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Critical Skills for Successful Leadership of Large Complex Projects

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Critical Skills for Successful Leadership of Large Complex Projects

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Abstract

This paper explores the critical leadership competencies required for the successful management of megaprojects—large-scale, complex ventures exceeding $1 billion in cost and spanning multiple years. Given that only 8.5% of megaprojects are completed on time, within budget, and with intended benefits, effective leadership is vital. Successful megaproject leaders combine technical expertise with systems thinking, transformational leadership, and the ability to navigate complexity and uncertainty. They prioritize stakeholder management, communication, and people leadership, while maintaining a strong foundation in project management. Drawing from existing frameworks, including the HELIX systems engineering effectiveness model, the article proposes a new framework for developing the unique skills needed for megaproject leadership. This framework emphasizes the integration of technical, interpersonal, and enterprise leadership skills, which are crucial for managing the challenges inherent in these large, multi-stakeholder projects. The paper advocates for a shift in how leaders are selected and developed, focusing on their adaptability, strategic thinking, and ability to lead in uncertain environments. The goal is to improve the success rate of megaprojects through more effective leadership development and selection strategies.

Introduction

According to the Oxford Handbook of Megaproject Management, megaprojects 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" (Flyvberg, 2017). These projects are often mega-systems and are marked by operational uncertainty, behavioral complexity, pluralistic decision-making, and external environmental volatility (Stevens, 2011). Megaprojects, as with many large, complex systems, have a lower-than-desired success rate. Flyvbjerg, a leading scholar in megaproject management, suggests that only 8.5% of megaprojects are completed on time and within budget while delivering the intended benefits. This means that more than 90% of megaprojects fail in at least one key aspect: cost, schedule, or intended outcomes (Flyvberg, 2014). As megaprojects cost billions of dollars and often involve the labor and cooperation of tens of thousands of people, improving the success rate of these projects is critical. Megaprojects are often distinguished from other large projects in that they create "temporary enterprises" due to scale and uniqueness, implying the need for leaders who can quickly build and scale new enterprises from sets of existing enterprise structures in a complex supply network. Merrow, an

authority in megaproject leadership, highlights that "the fate of difficult projects seems to hinge more on the project leaders than the results of simpler projects" (Merrow, 2011). In a study, co-authored with Nandurkdikar, Merrow examined 100 megaprojects and their leaders to determine the factors that differentiate between successful and less-successful leaders of large-scale, transboundary, complex projects. They found successful megaproject leaders spend more time on stakeholder management, communications, people management, and managing contractors and vendors; and spend less time on project processes, project controls, and engineering and technical tasks. However, they find project management is still important as a mastered set of skills. They also found that most successful megaproject leaders have engineering backgrounds (Merrow & Nandurdikar, 2018). This work found that the necessary intersection of engineering, project management, and megaproject leadership were most closely associated with systems engineering proficiencies.

A complex project leadership competency model developed by the International Centre for Complex Project Management (ICCPM) contends that the development of leadership skills follows a journey from Situational Leadership (leadership style adapts to the skills and needs of the team) to Contextual Leadership (leadership style adapts to the changing context of the business and its environment) to transformational leadership (leadership style motivates others to achieve shared vision and personal growth; ICCPM, 2021). This implies that successful megaproject leaders have evolved from engineering and technical program management roles to enterprise level roles and they have successfully combined technical leadership, enterprise leadership, and transformational leadership.

Our research focused on megaproject leaders across government and industry led projects. We found a strong correlation between past research on the proficiencies of effective systems engineers in the HELIX project (Hutchison et al., 2020), and as applied to technical leadership development (Pennotti et al., 2015) in earlier career stages. Both frameworks were developed by the SERC. This research used literature review and discussion with megaproject leaders to understand how successful megaproject leaders might evolve and be developed. We provide a new framework that details a set of unique competencies that are required for successful megaproject leadership, how these competencies can be distributed amongst a team, and how organizations seeking to initiate mega projects should think about the selection of the leadership team. Many of these competencies have foundations in systems engineering.

Existing Frameworks with Relevant Skills and Competencies

There are several existing frameworks that have relevance for the creation of megaproject leadership. If megaprojects are also mega-systems, systems engineering frameworks have relevancy, as do frameworks that deal with complexity and project and technical leadership.

Helix—HelixSE (systems engineering) resulted from research from the SERC that examines what makes systems engineers effective. As megaprojects are also mega systems, systems engineering skills are important inputs to megaproject leaders (Hutchison et al., 2020). The Helix framework is shown in Figure 1.

HelixEMP (employability skills) resulted from additional studies by SERC researchers Hutchison and McDermott, taking the foundational framework of HelixSE and expanding it to cover employability skills more generally. There are six sets of characteristics that emerged: foundational learning, domain knowledge and experience, systems knowledge and experience, self-leadership and learning, team leadership and collaboration, and complex problem-solving (McDermott et al., 2021). These provide the underpinning for the development of transformational leaders early in their careers and will be shown to form the nexus of our

megaproject leadership competencies framework, and the core of the early-stage learning for megaproject leadership.

Figure 1. HELIX Proficiencies of Effective Systems Engineers (helix-se.org)

Technical Leadership—Researchers from the SERC worked with leaders in the Defense Acquisition University (DAU) to develop a framework for explaining the skills required for effective technical leadership (Pennotti et al., 2015). This utilizes three lenses, which build in complexity: systems, business, and enterprise, as shown in Figure 2. The framework focuses on personal leadership strengths and competencies with a systems lens; team and group leadership skills necessary to execute a business; and the enterprise leadership skills necessary to enact change and move forward. As megaprojects are evolutionary, a key aspect of this framework is managing emergence and evolution of the system, in the context of business and enterprise change strategies.
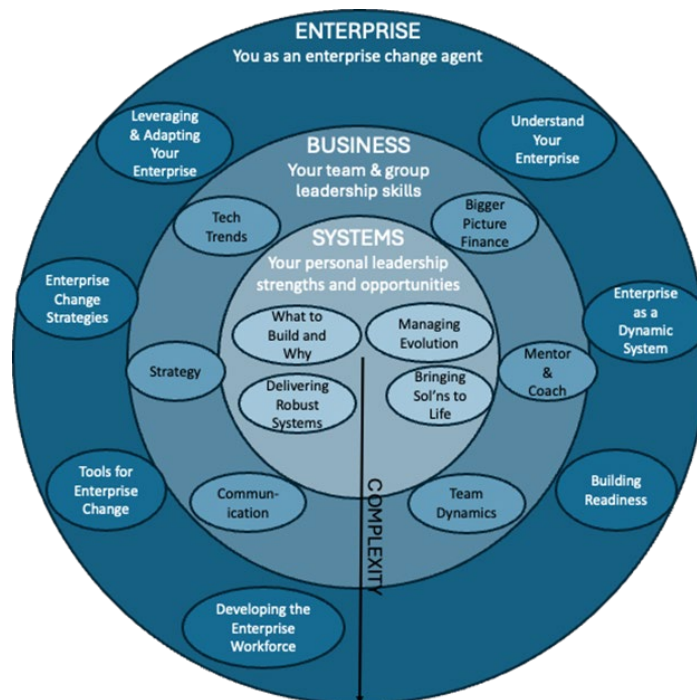

Figure 2. Overview of the Technical Leadership Skills Outlined in Pennotti et al. (2015)

Bass Transformational Leadership Theory—Bass defined two transactional and four transformational characteristics that contribute to high performance in leadership (Aarons,

2006). While transformational leadership motivates and inspires followers, transactional leadership is more focused on "exchanges" between leader and follower in terms of work tasks, penalties, and rewards (Van Wart, 2015). Van Wart further tested a framework in his case study of transformational leadership. This framework is important to megaproject leadership because both transactional (project management) and transformational (influence and followership) leadership skills are necessary. The two transactional characteristics are more related to the project plan and include: management by exception (deal with low-performing employees, avoid technical mistakes and blunders, deal with performance lapses, stabilize organization if needed) and contingent reward (pay, work-life balance). The four transformational characteristics are more motivational and include: individualized consideration (coaching, delegation, training opportunities), idealized influence (model exemplary behavior, avoid personal scandal, use charismatic communication), inspirational commitment (gain commitment to the work and the profession, teamwork), and intellectual stimulation (ensure the need for change, provide a plan, build internal support, ensure top management support, ensure external support, provide resources, institutionalize changes, pursue comprehensive change; Aarons, 2006). Figure 3 depicts how these characteristics come together in a project setting.
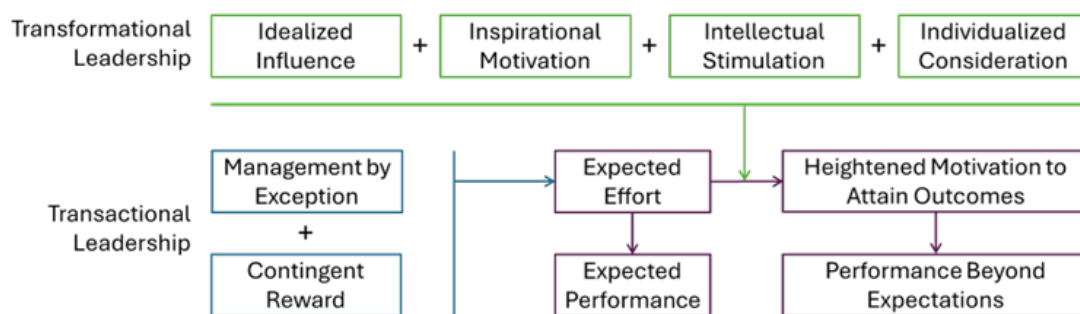

Figure 3. Bass Transformational Leadership Model (Aarons, 2006)

Complex Project Leadership Competency Standards—The International Centre for Complex Project Management (ICCPM) generated these standards via a collaborative effort of 169 individuals from 24 nations to identify the critical skills of complex project leadership. The framework addresses abilities to navigate complexities, foster innovative thinking, manage risks, and inspire high-performing teams. The framework integrates across three leadership theories: situational leadership, contingency theory of leadership, and transformational leadership. We found the career journey from situational leadership to transformational leadership is at the heart of megaproject leadership development—an integration of the HELIX and ICCPM frameworks. The ICCPM framework is divided into five main competency areas: drive systemic thinking and action (how leaders address complexity, uncertainty, and emergence), focus strategically on delivering project outcomes (the elements that lead planning and execution of megaprojects), engage collaboratively with stakeholders (strategic conversations with critical stakeholders), exercise contextual leadership awareness (self-aware), and apply system governance and delivery assurance (evolve the project to assure success; ICCPM, 2021).

Literature on Qualities and Skillsets of Megaproject Leaders

Any review of literature on megaproject leaders must start with Merrow and Nandurdikar's book, *Leading Complex Projects* (Merrow & Nandurdikar, 2018). This book provides deep insights into managing large-scale, complex projects, although focused solely on the oil and gas industry. The book discusses the unique challenges of such projects, emphasizing the need for strong leadership, effective communication, and rigorous planning. Key themes include managing uncertainty, stakeholder engagement, decision-making under

pressure, and balancing short-term objectives with long-term goals. The authors offer practical strategies based on research findings to help project leaders improve performance, mitigate risks, and navigate the complexities inherent in large, high-stakes projects. Historically, excellent program managers have been selected as megaproject leaders. But success in lower-complexity projects is not indicative of successes in more complex projects. "It is not even clear that a long career progression in smaller, less-complex projects is of any substantial value to the complex project leader at all." Skillsets for PMs overlap with megaproject leadership—but there are very different emphases. Most effective megaproject leaders have had:

- Broad and varied jobs. Most successful megaproject leaders have depth in the domain of the project but have worked more broadly and become generalists.

- Experience making timely decisions under conditions of uncertainty.

- Opportunities to watch others lead complex projects.

- Experience sorting out difficult interpersonal situations.

- Backgrounds in engineering (most megaprojects are engineered systems).

Critical skills for megaproject leaders as cited by Merrow and Nandurdikar (2018) include:

- Highly open to new experience, self-disciplined, engaging, stable, and test high in emotional intelligence (the five-factor model)

- Project management remains important but in the context of cooperation and not in transactional methods (as it is usually employed)

- Preference for spending time on people management, alignment, and communications over on work processes

- Highly aware of their own abilities for learning

This is the most comprehensive resource in the literature. In addition, more than 70 articles on megaproject leadership skills were reviewed and used to produce the framework in the next section.

Framework for Megaproject Uncertainties

Overall, several key themes appeared consistently across megaprojects literature. The foremost of these were the ability to manage complexity and project uncertainties (as opposed to risks). The research built an uncertainty framework to characterize types of uncertainties in megaprojects and strategies to deal with them, shown in Figure 4 (McDermott et al., 2024). This led to a playbook of project strategies across eight areas of uncertainty.

- In the Strategic Context, megaprojects are characterized by more **complexity** and **uncertainty** in external environment, context, and mission; and more complexity and uncertainty in their internal spans of control.

- In the System Context, megaprojects tend to be more **transformative** in the system outcomes; and more transformative in their processes associated with predictability of core concepts. Megaprojects need to plan and execute more **flexible** decision-making processes.

- In the Implementation Context, megaprojects tend to incorporate more novelty and innovation and have less knowledge of end design; and less knowledge of cross-domain relationships that create complexity. Projects should invest in **flexibility** to manage **risk**

and **uncertainty**, particularly modularity so that "unknowns" can be separated from "knowns."

- Finally in the <u>Stakeholder Context</u>, megaprojects tend to have less alignment of and trust between **stakeholders**; and need more strength in stakeholder relationships. Projects must focus more on maintaining and sharing project knowledge.
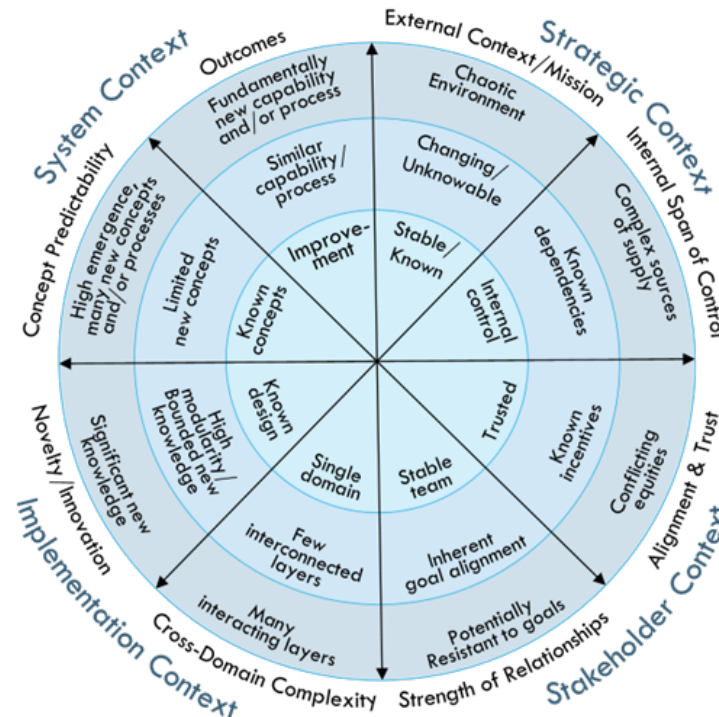

Figure 4. The Megaproject Uncertainty Framework

In particular, there were five major leadership and management capabilities that stood out as necessary for the successful completion of megaprojects. These are the abilities to **1) Manage Uncertainty, 2) Manage Complexity, 3) Lead Transformation, 4) Manage Stakeholders, 5) Create Flexibility, and 6) Manage Risk**.

Framework for Megaproject Leadership Skills

The critical skills and abilities (competencies) for megaproject leaders were identified based on the literature but also with these six abilities in mind. Each of the competencies outlined in the framework are necessary to successfully perform each of these six activities. Stated differently, it takes a number of individual competencies to deliver these capabilities effectively. We identified the following major competency areas required for megaproject leaders: **domain/discipline foundations**, **personal characteristics**, **mindset**, **thinking skills**, **interpersonal skills**, and **enterprise technical leadership**. Each of these six areas is defined and explained in the following subsections. Note that "mindset" and "thinking skills" are related. In general, mindset is about the attitudes and beliefs that influence how someone approaches situations while thinking skills are the cognitive tools and processes used to analyze and solve problems. These areas are related, and these skills go together, with mindset often shaping how effectively thinking skills are applied.

Domain/Discipline Foundations

Historically, technical leaders have been more effective when they have had deep experience in the primary domain and at least some experience with the most critical disciplines for the system. This is true at smaller scales of complex projects as well as at the megaproject level (Pennotti et al., 2015). Merrow and Nandurdikar's analysis of 100 megaproject leaders highlighted that most of the successful leaders had a technical background, often in engineering (Merrow & Nandurdikar, 2018). This does not mean that megaproject leaders should do engineering work, but that they should have enough technical depth to be able to make major technical decisions, have effective dialogs on technical/engineering concerns, and know when to consult experts in a given discipline. One important note in Merrow and Nandurdikar's work is that leaders who have experience in more than one domain—but include experience in the primary domain for a megaproject—are more likely to be successful. The specific domain(s) and discipline(s) needed are dependent upon the individual megaproject. In the example of successful megaproject leader Dzulkarniain Azaman, Merrow and Nandurdikar highlight:

> "This early experience . . . is similar to what we have seen in the early careers of other leaders: A solid grounding in the fundamentals of their domain with exposure to the world of project management is followed by managing smaller-scale mini-projects and, more importantly, seeing projects from end-to-end, which provides the learning of seeing one's design, engineering, and project management decisions play out in the field." (Merrow & Nandurdikar, 2018)

Thus, the successful megaproject leader moves from a single discipline with deep technical background to mastery of multiple disciplines, while retaining technical depth in one or more disciplines. They also develop deep project management and systems engineering skills. In the process they develop skills across multiple project-related roles including management of large complex teams and supply chains. This in itself is not enough, as they also have to move from transactional to transformational leadership styles. The remainder of the framework outlines the development of skills necessary to make this transition.

Personal Characteristics

Though personal characteristics are not always included in competency frameworks, in the case of megaproject leadership, these characteristics emerged so strongly that it is critical to include them. In as much as these characteristics are more intrinsic/difficult to change, they become critically important for the selection of the right individuals for megaproject leadership. There are six critical characteristics for megaproject leaders: Self-Aware, Self-Motivated, Humble, Open-Minded, and Courageous.

Self-Aware: The ability to understand and recognize one's own thoughts, emotions, and behaviors, and how they affect oneself and others. Self-aware leaders are more likely to critically assess their own judgements and decisions. This can help prevent unrealistic planning and forecasting that can lead to project failure (Flyvberg, 2017).

Self-Motivated: The internal state that helps us initiate, continue, or terminate a behavior. Self-motivated leaders are more likely to exhibit a transformational leadership style, characterized by high levels of enthusiasm, passion, and a strong commitment to project goals (Eweje et al., 2012).

Trustworthy: The quality of being deserving of trust or confidence, often demonstrated through dependability or reliability. Followers make a leader and for that followers need trust in their leaders (Merrow & Nandurdikar, 2018).

Humble: A modest view of one's own importance; a lack of pride and arrogance. In the context of megaproject leadership, a humble leader is one who sees their role as serving others.

The ability to search actively for evidence against one's beliefs, plans, or goals, and weigh such evidence fairly (University of Pennsylvania [UPenn], 2024).

Open-Minded: Able to consider something without prejudice or application of pre-conceived notions. Leaders who are open to different ideas, flexible in their thinking, and willing to revise their plans based on new information tend to achieve better project outcomes (Merrow, 2011).

Courageous: The ability to do something difficult or risky, even in the face of fear or danger. It essential for leaders to confront the inherent risks, uncertainties, and complexities of megaprojects. Courageous leaders are needed to make tough decisions, address underperformance, and challenge unrealistic expectations or assumptions, especially when facing pressure from stakeholders or political forces (Doherty, 2008; Flyvberg, 2017).

Mindset

Mindset is about the attitudes and beliefs that influence how someone approaches situations. These are closely related to the thinking skills that are discussed in the following section. The critical characteristics of the mindset of successful megaproject leaders are Comfort with Uncertainty (the ability to function in an environment of unpredictability and lack of sufficient information); Paradox Mindset (the ability to hold and balance seemingly opposed views and being able to easily move from one perspective to another; Hutchison et al., 2020); Strategic Thinking (essential for leaders of megaprojects due to the scale, complexity, and long-term implications of these endeavors, this involves the ability to envision the future, anticipate challenges, align resources, and make decisions that drive the project toward its objectives despite uncertainties); and Vision/Goal Setting (vision being broad idea of what the megaprojects is trying to achieve in the future, while goals are specific aims or steps that will help reach that vision. The ability to create the vision and then identify key steps to attaining it is critical for megaproject leadership.)

Comfort with Uncertainty: The ability to function in an environment of unpredictability and lack of sufficient information. Leaders must embrace uncertainty and ambiguity to navigate large, complex projects effectively, using adaptive leadership styles (Doherty, 2008).

Paradox Mindset: The ability to hold and balance seemingly opposed views and being able to easily move from one perspective to another. Strategic vision paired with the ability to explore details, and judgement to know when more detailed exploration is appropriate and necessary (Merrow & Nandurdikar, 2018; Pennotti et al., 2015; Royse, 2021).

Strategic Thinking: Considered essential for leaders of megaprojects due to the scale, complexity, and long-term implications of these endeavors. It involves the ability to envision the future, anticipate challenges, align resources, and make decisions that drive the project toward its objectives despite uncertainties. Strategic thinking is required for understanding the full scope of risks, setting realistic goals, and ensuring alignment between project objectives and broader organizational or governmental strategies (Doherty, 2008; Hutchison et al., 2020; Merrow, 2011; Merrow & Nandurdikar, 2018).

Vision/Goal Setting: A vision is a broad idea of what the megaproject is trying to achieve in the future. Goals are specific aims or steps that will help reach that vision. A clear vision is crucial for guiding decision-making and maintaining stakeholder alignment in complex megaprojects (Flyvberg, 2017; Merrow, 2011).

Thinking Skills

Thinking skills are the cognitive tools and processes used to analyze and solve problems. These are related to mindset (previous section), with mindset often shaping how

effectively thinking skills are applied. The critical thinking skills of successful megaproject leaders are Political Savvy, Recognizing Patterns, Solving Complex Problems, and Anticipating Future Situations.

Political Savvy: The ability to exhibit confidence and professional diplomacy, while effectively relating to people at all levels internally and externally (NIH). When teams believe the project is caught up in politics either from internal or external stakeholders, they can easily become distracted and discouraged. If the politics continually interfere, the team blames the project director and their confidence is undermined (Merrow & Nandurdikar, 2018).

Recognize Patterns: Abstraction is the quality of dealing with ideas rather than specific events. This is part of the ability to recognize patterns across different disciplines, domains, or contexts. Recognizing patterns in past projects is critical to anticipate potential pitfalls and optimize decision-making (Flyvberg, 2017).

Solve Complex Problems: Finding solutions to difficult or complex issues. Megaprojects are complex, involve a wide variety of stakeholders, and require the integration of multiple disciplines. By their nature, they will generate many problems which need rapid solutions. In complex problem solving, knowledge exchange and transfer within and across social networks is critical and knowledge visualization is a primary tool for developing shared understanding as a foundation for generating new knowledge.

Innovate: Coming up with new ways to do things; making changes to methods, processes, and approaches. Innovative approaches are critical for overcoming the inherent complexities and uncertainties of megaprojects (Flyvberg, 2017).

Anticipate Future Situations: The ability to predict what will happen or be needed in the future; foresight. This is closely related to the Mindset capability of Vision/Goal Setting. The ability to anticipate future situations is vital for navigating the complexities and uncertainties inherent in megaprojects. Leaders with foresight can better plan for long-term outcomes and adapt to evolving project environments (Flyvberg, 2017; Shenhar & Dvir, 2007).

Interpersonal Skills

By their nature, megaprojects involve a diverse set of stakeholders, both internally to the team and externally. Every reference in the literature review cited the importance of successfully managing stakeholders for the success of large, complex projects. These are closely tied to the competencies necessary for Enterprise Technical Leadership (following section). Success depends on proactive communication, trust building, and frequent engagement (Van Wart, 2015). A wide variety of interpersonal skills are required for megaproject leaders, though they can generally be grouped into the three main competencies: Communication, Relationship Building, and Negotiation/Persuasion.

Communication: Fundamentally, communication is the ability to convey and receive information effectively. There is a wide array of communication skills, deadline with how you express yourself, understand others, and adapt your communication style based on the audience. Successful megaproject leaders must master all aspects of effective communication. Communication is a focused task of successful complex project leaders (Merrow & Nandurdikar, 2018). Active listening is critical. Listening to understand versus listening to respond is a reflection of openness in communication style (Gil & Lundrigan, 2012). Ability to convey complex information clearly and succinctly (UPenn, 2024).

Relationship building: The process of creating and maintaining connections with people to create a sense of team or to achieve a purpose. Strong relationships enable better communication, risk management, and conflict resolution (Merrow, 2011). Communication must be at a higher, more visionary level in megaprojects (Merrow & Nandurdikar, 2018).

Negotiation/Persuasion: Megaprojects by nature have a diverse community of stakeholders. There will be conflicts between stakeholders and conflicts of priority within the team (e.g., trade-offs between budget, schedule, and performance). Managing stakeholders calls for negotiating and diplomatic skills (Merrow & Nandurdikar, 2018). Megaproject leaders need to be able to bring stakeholders together on critical decisions (Hutchison et al., 2020).

Enterprise Technical Leadership

By their nature, megaprojects are large, complex temporary enterprises. They require enterprise leadership skills in addition to the technical leadership skills required to oversee successful innovation. Enterprise Technical Leadership skills are: Promote Learning Culture, Foster Openness, Collaborate, Demonstrate Trust, Resolve Conflict, and Coach and Mentor.

Promote Learning Culture: Create an environment that encourages and prioritizes gaining new knowledge and skills. Learning is rewarded. The megaproject leader provides an example of continuous learning. Creating a learning culture in the context of megaprojects is critical to adapt to complexity, improve performance, and foster innovation. A continuous learning culture is necessary to address complexities and unforeseen challenges (Flyvberg, 2017).

Foster Openness: Encourage a culture of openness and communication and be open to new ideas and perspectives. This is closely linked with the individual leader's open-mindedness. Openness is a core competency for handling complex project dynamics, fostering transparency, and building trust. Openness, particularly in sharing information and acknowledging uncertainties, is key to building trust and achieving project success (Merrow, 2011).

Collaborate: The ability to work with others to produce or create something is a critical aspect of megaprojects. Building a collaborative team is critical to megaproject success. Collaboration across stakeholders, contractors, and teams is critical to effectively managing the complexities of megaprojects effectively (Aarons, 2006; Flyvberg, 2017).

Demonstrate Trust: Effective megaproject leaders create an environment that actively shows that they believe their team acts in good faith and will do their best to help the project achieve its goals. Being a reliable leader is being someone people can trust. You follow through on plans and keep your promises. You say something, and then you back it up with actions. Being dependable means meeting deadlines, being honest, and coming through in the clutch (Royse, 2021).

Resolve Conflict: Conflict resolution is the ability to peacefully settle disagreements between multiple parties. Effective conflict resolution is critical for managing diverse stakeholder interest and maintain project alignment (Flyvberg, 2017).

Coach and Mentor: Help to develop leadership skills, foster collaboration, and enhance trust and performance. Teaching and mentoring are about a leader thinking less about his or herself and more about how the team and overall company. When leaders teach and mentor, they help their teams develop professional skills and what they need to succeed at their jobs (Aarons, 2006).

Selecting and Developing Megaproject Leaders

Merrow and Nandurdikar highlight the current problems with selecting megaproject leaders (Merrow & Nandurdikar, 2018). Most specifically, success on smaller-scale simpler projects is not a good predictor for success on large-scale complex projects. However, most organizations select megaproject leaders based on their performance on considerably smaller projects. How can we improve the selection of individuals for these critical roles?

First, it is critical that megaproject leaders have experience in the primary domain(s) and discipline(s) for the megaproject. Merrow and Nandurdikar highlight that the majority of effective megaproject leaders in their study had an engineering background (Merrow & Nandurdikar, 2018). Even those who had been program managers for several years often had at least an undergraduate education in a more technical area. Selecting for individuals who have depth in an area and breadth across others (a "T-shaped" professional) again will improve the probability that the individual will have the necessary skillset to successfully navigate megaprojects.

The "Big 5" personality traits of neuroticism, extraversion, openness, agreeableness, and conscientiousness can be a useful indicator of whether and individual has a personality appropriate to megaproject leadership (Roccas et al., 2002). In general, successful megaproject leaders score high in extraversion, openness, agreeableness, and conscientiousness and low in neuroticism. They also develop strong emotional intelligence (Merrow & Nandurdikar, 2018). By utilizing an existing and widely used tool like the Five Factor model as well as emotional intelligence measurement indicators, project sponsors and owners can understand the personal characteristics of potential leaders. Candidates who are less likely to be effective can be weeded out more rapidly.

The HelixEMP employability skills provide a measurable foundation of these skills in earlier career development and can be used to diagnose potential trouble spots in the skills and mindsets of program managers that may not make good megaproject leaders (McDermott et al., 2021). Critical Helix characteristics relevant to megaprojects include strong technical foundations (technical depth) that are expanding to multi-disciplinary and trans-disciplinary abilities (trans-disciplinary means collaborating across disciplines to create new knowledge). These are applied in domains and megaproject leaders build their depth of domain experience by expanding to new roles and working with new collaborators. They also develop knowledge in systems approaches that allow them to make decisions more holistically, leading to less rule- and plan-following and more adaptability to address uncertainties with flexible approaches. HelixSE found two core mindsets that aid in managing uncertainties: comfort with uncertainty and paradox mindset. These are both also measurable (McDermott et al., 2021).

Self-Leadership and Learning capabilities are associated with a person's orientation to learning—how they respond to risk, uncertainty, and challenge and their ability to purposefully learn their way forwards to design, engage, fail, and learn and generate new knowledge which improves or transforms the job to be done (McDermott et al., 2021).

Situational leadership (where effective leaders adapt their style to each situation) is the foundational model for team leadership and collaboration—associated with individual and group learning capacity as it is manifested in relationships between people who are aligned around achieving a shared purpose of value (McDermott et al., 2021). This adaptation is essential in team learning. As a leadership and management career evolves, time as an executive leader—particularly a change leader—helps to increase core leadership competencies.

Megaproject leaders tend to have mastered transformational leadership (inspiration and followership). Doherty stated well the outcomes of this development in her study of the Heathrow Terminal 5 Project, what they called the "10/100/1000 rule":

> [Ten] senior leaders whose personal presence, vision and good judgement put
> the project on a course for success, often challenging existing industry norms.
> Another 100 leaders who by making critical differences, taking brave stands,
> interpreting new ideas and frameworks, leading by example, and ultimately
> creating an operating environment that enabled others to be successful. Another
> 1000 leaders who given that context were able to swim with the tide and do their

leadership role in a demanding workplace that had little space for error. (Doherty, 2008)

Conclusions

Effective leadership is the cornerstone of successful megaproject management, distinguishing projects that deliver on their promises from those that fail to meet cost, schedule, or outcome expectations. This paper has identified a comprehensive framework of six key competency areas—ranging from domain expertise and personal characteristics to advanced interpersonal and enterprise technical leadership skills—that are crucial for megaproject leaders. The findings underscore that while technical proficiency and experience in managing complex systems are essential, they must be complemented by strong interpersonal skills, a strategic mindset, and the ability to navigate uncertainty and risk. Moreover, the analysis reveals that successful megaproject leaders are characterized not only by their expertise but also by their capacity for self-awareness, openness, and a paradox mindset. Organizations should focus on these competencies when selecting and developing megaproject leaders, moving beyond conventional criteria that emphasize experience in smaller projects. Ultimately, by cultivating leaders with the right mix of skills and attributes, organizations can significantly increase the likelihood of megaproject success, achieving transformational impacts on infrastructure and society at large. This research offers a critical roadmap for understanding the complexities of megaproject leadership and suggests pathways for improving project outcomes through more effective leadership selection and development strategies.

Acknowledgements

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