NAC Executive Insights

Fragility

Key Points

- Fragility in project execution networks is defined as the ability to remain stable after perturbations at the "edges" of the project or to the internal network structure.
- As fragility increases, the project's robustness or ability to handle a wide range of significant variations decreases.
- Fragility emerges from increasing correlation across the project execution system.
- Fragility of construction execution networks is realized in several ways, ranging from management frustration, extensive rework, and the inevitable increased owner's oversight.
- Factors impacting productivity are leading indicators of potential future fragility.
- Reducing fragility starts with a recognition that quantification of outcomes through probabilistic risk analysis provides a false sense of confidence.
- Resistance to fragility must be built into the project.
- Fragility in project execution is realized by the interaction between normal activity duration uncertainties and management actions to respond to schedule slippage.
- Failure emergence can be detected in pattern formation that is detectable using today's artificial intelligence (AI) tools.
- As stakeholder engagement increases, the boundary conditions of the project change and the new expanded system (system of systems) exhibits increased robustness.

Introduction

While the final deliverable from a major construction project may be robust and, even better, resilient, the process of delivering that project all too often proves to be fragile.

The best people are deployed. The latest best practices are used. Yet the best planned and resourced projects often come off the rails, failing to deliver the project execution results that have been sought. This Executive Insight looks at some of the causes of fragility in construction projects and recommends what can be done to make them less fragile.

What is Fragility?

Fragility in systems, including project execution networks, is defined as the ability of the system to remain stable after perturbations at the "edges" of the project or to the internal network structure.

In an ideal situation, project execution approaches are less fragile (more stable even with disruptions), but also are more responsive (higher performance; sensitive to changes) to both internal and external stimuli. In other words, the project readily adjusts to change with a very low risk of coming off the rails.

Unfortunately, as one looks at both natural and technological systems, this is not the case. Networks, such as a project execution network, that are responsive (sensitive to change) also tend to be fragile; the more they are optimized for performance, the more fragile they become. That is, they are more likely to experience extreme blowouts in cost and schedule.

As fragility increases, the project's robustness or ability to handle a wide range of significant variations decreases. Conversely, a highly robust system, one able to sustain itself in the face of extreme risks and change, has low fragility and in the extreme would be viewed as antifragile, to adopt the terminology of Nassim Taleb.[1] Antifragile systems adapt when a failure occurs, exhibiting resilience and learning from failures.

The link between complexity and fragility can be seen in the all too frequent large project blowouts.

Figure 1 illustrates these relationships[2] between fragility, responsiveness, robustness, and complexity.

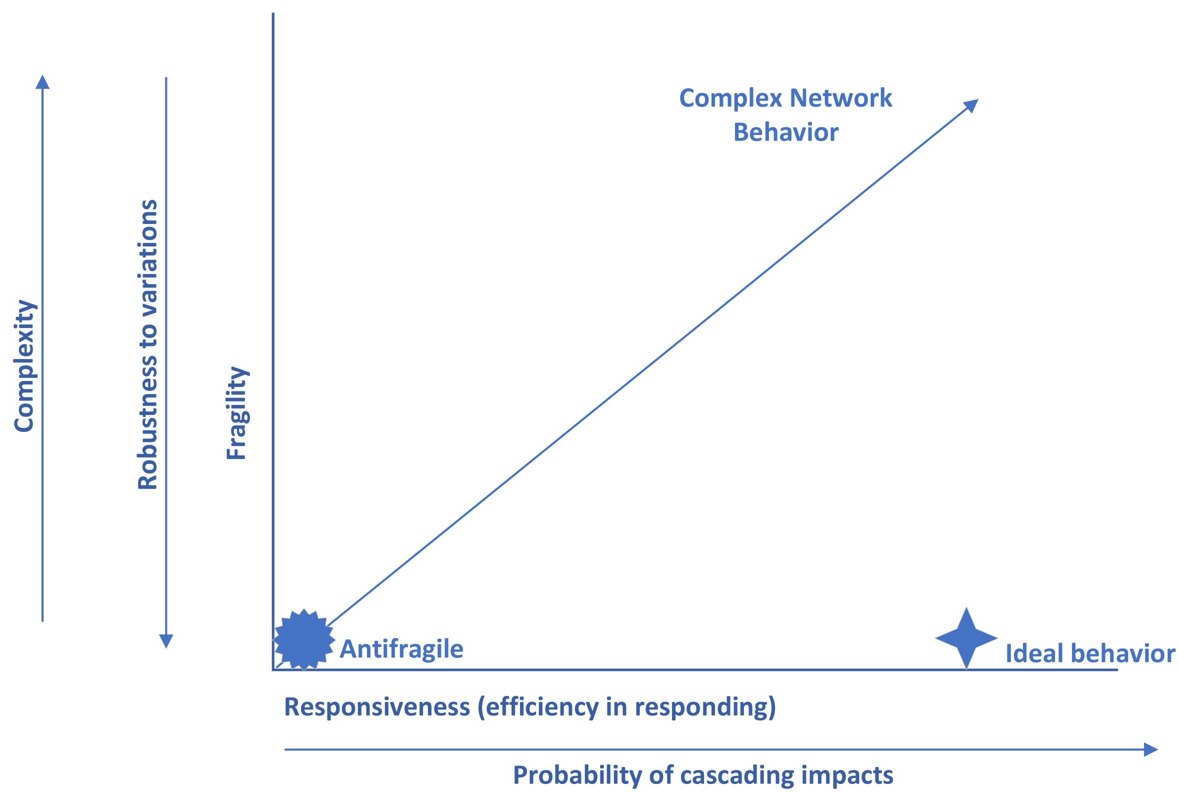

Figure 1. Hidden fragility

[1] Antifragile: Things that gain from disorder; Nassim Taleb
[2] A linear relationship is not implied in the chart.

What Causes Project Performance to be Fragile?

Fragility emerges from increasing correlation across the project execution system.[3] It can be the result of several factors. It is a property of complex systems and results in exponential amplification of even small effects. These include:

- Weak project governance[4] settings
- Inadequate owner readiness[5]
- Complex project execution networks with high degrees of task and constraint coupling (tight coupling[6]) and associated rapid propagation of information throughout the project execution network
- Inadequate stakeholder engagement[7] [8]
- Moral hazards where the creator of the risk does not bear the full cost (leads to Black Elephants[9])

Each of these factors, and likely others, contributes to the disruption in the planned sequence of construction execution.[10] The realized disruptions fall outside the forecast duration distributions used in constructing the project's construction schedule. These changed durations can be dramatically different than those used in baseline schedule construction. Even disruptions off the critical path can impact overall schedule performance as they impact the overall project through changed resourcing schedules, constraint coupling, and precedence linkages.

Even small but compounding disturbances can have an outweighted impact on overall project execution performance as schedule pressures mount. Efforts to return the project to the baseline often lead to a "sawtooth" management response that further degrades productivity and amplifies overall degraded performance.

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[3] As the number of components/activities in a project execution system grows, the system failure rate grows though at a slower rate than the sum of the individual failure rates.
[4] https://www.naocon.org/wp-content/uploads/Governance-Under-Program-Management.pdf
[5] https://www.naocon.org/wp-content/uploads/Owner-Readiness.pdf
[6] https://www.naocon.org/wp-content/uploads/Coupling-in-Large-Complex-Projects.pdf
[7] Keeping complexities away from public debate denies the project protection that would result when extreme events arise. It reduces the robustness of the project to variations, increasing fragility.
[8]https://www.researchgate.net/publication/273119019_Stakeholder_Management_in_Large_Engineering_Construction_Programs#fullTextFileContent
[9] https://www.researchgate.net/publication/343425486_Black_Elephants
[10] https://www.naocon.org/wp-content/uploads/Out-of-Sequence-Construction.pdf

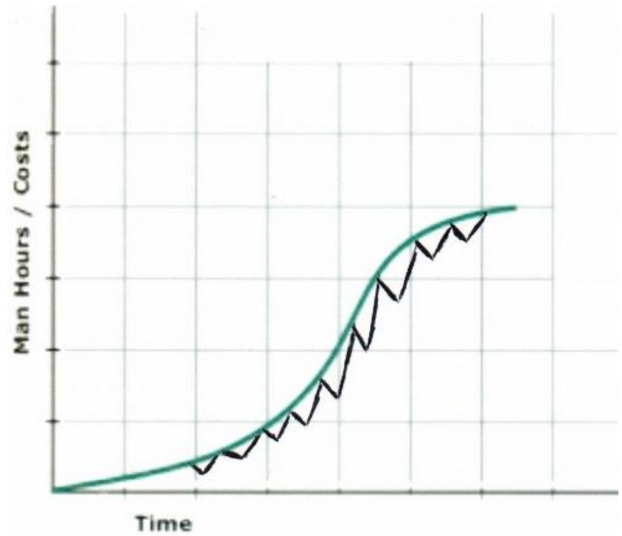

Figure 2. Sawtooth pattern

Contingency and risk provisions[11] are no longer realistic as this degradation in performance cascades through the project network. Importantly, impacts and effects are nonlinear and are further aggravated by the presence of multiple precedences and excessive coupling of activities.

Fragility of construction execution networks is realized in several ways, ranging from management frustration, extensive rework,[12] and the inevitable increased owner's oversight. Perhaps the best measure of the fragility a project execution plan is experiencing can be seen in changes in productivity.

Table 1 provides a partial listing of factors impacting productivity. These causal factors are leading indicators of potential future fragility in project execution and have been broadly grouped into foundational factors,[13] flow[14]/execution factors, and stakeholder-related factors.

Table 1	
Factors Impacting Productivity	
Foundations	• Inadequate or incomplete project execution foundations
	○ Lack of SBO (Strategic Business Objectives) clarity, agreement, and communication
	○ Owner readiness, including governance inadequate for project
	○ Risk identification, models, and modeling insufficient for project scale and complexity
	○ Incomplete scope
	○ Flawed project baseline

[11] https://www.naocon.org/wp-content/uploads/Contingency-vs.-Management-Reserves.pdf
[12] https://www.naocon.org/wp-content/uploads/Rework-in-Engineering-and-Construction-Projects.pdf
[13] https://www.naocon.org/wp-content/uploads/Foundations-for-Success.pdf
[14] https://www.naocon.org/wp-content/uploads/Flows-in-Large-Complex-Projects.pdf

Table 1	
Factors Impacting Productivity	
	○ Project plans lack robustness and adequate process and procedures
	• Complexity not assessed, planned for, or adequately managed
	• Inadequate project management and supervisory personnel and skills
	• Reduced workday due to labor logistics
	○ Security or other screening
	○ Lack of proximate labor accommodations (contractor provided)
	○ Inadequate labor support facilities (break rooms; changing rooms; mess; sanitary facilities)
	○ Unplanned PPE (personal protective equipment) requirements (masks; coincident proximate hazardous activity or operation)
	• Inadequate site and project infrastructure
	• Inadequate change management plan and process
	• Weak or delayed decision making
Flows	• Project disruption
	• Out of sequence work
	○ RFIs (Requests for Information)
	○ Equipment shortages or delays
	○ Rework due to poor quality control
	○ Field rework of fabricated items
	○ Scheduling conflicts
	○ Owner or regulator imposed holds
	• Late delivery of bulk materials
	• Late delivery of major equipment
	• Inadequate site material management methods and practices (identification, tracking, location, and retrieval of project equipment and material)
	• Inadequate labor resources or lower skilled than planned (weak human resource management)
	• Weather delays or work shifted into seasonal bad weather
	• Unavailability/substitution of planned construction equipment (including weak onsite maintenance practices)
	• Unanticipated execution complexity/sequencing
	• Congestion and overcrowding at workface
	• Congestion in or inadequately planned or managed logistical activities
	• Intermittent versus continuous work for crews or trades
	• Unplanned/intermittent temporary works

Table 1	
Factors Impacting Productivity	
	• Interferences from parallel work originally planned as serial
	• Poor jobsite conditions or housekeeping
	• Inadequate communication and information flows
	• Inspections not adequately provided for in project schedule
Stakeholders	• Weak project and site culture
	○ Negative attitudes and poor engagement
	○ Weak safety culture
	○ Weak skills and practices related to conflict management
	• Negative stakeholder relations
	○ Inadequate stakeholder engagement
	○ Lack of transparency

Hidden Fragility Limits Performance

Hidden project fragility limits performance, especially in complex projects. Think of this as the "ghost in the machine." Yet systems are able to deal with high degrees of complexity and uncertainty and yet not experience frequent extreme behaviors from disruption. Examples include the airline industry and air traffic control system in North America (airlines are stronger after a plane crash because the industry and vendors learn and adapt); commercial nuclear power (which improves through rigorous examination of each off-normal event); and human immune systems that grow stronger after each viral exposure and vaccine.

Reducing Fragility

Reducing fragility must start with a recognition that quantification of outcomes through probabilistic risk analysis provides a false sense of confidence regarding the degree of control that exists over project execution. While provisions for "off-normal" behavior may exist, it is not necessarily correlated to a reduction in uncertainty. The estimation and provision for rare events or complex behaviors is limited at best. Analogs for uncertainty reduction are founded on risk elimination (safety by design; elimination/minimization of high-risk activities such as work at height) and failing safe (think a dead-man's switch) such that an inability to complete one activity does not cascade through the project execution network.

Resistance to fragility must be built into the project including:

- Resisting the tendency to return to the baseline (disruptive sawtooth pattern in Figure 2).
- Accounting for systemic risk[15] factors, including Black Elephants.

[15] https://www.naocon.org/wp-content/uploads/Systemic-Risks-in-Large-Complex-Programs.pdf

- Ensuring robust scope[16] definition.
- Undertaking scenario-based planning.
- Developing and refreshing pre-planned contingency execution strategies.
- Precedence and coupling minimization.
- Multiple, flexible work fronts (modularization and preassembly).
- Inoculating the project, to the degree possible, to the potentials of systemic risks through involvement of stakeholders on the acceptability of risks (transparent and constant feedback).
- Clear division of responsibilities with independent quality[17] [18], safety,[19] and management oversight and audit.[20]

Fragility in project execution is realized by the interaction between normal activity duration uncertainties and the management actions to respond to schedule slippage. The project must be reset and the path forward replotted much like a sailor blown off course (Figure 3). Failing to do so allows the project to randomly reach a new and likely unacceptable equilibrium.

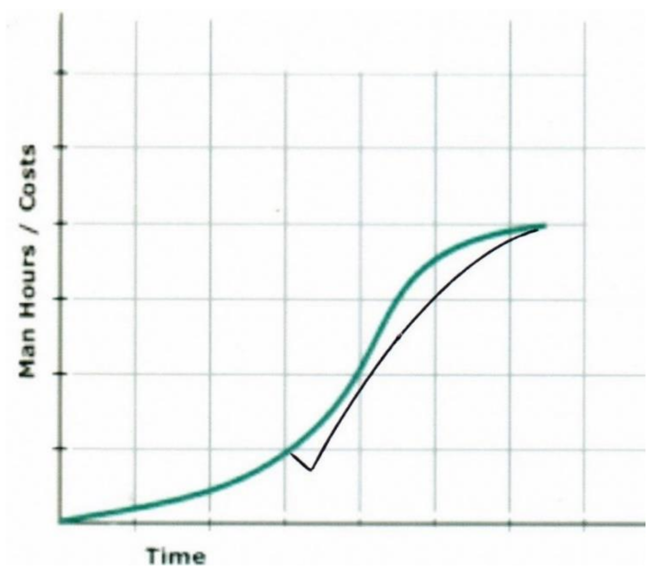

Figure 3. Replotting the course

[16] https://www.naocon.org/wp-content/uploads/Know-What-You-Are-Trying-to-Accomplish-The-Primacy-of-the-Scope-Baseline.pdf
[17] https://www.naocon.org/wp-content/uploads/Redefining-Quality.pdf
[18] https://www.naocon.org/wp-content/uploads/Quality-Transformation.pdf
[19] https://www.naocon.org/wp-content/uploads/Safety-Through-Design.pdf
[20] https://www.naocon.org/wp-content/uploads/Project-Pitfalls-or-The-Audit-Report-You-Never-Want.pdf

Detecting the Emergence of Fragility

When inoculation to prevent or reduce the likelihood of fragility falls short, all is not lost. Failure emergence can be detected in pattern formation that is detectable using today's AI tools,[21] [22] [23] where weak signals, often seen in volatile fluctuations of both signal and noise, are telltale signs. As the system becomes more volatile, it also becomes more responsive and more susceptible to external changes arising from stakeholder domains. This confirms the increased impact that stakeholder actions appear to have in failed projects that have experienced significant performance degradation. Because of the emergent nature of fragility, it cannot be predicted in advance. Earlier detection, however, is possible and is aided by improved modeling.

As robustness is built through increased stakeholder engagement, effectively the boundary conditions of the project change and the new expanded system (system of systems) exhibits increased robustness (lower fragility) and can evolve. Fragility of the project system is compensated for through greater robustness of the broader stakeholder system. The system of systems assesses its real-time situation and adapts in response to events that were not completely known at project initiation. (See Figure 4.)

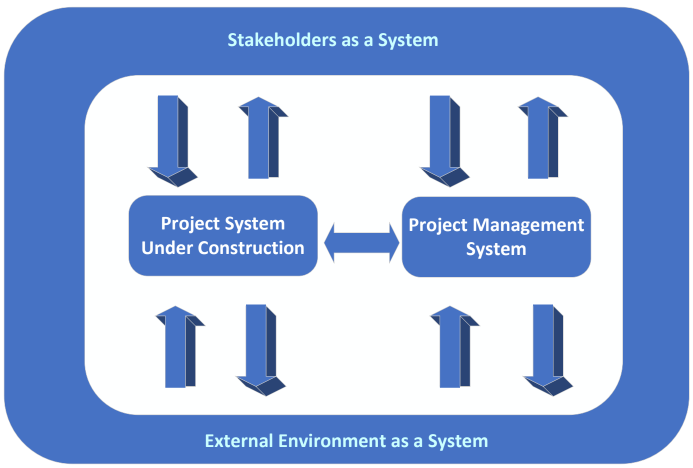

Figure 4. Expanded System of Systems Perspective Reduces Fragility

Detecting the emergence of fragility requires the project organization to remain open to further innovation[24] and adaption. As project executions stabilize, they act to constrain change and, with it, innovation and adaptation, the very traits needed to avoid a catastrophic collapse in performance. Successful performance acts to hide the very fragility that is most detrimental.

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[21] https://www.naocon.org/wp-content/uploads/Impacts-of-Artificial-Intelligence-on-Management-of-Large-Complex-Projects1.pdf

[22] https://www.naocon.org/wp-content/uploads/Artificial-Intelligence-Ethics-in-the-Project-Management-and-Civil-Engineering-Domains.pdf

[23] https://www.naocon.org/wp-content/uploads/Proper-Reliance-on-Artificial-Intelligence-in-Project-Management.pdf

[24] https://www.researchgate.net/publication/270283446_PM_World_Today_-_February_2011_Vol_XIII_Issue_II_Systemic_Innovation_and_the_Role_of_Program_Management_as_an_Enabler_in_the_Engineering_Construction_Industry_Is_the_Engineering_Construction_Industry_

The potential exists to improve outcomes through the use of system models analogous to the digital twins associated with physical elements of the project. Integration of 4D digital twins with dynamic systems models holds promise. Near-misses in execution hold the same potential for improvement that near misses in safety do.

Conclusion

Fragility is a major contributing factor to significant project cost and schedule performance blowouts. Owner and project preparation are key factors influencing fragility, as is stakeholder engagement. Developed construction execution activity networks, however, are also a significant contributing factor as complexity and fragility are closely linked.

Fragility, while not a property of scale or project duration, is a key consideration in large, longer duration projects. The concerns arise from an increased prevalence of highly coupled sets of activities. Fragility emerges from increasing correlation across the project execution system. Similarly, while project duration does not directly lead to fragility, it does act as a risk aggregator that may increase overall susceptibility.

As fragility increases, the project's robustness or ability to handle a wide range of significant variations decreases. Reducing fragility starts with a recognition that quantification of outcomes through probabilistic risk analysis provides a false sense of confidence. Resistance to fragility must be built into the project. Factors impacting productivity are leading indicators of potential future fragility.

Fortunately, as stakeholder engagement increases, the boundary conditions of the project change and the new expanded system (system of systems) exhibits increased robustness.

About the Author

Bob Prieto was elected to the National Academy of Construction in 2011. He is a senior executive who is effective in shaping and executing business strategy and a recognized leader within the infrastructure, engineering, and construction industries.