ACQUISITION INNOVATION RESEARCH CENTER

The Future of Megaproject Management
Playbook for Megaproject Management

PLAYBOOK
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ACRONYMS AND ABBREVIATIONS

AI	Artificial Intelligence
AIRC	Acquisition Innovation Research Center
CJADC2	Combined Joint All-Domain Command and Control
DAU	Defense Acquisition University
DoD	Department of Defense
EVM	Earned Value Management
FCS	Future Combat System
FLRAA	Future Long-Range Assault Aircraft
LRM	Last Responsible Moment
ML	Machine Learning
OUSD(A&S)	Office of the Under Secretary of Defense for Acquisition and Sustainment
OUSD(R&E)	Office of the Under Secretary of Defense for Research and Engineering
SERC	Systems Engineering Research Center
T5	(Heathrow) Terminal 5
TRL	Technology Readiness Level

INTRODUCTION

Megaprojects, according to the Oxford Handbook of Megaproject Management, are “large-scale, complex ventures that typically cost $1 billion or more, take many years to develop and build, involve multiple public and private stakeholders, are transformational, and impact millions of people” (Flyvbjerg, 2017). Megaprojects are often also often mega-systems that operate with dimensions of operational uncertainty, behavioral complexity, pluralistic decision-making, and volatility of the external environment (Stevens, 2010).

While project management encourages careful up-front planning of known-knowns and known-unknowns (risks), megaproject success is strongly linked to successful management of project unknown-unknowns or uncertainties. Management of project uncertainties fundamentally differs from the management of project risk. Often, projects are based on assumptions that have uncertainty, leading them to overly optimistic planning (Flyvbjerg & Gardner, 2023). While classical project management has a well-established tradition of risk management, the concept of uncertainty, particularly in large, complex projects, has not been adequately addressed in the literature or in practice. Frequently, project uncertainties and their underlying assumptions are not distinguished from project risks, despite the need for inherently different leadership and management approaches.

In this work, we introduce the concept of a “Project Uncertainty Framework,” developed from extensive literature review on both successful and non-successful megaprojects. This framework is evaluated based on historical case studies and an existing megaproject that is entering a phase of significant investment ramp-up. The outcome is a set of best practices and “Plays” for management of uncertainty in megaprojects.

This paper presents the Megaproject Management Playbook. To set the context, it begins with a discussion of megaproject characteristics, followed by a presentation of the Megaproject Uncertainty Framework, and concludes with our Playbook organized within that framework. Examples of best practices derived from the case studies are provided to illustrate the application of the Playbook.

MEGAPROJECTS HAVE A UNIQUE CONTEXT

Lenfle and Loch, in Chapter 2 of The Oxford Handbook of Megaproject Management, summarize three common causes of megaproject failures (Lenfle & Loch, 2017): underestimation of, or refusal to acknowledge uncertainty; stakeholder neglect or mismanagement; and inflexible contractor management. In the first cause, there is an assumption that the design and project plan can be fully defined at the beginning, even though it is impossible to plan for all uncertainties. This often leads to conflicts of control across critical stakeholders on decisions around uncertainty. Uncertainties are exacerbated by the second cause, stakeholder mismanagement, because megaprojects are coalitions of active partners and other non-active stakeholders. Stakeholder conflicts are a major source of poor project decisions and ignoring stakeholders or creating forced agreements are common conflict areas. Finally, stakeholder issues are often exacerbated by the third cause, inflexible contractor management. Many organizations have to cooperate for megaproject success, and transparency, honesty and incentives are needed. Many megaprojects fail because they are bid incorrectly or dishonestly, or just "priced to win," leading suppliers to behave in ways that maximize personal interests instead of larger megaproject goals. Interactions across these three causes enhance megaproject failure models. We note these three causes affect the "**Strategic Context**" of a megaproject, which attends to both the external and internal strategic management of the effort, and the "**Stakeholder Context**" of a megaproject which defines the leadership model for a successful megaproject.

While these three causes relate to project leadership and management concerns, megaprojects are also often "mega-systems." (Stevens, 2011) defines mega-systems as "large-scale, complex systems that cross traditional boundaries to provide a level of functionality not achieved by their component elements." Mega-systems are characterized by "their sheer scale, the nature and pace of change of their underlying technologies, the potential complexity of their interactions, and the fact that a single organization rarely owns and therefore completely controls" them (Stevens, 2011). Stevens adds two additional megaproject contexts to the strategic context and the stakeholder context – the "**Systems Context**" and the "**Implementation Context**." These four contexts form a framework to classify the dimensions of both a megaproject and a mega-system. The systems context acknowledges that mega-systems will "yield substantial operational benefits" that have business or military advantage. Because megaprojects are also dynamic with pluralistic decision making and external contextual influence, evaluation of these four contexts is a process that changes over time as knowledge of the megaproject and mega-system evolves.

Stevens also notes that mega-systems are "extended enterprises, where no single company owns the entire suite of hardware, software, and data. Rather, they are intermingled into an intricate, interconnected, and secure network" (Stevens, 2011). Flyvbjerg further notes that, "in delivering a megaproject one has to, over a relatively short period of time, set up, run, and take down a temporary organization that is the size of a billion-dollar corporation" (Flyvbjerg, 2017). While typical projects are often called "temporary initiatives," megaprojects are "temporary organizations" that must be both led and managed. They require a different set of focus areas, measurement strategies, and leadership skills than typically addressed in project management literature.

(Merrow & Nandurdikar, 2018) studied megaproject leadership in the oil and gas industry, concluding that organizations do not often select the right set of leaders for megaproject success. They note "the characteristic that generates so many problems for megaprojects is that most of them are complex, and it is complexity rather than size that triggers the pathway to failure. When smaller projects have the same degree of complexity, they too have an equally high rate of disappointing projects" (Merrow & Nandurdikar, 2018). They found that successful megaproject leaders often have deep technical background in the megaproject domain. But they are also generalists who are open to other experience and strong in the other factors of the "five-factor" personality model (Roccas, Sagiv, Schwartz, & Knafo, 2002): they are conscientious (exhibit constraint), extraverted, agreeable with others (non-antagonistic), are emotionally stable, and open to others. They also found these leaders tested quite high in emotional intelligence (Merrow & Nandurdikar, 2018). Successful megaproject leaders develop experience across a range of employment roles including participation in complex projects. Project management practice remains important to them, but in the context of project leadership causing them to spend less time "on work process…[and more] time on people management, alignment, and communication to all." In addition, they carefully select and mentor their leadership teams but also "make decisions" themselves (Merrow & Nandurdikar, 2018).

(Flyvbjerg, 2017) lists four "sublimes" that drive megaproject goals: technological or "the excitement engineers and technologists get in pushing the envelope for what is possible;" political or "the rapture that politicians get from building monuments to themselves and their causes;" economic or "the delight business people and trade unions get from making lots of money and jobs from megaprojects;" and aesthetic or "the pleasure designers and people who love good design get from building and using something very large that is also iconic and beautiful." These "sublimes" often lead to optimism bias and acceptance of project assumptions that have a great deal of uncertainty and planning variability at the start. Flyvbjerg goes on to list 10 characteristics of megaprojects that are summarized in the left column of Table 1, with potential management strategies summarized in the right column.

Table 1. Ten characteristics of megaprojects and potential management strategies (Flyvbjerg, 2017).

Megaproject Uncertainty Characteristic	Potential Management Strategies	Context
1) Inherently risky because of long planning horizons and complex interfaces	Practice risk management but also rigorously evaluate project uncertainties that may lead to risks in later stages	Strategic
2) Often led by planners and managers without deep domain experience, who keep changing throughout the long project cycles	Select leadership with both deep domain and megaproject leadership skills, and carefully manage leadership changes over time	Stakeholder
3) Multi-actor pluralistic decision making, planning, and management involving multiple stakeholders with conflicting interests	Build integrated teams and leadership strategies that create alignment to larger project goals and instill trust, utilize incentives to solve problems	Stakeholder
4) Often non-standard technology and design, leading to uniqueness bias among planners and managers	Limit technical risk, and mature critical technologies outside of project schedule and cost	Implementation

Megaproject Uncertainty Characteristic	Potential Management Strategies	Context
5) Overcommitment at the early project stages, leading to lock-in, poor alternatives analysis, and escalated commitment in later stages	"Think slow" – invest in knowledge development and uncertainty reduction in early project phases; involve critical external and internal stakeholders in incremental decision processes	Implementation
6) Involve large sums of money, leading to principal-agent problems, rent-seeking behaviors, and optimism bias	Structure contracts to emphasize management of uncertainty and problem-solving instead of assumed successful outcomes	Strategic
7) Project scope and ambitions typically change significant over time	Employ incremental decision making at the "last responsible moment"	Systems
8) Project delivery is a high-risk stochastic activity with overexposure to extreme events with massively negative outcomes	"Execute fast" – reduce exposure by accelerating schedule when burn rates are high; exercise scenarios for extreme events and build resilience strategies for project execution	Systems
9) Complexity and unplanned events are often unaccounted for, leading to inadequate budget and time contingencies	Build centralized risk pools and monetary incentives for problem solving	Strategic
10) Misinformation about costs, schedules, benefits and risks is the norm throughout project development and decision making	Employ emerging technologies for data analysis and visualization that can monitor and alert for emerging project risks	Stakeholder

(Merrow & Nandurdikar, 2018) list three types of complexity in megaprojects: complexity of scope or scale, organizational complexity, and "shaping complexity" which "is the process by which the benefits of a project are allocated among the various stakeholders along with the allocation of costs and management of risks" (Merrow and Nandurdikar, 2018). This is an internal view of megaproject complexity. (Stevens, 2011) proposes a framework to manage three types of complexity in the "mega-system" view: scope or scale, decision-making (which in megaprojects is more decentralized and more pluralistic), and the predictability of operational environment the mega-system is delivered into. More stable operational environments are more certain, more volatile operational environments are less certain. (Schindler, Fadaee, & Brockington, 2021) expand the complexity scope or scale into unitary or transformative "scale of impact" and expand the operational environment into "more material" versus "more imagined."

This leads to the question: how transformative is the megaproject/mega-system in the operational context where it will be deployed? Figure 1 presents two evaluation rubrics – the left view is from (Stevens, 2011) and the right view is derived from (Schindler, Fadaee, & Brockington, 2021). More material project case studies like the London Olympics, the Heathrow Terminal 5 (T5) project, and the F-35 fighter aircraft differ from more transformative (or "imagined") projects like the U.S. Army Future Combat Systems (FCS), NASA's Mission to Mars, and the Defense Department's Combined Joint All-Domain Command and Control (CJADC2) projects based on how transformative they are to the operational environment and their scale of impact. These more transformational megaprojects have additional complexities that must be accounted for in planning and execution. These complexities affect both the System Context and the Strategic Context of the project. Table 2 summarizes five characteristics of mega-systems as megaprojects, as well as potential management strategies (numbered 11-15). All the management strategies in Table 1 also apply to these categories and are not repeated in Table 2.

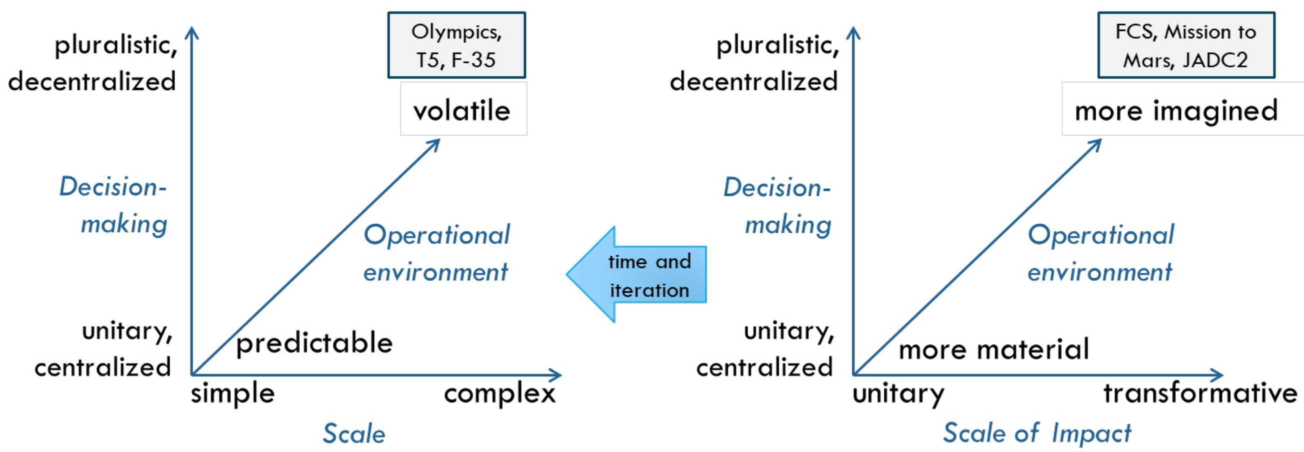

Figure 1. Two views of Mega-systems from literature.

Table 2. Five additional characteristics of mega-systems and potential management strategies.

Mega-system Uncertainty Characteristic	Potential Management Strategies	Context
11) Decentralized execution and leadership create diffusion of leadership and authorities	Develop strategies for multi-organizational alignment to larger project goals, often set by central authorities (governments)	Stakeholder
12) Envisioned large-scale system transformations defy traditional development and management processes	Develop transformative decision-making processes to execute the projects in addition to the system transformation	System
13) Difficult to predict which concepts will survive to the mega-system completion	Invest in experimentation to build knowledge and reduce uncertainties	System
14) Concept of equifinality: there are multiple routes to a specific set of outcomes	Conduct multiple planning cases, invest in parallel development of alternatives	Implementation
15) Difficult to predict the interactions between different systems and related disciplines, leading to non-holistic decisions	Model the adjunct relationships between different systems and decisions	Implementation

THE MEGAPROJECT UNCERTAINTY FRAMEWORK

The megaproject uncertainty framework is shown in Figures 2 and 3 and was adapted from a similar mega-systems classification framework in (Stevens, 2011). From this previous work we capture the four megaproject uncertainty contexts: Strategic, Systems, Implementation, and Stakeholder.

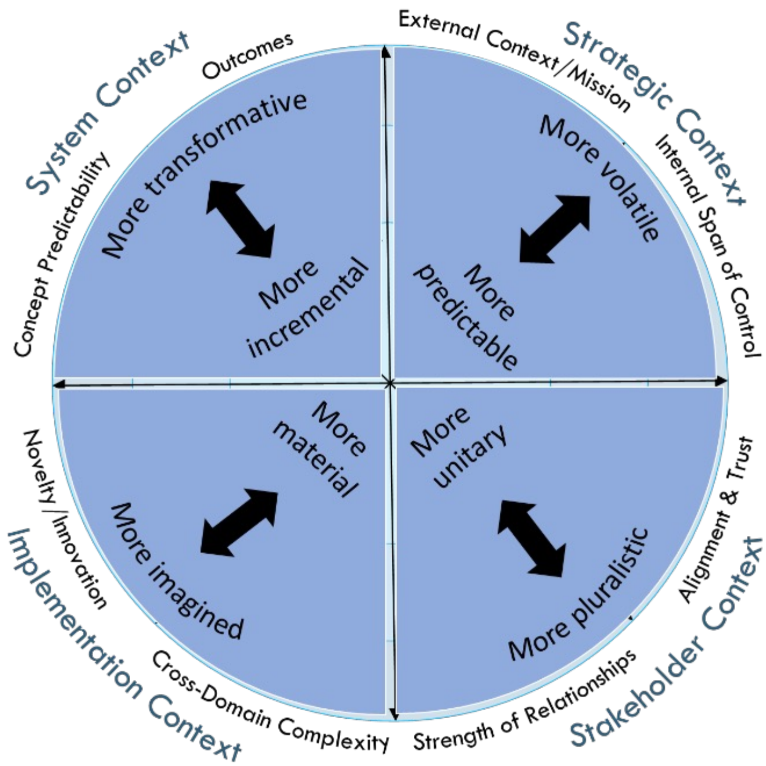

Figure 2. Contexts for Megaproject Uncertainty.

In the **Strategic Context**, megaprojects are characterized by more uncertainty in external environment and more uncertainty in internal environment. Organizational structures are more complex, and management of supply chains becomes more difficult. External stakeholders who might influence the project will need to be managed more closely as the stakes are higher.

In the **System Context**, megaprojects tend to be more transformative in the system concepts and outcomes, and more transformative in their processes. Megaprojects need to plan and execute more flexible decision-making processes. As there are many things that cannot be defined up front, critical decisions should be made later in the project, after more knowledge is accumulated.

In the **Implementation Context**, megaprojects tend to start as "more imagined" and have less knowledge of end design and less knowledge of cross-domain relationships. One must ask how imaginary vs. concrete is the implementation (at this point)? Projects should invest in flexibility to manage risk and uncertainty, particularly modularity so that "unknowns" can be separated from "knowns." Projects need to invest in digital models and environments for design and project execution so that all stakeholders at any level have system-level design visibility, Projects also need to invest in up-front experimentation and test in order to connect implementation with real-world context before commitment to scale project resources.

Finally in the **Stakeholder Context**, megaprojects tend to have less alignment of stakeholders and need more strength in stakeholder relationships. Decision-making is more pluralistic. Projects must focus more on maintaining and sharing project knowledge. Integrated product teams are necessary to encourage multi-disciplinary and pluralistic decision-making. These projects must choose leaders with megaproject leadership skills and build their capacity.

Each of these contexts has two assessment approaches that can be used to both drive megaproject leadership principles and to select and visualize key project performance metrics. These dimensions are shown in Figure 3.

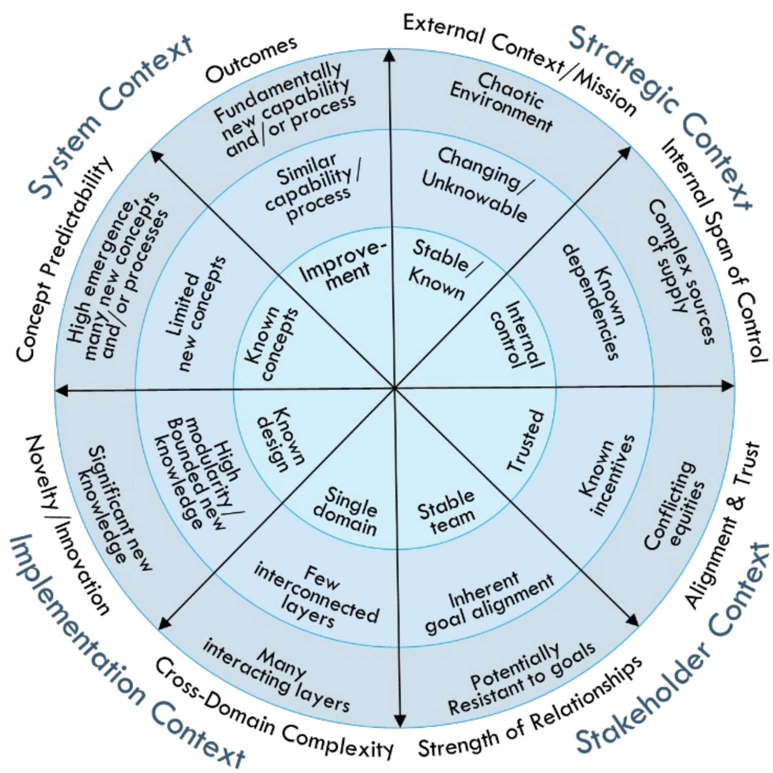

Figure 3. The Megaproject Uncertainty Framework.

MEGAPROJECT UNCERTAINTY, COMPLEXITY, AND RISK

There is not a direct correlation between megaproject complexity and megaproject uncertainty, although there are similarities. Uncertainty will nearly always accompany megaproject and mega-system systemic complexity, owing to the greater diversity of possible outcomes afforded by a complex system's many interacting relationships and levels of novelty. What is important is that project uncertainties are simpler to discuss with stakeholders than project complexities, even though uncertainty and risk are often confused.

(Perminova, Gustafsson, & Wikstrom, 2008) define project uncertainty simply as "an event or a situation, which was not expected to happen, regardless of whether it could have been possible to consider it in advance." This definition implies that uncertainties can be converted to knowns or risks when we come to expect them to happen. In other words, project uncertainties are converted to risks as they become known over time, and strategies can be pursued to either discover these uncertainties or safeguard against their impacts.

Literature on project uncertainty divide uncertainties into three categories: aleatory uncertainty or "known knowns" representing the inherent uncertainty that is always present in a project due to underlying probabilistic variability; epistemic uncertainty or "known unknowns" representing areas where we lack knowledge but can predict that project effort is required to gain that knowledge; and ontological or "deep uncertainty" also called "unknown unknowns" representing areas where we cannot predict additional effort or areas that are perhaps unknowable in advance. (Knight, 1921) initially classified the differences between risk and uncertainty, stating that risks are events subject to known or knowable probability, whereas uncertainty refers to events for which it is impossible to specify numerical probabilities.

USE OF THE FRAMEWORK

This framework serves several purposes:

1. As a way to organize structure and learning from case studies of historical megaprojects. The framework becomes an assessment tool and lessons learned guide for these case studies. This paper discusses how we have organized and structured the authors learning into a set of lessons learned.

2. As a playbook for megaproject leadership and management. The framework can be used to define a series of strategies and "plays" to improve megaproject success. The authors' initial playbook is the result of this effort and described in the playbook section.

3. As a high-level visualization dashboard for future megaprojects. The framework provides a holistic visualization tool for situational awareness of data-driven uncertainties across different dimensions of megaprojects. This tool is currently in development and will be reported on in separate publications.

4. As a megaproject leadership model. The characteristics of successful megaproject leaders can also be mapped to the framework and be used to guide leadership training in this domain. This final use will also be published separately.

THE FRAMEWORK AS AN ASSESSMENT TOOL

The initial derivation of the project uncertainty framework was to develop an assessment tool to help megaprojects understand and manage their uncertainties. This was done through a set of questions that were used to derive uncertainties and strategies broadly from literature on megaprojects and also as an interview method to address currently executing projects. The Army FCS program and the Heathrow Terminal 5 project had the largest body of detailed lessons learned documentation. To test the framework in an ongoing megaproject, the team conducted interviews with leadership on the U.S. Army Future Long Range Assault Aircraft (FLRAA) program. This provided a unique opportunity to assess a live program right as it is scaling from planning to execution phases. Sample questions for each area of the megaproject uncertainty framework are summarized in Table 3.

Table 3. Using the uncertainty framework as an assessment tool.

Uncertainty Dimension	Sample Questions
Strategic Context: External Context/ Mission	1. How would you characterize political/funding uncertainties for the program? 2. How certain or uncertain are overall project resources (funding, staffing, etc.)? 3. How aware are senior decision makers of the uncertainties that may affect the program? 4. What external disruptions to the program have you evaluated? In what timeframe?
Strategic Context: Internal Span of Control	1. What are the subcontracting relationships? How is the contract structured? 2. Was a sharing of risk part of the contract structure/ down-select criteria? 3. How are contract incentives used and to what tier of the supply chain? 4. How are contractors engaged to address uncertainties as they arise?
System Context: Outcomes	1. What fundamentally new capabilities will exist when this system is deployed? 2. What have you learned from prototypes and how will you use that learning? 3. What rough percentage of the total program cost has been spent on early-stage engineering? 4. What data/metrics are most valuable in evaluating uncertainties in key performance attributes?
System Context: Concept Predictability	1. What is the top-level concept of the program and how will it impact the mission? 2. What other new operational concepts will be enabled by these systems? How transformative are these (over current capabilities)? 3. How will current operational concepts be improved by these systems?

Uncertainty Dimension	Sample Questions
Implementation Context: Novelty/ Innovation	1. What capabilities are new/must be developed and what capabilities exist today? 2. What is the current level of knowledge for each of these new capabilities? 3. Can you easily divide the technical risks into individual modular sub-projects? 4. What low technology readiness levels currently worry you the most?
Implementation Context: Cross-Domain Complexity	1. Are there developmental dependencies on other programs? 2. Are there mission dependencies on other systems that provide capabilities? 3. How are the relationships between the program and external dependencies modeled?
Stakeholder Context: Strength of Relationships	1. How is information on the current state of project assumptions and uncertainties disseminated across the government and suppliers? 2. How is knowledge shared across government/ contractor teams? Can you describe a knowledge sharing activity? 3. How are senior leadership trained to manage megaprojects? Is there unique training and to what level? What leadership characteristics are emphasized? 4. How was the evaluation of knowledge and experience used to form the team? Who (or what?) are the primary "hubs" of knowledge on the program?
Stakeholder Context: Alignment and Trust	1. How often are senior leadership changes made? Government & contractor? 2. Is there a shared project "vision"? How is this communicated? Who promotes it? 3. How does program leadership arbitrate conflicts across the contractor teams? 4. Is there a common system to disseminate and access program data and information? Who has access to it? 5. What data/metrics are most valuable in evaluating stakeholder alignment across the supplier base?

THE MEGAPROJECT PLAYBOOK

Using the assessment questions, the authors mapped all of the answers to these questions from historical literature and project interviews to each of the dimensions of the Uncertainty Framework, leading to the Playbook in Table 4.

Table 4. Contents of a Playbook for Megaproject Uncertainty Management.

1. Establish clarity in the role of "the client"	Strategic Context: External Context/Mission
2. Continuously engage and manage stakeholders	Strategic Context: External Context/Mission
3. Integrate and coordinate the supply chain, maintain flexibility	Strategic Context: Internal Span of Control
4. Use standardized project management processes	Strategic Context: Internal Span of Control
5. Decide at the "Last Responsible Moment" (LRM)	System Context: Outcomes
6. Plan & define flexible project decision-making behaviors	System Context: Outcomes
7. Invest in flexibility to manage risk & uncertainty	System Context: Concept Predictability
8. Invest in digital models and environments for design and project execution	Implementation Context: Novelty/Innovation
9. Invest in experimentation and test	Implementation Context: Cross-Domain Complexity
10. Choose leaders with megaproject skills	Stakeholder Context: Strength of Relationships
11. Deploy integrated project teams	Stakeholder Context: Strength of Relationships
12. Maintain and share strategic knowledge	Stakeholder Context: Alignment and Trust

PLAY 1. ESTABLISH CLARITY IN THE ROLE OF "THE CLIENT"

(Denicol, Davies & Pryke, 2021) define a "Project System Organization" as a multi-level, single-purpose temporary or permanent organization that exists to oversee and manage the megaproject. They describe three top-level stakeholder roles as owner, sponsor, and client, as shown in Figure 4.

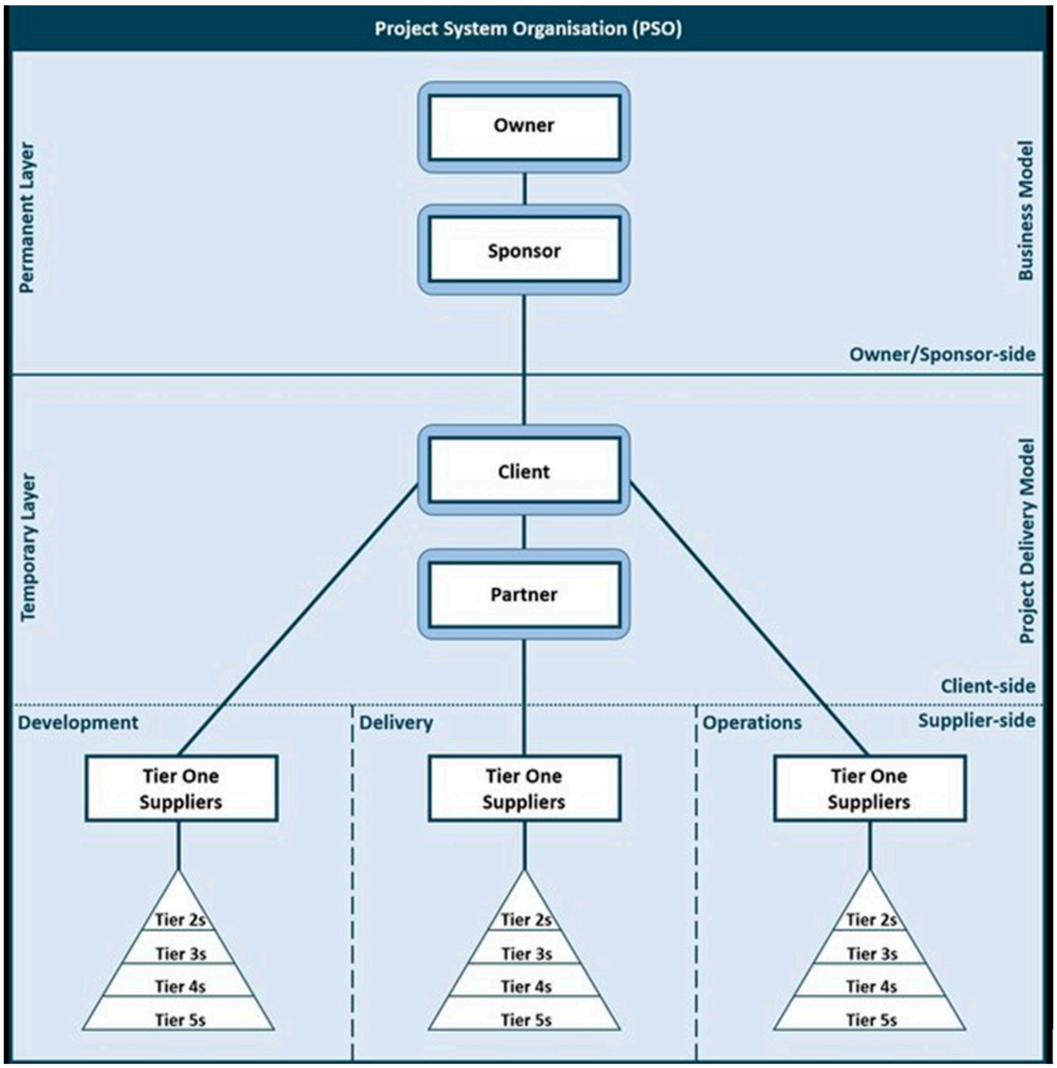

Figure 4. The Project System Organization in a megaproject (Denicol, Davies & Pryke, 2021)

1. There needs to be absolute clarity between the role of the sponsor, the role of the client or "deliverer", and the role of the owner (or operator). If there is not clarity in the home organizations, then the role of the client needs to be set up as the authority to manage the project. Often in government projects, particularly in defense related projects, the government and the "Lead Systems Integrator" have shared client roles that may vary by phase of the project. One must clearly define authorities in this relationship. This is not just a statement of work; it must clearly define who is responsible for all project decisions.

2. Sponsors set the requirements and manage the total scope. In government projects, this often overlaps with the client role because having a budget responsibility drives the sponsor into the client area. Often the contract that is written between the sponsor and client can create conflict if the client role is shared. Flexibility in this contract is critical.

3. The client (i.e., delivery authority), is a single-purpose temporary or permanent organization created and empowered by the sponsor to oversee the project. It is an enterprise, not just a project. The enterprise and its boundaries must be clearly defined. Many of the other plays in this playbook are defined around managing this relationship.

PLAY 2. CONTINUOUSLY ENGAGE AND MANAGE STAKEHOLDERS

External stakeholders often have a vested interest in megaprojects.

1. Megaprojects have a large number of diverse stakeholders; a key function of the leadership team's time is to interface with and insure all their needs are captured in regular project briefs. This is particularly true when critical decisions and/or changes are made both internal and external to the project.

2. Involve principal stakeholders in key decisions when they need to be made instead of at preplanned milestones. This promotes both optimal decision points and stakeholder engagement.

3. Limit dependencies on other projects that are not in the client's control. Use caution when carrying these dependencies across key decision points. Make sure they are mature.

4. Actively test project resilience by running scenarios for unknown/unknowns or other "black swan" events.

PLAY 3. INTEGRATE AND COORDINATE ACROSS THE SUPPLY CHAIN, MAINTAIN FLEXIBILITY

The client has a clear role to manage risk and uncertainty and set up a decision environment that will enable project success.

1. Define an integrated leadership and decision processes matching the client role (cross-organizational).

2. Use incremental option-based contracts to co-evolve the project at the client level. The role or relationship with the client may shift across phases. Options allow the flexibility to renegotiate and redefine incentives at major program phases.

3. Develop contracts that centralize risk pools at the client level to keep project funds in play rather than paying for risk up front in subcontracts. Allocating risk up-front to individual supplier contracts at every level locks up funds that might be best applied to another supplier set of activities to solve problems.

4. Create a standard subcontractor contract for all key players and hold consent at the client level over these contracts. The subcontractors also will find that this makes them feel part of the overall project experience.

5. In the supplier contracts include how incentives and risk pools will be used to jointly solve problems when things don't go to plan.

PLAY 4. USE STANDARDIZED PROJECT MANAGEMENT PROCESSES

Traditional project management practices such as earned value management (EVM) still apply to megaprojects, but they do not usually make project uncertainties visible and must be combined with project uncertainty management.

1. Map teamwide critical schedule milestones and make them visible to all. The T5 project had over 80 critical schedule milestones and published these to all suppliers involved in the project. (Doherty, 2008).

2. Each team must have a risk-assessment plan, risk assessments, live risk registers, control action plans, and risk and opportunity dashboards. Each team must go through monthly dashboard reviews as part of the program-management cycle.

3. Use earned value management and an integrated schedule. Earned value methods do not predict uncertainties, but they do measure the "heartbeat" of the program progress.

4. All supplier key performance indicators should be measured monthly. Corrective action meetings must be held for those who are not performing to team standards. Do not be afraid to remove suppliers who are not meeting team standards.

5. Hold Integrated Baseline Reviews about every six months. Most will find scope gaps that are not currently budgeted.

6. Invest in data and modern data analytics tools to learn much deeper than the reports.

PLAY 5. DECIDE AT THE LAST RESPONSIBLE MOMENT (LRM)

The LRM developed from the theory of constraints and popularized by the agile software movement. It is a strategy of delaying a decision until the moment when the cost of not making the decision is greater than the cost of making it. Rather than doing everything you need to do all at once, you do something either at the point at which you need it, or at the point at which it would be irresponsible not to do it. This can be carried out by any discipline and at any phase of a project (Ingeno, 2018).

1. Develop requirements iteratively, do not freeze requirements prior to the "last responsible moment" but rapidly execute afterward.

2. Develop the design iteratively, do not freeze design prior to the "last responsible moment" but rapidly execute afterward.

PLAY 6. PLAN & DEFINE FLEXIBLE PROJECT DECISION-MAKING BEHAVIORS

1. Choose a client who is very experienced in the domain of the project. (Merrow & Nandurdikar, 2018) found in their study of leadership in the oil and gas domain that domain experience combined with breadth of experience was required for successful megaproject leadership.

2. Maintain a balance between project requirements, technologies, and affordability at all phases. Do not carry forward any requirements or technologies unless you have evidence that they will be affordable. Unaffordable project requirements and technologies do not benefit any supplier on a megaproject. They may unnecessarily limit qualified suppliers, and may hide uncertainties that later create cost, schedule, and quality issues.

3. Maintain user touch points: map and update the map of the user journeys with every design decision. This keeps the user engaged in project decision-making behaviors.

PLAY 7. INVEST IN FLEXIBILITY TO MANAGE RISK & UNCERTAINTY

Deploy modularity:

1. Create modularity in design, modularity isolates necessary knowledge.

2. Enforce modularity in build, this simplifies integration and test.

Minimize technology novelty:

3. Used existing or well-established technologies as much as possible.

4. Do not carry low-Technology Readiness Level (TRL) technologies past any critical design decision points.

5. Validate critical technologies early with realistic field experiments.

PLAY 8. INVEST IN DIGITAL MODELS AND ENVIRONMENTS FOR DESIGN AND PROJECT EXECUTION

1. Invest in single modeling environments to allow all design teams to share all data, models, drawings and written design information.

2. Identify key performance drivers and invest in high fidelity models to evaluate/validate performance early.

3. Use multidimensional trades and value engineering to look at what could be simplified or reduced in scope without impacting customer experience.

4. Build predictive models of key parameters in the System Context.

5. Create guidelines and training that set out the principles of the design for all the team. This item is critical as it creates alignment between disciplines and suppliers on the goals of the design.

PLAY 9. INVEST IN EXPERIMENTATION AND TEST

1. Invest in realistic buildup of test articles: small scale prototypes, modules, etc.

2. Test to failure, collect failure data.

3. Test to validate models.

4. Plan for flexibility in the deployment stage, you cannot know the full value of a megaproject in the development phases.

PLAY 10. CHOOSE LEADERS WITH MEGAPROJECT SKILLS

1. Select leaders from among the best in the world to create a joined-up experience. In megaprojects, a team with a wide range of diverse skills provides its real strength.

2. Team experience should come from different sectors based on critical strengths and what they can bring to the project. Educate across domains. Each domain should have leadership responsibility on the project.

3. Senior leadership must never panic. There must be a great belief in the ability of the team to solve any problem thrown at them.

4. Select leaders who are highly aware of their own abilities for learning.

5. Rigorously assess the capabilities of the leadership.

6. Select/train leaders who spend less time on work processes and more time on people management, alignment, and communications.

7. Select/train leaders who promote psychological safety, debate, innovation, and knowledge transfer.

8. Select/train leaders who balance control & flexibility, Challenge over-optimism & misrepresentation.

PLAY 11. DEPLOY INTEGRATED PROJECT TEAMS

1. Keep the primary user teams resident in the program office.
2. Collocate internal functions (safety, security, etc.) and external statutory users (security, compliance).
3. Get the user excited and include user touch points in the program strategy.
4. All parties work as one team instead of a collection of separate project groups. Develop a ‘winning teams’ toolkit and educate and support people on the ‘what’ and ‘how’ of working together.
5. Make it clear to people that they will be asked to leave if they do not operate to team behavioral norms.

PLAY 12. MAINTAIN AND SHARE STRATEGIC KNOWLEDGE

On the Heathrow T5 program, “The message of being on time, on budget and delivering a quality program safely must run through all the channels and all of the verbal messaging” (Doherty, 2008).

1. Conduct regular strategic knowledge sharing events for task definition and scheduling. The team will value the openness and clear structure, and the fact that there were places where information would be shared and genuine debate could take place.
2. Maintain and share strategic knowledge across all critical stakeholders as a holistic project reference book.
3. Encourage early identification of changes through a system where anyone can raise an early warning notification to alert management to a potential issue before the decision is completed.

CONCLUSIONS

Despite the fundamental role of uncertainty management in megaproject leadership, the project management literature offers limited coverage on this topic. Similarly, practices for assessing and managing uncertainties have not been extensively analyzed. In response to these gaps, this study introduces a new assessment framework designed to categorize and provide plays to assess the dimensions of uncertainty in megaprojects. These methodologies were tested on historical case studies and ongoing megaprojects. Key findings include 1) the need to clearly define responsibilities of the client; 2) spend more time than you imagine managing critical stakeholders by involving them in decisions; 3) maintain flexibility in the supply chain and incentive suppliers for solving problems, not just cost/schedule; 4) make decisions iteratively and no sooner than necessary; 5) make targeted investments in digital models, modularity, testing, and trials to manage risk and uncertainty; 6) choose leaders with deep domain experience and megaproject experience; and 7) openly share knowledge across the project to all project teams and suppliers.

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