NAC **Executive Insights**

Coupling in Large Complex Projects

Key Points

- Tight coupling creates new risks in large scale projects and such risks are not well understood.
- Nine classes of coupling in large complex projects are defined.
- The greater the coupling between activities, the greater the complexity and likelihood of propagating disruptions.
- Classes of couplings that tend to forward changes from other classes are more disruptive.
- A key strategy to manage complexity is through systematic decoupling of activities.
- Temporal coupling (simultaneous undertaking of two or more activities) represents a new risk.

Introduction

The relationship between complexity and modularity of “systems” mirrors that of nature, where complex systems reward modularity and its ability to limit the effects of perturbations while at the same time recognizing that excessive modularity exposes the system negatively to the effects of even stronger, more systemic perturbations. The same is true for large complex projects.

Coupling refers to the interdependencies between activities where modules may be considered a special activity type. Precedence and unnecessary coupling of activities may harm a project’s performance in ways that may not be evident on initial inspection. Additionally, these flows are not static or predictable.

A key factor in understanding the risks associated with complexity involves understanding and assessing the various types of coupling to which a project is susceptible. Tight coupling, for example, creates new risks in large scale projects. This action is not yet adequately understood or managed. More traditionally sized projects, by contrast, are less susceptible. Coupling in large complex projects can be classified, and a classification system that recognizes the potential interaction between various classes of coupling is presented later in this Executive Insight.

Classes of Coupling

Nine classes of coupling in large complex projects can be defined as follows:

- **Control Coupling** – This is represented by the normal control flows that guide project execution and work activities (illustrated by arrows on a Gantt chart or on a work breakdown structure

(WBS). The control flow arrows are not dimensionless. A clear and comprehensive understanding of the assumptions, data, and interfaces implicit in the control flow must be made explicit for effective management. Data dictionaries and structures must be coherent and comprehensive to achieve effective control flows. Additionally, Strategic Business Objectives (SBOs) and clearly linked Key Performance Indicators (KPIs) must cascade throughout the control network. Traditional barriers to efficient workface activities include: waiting for information (knowledge); direction/decisions (importance of the value of time not clearly established); and materials and other resources, including completion of coupled tasks (this highlights importance of decoupling).

- **Co-dependent Coupling** – Interdependency between activities are such that a change in the data, outputs, or execution of one activity necessitates a change in a second activity. For example, excavation and dewatering activities are linked where a change in dewatering rates or volumes may influence excavation or ground stabilization and improvement activities.
- **Assumption Coupling** – Multiple activities share global assumptions, data, or other values. A change in assumptions, including through assumption migration, impacts multiple and otherwise disparate activities. Examples include assumed labor productivity improvement through the project, customs clearing times, or client approval cycles.
- **Constraint Coupling** – Also may be considered as shared resource coupling, where temporal or more systemic constraints may occur in a resource common to execution of multiple activities. Competition for resources with fixed supply rates (at least in the short term) is exacerbated by ex-project changes in demand.
  Second or third order constraint coupling is not easily visible in "complexity" and can result from non-critical-path activities without direct critical path dependencies. (Second or third order constraint coupling examples include constrained resources such as those found in a logistical chain impacted by remote non-project events; shortage of English to French technical translators at the required time because of other demands not foreseen; restricted access from preclusion of working underneath a crane staging materials for another unrelated task or contractor.) This in turn impacts critical path performance or bring about impacts from second or third order external phenomena. (Think about how the U.S. foreign exchange rate impacts oil price, capital expenditures, and national economies.)
- **External Coupling** – Multiple activities require externally-imposed inputs, controlled resources, approvals, or other interfaces. Permits and inspections exemplify external couplings. Changes in externally-imposed requirements may impact multiple activities. Added compliance requirements often associated with large complex projects (increase in percentage of work required to be performed by disadvantaged contractors in a robust local market as an example) may provide an unintended coupling of various management and other tasks with the unintended consequence of adding to project complexity.
- **Stakeholder Coupling** – This differs from external coupling since flows from these couplings are not imposed yet carry the risk of being less manageable and potentially more consequential. Stakeholder coupling impacts both activities as well as the connecting flows.

- **Message Coupling** – Messages, generally from management centers, are transmitted formally or informally throughout the project execution network, including to portions for which the message was never intended. This may cause unintended actions and consequences.
- **Temporal Coupling** – Simultaneous undertaking of two or more activities. Risk arises as a result of any temporally based constraint coupling. Multiple projects, carefully staged to spread out welder demand, fail when project schedule slippages push demand into the same time frame. **Uncoupling** – Describes the lack of apparent couplings of any kind between modules (physical or related packages of work). Module to module coupling may occur as a result of any of the classes of coupling described above.

The greater the coupling between activities, the greater the complexity and the likelihood of propagating disruptions. Standardization of systems, structures, components, and work processes and decoupling of activities that can be undertaken independently are essential. Precedence must be reduced and work plans must facilitate contingent execution.

Contingent execution requires increased awareness of actual or potential direct or indirect coupling, such as can happen when flows are coupled by second or third order constraints.

It is likely that the greater the number of classes of couplings present, then the greater the management challenge and the greater the risk of disruption. Additionally, classes of couplings that tend to forward changes from other classes are more disruptive.

Table 1 shows the classes that a given class of coupling may impact. Here we note that stakeholder type couplings are likely to be the most impactful from an overall disruption perspective. Instability measures reflect high forward coupling by particular classes of couplings. In effect, these are couplings which themselves may be susceptible to the effects of other couplings and more likely to translate those effects and pass them on.

Table 1
Relationship between Classes of Couplings

		Affected Classes									
		Control	Co-dependent	Assumption	Constraint	External	Stakeholder	Message	Temporal	Uncoupling	Total
Source of Inputs	Control	X	X					X		X	5
	Co-dependent	X	X						X		3
	Assumption	X	X	X	X			X	X	X	7
	Constraint	X	X	X	X			X	X		6
	External	X	X	X	X	X		X	X	X	8
	Stakeholder	X	X	X	X	X	X	X	X	X	9
	Message	X	X			X	X	X	X	X	7
	Temporal	X	X	X	X	X	X	X	X	X	9
	Uncoupling	X		X	X		X			X	5
	Total	9	8	6	6	4	4	7	7	7	

Cohesion, by contrast, looks at the range of actions that occur within a given activity and makes a judgement as to how related they are. For example, if a given activity requires painting all east-facing walls blue and changing washers in all four-inch valves, we would describe its cohesion as low. By contrast, an activity that requires welding flanges and making all connections in a particular fluid system would be viewed as having higher cohesion.

Table 2 synthesizes the relationships to define those classes of couplings most likely to contribute to project disruption. The ratio of stability to instability (# Incoming/# Outgoing or I/O) provides a relative measure of the contribution to disruption from various classes of couplings. Also, Table 2 shows an initial ranking of the classes with respect to their potential to broadly disrupt planned execution of the project.

Table 2
Ranking of Coupled Class Contribution to Disruption

	# Incoming (I)	# Outgoing (O)	Total (T)	Instability O/T	Stability I/T	I/O	Low to High Impact
Control	9	5	14	0.36	0.64	1.80	2
Co-dependent	8	3	11	0.27	0.73	2.67	1
Assumption	6	7	13	0.54	0.46	0.86	6
Constraint	6	6	12	0.50	0.50	1.00	5
External	4	8	12	0.67	0.33	0.50	8
Stakeholder	4	9	13	0.69	0.31	0.44	9
Message	7	7	14	0.50	0.50	1.00	4
Temporal	7	9	16	0.56	0.44	0.78	7
Uncoupling	7	5	12	0.42	0.58	1.40	3

Decoupling

A key strategy to manage this inherent complexity is through a systematic decoupling of activities that can be undertaken independently. Table 3 describes decoupling on a real-world project. It contrasts the original plan with the decoupled plan. Overall schedule was improved by 20 percent through a conscious decoupling of major elements of work that had previously been bundled to “simplify” project execution. The law of unintended consequences was clearly evident.

Table 3. Decoupling a Project

Original Plan

- Single design/build project for underground transit extension including several new stations.
- Tunnel to be developed by tunnel boring machine (TBM) with completion time four years after contract award considering lead time for TBM plus tunneling period.
- Systems to reflect latest available technology as of one year prior to installation or to be modified for compliance if ordered at an earlier point in time by contractor
- Stations have strong structural/architectural interfaces with surrounding structures and community. Approvals of station designs and egress points need extensive consultation and may take two years to complete.
- Award of contract paced by station approvals to secure a single fixed-price for project.

Decoupled Plan

- Pacing project element are stations' consultations and approvals. Coupling start of civil/structural work to these approvals delays start of project. Civil/structural design/build are decoupled from overall package and initiated while station consultations and approvals are underway. Work begins on project two years earlier.
- Systems work is packaged as a separate design/build package since no systems work can be completed until TBM finished and removed from tunnel. Equipment can be procured two years later than under the single design/build package approach, providing one generation later technology and eliminating cost and uncertainty of modifications.
- Station finishes can be separately procured without impacting schedule.

This decoupling of major elements also should consider careful elimination of any precedence to increase the opportunity for contingent execution, which is a reality of large project execution.

Other Aspects of Coupling on Large Projects

In general, for large complex projects, project requirements must reflect not just final "task" states, but also the coupling transformative flows.

Temporal coupling now represents a new risk point given the various influencing flows that a large complex project faces. (Consider two tasks, one delayed by externally created influencing flows that wish to access the same space or critical, scarce resources at the same time. For example, this could be late installation of an externally delayed critical plant component requiring use of the main "alley" that is used for final commissioning activities.)

Strong and often unseen coupling within the project system offers us a chance to understand where indirect coupling should be made into direct coupling (because we can witness improvements in outcomes as we strengthen select links; an example might be tighter integration of supply chains) and importantly where we should seek to decouple transformative activities that do not require to be linked.

Interrelationships between stakeholders and project actors provide a coupling and reinforcing mechanism that warrants increased attention and monitoring. Such interrelationships influence the existence and strength of interdependences, but also can be exploited for resolution of coupling constraints.

As we more tightly link supply chains into project processes, we begin to see some of the flow considerations that are core in the realm of logistics as being analogs for efficient project management. Precedence and unnecessary coupling of activities may harm a project's performance in ways that may not be evident on initial inspection.

Assessment of project complexity, especially the inherent coupling likely to be present, is intended to help evaluate alternative execution approaches and provide guidance on the confidence we should have in planned or predicted results.

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.