NAC Executive Insights

Flows in Large Complex Projects

Key Points

- The theory of projects is built on several precepts on the transformation of inputs to outputs and its tasks being well-bounded. This Executive Insight challenges some of these precepts on large complex projects.
- Flows represent the transfer of "something" from one place to another, and a partial listing of flows impacting large complex projects is provided.
- Three types of flows are presented:
    1. *Transformative Flows* include those in discrete tasks representing parts of the decomposed project. They also include the outputs of one or more tasks becoming inputs for subsequent tasks.
    2. *Influencing Flows* arise from large stakeholder influences; emergence of new outcomes and stakeholders over extended delivery timeframes and lifetimes; and the sheer number of ex-project inputs and assumption drivers.
    3. *Induced Flows* arise from the interaction of *Influencing Flows* and the eddies they create with planned *Transformative Flows*. These eddies and Induced Flows can arise suddenly, be highly disruptive, and disappear just as suddenly.

Introduction

This Executive Insight focuses on the "flows" present in all projects. The emphasis here is on flows that large complex projects experience. We will briefly review the "theory of projects," define the concept of "flows," and provide examples. We also will describe three different types of flows experienced by large complex projects. Recommendations are offered on how to better assess the potential for disruption from these flows and strategies are outlined to mitigate their effects.

Theory of Projects

The existing theory of projects goes back to the emergence of management theory associated with industrialization. Projects in that early era were largely executed within the four walls of a new industrial facility employing serial manufacturing, progressively moving a series of inputs towards an ultimate output. At each step of the manufacturing process an output from a prior step was further transformed.

Frederic Taylor in *The Principles of Scientific Management* laid out a series of management principles that in many ways mirrored many aspects of the manufacturing process itself. Among these principles

was a division of work, a decomposition of efforts if you will, undertaken by trained workers in a prescribed and specified way. Henry Gantt, who worked for Taylor, extended this thinking into the execution of projects.

The prevailing theory of projects that resulted was built on several precepts regarding the transformation of inputs to outputs. Those precepts include:

- A comprehensive set of requirements at the outset of the project that can be decomposed with the work to be executed.
- Independence of discrete and *bounded* tasks (except for sequential relationships).
- A high certainty of the requirements to be met.
- Clarity on how the tasks are to be performed.
- The totality of work to be performed can be described by a top-down decomposition of the transformation effort.

Extensions to the classical theory of projects have emerged (lean, agile, extreme project management) and comments on these are offered at the end of this Executive Insight.

Now we will focus on two aspects of classical project management theory that the author has found lacking in large complex projects: (1) the recognition of only one type of "flow," the *Transformative Flow,* and (2) the notion of tasks and projects as being well-bounded.

Regarding Gantt's perspective as the classical theory projects was evolving, projects at that time certainly were occurring within the four walls of a new industrial plant. In addition, the owner, plant manager, and client project manager often were the same individual. The four walls did provide a well-bounded setting with external influences limited and likely nonexistent.

Today's large complex projects take place in a very different setting.

Concept of Flows

In the world of Gantt, work progressed steadily from left to right on his now famous Gantt charts. Whether it is those classical Gantt charts or the modern work breakdown structures, we see a series of tasks connected by dimensionless arrows. They serially perform a set of transformative processes to deliver a well-defined output.

The only flows present in the project in Gantt's era were:

- *Transformative Flows* within the discrete tasks representing parts of the decomposed project.
- *Transformative Flows* of the project as the outputs of one or more tasks became inputs for a subsequent task or tasks.

Flows represent the transfer of *something* from one place to another. We will look at what these *somethings* may be shortly. In the context of classical project management theory, however, the *somethings* then were the transfer of outputs from one task to serve as inputs for a subsequent one. Flows include not just a starting point and endpoint, but also a path (of interaction) and a driving force. Think of the myriad of arrows on that Gantt chart.

A point worth noting is that in reality these “dimensionless” arrows connecting decomposed tasks are anything but dimensionless, as the short example in the box below illustrates.

Focus on Flows

A $10 billion natural resources project located in French speaking equatorial Africa was to be delivered utilizing an engineer, procure, construction manager (EPCM) project delivery method. The delivery partners consisted of a U.S. EPCM lead and a French partner who would lead the Africa-based construction manager (CM) portion, where supervision would be in French. The procurement scope was divided between the two firms.

The original project execution plan and master schedule showed preliminary and final engineering occurring in the U.S., with final documents prepared for transfer to field forces based in Africa for construction.

Equipment procurement was linked to overall engineering activities and was envisioned as being undertaken in the U.S., while materials of construction and ancillary equipment would be bought in France.

Well into the preliminary engineering phase, the client decided for political reasons to execute final design in France and called for preliminary engineering to be transferred there when complete.

The project schedule suffered.

Those dimensionless arrows from preliminary to final engineering turned out to not be so dimensionless. The original plan had final construction drawings, but not any of the supporting documentation, translated into French. Similarly, the conversion from English to metric units was not to occur until the last stages of final engineering.

The revised execution approach required the translations and conversions to be completed before final engineering could be initiated, delaying the ordering of plant equipment. When the execution approach was changed, inadequate attention was paid to the flow of the project even though the major activities were unchanged.

In large complex projects, in particular, it is important to recognize that the arrows between schedule activities are not dimensionless. Instead, they have assumptions built in that, in effect, are prerequisites for subsequent activities. In this particular case, the sequencing of translation and unit conversion changed, and it was later discovered that productivity and work week schedules also changed. All of this adversely impacted the accelerated delivery of this project.

This is an example of why focusing on flows is critical, remembering that sometimes the arrows present more challenges to the project than the activities that the project has been decomposed to include.

From the author's experience, this notion of a singular type of flow operating in a well-bounded environment does not fully describe the full range of flows that occurs in large complex projects. We now will define three types of flows in large complex projects: the classical ***Transformative Flows,*** but now accompanied by additional flows we call ***Influencing Flows***, which arise from outside the project since large complex projects are not so well bounded (certainly not as Gantt would have experienced), and a third type of flow, ***Induced Flows***, that arise from the interaction of a multiplicity of flows with each other.

Before defining and looking at each of these flows more closely, it is useful to return to the notion of the *somethings* that may flow.

What Is *Something*?

Flows represent the movement of *something* from one place to another. What are the *somethings* that flow in large complex projects? Table 1 provides a partial listing of flows that may impact large complex projects, with the potential impacts being related to:

- Whether they were planned or unplanned.
- Whether they were coupled or decoupled temporally and otherwise.
- The point and place at which they arise.
- The extent of their influence (number of tasks affected; number of other flows affected).
- Their persistence (duration); stability (static, dynamic, chaotic); and second (and third) order effects.

Table 1 broadly groups the flows as:

- Logistical
- Information
- Economic
- Environmental
- Stakeholder
- Technological

Table 1
Partial Listing of Flows Impacting Large Complex Projects

Logistical	• Logistical flows[1] between tasks (movement of people, materials and equipment) • Supply chain flows[2] from raw materials through intermediate goods to final items of supply and their transfer to site • Flow of indirect factors such as food, shelter (man-camp), fuel and other consumables • Logistical disruptions on project-related flows arising from project activities or arising from others • Logistical disruption of others arising from project-related flows
Information	• Delayed, non-transparent information flows giving rise to degradation of trust, slowness in response and undertaking required actions • Non-secure information flows create project impacting cyber-risks[3] • Poor knowledge latency associated with weak knowledge management[4] • Social media creates uncontrolled or even fake narratives
Economic	• Market based factors (supply, demand, price point) modify planned flows and flow rates of materials and equipment • Economic based factors (inflation/deflation; availability of capital; currency stability and convertibility) act to modify project objectives and schedule • Financial factors may act to limit availability of subcontractors and suppliers that the project requires (unavailability of bonding; inadequate capitalization) • Labor market constraints derived from either aggregate labor demands; skilled labor shortages; or industrial actions
Environmental	• Flows arising from the physical environment (heat, wind, water, dust/sand)[5] • Changing constraints with respect to the project's interaction with the physical environment (e.g. noise levels lead to reduced work hrs) • Flows from the natural environment impacting the project (disease, pestilence, fire) • Flows from the project adversely impacting the natural environment (discharges, spills, runoffs, destruction of protected areas)
Stakeholder	• Investor/owner stakeholder changing requirements (SBOs change)[6] or constraints (e.g. cash flow) • Politically driven changes that accelerate, decelerate, modify through sovereign action, legislation • Regulatory driven requirements requiring response or modify work processes and timing. Delayed permits and authorizations • Tort and other judicial actions impacting project objectives; funding and financing; schedule and sequence of activities; means and methods • A change in stakeholder interest create "interest flows" (e.g. sustainability; social justice) • Directly affected third parties (traditional view of stakeholders) whose support and acceptance is effectively required and whose actions/inactions impact the project • Indirectly affected third parties (issue- oriented organizations and non-government organizations (NGOs)) whose support is desirable but who act and influence project processes either directly (through political, regulatory or judicial action) or indirectly (through interaction with owners/operators or directly affected third parties) • Broader ecosystem of stakeholders[7] which represent a source of modifying behaviors on all parties directly and indirectly affected third parties and from which new issues and requirements may emerge • Collectively, stakeholders are not manageable but can be engaged and influenced, effectively modifying what otherwise may have been more disruptive flows impacting the project • A significant set of flows can give rise to changed stakeholder behaviors. These impacts may be positive (economic activity; jobs; community improvements) or negative (traffic congestion; environmental degradation; negative social effects)
Technological	• New technologies[8] arising during project execution can modify project requirements; means and methods; stakeholder expectations

[1] Executive Insight: Post Disaster Logistics
[2] Executive Insight: Procurement Management in Large Complex Projects
[3] Executive Insight: Cybersecurity in Engineering and Construction
[4] Executive Insight: Knowledge Management
[5] Executive Insight: Location Factors in Large Complex Projects
[6] Executive Insight: Importance of Strategic Business Objectives
[7] Executive Insight: Stakeholder Management in Large Complex Projects
[8] Executive Insight: Convergence of Construction Technology

The various flows can occur in three fundamental ways:

1. *Transformational Flows*, first envisioned by Gantt, yet as suggested in Table 1 may no longer be as static and predictable. Complexity and both unnecessary and hidden coupling of activities and constraints further act to impact projects.
2. *Influencing Flows* that arise from outside the project team from a myriad of directions, as suggested in Table 1.
3. *Induced Flows* that arise from the interaction of the various *Transformative* and *Influencing Flows*. In some instances, these may represent second or third order effects, while in other cases they may represent short-lived but turbulent and impactful events.

These are discussed in the next section.

Pandemic Derived Flows

In 2020, the world witnessed the emergence of a global pandemic, COVID-19. The impacts from COVID's ***Influencing Flow*** on construction projects were both direct and immediate. Many projects were paused or even stopped for an extended period. Workers became sick and worksites implemented new safety protocols. The ***Transformational Flows*** implemented by established means and methods were modified due to the pandemic. Resulting ***Induced Flows*** ranged from a shortage of toilet paper to a redirection of N95 respiratory masks to emergency workers as well as a disruption and reconfiguration of global supply chains.

Flows

Large complex projects do not follow classical transformation models (see Figure 1, next page). The activity-based focus, memorialized in work breakdown structures, neglects the importance and impact of "flows" within the project context. As supply chains become more tightly linked to project processes, some of the flow considerations now can be seen as core to logistics and as being analogs for efficient project management. Precedence and unnecessary coupling of activities, in fact, may harm a large complex project's performance in ways perhaps not evident on initial inspection.

Additionally, large complex projects are far from being bounded as classical project management theory would suggest. Rather than well-defined boundary limits, we discover semi-permeable boundaries across which *Influencing Flows* transit, impacting the *Transformational Flows* within the project proper. These flows arise from a multiplicity of stakeholders and other agents, who in turn are influenced by the project itself.

These *Influencing Flows* then interact with a project's *Transformational Flows* and with each other. They may give rise to *Induced Flows,* which while often are short-lived (such as the COVID-19 derived flows described previously) can be particularly turbulent and impactful on the project.

Let's look at each of these more closely.

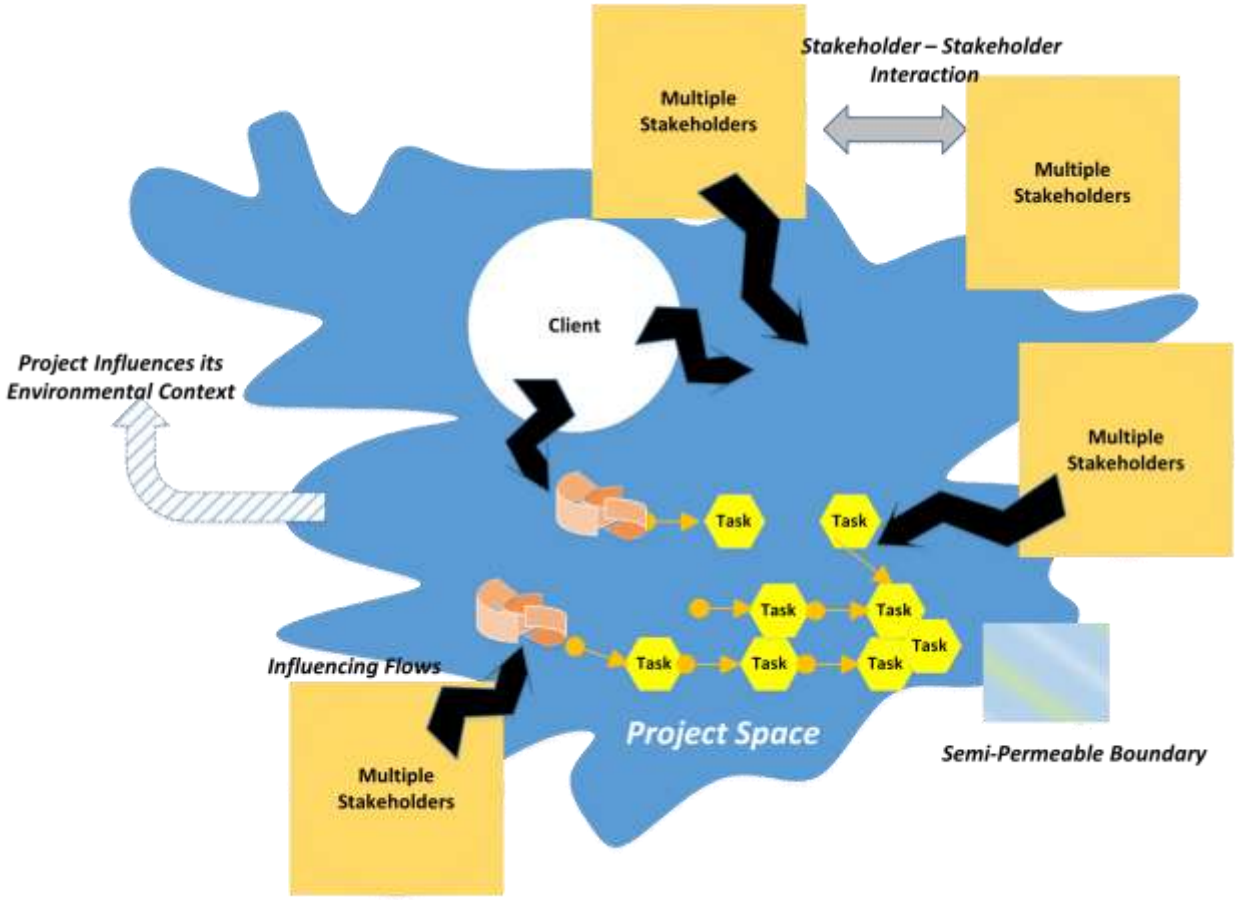

Figure 1. Large complex projects and influences and flows

Transformational Project Flows

Transformational Flows encompass both the *Transformational Flows* that occur within the tasks that collectively comprise a decomposed project as well as the *Transformative Flows* distinct from individual task execution. Together they represent executing each task in an optimal sequence.

Large complex projects require us to focus not only on task inputs and outputs, but importantly on the *Transformative Flows* between tasks (recall the earlier story on the project in Africa). During the execution phase of a project these flows are representative of the construction process itself and the selected means and methods. To improve overall execution in this phase, it is necessary to expand our business basis of design (BOD^x)[9] to specifically include construction-related factors, preferences, and choices. Consideration of factors impacting project flows is essential.

[9] Executive Insight: Business Basis of Design

Influencing Flows

Large complex projects both shape the world around them and are directly influenced by it. This direct interaction is our first indication that perhaps our project is not so well bounded. In some sense large complex projects distort both time and space (see Figure 2).

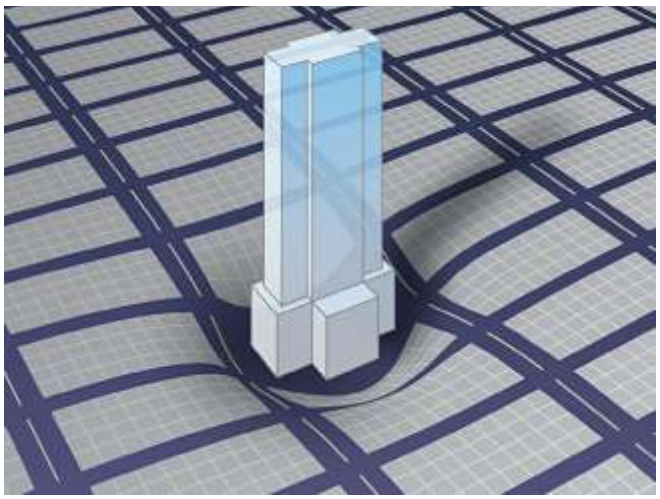

Figure 2. Time and space distortions

Large complex projects are not well bounded, at least not as described in classical project management theory. Large stakeholder influences; new outcome requirements; stakeholder needs over extended delivery timeframes and lifetimes; and the sheer number of outside project inputs and assumption drivers all act to create a semi-permeable boundary across which there are many informational and *Influencing Flows*. Table 1 (page 5) provides a good starting point for identifying *Influencing*[10] *Flows*.

This porous project boundary, combined with the self-defining and emergent nature of the project, characterizes the non-deterministic system that best describes large complex projects[11].

Influencing Flows can act to shape the project's *Transformative Flows.* Those are well known in classical theory and described above. These *Influencing Flows* arise from flows crossing the semi-permeable project boundary as well as the interaction between two or more *Transformative Flows* present within the project context. Here are two key points: (1) large complex projects are not easily isolated and (2) just as they are susceptible to changing externalities, these large projects also act to change the external environment that they affect. In essence, the *Influencing Flows* we find in the large project environment can be described as semi-permeable.

Influencing Flows often change the number and nature of tasks to be undertaken as well as how the various process flows define, interact with, and drive forward the transformation process. This is significantly different than classical theory's execution of each task in an optimal manner with optimal process flows. This leads to an important recognition that planning activities must address two key elements:

[10] Influence: From medieval Latin "influential", meaning "in-flow"
[11] Executive Insight: Large Complex Projects as Open Systems

1. Tasks, including the work flows within those tasks.
2. Flows, including *Transformative (or systems) Flows* between tasks as well as new flows induced by these *Influencing Flows.*

Disruptive flows into a project often result from a lack of transparent and robust communication with stakeholders.

Induced Flows

The *Influencing Flows* arising from a multiplicity of stakeholders (Figure 1, page 7) and eddies they create in the planned *Transformative Flows* are shown together with a new flow that arises from this interaction between flows: *Induced Flows* that can arise suddenly, be highly disruptive, and disappear just as suddenly. (Refer to the *Induced Flows* described in regard to the COVID-19 pandemic.)

Large complex projects act equally on their environment as the environment acts on the project. We must be cognizant of feedback loops that translate an internal project action to a new or modified *Induced Flow.*

A Flow Analog: The importance of Transparent, Real-Time Awareness of the Broader System

You set out in your car for your daily commute to work. Like on most days, however, the broader transportation network has been changed by a set of emergent events (traffic accidents; police actions; overnight construction delays; planned and unplanned road closures; broken water main; special events modifying route availability or inducing increased demand). This is analogous to the broader ecosystem in which we undertake large complex projects.

Like the road network on our morning commute, we experience a network that changes over time. The strength and direction of flows are dynamic, intersecting and influencing each other, and latency functions govern pathway resistance. In the case of the road network, congestion is created.

As a traveler (project) in a broader environment, you interact directly and indirectly with others. Some are trying to go in the same direction as you; some take different paths than you, but at points they overlap with your planned route at an intersection; some take paths that do not impact you at all.

Each morning you must make a series of choices on the route to take while recognizing the environment today may not be similar to what you have previously experienced. Also your route is not static, but rather is dynamically changing. A predicted road closure may be cleared as you reach that point in one route option. Conversely, congestion at another point may only grow worse. How do you make your route choice?

We make our daily route choice based on:

- Our experience (from previous trips) and preferences—either our own or those traveling with us (e.g., stay on the highway and avoid the local streets).
- Feedback of information about the traffic network and its current and projected performance and condition. The network is analogous to our project ecosystem.

Information about the condition and performance of the network comes from our outward and forward-looking traffic app and/or the radio traffic commentator. Our choices are influenced by our assessment of the strength and transparency of the information flows we receive. The predictive capabilities of our artificial intelligence-enabled, crowd-sourced traffic app recognizes that:

- Transparent information flows change behaviors.
- The network represents a situation under uncertainty.
- Dynamic transportation network flows impacting a single vehicle (ours or another's) may modify behaviors based on information flows.

The resulting traffic forecast is a realization of many long-range correlations.

Projects travel in a similar dynamic space, and like the commuter, their choices improve when they are better informed. Projects influence the broader ecosystem (network) they are part of and, in turn, are directly influenced by it.

Recommendations to Assess Flows

In our management of projects, the vast majority of our controls are inward facing, focused on the *Transformative Flows* we have selected and which we seek to manage every day. These important *Transformative Flows*, both within discrete project tasks as well as the project's *Transformative Flows* we have defined to optimally deliver the overall project, however, are subject to disruption from flows outside our direct control and ones that our project control efforts have not historically been focused on.

We must complement our inward-looking assessment of project planning, performance, and trends with in-kind efforts that are externally focused. We must look at the evolving situation from different points of reference. Specifically:

1. Strategic Business Objectives (SBOs) become more important than mere scope requirements in achieving ultimate success. In some instances, projects may be faced with emergent SBOs, especially when *Influencing Flows* cross the semi-permeable project boundary over an extended project timeframe.
2. The semi-permeable boundaries of large complex projects represent an important management frontier to be posted with "sentries" on the lookout, giving visibility to flows across this boundary and identifying emergent outcomes. Many good things happen at this frontier, including exchange of information and knowledge as we engage stakeholders, thus obtaining valuable insights on factors affecting the outcome. Not all things crossing this frontier, however, are necessarily reinforcing of the desired project outcomes or the efficiency and effectiveness of the various sets of ongoing *Transformational Flows* in the project.
3. Stakeholder influences now define a surrounding and interacting ecosystem that includes stakeholder-to-stakeholder interactions, but also an ecosystem that the project acts on and influences through so-called "ambassadors." While not predictable, **disturbances in flows, such as from eddies and *Induced Flows*, become signatures of the direction of likely system emergence**. Our predictive project efforts employing big analytics[12] may be better aimed at flow patterns, especially those crossing the semi-permeable project boundary and the broader externalities driving and shaping them. (***Note****: Emergence is when projects exhibit properties and behaviors which are attributed to the whole, not to its various tasks. Emergent behavior in projects is a result of the interactions and relationships between project elements and tasks rather than the behavior of individual elements. It emerges from a combination of the behavior and properties of the project elements and the project structure, both physical and execution process, and the potential interactions between them.)*
4. Carefully monitor project frontiers with "sentries" looking out for new flows, changes in existing flows, and assumption migration; environmental "scouts" seeking out new flow drivers, emerging flows, and emerging actors; and engagement of stakeholders through "ambassadors." Look for patterns and points of change that can trigger new patterns, new *Influencing Flows,* and that can create new *Induced Flows*.
5. Recognize that emergent risks represent a key driving force of many flows.
6. Identify hidden reservoirs of stakeholder power and potential vectors of influence.

Recommendations to Mitigate Impacts

Management of flows can be improved, especially those external to the project. Failures of large complex projects often arise from factors outside the direct control of the project team. That does not

[12] Executive Insight: Impacts of AI on Management of Large Complex Projects

mean they cannot be managed. They can, but only if we are looking in the right direction and building the foundations necessary to deal with the inevitable challenges and changes.

Some recommendations to manage flows more effectively include:

1. Standardization of systems[13], structures, components, work processes, and de-coupling[14] of activities that can be undertaken independently is essential.
2. Precedences must be reduced. Work plans must facilitate **contingent execution[15]**. This elimination of precedences relies on a careful understanding (and subsequent tracking) of the project's numerous underlying assumptions[16], and a keen understanding of the minimum prerequisites for a given task or activity. Despite best efforts, new couplings may emerge in the course of the project driven by "assumption migration" or the effects of project disruption caused by out-of-plan flows.
3. Management information must include information on how the output of a preceding task will flow to the subsequent task and how outputs will flow onwards. These flows have characteristics with respect to whether they are planned or contingent, when they will actually occur, and whether any buffering mechanisms are present in order to optimize overall project flows.
4. Project execution must include a contingent capability to redirect and re-time various flows, or restore already influenced flows to an optimal state, recognizing this may be significantly different than the original transformative plan. On one large complex project, 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.
5. Increased awareness of actual or potential direct or indirect coupling, such as may happen when flows are coupled by second or third order constraints (constraint coupling).
6. Managing the impacts of *Influencing Flows* begins with better awareness of the changing nature of a large complex project's stakeholder ecosystem.
7. Ecosystem awareness must be complemented by stakeholder engagement, seeking to influence flows and their timing.
8. Continuous improvement in information flows improves team and project performance.

[13] Executive Insight: Modularization
[14] Executive Insight: Coupling in Large Complex Projects
[15] Executive Insight: Contingent Execution
[16] Executive Insight: Assumptions, Risk Driver and Constraint Tracking

Contingent Execution

Large complex projects require an increased focus on "flows," importantly recognizing that even in the most robust plans variability may require related tasks to be either accelerated or delayed to reflect project realities. This variability is made more acute as *Influencing Flows* enter and interact with project plans and activities.

Management of this variability requires an ability to plan and execute project activities on a contingent basis, responding to or taking advantage of temporal variability in the execution and completion of the myriad of project activities and tasks. In effect and to the extent possible, project plans must have a degree of temporal flexibility[1]. This flexibility may be achieved through contingent execution, but also through buffers and "distributed float," although the latter is not optimal. The interaction of action conditions and execution timing gives rise to uncertainty of action durations[2] that may have cascading effects on the project execution plan.

Characteristics of contingent execution have typically encompassed strong centralized planning with temporally flexible plans. The multiplicity of stakeholders and arising *Influencing Flows* are further supportive of more distributed and decentralized planning and execution, albeit with centralized consistency checking. Asynchronous input streams and changing resource availability and execution options are hallmarks of large complex projects.

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[1] *Robust Execution of Contingent, Temporally Flexible Plans; Block, Wehowsky, Williams; 2006*

[2] *Expected Utility Distributions for Flexible, Contingent Execution; Bresina, Washington; 2001*

Evolving PM Approaches

Agile — moves us beyond traditional project management (PM) theory with considerations of iterative human interactions. Agile relies on a series of small, discrete tasks conceived and executed to conclusion as required. Task execution is contingent, executed as required and in an adaptive manner rather than executing a pre-planned process. Key to successful use is active client and stakeholder involvement throughout the project and real-time decision making.

Lean — begins the integration of traditional methods and human characteristics. System "flows" replace the pure input/output measures of traditional project management. Lean project management provides flexibility in responding to dynamic systems, moving beyond the more static constructs of traditional PM theory, but potentially introducing risks as capabilities and capacities are narrowed to reduce waste and internal variability. Large complex projects require a higher degree of resilience.

The emergence of **Extreme Project Management** moves project management theory into the world of dynamic, non-deterministic systems. The control point is focused on how one responds to the reality that you have no (or at least limited) control. The theoretical constructs of extreme project management are as different from traditional PM theories as Newtonian physics is from Einstein's theory of relativity. Each is reasonable within their respective scales. This is a key point: extreme project management has

applicability only in the world of dynamic, non-deterministic projects with the properties of scale, uncertainty, and emergence.

Conclusion

The concept of self-organization reflects a simple reality of large complex projects—central direction by a management team is no longer practical. Rather, project management must create context, capacities, and capabilities while recognizing the delicate balance between formal and informal systems essential in avoiding chaos on large complex projects. The project co-evolves with its environment. The tools of the project manager must include a combination of positive and negative feedback loops (such as those shown in Figure 1) to guide the project to its final state. Proper application of these loops relies not just on traditional command and control strategies and metrics, but also on knowledge gained from a learning organization.

Time is no longer just a pacing and synchronization point. It is now something that is increasingly valued, extended beyond what we may encounter in more traditional projects, and a tool to gauge and control the various flows the project experiences. Temporal coupling now represents a new risk point, given the various *Influencing Flows* that a large complex project faces.

About the Author

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