as we think about the range of external stakeholders acting along each supplier, link and flow along a global supply chain. Change is the norm in all human endeavors, unlike what Taylor and Gantt sought to achieve in their early management efforts in a repetitive industrial setting. This continuous, multi-directional and ever evolving set of changes results in turbulence in the broader ecosystem of which the project is a part. This turbulence shapes the stakeholder ecosystem and drives that system to change and new patterns and relationships to emerge. This emergent behavior is a key characteristic of the stakeholder environment of which the project is a part.

  This emergence does not stop at the project boundary but acts on the project as well.

- **Giving rise, from its inherent turbulence, to "influencing flows"** which shape the stakeholder ecosystem; drive it to a new and emergent state; and transverse the project boundary shaping and impacting planned transformative flows within both project activities and tasks but also the flows between these activities and tasks. (Discussed further in Precept 7)

- **Observable and fungible, but only to the extent that we become part of it** and understand its flows and patterns. We cannot manage but we can engage and through that engagement at least achieve earlier detection of new influencing flows and in some instances act "in" this web of relationships to shift forces in more supportive ways. This leads to a new engagement construct focused on sentries, scouts and ambassadors.

- **Requiring a more comprehensive assessment of project success "that takes into account the views of multiple stakeholders over multiple time frames."**[58] [59] New measures are required to anticipate stakeholder perceptions of project actions and impacts. These new measures represent a key portion of an expanded set of control points focused externally

[57] Alfred Korzybski, developed the field of general semantics
[58] This underscores the importance of "frames of reference" that we see in QT
[59] Forecasting Success on Large Projects: Developing Reliable Scales to Predict Multiple Perspectives by Multiple Stakeholders Over Multiple Time Frames; Rodney Turner, Roxanne Zolin; 2012

to the project. Stakeholders throughout the full project life cycle must be considered since success or failure is often judged well after initial construction has been completed. However, work on project success factor scales[60] have shown the strongest correlations to be with:

- **Public stakeholder satisfaction**
- **Contractor satisfaction**
- **Supplier profitability**

The influencing flows described above are observable, but only if we are looking. Project management today often focuses all of its management and project control efforts within the project context. Developing efforts in predictive analytics will let us see degrading performance earlier and likely quantify its impacts if not addressed. But both efforts fall short of what large complex projects demand, namely, awareness and where possible influencing the drivers of change themselves. We may be looking in all the wrong places and further blind ourselves through the assumptions we make at the outset of the project and take as constant forever.

Precept 7. Flows arise from the surrounding ecosystem impacting the LCP

The existing theory of projects goes back to the emergence of management theory[61] associated with industrialization. Projects in that early era were largely executed within the four walls of a new industrial facility employing serial manufacturing, progressively moving a series of inputs towards an ultimate output. At each step of the manufacturing process an output from a prior step was further transformed.

Frederic Taylor in The Principles of Scientific Management[x] laid out a series of management principles that in many ways mirrored many aspects of the manufacturing process itself. Among these principles was a division of work, a decomposition of efforts if you will, undertaken by trained workers in a prescribed and specified way. Henry Gantt, who worked for Taylor, extended this thinking into the execution of projects.

[60] ibid
[61] Theory of Management of Large Complex Projects (Section 5.3); Construction Management Association of America (2015); ISBN 580-0-111776-07-9

Illustrated by Dall-e

The prevailing theory of projects that resulted was built on several precepts regarding the transformation of inputs to outputs. Those precepts include:

- A comprehensive set of requirements at the outset of the project that can be decomposed with the work to be executed.
- Independence of discrete and bounded tasks (except for sequential relationships).
- A high certainty of the requirements to be met.
- Clarity on how the tasks are to be performed.
- The totality of work to be performed can be described by a top-down decomposition of the transformation effort.

We will focus on two aspects of classical project management theory that do not serve LCP well:

- Recognition of only one type of "flow," Transformative Flow
- Notion of tasks and projects as being well-bounded

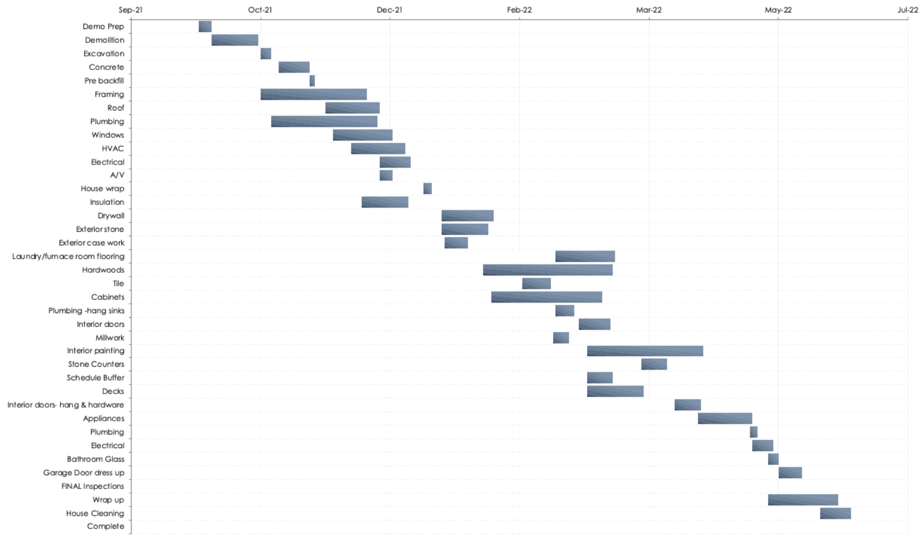
From Gantt's perspective, classical theory described the evolving projects which were occurring within the four walls of a new industrial plant. In addition, the owner, plant manager, and client project manager often were the same individual. The four walls did provide a well-bounded setting with external influences limited and likely nonexistent.

Today's large complex projects take place in a very different setting.

For Gantt, work progressed steadily from left to right on his now famous Gantt charts. Whether it is those classical Gantt charts or the modern work breakdown structures, we see a series of tasks connected by dimensionless arrows. They serially perform a set of transformative processes to deliver a well-defined output.

CONSTRUCTION GANTT CHART TEMPLATE

TASK NAME	START DATE	END DATE	DURATION IN DAYS
Demo Prep	10/01/21	10/06/21	5
Demolition	10/06/21	10/24/21	18
Excavation	10/25/21	10/29/21	4
Concrete	11/01/21	11/13/21	12
Pre backfill	11/13/21	11/15/21	2
Framing	10/25/21	12/05/21	41
Roof	11/19/21	12/10/21	21
Plumbing	10/29/21	12/09/21	41
Windows	11/22/21	12/15/21	23
HVAC	11/29/21	12/20/21	21
Electrical	12/10/21	12/22/21	12
A/V	12/10/21	12/15/21	5
House wrap	12/27/21	12/30/21	3
Insulation	12/03/21	12/21/21	18
Drywall	01/03/22	01/23/22	20
Exterior stone	01/03/22	01/21/22	18
Exterior case work	01/04/22	01/13/22	9
Laundry/furnace room flooring	02/16/22	03/11/22	23
Hardwoods	01/19/22	03/10/22	50
Tile	02/03/22	02/14/22	11
Cabinets	01/22/22	03/06/22	43
Plumbing -hang sinks	02/16/22	02/23/22	7
Interior doors	02/25/22	03/09/22	12
Millwork	02/15/22	02/21/22	6
Interior painting	02/28/22	04/14/22	45
Stone Counters	03/21/22	03/31/22	10
Schedule Buffer	02/28/22	03/10/22	10
Decks	02/28/22	03/22/22	22
Interior doors- hang & hardware	04/03/22	04/13/22	10
Appliances	04/12/22	05/03/22	21
Plumbing	05/02/22	05/05/22	3
Electrical	05/03/22	05/11/22	8
Bathroom Glass	05/09/22	05/13/22	4
Garage Door dress up	05/13/22	05/22/22	9
FINAL Inspections	05/02/22	05/02/22	0
Wrap up	05/09/22	06/05/22	27
House Cleaning	05/29/22	06/10/22	12
Complete	06/01/22	06/01/22	0



The only flows present in the project were:

- Transformative Flows within the discrete tasks representing parts of the decomposed project.
- Transformative Flows of the project as the outputs of one or more tasks became inputs for a subsequent task or tasks.

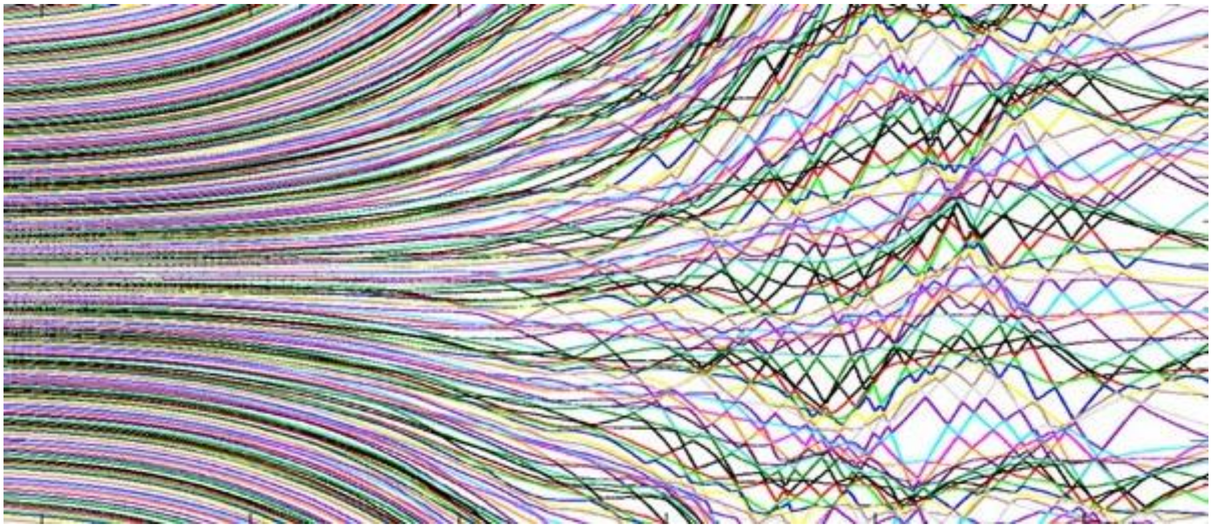
Flows[62] represent the transfer of something from one place to another. We will look at what these "somethings" may be shortly. In the context of classical project management theory, however, the somethings then were the transfer of outputs from one task to serve as inputs for a subsequent one. Flows include not just a starting point and endpoint, but also a path (of interaction) and a driving force. Think of the myriad of arrows on that Gantt chart.

A point worth noting is that these "dimensionless" arrows connecting decomposed tasks are anything but dimensionless.

7.1 Flows

Flows are no longer simple/ linear/ dimensionless. Rather they are complex/ non-linear/ dimensioned and turbulent.

[62] Flows in Large Complex Projects; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Flows-in-Large-Complex-Projects.pdf



The notion of a singular type of flow operating in a well-bounded environment does not fully describe the full range of flows that occur in LCP. Large complex projects do not follow classical transformation models. The nature of flows changes:

- Temporal coupling now represents a new risk point given the various influencing flows that a large complex project faces. Temporal coupling is defined as:
  - When two actions are bundled together into one module just because they happen to occur at the same time
  - Coupling that occurs when there are two or more members of a class that need to be invoked in a particular order. It occurs when there is an implicit relationship between the members of a class requiring one member to be invoked before the other. This tightly couples the members in the temporal dimension.
  - When processes are temporally and referentially coupled, coordination takes place in a direct way. When processes are temporally coupled but referentially decoupled, coordination is event based.[63]
- Precedences must be minimized, or at the very least limited, and clearly understood. Tasks must be increasingly decoupled.
- 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.
- While not predictable, perturbations in flows become signatures of the direction of likely system emergence.

QPM defines three types of flows in an LCP:

- Classical Transformative Flows

[63] M. van Steen and A.S. Tanenbaum, Distributed Systems, 3rd ed., distributed-systems.net, 2017

- Influencing Flows, that accompany Transformative Flows, which arise from outside the project since large complex projects are not so well bounded (certainly not as Gantt would have experienced)
- Induced Flows, that arise from the interaction of a multiplicity of flows with each other.

Flows represent the movement of something from one place to another. What are the somethings that flow in large complex projects? Table 7.1-1 provides a partial listing of flows that may impact large complex projects, with the potential impacts being related to:

- Whether they were planned or unplanned.
- Whether they were coupled or decoupled temporally and otherwise.
- The point and place at which they arise.
- The extent of their influence (number of tasks affected; number of other flows affected).
- Their persistence (duration); stability (static, dynamic, chaotic); and second (and third) order effects.

Table 7.1-1 broadly groups the flows as:

- Logistical
- Information
- Economic
- Environmental
- Stakeholder
- Technological

Table 7.1-1 **Partial Listing of Flows Impacting Large Complex Projects**	
Logistical	• Logistical flows[64] between tasks (movement of people, materials and equipment) • Supply chain flows[65] from raw materials through intermediate goods to final items of supply and their transfer to site • Flow of indirect factors such as food, shelter (man-camp), fuel and other consumables • Logistical disruptions on project-related flows arising from project activities or arising from others • Logistical disruption of others arising from project-related flows
Information	• Delayed, non-transparent information flows giving rise to degradation of trust, slowness in response and undertaking required actions

[64] Post Disaster Logistics; National Academy of Construction Executive Insight
[65] Procurement Management in Large Complex Projects; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Procurement-Management-in-Large-Complex-Programs.pdf

Table 7.1-1 Partial Listing of Flows Impacting Large Complex Projects	
	• Non-secure information flows create project impacting cyber-risks[66] • Poor knowledge latency associated with weak knowledge management[67] • Social media creates uncontrolled or even fake narratives
Economic	• Market based factors (supply, demand, price point) modify planned flows and flow rates of materials and equipment • Economic based factors (inflation/deflation; availability of capital; currency stability and convertibility) act to modify project objectives and schedule • Financial factors may act to limit availability of subcontractors and suppliers that the project requires (unavailability of bonding; inadequate capitalization) • Labor market constraints derived from either aggregate labor demands; skilled labor shortages; or industrial actions
Environmental	• Flows arising from the physical environment (heat, wind, water, dust/sand)[68] • Changing constraints with respect to the project's interaction with the physical environment (e.g., noise levels lead to reduced work hours) • Flows from the natural environment impacting the project (disease, pestilence, fire) • Flows from the project adversely impacting the natural environment (discharges, spills, runoffs, destruction of protected areas)
Stakeholder	• Investor/owner stakeholder changing requirements (SBOs change)[69] or constraints (e.g., cash flow) • Politically driven changes that accelerate, decelerate, modify through sovereign action, legislation • Regulatory driven requirements requiring response or modify work processes and timing. Delayed permits and authorizations • Tort and other judicial actions impacting project objectives; funding and financing; schedule and sequence of activities; means and methods • A change in stakeholder interest create "interest flows" (e.g., sustainability, social justice) • Directly affected third parties (traditional view of stakeholders) whose support and acceptance is effectively required and whose actions/inactions impact the project • Indirectly affected third parties (issue- oriented organizations and non-government organizations (NGOs)) whose support is desirable but who act and influence project processes either directly (through political, regulatory or judicial action) or indirectly (through interaction with owners/operators or directly affected third parties)

[66] Cybersecurity in Engineering and Construction; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Cybersecurity-in-Engineering-and-Construction.pdf
[67] Knowledge Management; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Knowledge-Management.pdf
[68] Location Factors in Large Complex Projects; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Location-Factors-in-Large-Complex-Projects.pdf
[69] Importance of Strategic Business Objectives; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/The-Importance-of-Strategic-Business-Objectives.pdf

Table 7.1-1 Partial Listing of Flows Impacting Large Complex Projects	
	• Broader ecosystem of stakeholders[70] which represent a source of modifying behaviors on all parties directly and indirectly affected third parties and from which new issues and requirements may emerge • Collectively, stakeholders are not manageable but can be engaged and influenced, effectively modifying what otherwise may have been more disruptive flows impacting the project • A significant set of flows can give rise to changed stakeholder behaviors. These impacts may be positive (economic activity; jobs; community improvements) or negative (traffic congestion; environmental degradation; negative social effects)
Technological	• New technologies[71] arising during project execution can modify project requirements; means and methods; stakeholder expectations

The various flows can occur in three fundamental ways:

1. Transformational Flows, first envisioned by Gantt, yet as suggested in Table 7.1-1 may no longer be as static and predictable. Complexity and both unnecessary and hidden coupling of activities and constraints further act to impact projects.
2. Influencing Flows that arise from outside the project team from a myriad of directions, as suggested in Table 7.1-1.
3. Induced Flows that arise from the interaction of the various Transformative and Influencing Flows. In some instances, these may represent second or third order effects, while in other cases they may represent short-lived but turbulent and impactful events.

Large complex projects do not follow classical transformation models (see Figure 7.1-1). The activity-based focus, memorialized in work breakdown structures, neglects the importance and impact of "flows" within the project context. As supply chains become more tightly linked to project processes, some of the flow considerations now can be seen as core to logistics and as being analogs for efficient project management. Precedence and unnecessary coupling of activities, in fact, may harm a large complex project's performance in ways perhaps not evident on initial inspection.

Additionally, large complex projects are far from being bounded as classical project management theory would suggest. Rather than well-defined boundary limits, we discover semi-permeable

[70] Prieto, R. (2011). Stakeholder Management in Large Engineering & Construction Programs, Second Edition, PM World Journal, Vol. X, Issue VII, July 2021. Originally published in PM World Today, October 2011
[71] Innovation and Technology Convergence; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Innovation-and-Technology-Convergence.pdf

boundaries across which *Influencing Flows* transit (arising from tunneling in some instances), impacting the *Transformational Flows* within the project proper. These flows arise from a multiplicity of stakeholders and other agents, who in turn are influenced by the project itself.

These *Influencing Flows* then interact with a project's *Transformational Flows* and with each other. They may give rise to *Induced Flows,* which while often are short-lived (such as the COVID-19 derived flows) can be particularly turbulent and impactful on the project.

Let us look at each of these more closely.

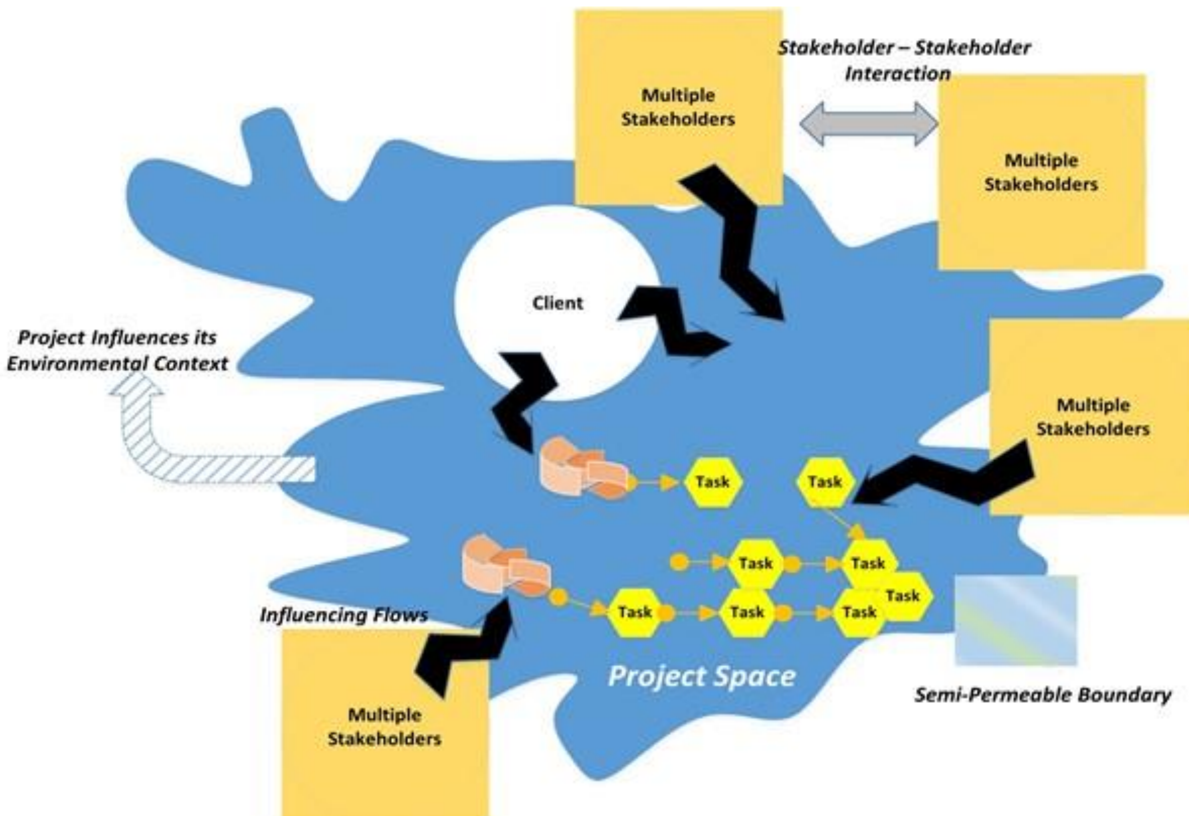


Figure 7.1-1. Large complex projects and influences and flows

Transformational Project Flows

Transformational Flows encompass both the *Transformational Flows* that occur within the tasks that collectively comprise a decomposed project as well as the *Transformative Flows* distinct from individual task execution. Together they represent executing each task in an optimal sequence.

Large complex projects require us to focus not only on task inputs and outputs, but importantly on the *Transformative Flows* between tasks. During the execution phase of a project these flows are representative of the construction process itself and the selected means and methods. To improve overall execution in this phase, it is necessary to expand our business basis of design (BOD^x)[72] to specifically include construction-related factors, preferences, and choices. Consideration of factors impacting project flows is essential.

Influencing Flows

Large complex projects both shape the world around them and are directly influenced by it. This direct interaction is our first indication that perhaps our project is not so well bounded. In some sense large complex projects distort both time and space (see Figure 7.1-2).

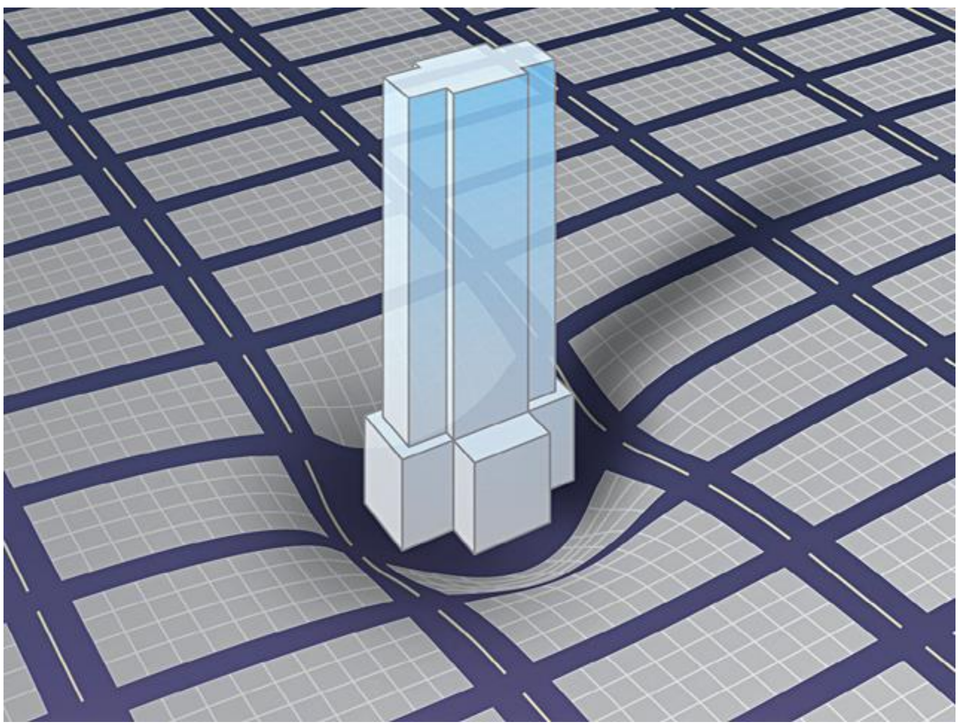


Figure 7.1-2. Time and space distortions

Large complex projects are not well bounded, at least not as described in classical project management theory. Large stakeholder influences; new outcome requirements; stakeholder needs over extended delivery timeframes and lifetimes; and the sheer number of outside project inputs and assumption drivers all act to create a semi-permeable boundary across which there are many informational and *Influencing Flows*.

[72] Business Basis of Design; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Business-Basis-of-Design.pdf

This porous project boundary, combined with the self-defining and emergent nature of the project, characterizes the non-deterministic system that best describes large complex projects[73].

Influencing Flows can act to shape the project's *Transformative Flows.* Those are well known in classical theory and described above. These *Influencing Flows* arise from flows crossing the semi-permeable project boundary as well as the interaction between two or more *Transformative Flows* present within the project context. Two key points:

- large complex projects are not easily isolated, and
- just as they are susceptible to changing externalities, these large projects also act to change the external environment that they affect.

In essence, the *Influencing Flows* we find in the large project environment can be described as crossing a project boundary that is semi-permeable.

Influencing Flows often change the number and 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. This leads to an important recognition that planning activities must address two key elements:

- Tasks, including the workflows within those tasks.
- Flows, including *Transformative (or systems) Flows* between tasks as well as new flows induced by these *Influencing Flows.*

Disruptive flows into a project often result from a lack of transparent and robust communication with stakeholders.

Induced Flows

The *Influencing Flows* arising from a multiplicity of stakeholders and eddies they create in the planned *Transformative Flows. Induced Flows* can arise suddenly, be highly disruptive, and disappear just as suddenly.

Large complex projects act equally on their 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.*

7.2 Assessing Flows

In our management of projects, most of our controls are inward facing, focused on the Transformative Flows we have selected and which we seek to manage every day. These important Transformative Flows, both within discrete project tasks as well as the project's Transformative Flows we have defined to optimally deliver the overall project, however, are subject to disruption

[173] Large Complex Projects as Open Systems; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Large-Complex-Programs-as-Open-Systems.pdf

from flows outside our direct control and ones that our project control efforts have not historically been focused on.

We must complement our inward-looking assessment of project planning, performance, and trends with in-kind efforts that are externally focused. We must look at the evolving situation from different points of reference. Specifically:

1. Strategic Business Objectives (SBOs) become more important than mere scope requirements in achieving ultimate success. In some instances, projects may be faced with emergent SBOs, especially when Influencing Flows cross the semi-permeable project boundary over an extended project timeframe.

2. 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 (or where tunneling is present, through) this boundary and identifying emergent outcomes. Many good things happen at this frontier, including exchange of information and knowledge as we engage stakeholders, thus obtaining valuable insights on factors affecting the outcome. Not all things crossing this frontier, however, are necessarily reinforcing of the desired project outcomes or the efficiency and effectiveness of the various sets of ongoing Transformational Flows in the project.

3. Stakeholder influences now define a surrounding and interacting ecosystem that includes stakeholder-to-stakeholder interactions, but also an ecosystem that the project acts on and influences through so-called "ambassadors." While not predictable, disturbances in flows, such as from eddies and Induced Flows, become signatures of the direction of likely system emergence. Our predictive project efforts employing AI enabled 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. (Note: Emergence is when projects exhibit properties and behaviors which are attributed to the whole, not to its various tasks. Emergent behavior in projects is a result of the interactions and relationships between project elements and tasks rather than the behavior of individual elements. It emerges from a combination of the behavior and properties of the project elements and the project structure, both physical and execution process, and the potential interactions between them.)

4. Carefully monitor project frontiers with "sentries" looking out for new flows, changes in existing flows, and assumption migration; environmental "scouts" seeking out new flow drivers, emerging flows, and emerging actors; and engagement of stakeholders through "ambassadors." Look for patterns and points of change that can trigger new patterns, new Influencing Flows, and that can create new Induced Flows.

5. Recognize that emergent risks represent a key driving force of many flows.

6. Identify hidden reservoirs of stakeholder power and potential vectors of influence.

7.3 Mitigating Impacts

Management of flows can be improved, especially those external to the project. Failures of large complex projects often arise from factors outside the direct control of the project team. That does not mean they cannot be managed. They can, but only if we are looking in the right direction and building the foundations necessary to deal with the inevitable challenges and changes.

Some recommendations to manage flows more effectively include:

1. Standardization of systems, structures, components, work processes, and de-coupling of activities that can be undertaken independently is essential.

2. Precedences must be reduced. Work plans must facilitate contingent execution[74]. This elimination of precedences relies on a careful understanding (and subsequent tracking) of the project's numerous underlying assumptions, and a keen understanding of the minimum prerequisites for a given task or activity. Temporal flexibility (temporal decoupling) may take advantage of buffers in the project schedule to accommodate delays or extended durations and resequencing of project activities (accelerating into a buffer period) although attention must be paid to the potential to create rework. Despite best efforts, new couplings may emerge during the project driven by "assumption migration"[75] or the effects of project disruption caused by out-of-plan flows.

3. Management information must 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 to whether they are planned or contingent, when they will occur, and whether any buffering mechanisms are present to optimize overall project flows.

4. Project execution must include a contingent capability to redirect and re-time various flows, or restore already influenced flows to an optimal state, recognizing this may be significantly different than the original transformative plan. On one large complex project, the overall schedule was improved by 20 percent 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.

5. Increased awareness of actual or potential direct or indirect coupling, such as may happen when flows are coupled by second or third order constraints (constraint coupling). Constraints related to labor, material, energy, and financial and informational flows must be considered.

6. Managing the impacts of Influencing Flows begins with better awareness of the changing nature of a large complex project's stakeholder ecosystem.

7. Ecosystem awareness must be complemented by stakeholder engagement, seeking to influence flows and their timing.

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[74] Contingent Execution; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Contingent-Execution.pdf

[75] Assumption, Risk Driver and Constraint Tracking; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Assumption-Risk-Driver-and-Constraint-Tracking.pdf

8. Continuous improvement in information flows improves team and project performance. AI can play a role here by using AI predictions to focus and strengthen the depth of project reviews and diagnosis. AI tells us the project has a "fever" but management, especially more senior levels of management with broader more holistic views, must seek the underlying causes and develop a treatment plan.

Precept 8. Neither the LCP nor the surrounding universe are static. Potential for significant impacts grows with time.

This precept recognizes the dynamic nature of not only the LCP but also the universe surrounding it. Events in this surrounding ecosystem create "flows" that impact spacetime broadly and the LCP in particular. The most significant of these disruptive events, "events at scale," creates ripples that permeate all spacetime. These are analogous to RT gravitational waves that ripple through spacetime which is stretched by the passage of time, growing the potential energy (dark energy) of the universe.

The broad ecosystem within which an LCP sits and which it is influenced by (and in turn influences) sees its potential for creating havoc with the LCP grow as the LCP's spacetime is stretched. The linkage between traditional scalars and time is important as even the passage of time can add to the potential energy resident in the now stretched spacetime.

Illustrated by Dall-e

8.1 Gravitational Waves and LCP

In relativistic physics, gravitational waves are ripples in space-time, events that literally cause the displacement of space-time itself. In the simplest terms they result from asymmetrical energetic events. The amplitude of the resultant waves is inversely proportional to their distance from our system (as opposed to energy dissipation which is inversely proportional to the square of distance). Amplitude is also proportional to the energy of the initiating event. One source of these gravitational waves are black holes that interact with or combine with other black holes in some energetic way.

In our project system, large, proximate black holes, regions of potentially catastrophic risk, are capable of suddenly changing the space-time of our project system. The nature of the sudden realization of this potentially disruptive event and what causes its sudden emergence remain a subject for further consideration. But what is known is that the emergence of these events and the resultant amplitude they create in space-time can have catastrophic effects on our project. In our project system we refer to these sudden unexpected events with catastrophic consequences as Black Swans. There may be more to discover about the impacts of the project equivalent of gravitational waves by recognizing that they originate from four different types of originating events[xi]. Perhaps Black Swans have some relatives not yet recognized.

8.2 Changed Perspectives

Projects today require us to adopt expanded perspectives (consider multiple frames of reference) to ensure our project's foundations are truly well formed.

First, our project perspective must become increasingly holistic. It is no longer sufficient to be good project managers and engineers. We must add the broader perspectives of the humanist, not only addressing, in a check-the-box fashion, the so called environmental and social bottom lines, but rather embracing them as fundamental to a successful project. This requires us to adopt a perspective more encompassing in scope than perhaps we have been trained for. This is a question not just for project managers but the society that we serve. Must we return to the pre-Renaissance definition of the arts, encompassing both Artes Liberales (liberal arts) and Artes Mechanicae (mechanical arts)?

Second, our project perspective requires a temporal adjustment. Today we think about planning, design and construction. But that in many ways represents only the initial birthing of a project. Its real value lies in the balance of its lifetime and in many instances, its biggest impacts are in the sometimes even longer societal affecting post lifetime period. Even as major projects grow into "giga" programs with project execution periods often measured in decades, actual project lifetimes are even longer. Today we see projects with design basis lifetimes of a century, and we know many of our project works have lasted even longer. Our project foundations must consider these fuller lifecycles across all the broader perspectives of the humanist.

Importantly, as we consider these longer temporal horizons we must challenge our confidence in knowing or predicting the future. Uncertainty must become a fundamental project planning basis and a key factor in project execution. Things become more uncertain over time, just as a black hole grows over time.

The third point on changed perspectives is quite simple. Consider, look at and challenge a project's foundations, it is very *raison d'être*[76], from every available perspective. Develop

[76] Project Selection in Large Engineering and Construction Programs; National Academy of Construction Executive Insights https://www.naocon.org/wp-content/uploads/Project-Selection-in-Large-Engineering-and-Construction-Programs.pdf

frameworks that help you adopt these different perspectives such as the ESPRIT[77] framework I have used for years in looking at international construction and development projects. ESPRIT, an acronym for economic, social, political, religious, intellectual and technology, allows us to better ensure that foundations are strong before we set out, in spacetime, to boldly go where no one has gone before.

Part C. The Maths

In this section we take a closer look at "The Maths" associated with relativity (General and Special) and quantum mechanics and draw parrels to observed behaviors in LCP. While not the subject of this paper, the analogies suggest further areas for research, discovery, modeling and quantification of various parameters as applied to LCP.

Illustrated by Dall-e

Einstein Field Equation

The Einstein field equation is the fundamental equation of general relativity that links the geometry of spacetime to the distribution of matter and energy within it. It is a tensor equation that consists of 10 nonlinear partial differential equations that can be written as:

[77] Prieto, R. "The Challenges of International Development and Construction Projects." Columbia University. 2003. https://www.researchgate.net/publication/271850142_The_Challenges_of_International_Development_and_Construction_Projects#fullTextFileContent

$$R_{\mu\nu} - 1/2\, g_{\mu\nu} R + g_{\mu\nu} \Lambda = 8\pi G/c^4\, T_{\mu\nu}$$

The left hand side of the equation ($R_{\mu\nu} - 1/2\, g_{\mu\nu} R + g_{\mu\nu} \Lambda$) describes the geometry of spacetime while the right hand side ($8\pi G/c^4\, T_{\mu\nu}$) describes how matter, understood in a broad sense, is distributed in the universe.

The mathematical framework known as Riemannian geometry studies spaces which are in a certain sense *smooth*, and that are equipped with a metric tensor ($g_{\mu\nu}$), or metric, that allows distances and angles to be defined. The metric tensor defines the geometry of spacetime (smoothness or distortions). The Riemann tensor provides additional information on what is going on in spacetime but is typically simplified to the Ricci tensor which appears in the field equation. For an LCP this would be analogous to having an accurate description of the complete project ecosystem and the relationship of the various masses, energy, and momentum.

The energy–momentum tensor ($T_{\mu\nu}$), describes the density and flux of energy and momentum in spacetime. In an LCP it is analogous to the various flows into the project (labor, materials, equipment, information).

Einstein's Field Equation is simplified by defining an Einstein tensor ($G_{\mu\nu}$) defining and transforming units such that c=1, so that the Field Equation becomes:

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

The Einstein tensor ($G_{\mu\nu}$) represents the curvature of spacetime due to gravity and is derived from the metric tensor ($g_{\mu\nu}$), that describes the geometry of spacetime. For an LCP the relationship between a project's scale, its rate of development, and, importantly, the surrounding ecosystem is all important. The cosmological constant (Λ) is sometimes included to account for the accelerated expansion of the universe and would be analogous to a project (or aspects of it) whose reach grew rapidly over the course of the project.

$8\pi G$ is Newton's constant, where G is the gravitational constant. In effect for an LCP, we are seeing traditional project behavior ($8\pi G$) modified by the energy-momentum tensor ($T_{\mu\nu}$) which becomes important at scale. LCP are truly different than more conventionally sized projects.

The Field Equation reveals the deep connection between gravity and geometry. For an LCP, its analog reveals the deep connection between a project's growing mass (through project execution) and the "shape" of its surrounding ecosystem.

Equations of Special Relativity

Time Dilation

There are two types of time dilation. The first is a consequence of General relativity where time passes more slowly in a strong gravitational field.

The second is a consequence of special relativity which deals with objects moving at high speeds where time for that object appears to move more slowly for an observer at rest. This time dilation is described as:

$$\Delta t' = \frac{\Delta t}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$\Delta t'$ is the time interval as measured in a frame of reference that is moving at velocity v

Δt is the time interval as measured in the stationary frame

As the velocity increases, time moves slower in the moving frame of reference.

We see this in an LCP where work in the "moving" project execution frame of reference appears to move more slowly than what the initial project plan expected.

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

is referred to as the Lorentz factor.

Illustrated by Dall-e

While the speed of light does not translate directly to an LCP, there is none the less a maximum rate of advance on the project that is possible and v/c represent the fractional rate of advance compared to some theoretical maximum. Remembering that c, the speed of light varied depending upon the medium it was transiting[78], we might expect the theoretical maximum rate of advance on LCP to vary by classes of projects.

Length Contraction

When an object is in motion relative to an observer, the object in motion may disagree on the measurements of lengths and durations. This length contraction is described as:

$$L' = L\sqrt{1 - \frac{v^2}{c^2}}$$

In an LCP, the perception of progress varies with your frame of reference with the project execution team seeing less real progress than what a static observer may perceive.

Relativistic Mass-Energy Equivalence

The total energy of an object is:

$$E^2 = (mc^2)^2 + (pc)^2$$

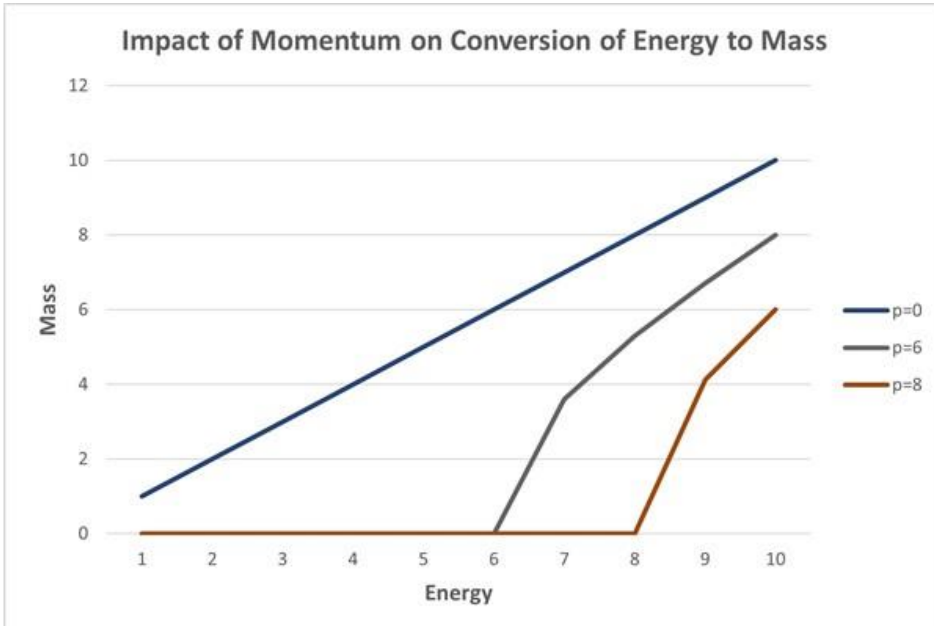
Where p is the momentum of an object. When an object is at rest (p=0) the equation become the more familiar:

$$E = mc^2$$

As the object accelerates, the kinetic energy term $(pc)^2$ becomes more pronounced.

This is analogous to what we see in an LCP. As a project gains momentum, it takes more energy to get an equivalent output of mass. In part this effect is evident when trying to recover lost productivity in an LCP.

[78] Remember the traditional definition of speed of light was related to its movement through a vacuum.



Quantum Mechanics Formula

In this section we will look at three "formula" related to quantum mechanics and how they relate to LCP:

- Schrodinger Equation
- Heisenberg Uncertainty Principle
- Quantum Tunneling

Schrodinger Equation

The Schrodinger equation describes how the quantum state of a system changes over time and comes in two forms as shown below.

<u>Time-Dependent Schrodinger Equation</u>

$$i\hbar\partial\Psi\frac{\partial\Psi}{\partial t} = H\Psi$$

<u>Time-Independent Schrodinger Equation</u>

$$H\Psi = \mathrm{E}\Psi$$

In these equations:

Ψ is the wave function which describes the quantum state of the system. Its square modulus ($|\Psi|^2$) gives the probability density[79] (Born's interpretation).

$\hbar$ is the reduced Planck constant ($\frac{h}{2\pi}$), where h is the Planck constant.

H is the Hamiltonian operator which represents the total energy of the quantum system.

E is the eigenvalue corresponding to the total energy of the system, which in a time-independent form has a potential energy that is not explicitly dependent on time.

In an LCP, the potential energy of the project is converted to mass through the application of kinetic energy, more suggestive of the time-dependent Schrodinger Equation. The condition of the project is described by the wave function or more specifically its square modulus. The square modulus of a complex number typically yields a non-negative real number. The distribution of these non-negative values may or may not resemble a normal distribution, depending on the specific context and the distribution of the complex numbers. It is important to remember that the wave function exists both within and outside the nominal project boundaries (see Quantum Tunneling).

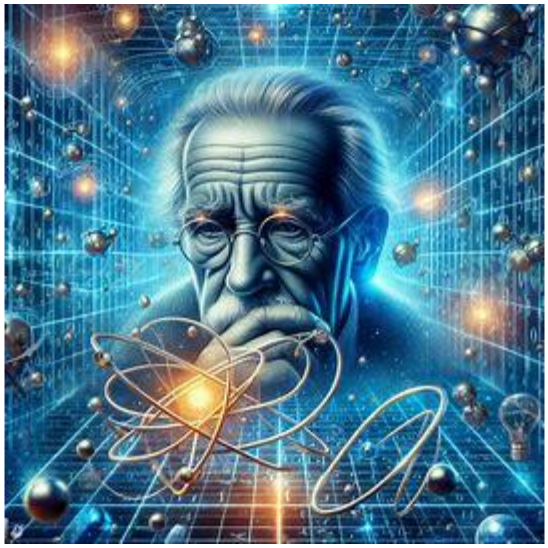
Heisenberg Uncertainty Principle

The Heisenberg uncertainty principle is not an equation per se, but rather a fundamental concept in quantum mechanics. Simply stated, the more precisely we know position, the less certain we are about momentum.

It is written as:

$$\Delta \boldsymbol{x} \Delta \boldsymbol{p} \geq \frac{\hbar}{2}$$

[79] The total probability over all space must be equal to 1.



Illustrated by Dall-e

Quantum Tunneling

The square modulus is key to probability interpretation in quantum mechanics where it represents the probability distribution of finding a particle at a particular position. In quantum tunneling the probability of finding a particle that has tunneled through a barrier is related to the amplitude of the wave function on both sides of the barrier, where the transmission coefficient (T) is a measure of the probability that a particle will pass through a barrier. The higher the coefficient the greater the probability of tunneling.

$$T \propto \frac{|\Psi_{final}|^2}{|\Psi_{initial}|^2}$$

The square modulus is directly linked to the probability interpretation in quantum mechanics. While the probability of tunneling is not characterized by a "fat tail" in the conventional sense, it none the less results in finding things that should not be there based on classical physics. The shape of the probability distribution is determined by the form and energy of the wave function and the characteristics of the barrier being tunneled through.

In an LCP we find low probability (improbable) events and outcomes that occur more frequently than conventional project management would suggest. Given the "energy" associated with an LCP, we should not be surprised by the improbable. A deeper understanding of the susceptibility of an LCP to improbable behaviors requires us to know more about the form of a particular project's wave function.

Illustrated by Dall-e

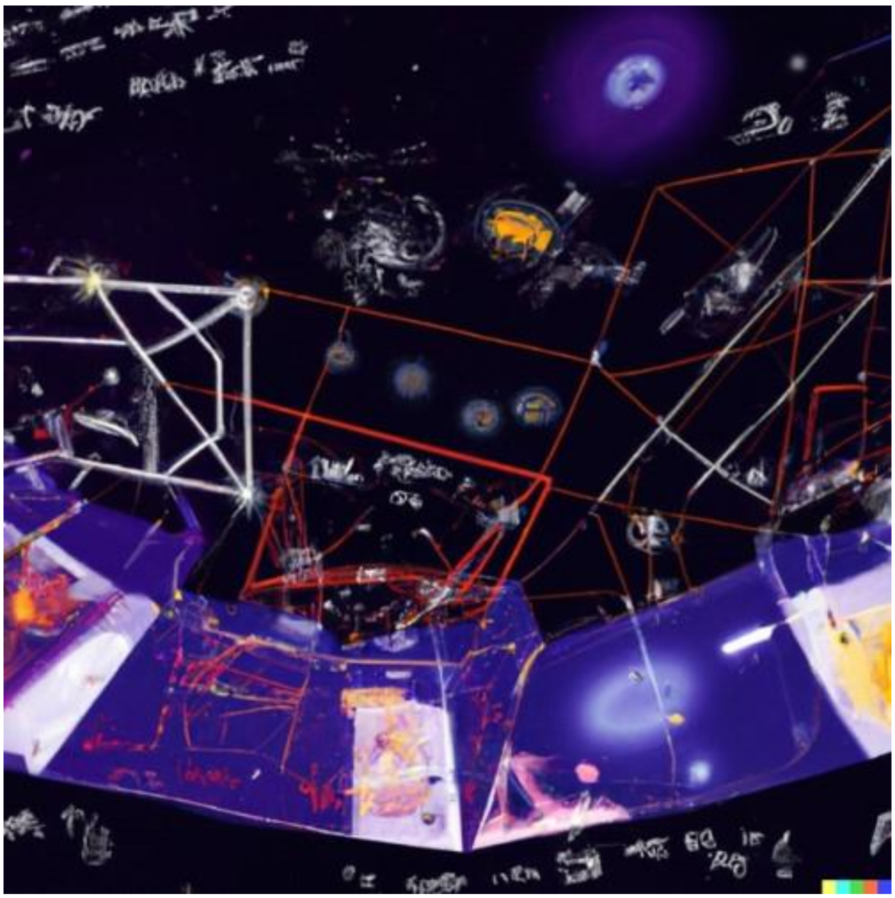
In some instances, we find a mathematical analogy between the Cauchy distribution and a certain type of wave function that might be related to tunneling.

Cauchy Probability Density Function	Tunneling Related Wave Function
$$f(x; x_0, \gamma) = \frac{1}{\pi\gamma\left[1 + (\frac{x - x_0}{\gamma})^2\right]}$$	$$\Psi(x) \propto \frac{1}{1 + (\frac{x - x_0}{\gamma})^2}$$
x_0 is the location parameter γ is the scale parameter	$\propto$ means proportional to

In certain contexts, wave functions related to tunneling can have similar shapes to a Cauchy distribution. The exact relationships are complex and specific to the problem or project at hand, yet Cauchy serves as a simplified analogy. The Cauchy distribution analogy is a heuristic way to draw parallels in LCP, but, while convenient it is not a direct correspondence.

Part D. Employing QPM for Success

Quantum Project Management introduces a new management paradigm to replace classical project management as applied to large complex projects. QPM draws a strong analogous framework from both relativistic theory and quantum theory, providing a robust framework for conceiving, planning, and executing large complex projects.



Illustrated by Dall-e

The main differences between classical project management and Quantum Project Management (QPM) can be summarized as follows:

1. Nature of Projects:

- Classical Project Management: Based on a "Newtonian" view, which is mechanistic and deterministic.

- Quantum Project Management: Embraces relativistic and quantum behaviors, recognizing change and unpredictability as inherent characteristics of large complex projects.

2. Nature of PM Control:
- Classical Project Management: Emphasizes reductionist, synthesis thinking.
- Quantum Project Management: Adopts an anti-reductionist, holistic approach, acknowledging the interconnectedness of systems and the need for open exchange with the environment.

3. Project Boundary:
- Classical Project Management: Views projects as well-bounded, closed systems.
- Quantum Project Management: Recognizes projects as open systems with ongoing relationships with their environment, part of a larger System of Systems (SoS).

4. View of Project:
- Classical Project Management: Considers projects as well-bounded entities.
- Quantum Project Management: Views projects as embedded in and interacting with other systems, acknowledging the interdependence of tasks and the influence of surrounding ecosystems.

5. Planning Basis:
- Classical Project Management: Operates under the assumption that the environment is "knowable" and predictable.
- Quantum Project Management: Emphasizes continuous stakeholder engagement and acknowledges the potential for disequilibrium and the impact of flows in the environment.

6. Uncertainty and Probabilities:
- Classical Project Management: Tends to overlook the significance of uncertainty and probabilities in large complex projects.
- Quantum Project Management: Acknowledges uncertainty, multiple paths/outcomes, and the importance of time as an integral property of projects.

These differences highlight the shift from a deterministic, reductionist approach in classical project management to a more adaptive, interconnected, and probabilistic approach in Quantum Project Management, reflecting the influence of relativistic and quantum theories on project management practices.

Quantum Project Management (QPM) addresses the challenges of time dilation and perception of progress in large complex projects through its adaptability, flexibility, and acknowledgment of uncertainty.

QPM tackles these challenges such as:

1. Time Dilation:
- QPM draws inspiration from relativistic behaviors, such as time dilation, by recognizing that schedules in large complex projects may extend, and the perception of progress varies based on perspectives.
- QPM acknowledges that the mass of the project and the strength of its distortion on local space-time create a degree of difficulty not experienced with smaller projects, leading to a tendency to underestimate the real-world time required for an LCP.
- By embracing the concept of time dilation, QPM encourages project teams to navigate the slower progress of large complex projects with adaptability and a mindset that accommodates uncertainty, similar to the behavior of particles in superposition.

2. Perception of Progress:
- QPM recognizes that large complex projects involve various factors, making outcomes unpredictable until completion, similar to the uncertainty in quantum systems.
- QPM encourages rapid adaptation to changing conditions, resembling the behavior of particles in superposition, allowing for simultaneous exploration of multiple solutions until a clearer path emerges.
- The approach of QPM acknowledges the interconnected nature of tasks in complex projects, where changes in one area can impact the entire system, similar to quantum entanglement.

By embracing the principles of quantum mechanics, QPM aims to navigate the challenges of time dilation and the perception of progress in large complex projects by leveraging agility, adaptability, and creative problem-solving, ultimately providing a framework that accommodates uncertainty and the dynamic nature of such projects.

Uncertainty enters large complex projects through various channels, influencing their planning, execution, and outcomes. Quantum Project Management provides insights into the sources and implications of uncertainty in large complex projects.

Some ways uncertainty enters such projects includes:

1. Incomplete Information:
- Large complex projects often face uncertainty due to incomplete or inadequate information, making it challenging to gain a comprehensive understanding of all project aspects.

2. Complexity of Project Design and Execution:
- The complexity of selected project design, technology, or execution approach introduces uncertainty, as the interactions and interdependencies within complex systems can lead to unpredictable outcomes.

3. Stakeholder Dynamics:
- The diverse and dynamic nature of stakeholders, along with their changing, competing, and conflicting demands, contributes to uncertainty in large complex projects.

4. Organizational and Environmental Factors:
- Uncertainty arises from the lack of clear organizational culture, ambiguous information, industry capabilities, geopolitical forces, and regulatory landscapes in turmoil or transition.

5. Project Scope and Decision Making:
- Uncertainty is present in the ever-changing project scope, turbulence of project objectives, and inadequate or untimely decision-making processes, impacting the project's trajectory.

6. External Influences:
- Geopolitical forces, industry, market and supply chain capabilities, and capacities, as well as governmental and institutional decisions, introduce uncertainty into large complex projects.

These sources of uncertainty highlight the multifaceted nature of large complex projects and the challenges they face in managing unpredictability, variability, and ambiguity. Understanding and addressing these sources of uncertainty is crucial for effective project management and risk mitigation in the context of large complex projects.

Illustrated by Dall-e

To be successful, large complex programs must:

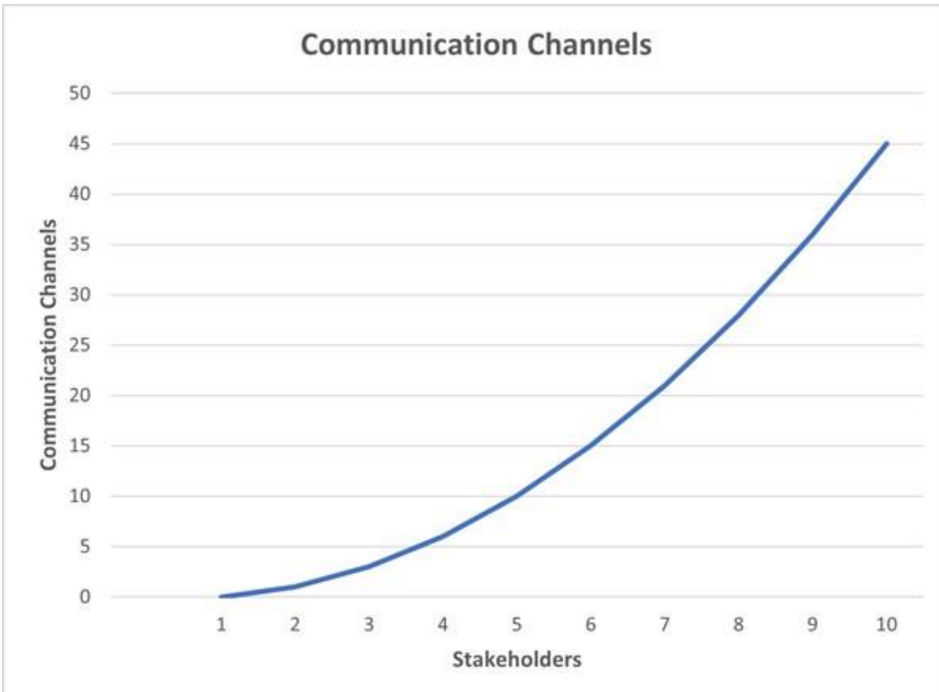
- Ensure alignment, continuous alignment, on the program's strategic business outcomes and individual project objectives[80]. This begins with strong and continuous communication, especially important given the dynamic nature of implementing organizations over the extended timeframes often associated with such programs. Feedback is essential.
- Continuously engage stakeholders in reaching consensus on the newly emergent stakeholder issues that are inevitable given the fluid and porous boundaries associated with large complex projects.
- Seek broader input into what is often dynamic problem solving. This expertise may be crowd sourced in manners like those employed in open innovation. The crowd may include stakeholders recognizing that owner led 'engagement' often shifts to a perceived 'management' of stakeholders as the execution team is established and begins operations. During execution, engagement grows in importance and the notion of stakeholder management should be discarded to the dustbin of failed best practices.
- Recognize that project plans, no matter how well developed, will likely not survive real world contact. Work sequencing and established organizational and communication hierarchies will break down to different degrees. The resultant requirements of contingent execution and broad 360°communication represent organizational properties which must be inoculated into project planning. Agility is essential.
- Incentives work and careful pre-thought about the best type of incentives to be deployed (given the project setting), the level of such incentives, the clarity of outcomes to be achieved to earn such incentives and importantly, the timing of their use. This last point is important. All too often incentives are deployed when the program has already come off the rails whereas they may be more effective in keeping the program on the rails. One excellent example is in mature safety programs where safety bonuses are earned as the projects advance and lost until sustained safe performance returns for a defined period.
- Focus on flows[81], better managing their timing and coordination; understanding their impact on other flows; and, importantly, anticipating their changes and rates of change[82].
- Prepare the organization and execution strategies and plans for four types of operations:
    - Regular
    - Irregular (often the norm)
    - Emergency

[80] LCP are more characteristic of programs effectively having multiple projects within them
[81] See R. Prieto, Theory of Management of Large Complex Projects; Construction Management Association of America (2015); ISBN 580-0-111776-07-9
[82] R. Prieto, Generalized Analysis of Value Behavior over Time as a Project Performance Predictor, PM World Journal, Vol. I, Issue III – October 2012 PMWJ3-Oct2012-PRIETO-GeneralizedAnalysisValueBehavior-Featured-Paper.pdf (pmworldlibrary.net)

  - Catastrophic/contingent – this mode of operations focuses on true resilience of the program execution operation and plan. It most certainly aids in handling Black Swans but also the Black Elephants[83] we often ignore. This concept of operations is characterized by flexibility, adaptability, responsiveness, capabilities and capacities.
- Define team to include not only the resources immediately available and under the program's day to day control but also the broader set of skills, knowledge and authorities that will act to enable execution. Importantly, stakeholders need to be viewed as team members and not adversaries and appropriately engaged in successful program delivery. This last concept is often the very antithesis of traditional project management's closed system thinking.
- Empower the execution team by defining outcomes, expectations, behaviors, values, responsibilities and engagement with the broader team. Emphasize 360°communication and prudent risk taking. Emphasize use of self-directed teams focused on contributing to achievement of overall outcomes (SBOs). This is the antithesis of Taylor's assembly line where each team member is only focused on a narrow accomplishment.
- Ensure team composition matches the range of potential changes and challenges in the external environment. Adequate team diversity of skills, experiences and thoughts is essential. When problems are complex, diversity (cognitive differences) trumps ability. Access to required diversity can be accomplished by access to others outside the project team.[84]
- Recognize that sole-decision making may be required under chaos but even then decisions benefit from a diversity of views and challenges.
- Strong process, procedures and performance are supported by strong social capital. Connections between people (team members; stakeholders) must be built early and continuously sustained and nurtured. Alignment, collaboration and true leadership act to increase social capital. Effective use of social networks to gather knowledge and support are leading indicators of project success. Holistic perspectives are essential.
- Risk and opportunity must be equally managed. Recognize that entropy (disorder and randomness) are present and create or contribute to threats and opportunities depending on how we address them.
- Ensure comprehensive understanding of changes, including disruptions, throughout the entirety of the program. They are not discrete or localized events; they change the program in ways we must seek to understand. Emergent properties are visible only when considering the program as a whole.

[83] R. Prieto, On the Subject of Black Elephants, PM World Journal Vol. IX, Issue VII – July 2020 pmwj95-Jun2020-Prieto-Letter-to-Editor-on-black-elephants.pdf (pmworldlibrary.net)
[84] Law of requisite variety from cybernetics

- Related to this is ensuring root causes are understood and not acting elsewhere in the program or subject to recurrence at a later stage.
- Recognize that stakeholders do not exist in isolation and that they are part of a broader interacting ecosystem. Even when the number (N) of potential stakeholders may be limited there are still $(N^2 - N)/2$ potential communication channels between them that may act as sources/precursors to influencing flows.



- Understand that traditional project control systems control nothing but rather act to inform[85] and influence the real control points, the individuals on the team and to a lesser degree various stakeholders. This does not alleviate the need to strengthen project foundations[86]. Also recognize the broader environment often acts to constrain or otherwise dictate the actions which individuals can or choose to take. Leadership is important.
- Recognize the key points of leverage in large complex programs shown in Table D-1 in order of significance.
- Meaningfully deploy strategies for leverage shown in Table D-2 to guide the program to its desired outcomes.

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[85] Estimating uncertainty and measuring variance
[86] Foundations for Success; National Academy of Construction Executive Insight https://www.naocon.org/wp-content/uploads/Foundations-for-Success.pdf

Table D-1 **Key Leverage Points in Large Complex Programs**
1. Business and environmental context in which the industry, enterprise or program exists
2. Strategic Business Outcomes (SBO) the program is to deliver
3. Who makes the rules (shareholders, stakeholders, regulators)
4. Rules that impact program execution (resources, constraints, incentives, penalties, latent risks and opportunities)
5. Information flows (leading (insight), contemporaneous, lagging; information vs noise)
6. Logistical flows (supply chain; management/sequencing/coordination of engineering and construction)
7. Advantaging negative feedback loops (stabilizing)
8. Limiting/controlling positive feedback loops (drive multi-finality)
9. Monitoring/controlling assumption migration
10. Fixed parameters, standards, regulations

Table D-2 **Strategies for Leverage**[87]
Preserve flexibility of response (contingent execution)
Provide for decentralization of decision making and action (Workface Planning)
Encourage 360°communication
Resist opening of regulatory and control loops without dealing with full effects on the program (Law of unintended consequences)
Identify critical points of weakness or control and act upon to reinforce or retard change
Decentralize program and project control to retain overall control on large complex programs
Resist changes unless full program impacts understood. AI can aid in pattern recognition.
Do not remove or impose constraints without understanding why they existed initially or the systemic impact of imposing them
Encourage diversity of thought (Avoid cognitive lock and bias)
Encourage prudent risk taking and require people to “tell, tell, tell”[88]
Set outcomes. They allow for feedback.
Transparent broad distribution of information leads to good outcomes[89]
Value time and timing

[87] Adopted from De Rosnay “The Ten Commandments” of the Systemic Approach”
[88] Admonishment to young staff earlier in my career: “If you don’t screw up at least once a day you are not doing your job!” Corollary was “tell, tell, tell.” Then we can help you fix it and learn from it.
[89] Knowledge is most powerful if everyone has it.

Classical project management falls short when applied to large complex projects due to several inherent limitations that are magnified in such contexts. This document highlights these shortcomings. Areas where classical project management is challenged in the context of large complex projects include:

1. Deterministic Approach:
- Classical project management is based on a deterministic approach, assuming that the project environment is predictable and controllable. However, in large complex projects, the level of uncertainty and the interconnectedness of various elements make it difficult to apply deterministic models effectively.

2. Well-Bounded Systems Assumption:
- Classical project management often assumes that projects are well-bounded, closed systems with clear boundaries. In reality, large complex projects are part of larger systems and are influenced by external factors, making the well-bounded systems assumption inadequate.

3. Reductionist Thinking:
- Classical project management tends to rely on reductionist thinking, breaking down projects into discrete tasks and assuming that the whole can be understood by analyzing its parts. In large complex projects, the interconnectedness of systems and the emergent behavior of the project as a whole challenge this reductionist approach.

4. Overlooking Uncertainty and Adaptability:
- Classical project management may overlook the significance of uncertainty and the need for adaptability in the face of unpredictable outcomes. Large complex projects require a more flexible and adaptive approach to navigate uncertainty and emergent behaviors.

5. Lack of Stakeholder Engagement:
- Classical project management may not fully account for the complexity of stakeholder relationships and the dynamic nature of stakeholder demands in large complex projects. Effective stakeholder engagement and management are critical in such contexts.

6. Inadequate Planning Basis:
- Classical project management operates under the assumption that the project environment is "knowable" and predictable. However, in large complex projects, the environment is dynamic, and planning must accommodate uncertainty and changing conditions.

These limitations demonstrate the mismatch between the assumptions and methodologies of classical project management and the realities of large complex projects, emphasizing the need for a more adaptive, holistic, and probabilistic approach, as proposed by Quantum Project Management (QPM).

LCP are not well served by traditional PM theory and require a significantly changed perspective, defined in this paper as QPM. The nature of LCP more closely resembles open systems first defined as part of General Systems Theory and embodied in RT and QT. This paper highlights analogs with QT and RT; captures the open systems nature of LCP, again analogous to what we see in RT and QT; contrasts it with traditional PM theory; and, importantly, provides meaningful guidance on mindsets, behaviors and practices required to improve achievement of successful outcomes.

While elements of the thinking and approaches outlined in this paper may be found in other project management theories that seek to move past classical project management theory, QPM seeks to provide a comprehensive framework for these approaches, observations and ideas.

Appendix 1

Analogs and Definitions

As we moved through this paper, we defined some project management analogs that are embodied in QPM as derived from our various physics analogs.

Illustrated by Dall-e

QPM Definition: Spacetime

Spacetime recognizes the innate linkage between the various scalars which describe the space within which our LCP resides and the impacts in time that it has. The distortion of spacetime increases with the mass/energy (scale) that the LCP is imbued with.

QPM Definition: Mass

Mass, or more appropriately mass/energy, represents the scale of the LCP. This may be thought of as either the physical scale of the LCP or the energy imbedded in the LCP as it addresses its inherent complexity. Most LCPs incorporate both scalar and energy related aspects deriving from physical or financial scale and LCP deliverable or execution complexity.

QPM Definition: Universe

The universe represents the totality of all ecosystems, stakeholders, forces and flows in a system of systems context that directly or indirectly acts on the LCP. It grows with time, stretching spacetime and increasing the dark energy within the universe.

QPM Definition: Dark Energy

The total potential energy present in the LCPs universe grows as spacetime is stretched. The potential for ecosystem actions grows with time.

QPM Definition: Gravitation waves (Events of Scale)

Gravitation waves result in universe wide ripples through spacetime resulting from significant events of scale.

QPM Definition: Time Dilation

Flows take longer because of time dilation arising from the distortions (gravity) arising from the mass-spacetime interaction. In LCPs, this underscores that the source of flows, while important, may not be as important as the path the flows take.

QPM Definition: Black Holes

Super massive distortion of space time from which practically nothing can escape once crossing the event horizon. LCPs which continue to grow in scale as want after want is added to the detriment of meeting initial SBOs, collapse under their own weight.

QPM Definition: Frames of Reference

Frames of reference in LCPs explain how observers in different reference frames might perceive events differently, especially regarding the concept of time dilation. Understanding the interplay between different frames of reference is essential in delivering an LCP.

QPM Definition: Precession

Precession is the rotation on the axis of spin, in the presence of a large mass. LCPs see precession in alignment and performance of stakeholders, broadly. This may manifest as either increased alignment with the LCP or complete unalignment with the LCP SBOs

LCPs require relative stability. Outside forces that act to change SBO alignment will have unplanned impacts on the LCP and its stakeholders

QPM Definition: Probabilistic Outcome

Probabilistic outcomes are a fundamental characteristic of QT. LCPs exhibit similar outcomes behaviors. Behaviors in each are influenced by structure, interactions, feedback loops, and external influences.

QPM Definition: Uncertainty Principle

It is impossible to have a precise prediction for a measurement of position and at the same time momentum. In LCPs we cannot predict, with certainty, the project's progress and instantaneous productivity precisely no matter how well we have planned and executed.

QPM Definition: Tunneling

There is an inability to completely isolate a system. Project boundaries are semi-porous and not well bounded as assumed in classical PM theory.

QPM Definition: Entanglement

Properties of the various subsystems[xii] *of an LCP become so intertwined that a description of the whole solely in terms of the individual parts is no longer possible. Decomposition of projects does not describe overall project performance.*

QPM Definition: Emergence

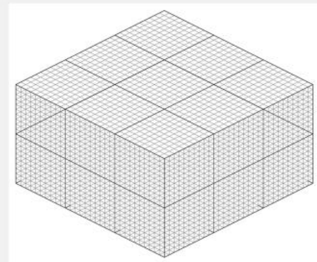
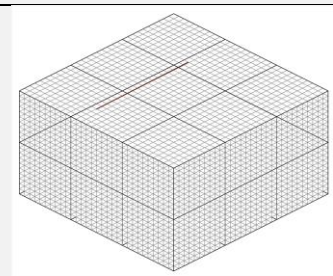
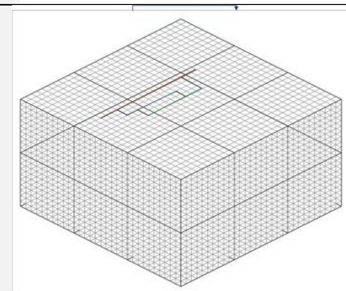
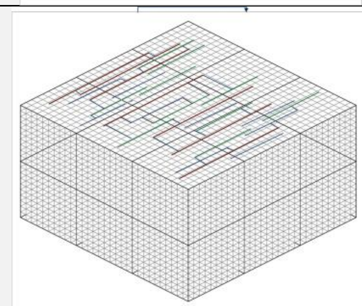
LCPs demonstrate emergent properties and behaviors not reducible to the intrinsic properties of its parts.

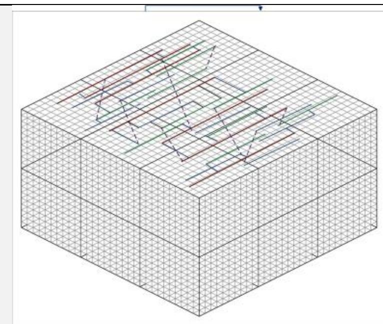
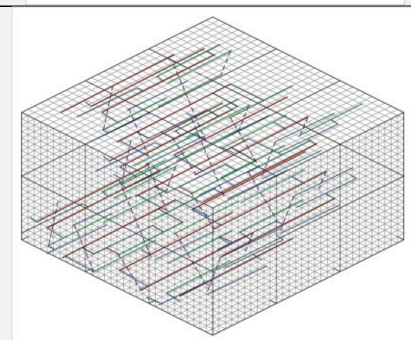
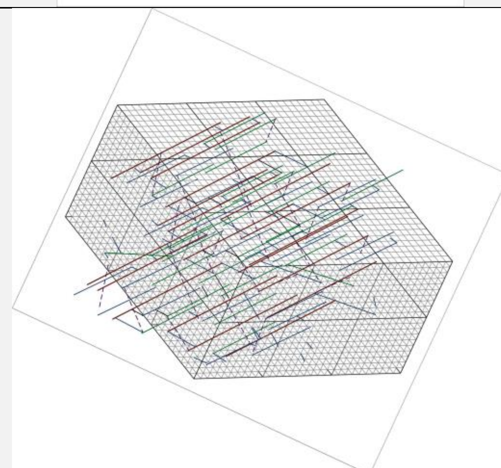
QPM Definition: Decoherence

LCPs may lose coherence in their execution as a result of the strength of the surrounding stakeholder environment.

Appendix 2

Complex Project Analogy

Let us think about a stack of graph paper.	
On the top sheet we draw a line along one of the horizontal graph lines with each vertical line representing the ending of one activity and the beginning of the next.	
This would represent a simple project and the project would remain simple even if we add a couple horizontal lines with just a few vertical connecting lines.	
Now let us think about a project with many horizontal and vertical lines essentially encompassing all the boxes on that top sheet of graph paper. We would describe such a project as complicated.	

Finally, let us take that complicated project with many horizontal and vertical connections and add two new elements. The first, diagonal lines between seemingly random nodes on this top sheet representing precedence and constraint coupling.	
And second, lines penetrating down through the stack of graph paper connecting other complicated activity sets.	
Each of these other sheets of graph paper are not static. Rather they are being tugged and rotated by various externalities and stakeholders. We call this very dynamic project, complex.	
If we continue with this analogy, for just a second, when large complex projects come off the rails they tend to go through a chaotic phase, the stack of graph paper is thrown up in the air and stability does not return until the project manager gathers up and reorganizes that stack of graph paper.	

Appendix 3

Heuristic Biases Affecting Project Selection

Heuristic Biases Affecting Project Selection	
Motivation bias	**Motivation bias -** Motivational biases can affect estimates and forecasts whenever those doing the estimating believe that the judgments expressed may affect them personally. For example, managers may have an incentive to overstate productivity forecasts to reduce the risk that the capital dollars allocated to their business units will be reduced. More subtle biases also affect estimates provided by managers, and the influence can depend on the individual.
Status Quo bias	**Status Quo Bias** – The inclination of decision-makers to like things to stay relatively the same. This bias explains why ineffective management procedures often are not changed and why outdated technology is not replaced.
Perception bias	**Perception Bias** is a broad term used to describe different situations in which we perceive inaccuracies in our environment. It is a type of cognitive bias that occurs when we subconsciously form assumptions or draw conclusions based on our beliefs, expectations, or emotions.
Risk aversion	**Risk aversion -** Risk aversion is a preference for a sure outcome over a gamble with higher or equal expected value.
Optimism bias	**Optimism Bias –** The tendency to be overly optimistic about the outcome of planned actions. This bias manifests itself in project planning and forecasting. Project managers often overestimate the probability of successful project completion and underestimate the probability of negative events. The optimism bias is also related to wishful thinking
Comfort zone bias	**Comfort zone bias -** Comfort zone biases refers to a category of powerful cognitive biases with the common characteristic that their effect is to promote behavior that is comfortable rather than reasoned.

Wishful thinking	**Wishful Thinking** – The formation of beliefs and decision-making according to what might be pleasing to imagine instead of by appealing to evidence or applying rationality. For example, making estimates based on positive results desired instead of what is possible to achieve. Wishful thinking is related to the optimism bias.
Group think	**Group think -** Groupthink is a psychological phenomenon that occurs within a group of people in which the desire for harmony or conformity in the group results in an irrational or dysfunctional decision-making outcome. Cohesiveness, or the desire for cohesiveness, in a group may produce a tendency among its members to agree at all costs. This causes the group to minimize conflict and reach a consensus decision without critical evaluation.
Uncertainty bias	**Uncertainty Bias** – Failure to adequately consider the uncertainty inherent in drivers and outcomes. Uncertainty can range from predictable futures (the most comfortable) through alternate futures (A or B will happen) to a broad range of futures (multiple scenarios to be considered) to true uncertainty or ambiguity (such as one may see in technology adoption rates,)
Judgmental biases	**Judgmental biases -** Judgment bias refers to systematic patterns of deviation from norm and/or rationality in judgment. Actual bias is subjective and deals with the state of mind, while apparent bias is objective and deals with the conduct and the surrounding circumstances.
Sunk cost bias	**Sunk-Cost Bias** – The tendency to make a choice considering the cost that has already been incurred and cannot be recovered (sunk cost). Sunk costs affect the decisions due to the loss-aversion effect. Sunk costs may cause cost overruns and may also lead to investment in a project that now has no value.
Confirmation bias	**Confirmation Bias -** Confirmation bias is the tendency to seek out and attribute weight to pieces of evidence that support the hypothesis and ignore evidence which disproves it. It also manifests itself in the tendency to interpret ambiguous evidence as supportive of one's own hypothesis.

Contradictory evidence avoidance	**Contradictory Evidence Avoidance** – Ignoring facts that do not fit with your belief set or existing hypothesis. Often when your deepest convictions are challenged by contradictory evidence, your beliefs get stronger.
Biased argument framing	**Biased Argument Framing** - The framing effect occurs when people react differently to something depending on whether it is presented as positive or negative. In other words, our decision is influenced by how the information is presented rather than what is being said.
Anchoring	**Anchoring** is a cognitive bias whereby an individual's decisions are influenced by a particular reference point or anchor. Both numeric and non-numeric anchoring can occur. In numeric anchoring, once the value of the anchor is set, subsequent arguments, estimates, etc. made by an individual may change from what they would have otherwise been without the anchor.
Illusion of control	**Illusion of Control** – The tendency of decision-makers to believe they can control or influence outcomes over which they have no influence. They plan under the assumption that they can control most processes, which they cannot.
Planning fallacy	**Planning Fallacy** – The planning fallacy is a phenomenon in which predictions about how much time will be needed to complete a future task display an optimism bias and underestimate the time needed. This phenomenon sometimes occurs regardless of the individual's knowledge that past tasks of a similar nature have taken longer to complete than generally planned.
Semmelweis reflex	**Semmelweis reflex** – Tendency to reject new evidence that contradicts an established paradigm.
Bounded awareness	**Bounded Awareness** - Bounded awareness is a serious problem. Rather than make use of all information necessary to make an informed decision, people attend to only the limited set of data that is most directly in front of them and fail to seek out other data that is clearly needed. People, especially when overly focused, fail to recognize and detect changes to what should be obvious visual, auditory and other sensory data and routinely overlook information that can be crucial for decision making.

Reasoning by analogy	**Reasoning by Analogy** - A cognitive process where one uses a comparison between two things to understand or solve a problem. It involves identifying the underlying relationships and mapping them from one domain to another. Reasoning by analogy is a type of inductive argument, which means it can be valid or invalid depending on the strength of the similarity and the relevance of the differences.

About the Author

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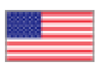

Bob Prieto is a senior executive effective in shaping and executing business strategy and a recognized leader within the infrastructure, engineering, and construction industries. Currently Bob heads his own management consulting practice, Strategic Program Management LLC. He previously served as a senior vice president of Fluor, one of the largest engineering and construction companies in the world. He focuses on the development and delivery of large, complex projects worldwide and consults with owners across all market sectors in the development of programmatic delivery strategies. He is author of nine books including “Strategic Program Management”, “The Giga Factor: Program Management in the Engineering and Construction Industry”, “Application of Life Cycle Analysis in the Capital Assets Industry”, “Capital Efficiency: Pull All the Levers” and, most recently, “Theory of Management of Large Complex Projects” published by the Construction Management Association of America (CMAA) as well as over 800 other papers and presentations.

Bob is an Independent Member of the Shareholder Committee of Mott MacDonald and a member of the board of Dar al Riyadh. He is a member of the ASCE Industry Leaders Council, National Academy of Construction, a Fellow of the Construction Management Association of America, and member of several university departmental and campus advisory boards. Bob served until 2006 as a U.S. presidential appointee to the Asia Pacific Economic Cooperation (APEC) Business Advisory Council (ABAC), working with U.S. and Asia-Pacific business leaders to shape the framework for trade and economic growth. He is a member of the Millennium Challenge Corporation advisory board where he had previously served. He had previously served as both as Chairman of the Engineering and Construction Governors of the World Economic Forum and co-chair of the infrastructure task force formed after September 11th by the New York City Chamber of Commerce. Previously, he served as Chairman at Parsons Brinckerhoff (PB) and a non-executive director of Cardno (ASX).

Bob serves as an honorary global advisor for the PM World Journal and Library and can be contacted at rpstrategic@comcast.net.

End Notes

[i] Quantum Field Theory (QFT) seeks to combine these two theories and classical physics into a unified theory. Challenges remain but both QT and RT remain relevant and verifiable.
[ii] https://farside.ph.utexas.edu/teaching/qm/lectures/node4.html
[iii] Performance (Blackbody Radiation) is over predicted by classical theory. Scaling (frequency/energy grow) leads to lower unit performance (energy density). The parentheticals relate to Einstein's findings on Blackbody Radiation.
[iv] Quantum field theory (QFT) is a theoretical framework in physics that combines quantum mechanics and special relativity to describe the fundamental forces and particles in the universe. It treats particles as excitations of underlying fields, each associated with a specific force or particle type. In QFT, these fields obey quantum rules, allowing for the creation, annihilation, and interaction of particles. The Standard Model of particle physics is a well-established example of a quantum field theory, successfully explaining the electromagnetic, weak, and strong nuclear forces, along with the particles that mediate these forces.
[v] Mass merely represents a concentrated form of energy as shown famously as $E=mc^2$
[vi] Such as the optimism bias created by Kahneman's "framing questions"
[vii] The ability to do reference class forecasting is exceedingly difficult for companies still storing their project data on spreadsheets and disparate systems. But with Finario, a purpose-built capital planning tool, it's not only possible — it's a built-in feature. Called Finario Predict, the system's AI automatically queries the company's project database and selects the historical projects that are most likely to be more predictive of a candidate project's performance and provides a cost and ROI prediction for the proposed project based on that data. Needless to say, the more project data your company has to reference, the better.
[viii] Time dilation is a concept in the theory of relativity that describes the difference in the elapsed time between two observers, which is caused by differences in their relative motion or gravitational fields. There are two main types of time dilation:

1. Special Relativity Time Dilation:
   - This type of time dilation is a consequence of Albert Einstein's theory of special relativity, which deals with objects in inertial (non-accelerating) frames of reference moving at constant velocities relative to each other.
   - The key idea is that time is relative, and it can pass at different rates for observers in different inertial frames. The faster an object is moving relative to an observer, the slower time appears to pass for that object, according to an outside observer.
2. Gravitational Time Dilation:

- This type of time dilation is a consequence of general relativity, which is Einstein's theory that describes gravity as the curvature of spacetime caused by mass and energy.
- In a gravitational field, time passes more slowly for observers in stronger gravitational fields. This means that time at the surface of a massive object (like a planet or a star) flows more slowly than it does for an observer at a greater distance from the massive object.

In summary, special relativity time dilation is associated with relative motion, while gravitational time dilation is associated with differences in gravitational potential. Both effects have been experimentally confirmed and are crucial aspects of the broader theory of relativity

[ix] The Born Rule says what and how we measure determines what we get. Think of Schrödinger's cat.

[x] Taylor, Frederick Winslow, 1856-1915. The Principles of Scientific Management. New York, NY :Cosimo Classics, 2010.

[xi] There are four main types of events that can generate detectable gravitational waves:
Binary Neutron Star (BNS) mergers: This occurs when two neutron stars, which are incredibly dense remnants of massive stars, orbit each other and eventually collide. The merger of neutron stars can produce intense gravitational waves.
Binary Black Hole (BBH) mergers: Similar to BNS mergers, binary black hole mergers involve the collision and merger of two black holes. As the black holes spiral inward and merge, they emit gravitational waves.
Compact Binary Coalescence (CBC): This category encompasses mergers of compact binary systems, which include binary neutron stars and binary black holes. CBC events are a general term for the merger of two compact objects, regardless of their specific nature.
Continuous Gravitational Waves: These waves are produced by asymmetrical, non-axisymmetric rotating neutron stars. If a neutron star is not perfectly spherical and rotates, it emits continuous gravitational waves. This type of source is different from the binary mergers mentioned above, which are transient events

[xii] Subsystems may be subparts of the LCP or physical, natural, human and informational systems