COMPLEXITY IN ENGINEERING PROCUREMENT & CONSTRUCT PROJECTS

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Has extensive senior management experience in setting up operational ‘best practices’ across a portfolio of projects. This includes the identification, creation, measurement and reporting of key performance lead indicators and translating them into easily understood insights.
This is the first article in a three-part series that will investigate how the field of complexity is applied in the Engineering, Procurement, and Construction (EPC) projects in the construction sector. In this first article, the basics of complexity will be translated into EPC projects. A risk trend of how the emergent impacts from complexity could generate cost volatility will be provided. These risk trends will highlight the fact that complexity is not a single characteristic of a project but a dynamic attribute that ebbs and flows over time.

In the second article these foundations will be used to create a toolkit for construction project directors and their teams. The toolkit will help identify when emergent risks may arise from complexity, and how to systematically tackle them. An enterprise governance framework will be created to complement the toolkit.

Finally, in the last article of the three-part series, the toolkit and framework will be aligned with modern digital practices to highlight how enterprise architecture strategies and key practices, including risk management, need to be modified in order to leverage the large data sets most companies now create.

**BASICS OF COMPLEXITY**

Any system where entities are interrelated can result in a dynamic, uncertain, and often ambiguous environment, with any events potentially creating unpredictable effects. Further, aspects of the system (such as levels of detail, properties, dimensions, states, probabilities of events, etc.) are not universal constants, but dependent on the observer / stakeholder frame of reference.

In the case of groups/parties of people working in these types of systems, the efforts of each party to collaborate, cooperate, and compete will also have an impact that is unpredictable. This unpredictability is due to the interdependence and dynamic interaction across the system of these groups/parties.

How and why does this unpredictability arise? Over time, there is the possibility that small interactions within the system will have a compounding effect and that this will create the emergence of a new property in the system. The event that creates the interactions between entities will have a non-linear impact on the system and the result will have a qualitatively different characteristic. Systems are co-creating their environment.

**COMPLEXITY IN PROJECTS**

The complexity of a project typically scales with the number of its elements, the number of interactions, the complexity of the elements, and the complexities of the interactions.

Following Remington & Pollack (2007), we identify four elements of projects:

1. **Hierarchy**: project systems have subsystems (in EPC projects subsystems of the Design function include cost planning, specifications, procurement, others)
2. **Information**: how well parties are communicating (in EPC projects this includes whether teams are co-located, project organisational structure, meeting protocols, etc.)
3. **Control**: the ability of the systems and teams to maintain stability (in EPC projects the Project Management Plan integrates all the other control systems, policies and procedures)
4. **Adaptiveness**: ability of the systems and teams to respond to change (in EPC projects adaptiveness is impacted by the capability level of the team and the level of bureaucracy)

Since these elements are interrelated, the dynamic interactions increase the unpredictability that any event will have on the project. Thus, a larger project will have a larger inherent attribute of complexity. Unpredictability in projects has two other contributors: 1) understanding the product of interactions of system parts and 2) the impact of “agents”.

5. **The essential or defining properties of a system are properties of the whole, which are the product of interactions between the parts, not from any individual part itself** (Ackoff & Emery, 2006).
6. Complex adaptive systems include “agents” that have the freedom to act in ways that are not always totally predictable and can change the context for other agents (Holden, 2005). In EPC projects agents can be anyone involved in the project: someone from the project team or an external stakeholder. Agents are also subject to biases which lead to deviations from rationality in judgement. In EPC projects, forecasting the remaining work for design drawings is often underestimated due to the impact that small changes have to the overall program.

Fortunately, complex adaptive systems do share certain fundamental behaviours (Gore, 1996; Lowe & Ng, 2006) which allow us to start to organise and manage them. These include emergence, adaptive self-organisation, and information processing.

- **Emergence** in project systems is where two or more elements, agents, or parties interoperate and produce a property or behaviour that none can produce on their own. These properties which cannot be predicted from prior knowledge of the agents, in turn affect the environment. Feedback loops create a multiplier effect that can accelerate this effect.

- Complex systems tend to adapt to their environment and can self-organise into more highly ordered states.

- Complex systems exhibit the ability to process information sensed from the environment and react to it based on internalised models. It creates interacting feedback loops, which cause highly non-linear behaviour.

**ENGINEERING, PROCUREMENT, CONSTRUCTION (EPC) PROJECTS IN THE CONSTRUCTION SECTOR**

The lifecycle of an asset has many phases including: Concept, Development, Design, Construction, Commission, Operation, and Decommissioning. The Design phase usually includes Engineering and Procurement activities. This article will focus on Design, Construction, and Commissioning phases of projects.

Engineering or Design: This phase usually interfaces with the Concept or Development process which generates the project brief and is the pre-cursor to an EPC project being initiated. Planning, product design, innovation from the supply chain, and risk and opportunity optimisation are key activities that define this phase.

Construction: This phase is primarily defined by the focus on disciplined delivery and creating certainty in the commercial outcome of the project. It also incorporates procurement.

Commissioning & Start-up: This phase is the validation and verification of what has been designed and delivered. Requirements can be driven by the customer (e.g. fit for purpose), certifiers (e.g. fire, electricity), authorities (e.g. state or federal), or other stakeholders (e.g. equipment supplier, user groups).

Figure 1 demonstrates an indicative project life cycle phases by project effort (defined as “cost to complete”).

![Figure 1: EPC project life cycle phases](image)

The phases of an EPC project overlap, with most work inter-related and taking place in parallel and (usually) managed through a sophisticated governance system. An example of the inter-relation between Design and Construction phases is the design buildability process which ensures that work methods are integrated into technical solutions.
COMPLEXITY IN EPC PROJECTS

While a general indication of complexity can be identified at inception, feedback loops, social dynamics, and health of systems will dramatically alter how a project reacts to an event or any other change. The interplay of two or more aspects of a system over time will also increase the risk of a compounding effect taking place, adding to the complexity of the project.

Numerous models and frameworks have been proposed for complexity including Mitleton-Kelly’s Ten Principles (2003), Curlee and Gordon (2011), Oberthur and Stokke (2011) and many others. Remington & Pollack define complexity by four key attributes:

1. Structural: difficulty in managing and monitoring many different interconnected tasks and activities.
2. Technical: unique design challenges or techniques without precedents.
3. Directional: hidden agendas, mis-aligned goals, or poor project definition.
4. Temporal: shifting environmental conditions outside the control of the project team

In EPC projects, assumptions can be made of how likely inputs to a scenario will result in a compounding effect occurring, which in turn contributes to the complexity of the project.

In the following sections we bring together all the concepts defined in this paper. The inputs inherent in EPC projects will be overlayed with the aspects of complexity and the four attributes of complexity will be used to define the output risk profile.

1. STRUCTURAL COMPLEXITY TREND IN EPC PROJECTS

Structural complexity is a result of a project having many different interconnected tasks and activities. The key factors in an EPC project that contribute to this characteristic are:

In the early Design phase, complexity risk is driven from interfaces with external stakeholders:
- Numerous State and Federal authorities
- Capacity upgrades for infrastructure and utilities
- Understanding community impacts (e.g. pedestrians & vehicles)

In the Construction phase, complexity risk is driven from the large number of tasks:
- Size of the project and peak effort level
- Time constraints potentially driving an increase in work fronts
- Size of the project team
- Complex supply chains devolving responsibility for competence
- Access, logistics, progressive staging

In the Commissioning phase, complexity risk is again driven from interfaces with external stakeholders:
- Independent certifications (fire services, electrical, water, etc.)
- Fit outs and equipment
- Customer validation and verification requirements

Figure 2 demonstrates a probable risk trend of structural complexity.

![Figure 2: Structural complexity risk trend in EPC project life cycle phases](image-url)
2. TECHNICAL COMPLEXITY TREND IN EPC PROJECTS

Technical complexity is a result of a project having unique challenges without precedents. The key factors in an EPC project that contribute to this characteristic are:

- Most technical challenges are identified and managed in the Design phase. The heightened complexity comes from the need to support discovery while maintaining a schedule.
  - Ambiguity around alternative options
  - Communications between highly skilled individuals
  - Integration of solutions into the larger system
  - Impacts on existing infrastructure
- In the Construction phase, complexity risk is driven from the secondary impacts of scope changes.

Figure 3 demonstrates a probable risk trend of technical complexity.

![Figure 3: Technical complexity risk trend in EPC project life cycle phases](image)

3. DIRECTIONAL COMPLEXITY TREND IN EPC PROJECTS

Directional complexity is a result of a project having unclear or competing goals or political agendas. The key factors in an EPC project that contribute to this characteristic are:

- Leadership impact on the project team forming process. This is more pronounced in the start-up of the Design and Construction phases.
- Identities of key personnel and their ability to react to challenges both individually and as a team
- Tensions between desires for design innovation and minimizing risks in delivery
- In the Construction phase, complexity risk contributors include:
  - Project sub-teams are continuously forming to deliver various scope elements
  - Contracting mechanisms at play
  - Supply chain robustness

Figure 4 demonstrates a probable risk trend of directional complexity.

![Figure 4: Directional complexity risk trend in EPC project life cycle phases](image)
4. TEMPORAL COMPLEXITY TREND IN EPC PROJECTS

Temporal complexity is a result of a project’s uncertainty in the anticipation of a shift in environmental conditions. The key factors in an EPC project that contribute to this characteristic are:

- Robustness of change management processes
- Agility of the project team (structure, protocols, and decision rights)
- Social interactions with stakeholders and experts, with each reacting to information potentially resulting in the emergence of new behaviours
- Turnover rate of key leadership roles
- Supply chain performance and power dynamics

Figure 5 demonstrates the risk trend of temporal complexity.

CONCLUSION

Complexity is not a single characteristic of a project; it is a dynamic attribute that ebbs and flows over time. Aligning project governance and oversight efforts to this rhythm will allow a business that manages a portfolio of projects to improve how they perceive and react to the various risks that this complexity poses. A framework of business and EPC project tools can be created, each relevant to the lifecycle phase and type of complexity. This framework will be the focus of the next (second) article in this three-part series.
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