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Complexity in Large Engineering &
Construction Programs
by Bob Prieto

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Chairman & CEO
Strategic Program Management LLC

Increasingly, today's large projects are complex. While recognizing this property of these projects we seemingly gloss over it, giving it much less attention than more traditional project properties.

A review of even the best developed project baseline documents will highlight efforts placed on defining and quantifying scope; delineating costs; and ascribing time to the various means & methods we will employ to deliver the project. But our focus on thorough characterization goes further assessing and addressing how risks will be provided for, tracked and managed; how safety and quality will be assured; and even how operational stage considerations will be brought forward.

But throughout our robust stage setting and subsequent management efforts we acknowledge complexity but do little to assess it, and maybe even less to manage it. While we measure changes in cost and schedule and risk profile we lack even a metric for measuring similar changes in complexity.

Complexity is not unique to the large engineering and construction projects we undertake but is a property of all large systems. How can we learn from these analogs and what strategies may help us better manage the complexity we face on these projects?

This is the "century of complexity" according to Steven Hawking, transcending the domain of experts, taking us into a realm of emergence where the multi-finality of even well-developed programs must be acknowledged and provided for. The complex may even behave chaotically, amplifying the need for timely, responsive management interventions on project paths not previously well traveled. Returning from chaos to complexity requires leadership and broad engagement of the wisdom of the team.

But our traditional organization charts and their associated position descriptions understate the management and leadership skills and attributes required to respond to the complexity these programs will inevitably face. These skills include pattern

PM World *Journal*
Vol. VI, Issue XI – November 2017
www.pmworldjournal.net   Featured Paper

Complexity in Large Engineering &
Construction Programs
by Bob Prieto

recognition, dealing with ambiguity, real time coaching and facilitation, and the ability to manage transformations not just transitions.

Nature's complex systems offer some hints we should heed. They 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 perturbations. Here modules can be thought of "as a set of nodes densely connected among themselves but loosely connected to other parts"[i] .

But perturbations can spread even in highly modular systems with these stronger perturbations occurring along couplings not readily apparent such as what we see with constraint coupling (See Appendix 1) or other interlacing networks interacting with multiple elements of our project, potentially amplifying otherwise more manageable permutations.

Modularity in project design and management can also carry risks associated with unintended impediments of delays in information flows and decision making.

I've touched on organizational skills and leadership aspects to be more strongly considered when we undertake complex projects. I've also highlighted benefits of modularity as a project design principle but also the risks associated with unrecognized couplings. I'd like to turn now to the subject of measuring complexity. Again, here work has been done in other fields in the form of cyclomatic complexity analysis in software codes, the largest of which resemble the 50 – 100,000 activity schedules we see in large complex programs. Cyclomatic complexity is focused on control flows or the myriad of arrows we see in our project activity models and pay insufficient attention to. I have discussed this previously.[ii]

In a project context both module and overall program complexity need to be considered with overall program complexity considering only those connections (both apparent and otherwise) between the densely coupled modules and the rest of the program network. Application of an approach akin to cyclomatic analysis allows for a comparison of execution strategies for complex projects where today we accept but don't seek to mitigate complexity and its threats to large complex projects.

Hawking was right, this is the "century of complexity", but our projects do not need to be its victims.

PM World *Journal*
Vol. VI, Issue XI – November 2017
www.pmworldjournal.net   Featured Paper

Complexity in Large Engineering &
Construction Programs
by Bob Prieto

Thoughts on Perturbations

In the previous section I looked at the relationship between complexity and modularity of "systems". I noted that Nature's 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 perturbations.
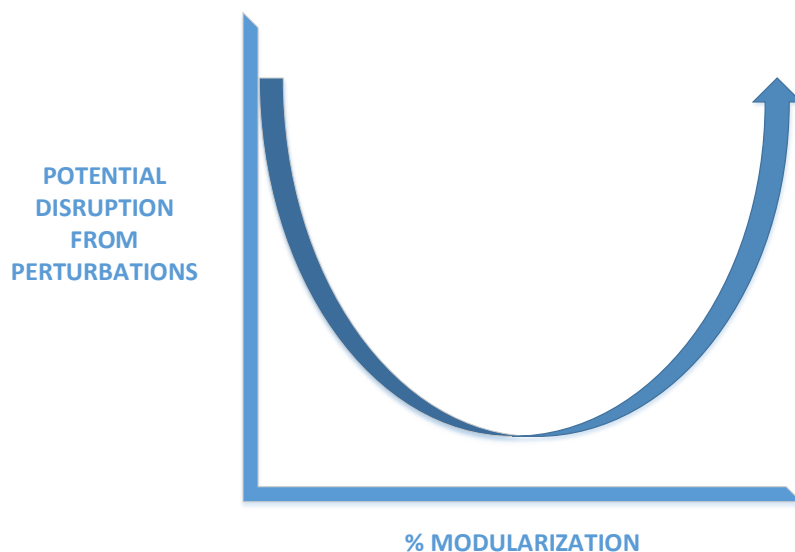
In this section I further explore this linkage between modularity and complexity as well as begin to consider ways of defining and measuring complexity at least on a relative basis.

Let's begin by considering two systems in the engineering & construction ecosystem. The first represents the physical project to be designed and constructed and the second represents the project execution plan that may encompass as many as 100,000 discrete activities on a large project.
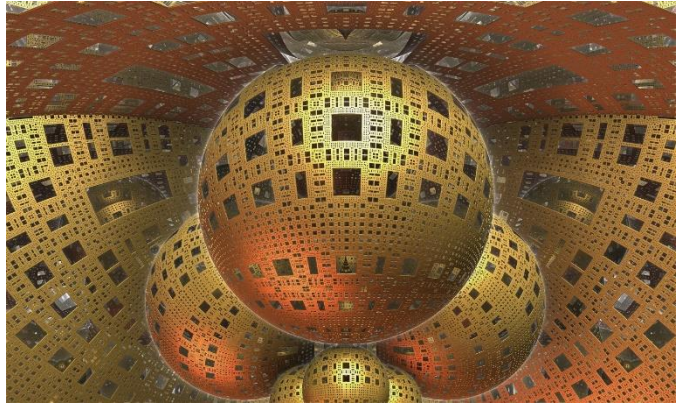
We see from natural and other complex system analogs that the potential disruption from perturbations declines with modularization, reaching some minimum potential after which further increases in modularization increase the level of disruptions from perturbations as shown in Figure 1.

Figure 1

POTENTIAL DISRUPTION FROM PERTURBATIONS

% MODULARIZATION

PM World *Journal*
Vol. VI, Issue XI – November 2017
www.pmworldjournal.net

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This behavior in the impacts of perturbations can be understood by considering two different classes of perturbations. The first is associated with purely random discrete events. As we increase the modularization of the system, susceptibility to these random perturbations are more localized and contained. Conversely as we increase the modularization of the system susceptibility of the system to perturbations more systemic in nature grows. In the second class of perturbations second and third order couplings, including coupling through constraints, grows in scope and importance. We can see the behavior of each of these classes of perturbations in Figure 2.
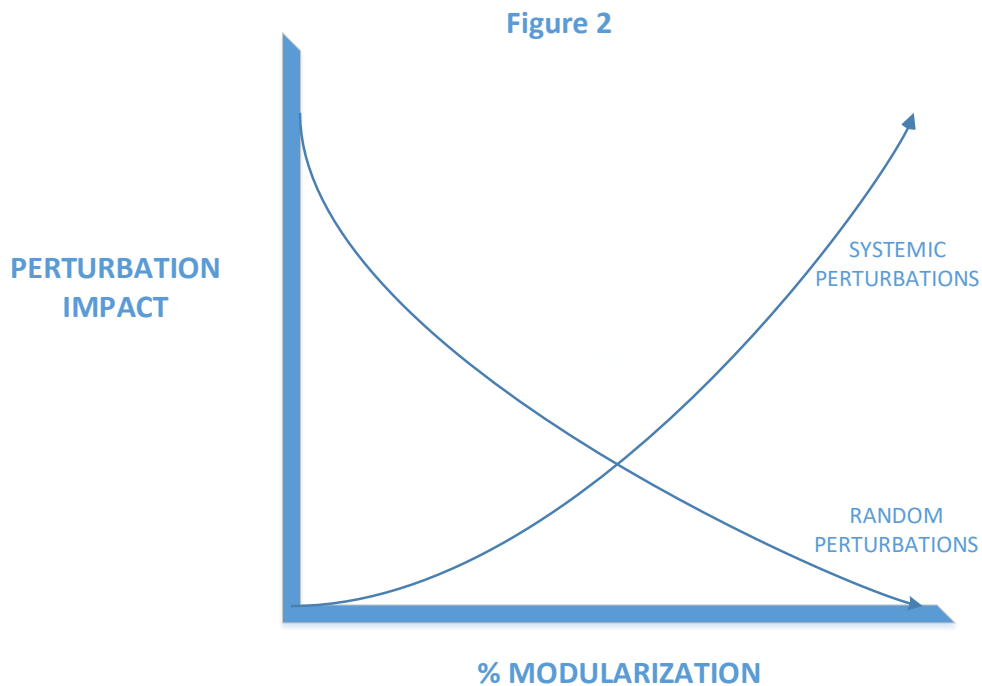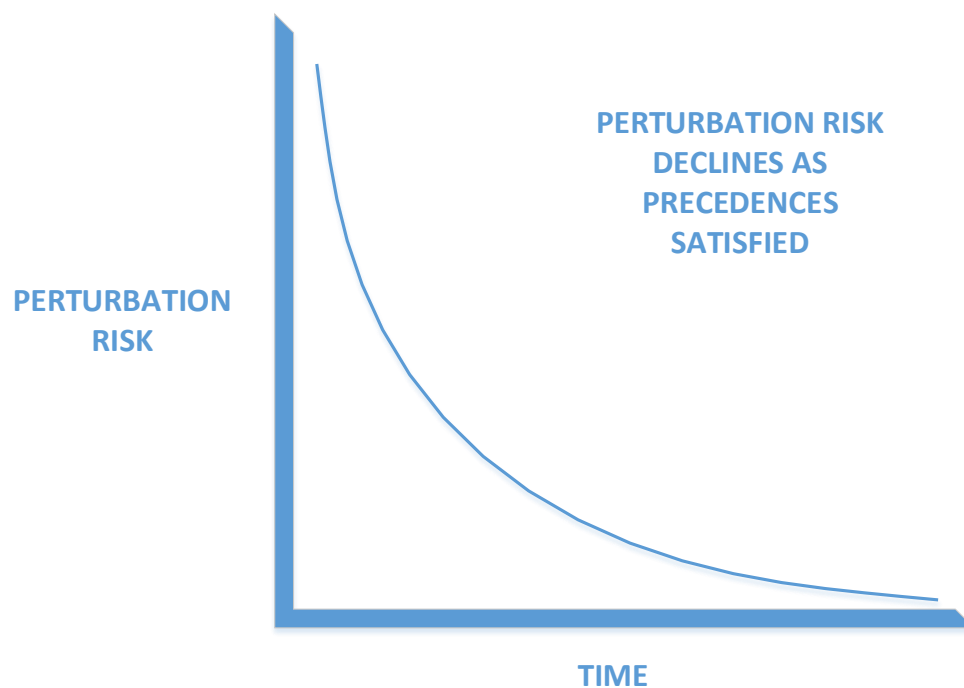
Figure 2

The symmetrical behavior shown in Figures 1 and 2 is not intended to indicate that these perturbation classes behave in similar manners and to the contrary we should expect them to materialize and deteriorate at different rates.

The figures above represent a snapshot of the totality of the planned project and its execution approach at project initiation. They can provide guidance in optimizing modularity of both design and project execution to minimize the risks from various perturbations.

It is important to recognize that perturbation risks, once a level of project modularization has been established, are not constant throughout the project execution period. This can be seen in Figure 3 where perturbation risk attenuates over time as various precedences are realized and successfully transcended.

PM World *Journal*
Vol. VI, Issue XI – November 2017
www.pmworldjournal.net   Featured Paper

Complexity in Large Engineering &
Construction Programs
by Bob Prieto

PERTURBATION RISK
DECLINES AS
PRECEDENCES
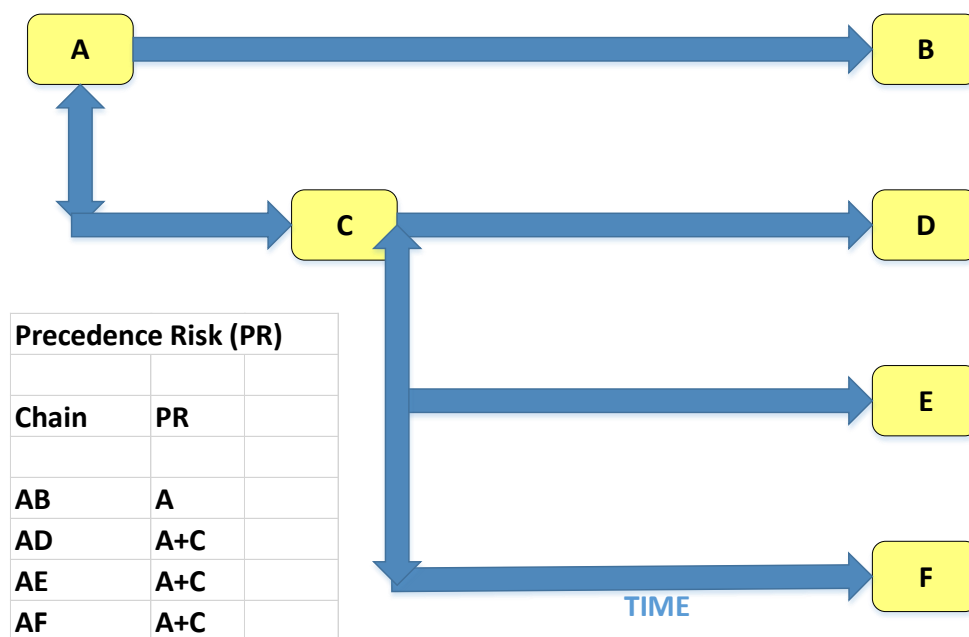SATISFIED

PERTURBATION
RISK

TIME

It may be possible to define and measure precedence risk on at least a first order basis by considering the number of paths through the project, where modules count as a singular activity in the overall project network. We can see this in very simple terms in Figure 4 where the precedence risk of each activity chain is the sum of the number of precedences embedded in the activity chain.

In this example activity chain AB has a single precedence, A, which once completed reduces the number of precedences in the chain to zero. Alternately, looking at the three other activity chains, precedences are characterized as A plus C, and completing A would reduce the precedence risk to that associated with C.

PM World Journal
Vol. VI, Issue XI – November 2017
www.pmworldjournal.net   Featured Paper

Complexity in Large Engineering &
Construction Programs
by Bob Prieto

Figure 4

PRECEDENCE RISK

Precedence Risk (PR)		
Chain	PR	
AB	A	
AD	A+C	
AE	A+C	
AF	A+C	

The above example treated each precedence equally in terms of its susceptibility to disruption. While modules act to limit the effects of perturbations on the overall system their aggregate system risk would reasonably be expected to be greater than one average activity in the non-modularized part of the system. Similarly all activities are not created equally in terms of their susceptibility to perturbations and as such it will be important to create a weighting system reflecting activity susceptibility to disruption. This may be accomplished through consideration of couplings discussed later in this paper.

In the example above we treated A and C equally. If the preponderance of perturbation susceptibility lay with activity A, then completing activity A would remove a disproportionate amount of precedence risk. Conversely if the susceptibility to perturbation risk was much greater in C then completing A may not have significantly improved our risk posture with respect to disruption.

In order to draw some insight into how to view susceptibility to perturbation risk, let us look at the special case of an activity that represents a completed module. If we can draw some insights around this special activity's perturbation risk, we may be able to generalize for a broader set of activities.

PM World *Journal*
Vol. VI, Issue XI – November 2017
www.pmworldjournal.net   Featured Paper

Complexity in Large Engineering &
Construction Programs
by Bob Prieto

Module Perturbation Risk

Let's begin by defining some properties of a module:

Module Density (MD) – This may be considered to either represent the number of connections (physical or activities) within the module or expressed more fully as the number of perturbation "sites" which may better describe some of the coupling that exists within the module itself.

Module Coupling (MC) – This represents the number of external module connections or couplings of all kinds. The greater MC the less isolated from the broader system the module is. These couplings include both incoming couplings (IC) and outgoing couplings (OC) as shown in Figure 5. The potential for effectively bi-directional coupling or feedback loops exist but have been treated as separate IC and OC components.

Figure 5
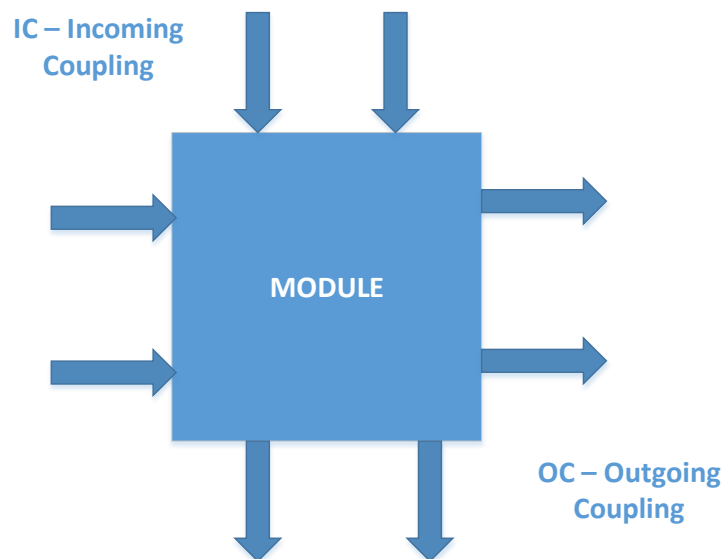
The disruption risk from a module to the overall system can be thought of as the sum of two behaviors. The first looks at the risk the module itself has to disruption. This can be thought of as being related to the overall internal susceptibility related to the Module Density, MD, and the number of incoming couplings, IC. The greater IC, the less insulated from disruption the module is. In this case effective modularity may be less than apparent modularity.

The second behavior we must consider in looking at the module's impact on overall system disruption risk is associated with the number and strength of the outgoing

PM World *Journal*
Vol. VI, Issue XI – November 2017
www.pmworldjournal.net   Featured Paper

Complexity in Large Engineering &
Construction Programs
by Bob Prieto

couplings, OC. Each OC feeds into one or more chains of subsequent activities which it acts as a precedence for. Thus the greater OC, the more potential paths for disruption from perturbations. This leads us to think carefully about where modules sit in the overall project and execution plans. We should seek to minimize forward disruption risk from disruptions to modules.

Thus the overall Disruption (or Perturbation) risk associated with a given module can be described as:

$$Module\ Disruption\ Risk = f(MD:IC) + f(\textstyle\sum Chain\ Risk(OC))$$

In plain English, the first term looks at the number of potential perturbation sites within the module and the number of incoming couplings. These incoming couplings represent potential disruption paths from more systemic type perturbations. The second term looks at the ability of a disruption that effects the module to propagate through the broader system, considering all possible outgoing couplings. This second term can be generalized to apply to any activity in the overall system network.

Generalizing Activity Disruption Risk

As shown above for the special case of modules, an activity's contribution to overall perturbation risk can be described as $f(\sum Chain\ Risk(Connected\ Pathway))$. Whether such pathways should be further weighted to consider the broader connectivity of individual activities such as was reflected in the special case of modules remains to be answered.
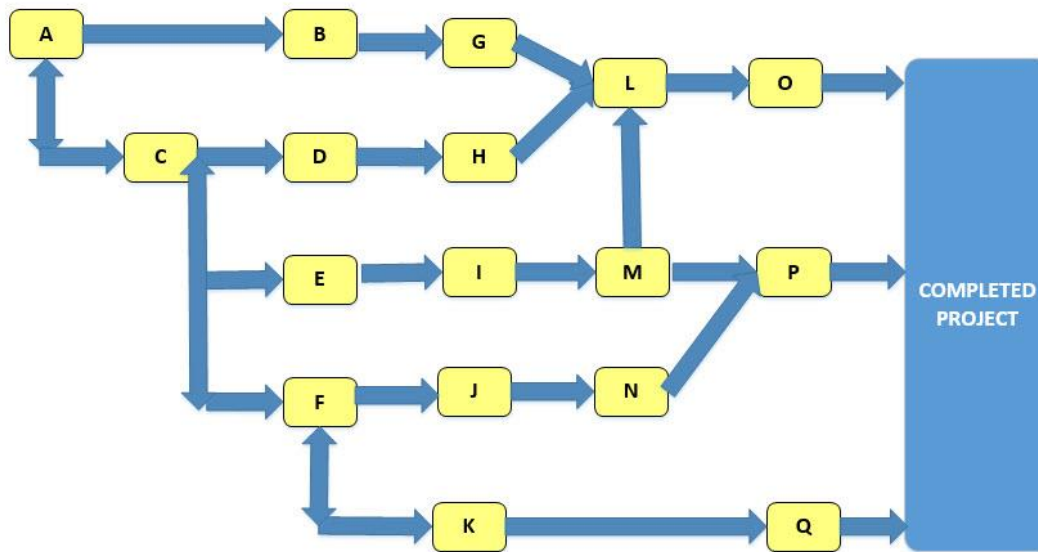
Ignoring weighting we come to recognize that the more activities one activity is connected to, the greater the perturbation risk and thus the greater complexity of the system. This is analogous to what was determined in the IT industry and leads itself to calculation of cyclomatic complexity.

In considering large complex projects in our industry it will be important to calculate not only apparent complexity, associated with direct couplings, but also actual complexity considering additional couplings which increase system exposure to systemic risks. I will touch on these later in this paper.

Apparent Complexity of Large Complex Projects

Apparent complexity looks only at direct couplings or connected components as described by graph theory. In Figure 6 we see one system representation consisting of 18 nodes, 22 couplings and 1 exit point (completed project).

PM World *Journal*
Vol. VI, Issue XI – November 2017
www.pmworldjournal.net   Featured Paper

Complexity in Large Engineering &
Construction Programs
by Bob Prieto

Figure 6
Apparent Complexity

In an assessment of complexity analogous to one formulation of cyclomatic complexity, complexity would be assessed as Couplings – Nodes + Exit Points[iii] (first Betti number). In the Figure 6 example this would equate to 22-18 + 1 or 5. From a program perspective, illustrated in Figure 7, where O, P, Q each represent independent projects in the overall program we would have 17 Nodes, 19 Couplings and 3 exit points. Complexity would be described as 19-17 +3 or 5. The complexity of the challenge at hand is not affected by terminology when assessing apparent complexity.

In Figure 8 we have removed one of the couplings reducing complexity to 4.

Returning to Figure 7, we can define the number of independent pathways as 6 including:

A-B-G-L-O

A-C-D-H-L-O

A-C-E-I-M-L-O

A-C-E-I-M-P

A-C-F-j-N-P

A-C-F-K-Q

Whereas in Figure 8, the five independent pathways consist of:

PM World Journal
Vol. VI, Issue XI – November 2017
www.pmworldjournal.net   Featured Paper

Complexity in Large Engineering &
Construction Programs
by Bob Prieto

A-B-G-L-O

A-C-D-H-L-O

A-C-E-I-M-P

A-C-F-j-N-P

A-C-F-K-Q

By contrast the simplified system described in Figure 9 has only 5 Nodes and 4 Couplings and 1 Exit Point and a complexity of zero (4-5+1). In the complexity formulation just described the number of independent pathways is equal to apparent complexity plus 1.

Figure 7
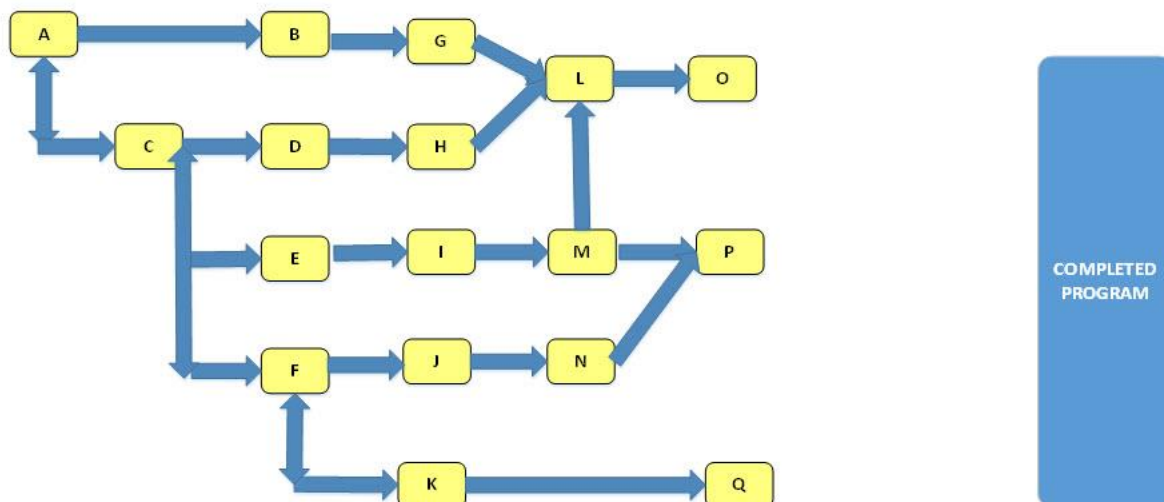Apparent Complexity Program Perspective

PM World *Journal*
Vol. VI, Issue XI – November 2017
www.pmworldjournal.net   Featured Paper

Complexity in Large Engineering &
Construction Programs
by Bob Prieto

Figure 8
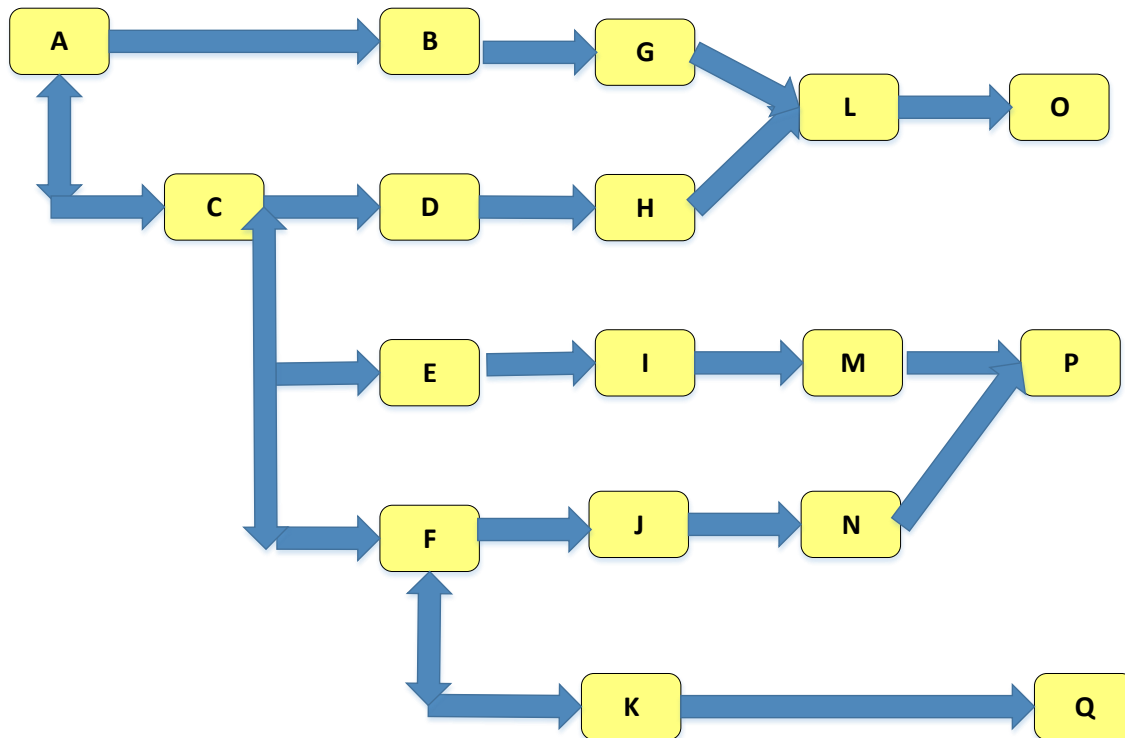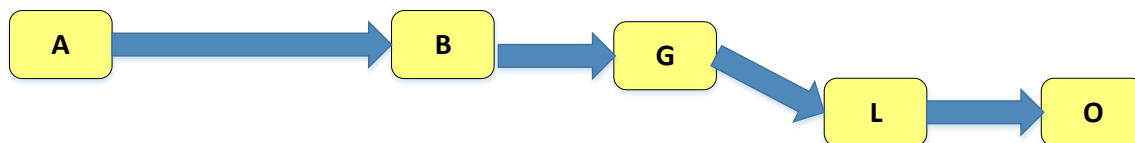**Apparent Complexity**
Eliminating a Coupling

Figure 9
Apparent Complexity
Simple System

Recognizing that the level of detail reflected in design or management program details can vary, affecting the magnitude of the overall complexity number, it may be useful to construct a complexity index to provide guidance across project phases and to compare alternative project execution strategies. This index can be described as:

Complexity Index $= \dfrac{Couplings + Exit\ Points}{Number\ of\ Nodes}$

Returning to the examples in the above Figures we would see Complexity Index values of:

*PM World **Journal***
Vol. VI, Issue XI – November 2017
www.pmworldjournal.net
Featured Paper

Complexity in Large Engineering &
Construction Programs
by Bob Prieto

	Complexity Index
Figure 6	=23/18 = 1.28
Figure 7	=22/17 = 1.29
Figure 8	=19/17 = 1.18
Figure 9	=5/5　 = 1.00

Clearly the simpler networks reflected in Figures 8 and 9 are shown. The slight difference between Figure 6 and 7 values associated with project vs program perspective requires further examination when considering apparent complexity. As we move towards considering actual complexity this difference may become less important.
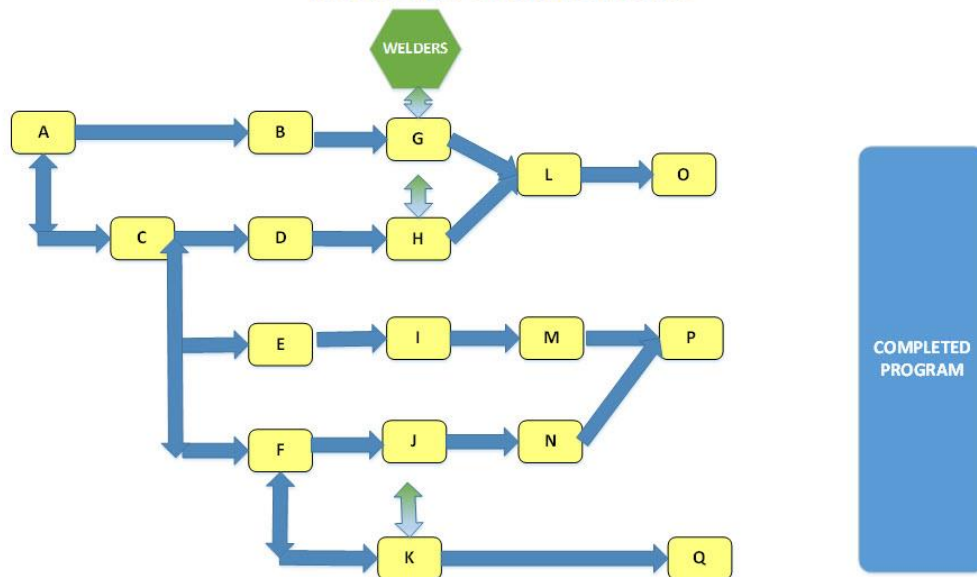
Actual Complexity

Let's turn our attention now to evaluating actual complexity. Actual complexity seeks to assess second and third order couplings which are not readily apparent from a review of the project execution plan and network. In effect the number of couplings grows while the number of discrete nodes remains unchanged, concomitantly, complexity grows.

These hidden couplings are a characteristic of large complex programs and can result in severely impactful perturbations.

There are several classes of second and third order coupling that may be considered. These include assumption coupling[iv] and perhaps more specifically a related form of coupling, namely, constraint coupling. I have previously written about constraint coupling and have included an example as Appendix 1. In this paper I will focus on illustrating its effect on complexity.

Let's consider one particular constraint which is availability of a particular skilled trade such as a welder. In Figure 10 we illustrate the potential coupling created by this skilled trade, recognizing that availability is both market and temporally driven. Activities G, H, and K all rely on this constrained resource. Detailed project planning may have been based on slightly staggering demand for this resource while assuming an overall pool availability. If the pool contracts activities G, H, and K may all be adversely effected. Figure 10 illustrates strong temporal coupling and as such changes in the overall welder pool will be particularly important. Activities can be taken to minimize the probability of such coupled constraints but if they occur they create strong perturbations and significant project disruption. They most certainly add to project complexity and as such must be modeled when considering actual complexity.

PM World *Journal*
Vol. VI, Issue XI – November 2017
www.pmworldjournal.net
Featured Paper

Complexity in Large Engineering &
Construction Programs
by Bob Prieto

Figure 10
Actual Complexity
Illustrating a Coupled Constraint

Let's consider both apparent and actual complexity in Figure 10. We previously saw that apparent complexity for this system was 4 (Figure 8) described by 18 Couplings – 17 Nodes + 3 Exit Points (O, P, Q). Actual complexity would consider these three added couplings to G, H, and K and the added "Welder" node which is also an exit point since the program itself acts to shape and size this constrained resource. This yields 21 Couplings – 18 Nodes + 4 Exit Points or a complexity value of 7. Actual complexity is greater than apparent complexity.

In assessing actual complexity it is important to focus on the most impactful second and third order couplings. Similarly, the treatment of the added coupling node as also an exit point requires a judgement as to whether the program itself is a significant part of the overall constraint. In the Figure 10 example I assumed this to be the case and added one more Exit Point but in another setting the project demand may have represented a much smaller part of the overall demand for the constrained resource.

Much in the same manner as we calculated an apparent complexity index of 1.18 (Figure 8) we can calculate an actual complexity index of 1.39 (Figure 10) here. The ratio of actual to apparent complexity provides an additional measure of project performance uncertainty as we manage based on the defined project execution network but face risks from out of network perturbations. This uncertainty measure related to complexity would have a value equal to 1.39/1.18 or **Complexity Uncertainty** = 1.18. The greater the uncertainty the greater the susceptibility to "white space" and Black Swan risk.

PM World *Journal*
Vol. VI, Issue XI – November 2017
www.pmworldjournal.net   Featured Paper

Complexity in Large Engineering &
Construction Programs
by Bob Prieto

Recap on Complexity

Up to this point I have looked at the relationship between complexity and modularity of "systems". I explored the linkage between modularity and complexity and began to consider ways of defining and measuring complexity at least on a relative basis.

I drew several inferences and posited several new measures related to complexity in large complex projects. These include:

- **Modularization** reduces susceptibility to random perturbations but increases susceptibility to systemic perturbations
- **Perturbation risk, the sum of the number of precedences in the activity chain,** declines as precedences are satisfied
- **Module Density (MD)** representing the number of connections (physical or activities) within the module or expressed more fully as the number of perturbation "sites" that exists within the module.
- **Module Coupling (MC)** representing the number of external module connections or couplings of all kinds. The greater MC the less isolated from the broader system the module is. These couplings include both incoming couplings (IC) and outgoing couplings (OC).
- $Module\ Disruption\ Risk = f(MD:IC) + f(\sum Chain\ Risk(OC))$
- **Apparent Complexity** = Couplings – Nodes + Exit Points
- **Complexity Index** = $\frac{Couplings + Exit\ Points}{Number\ of\ Nodes}$
- **Actual complexity** seeks to assess second and third order couplings which are not readily apparent from a review of the project execution plan and network. In effect the number of couplings grows while the number of discrete nodes remains largely unchanged, concomitantly, complexity grows
- **Complexity Uncertainty** - The ratio of actual to apparent complexity provides an additional measure of project performance uncertainty as we manage based on the defined project execution network but face risks from out of network perturbations.

Several areas warrant future development including development of a simplified weighting system for activity's susceptibility to perturbation risk and modeling of modules incorporated into a larger activity chain. Here the work above on Module Disruption Risk represents a starting point. Classes of couplings are discussed in the next section and warrant further development but it is important to note that these flows are largely from external or stakeholder sources, represent the biggest source of incremental complexity and their disruption effect is consistent with observation.

PM World *Journal*
Vol. VI, Issue XI – November 2017
www.pmworldjournal.net   Featured Paper

Complexity in Large Engineering &
Construction Programs
by Bob Prieto

Classes of Coupling

Up to this point I have looked at the relationship between complexity and modularity of "systems". I noted that Nature's 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.

I further explored this linkage between modularity and complexity as well as considered ways of defining and measuring both apparent and actual complexity at least on a relative basis. A complexity index was suggested and the subject of coupling introduced. It was suggested that coupling in large complex projects could be classified. This section suggests one possible classification system, recognizes the potential interaction between classes and provides an initial ranking of these classes with respect to their potential to broadly disrupt planned execution of the project.

Coupling refers to the interdependencies between activities where modules may be considered as a special activity type. Nine classes of coupling in large complex projects have been defined as follows:

Control Coupling – This is represented by the normal control flows that guide project execution and work activities; those arrows on the Gantt chart or WBS if you will. The control flow arrows are not dimensionless and a clear and comprehensive understanding of the data, information 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 associated kpi's must cascade throughout the control network.

Co-dependent Coupling – Interdependency between activities are such that a change in the data, outputs or execution of one activity necessitates a change in the second. 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, otherwise disparate, activities. Examples could 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.

External Coupling – Multiple activities require externally imposed inputs, controlled resources, approvals or other interfaces. Permits and inspections would be an example of external couplings. Changes in the externally imposed requirements may impact multiple activities.

Stakeholder Coupling – Different than External Coupling since flows from these couplings are not imposed but 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. 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. It is likely the greater the number of classes of couplings present 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 may impact. Table 2 synthesizes these relationships to define those classes of couplings likely to most contribute to project disruption. 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. The ratio of stability to instability (I/O)

PM World **Journal**
Vol. VI, Issue XI – November 2017
www.pmworldjournal.net   Featured Paper

Complexity in Large Engineering &
Construction Programs
by Bob Prieto

provides a relative measure of the contribution to disruption from various classes of couplings.

Together with the Complexity Index and Complexity Uncertainty previously described, I/O provides another measure of the contribution of coupling to disruption.

		Table 1 Relationships Between Classes of Couplings								
		Affected Classes								
		Control	Co-dependent	Assumption	Constraint	External	Stakeholder	Message	Temporal	Uncoupling
	Control	x	x				x	x		x
Source of Inputs	**Co-dependent**	x	x						x	
	Assumption	x	x	x	x			x	x	x
	Constraint	x	x	x	x			x	x	
	External	x	x	x	x	x		x	x	x
	Stakeholder	x	x	x	x	x	x	x	x	x
	Message	x	x			x	x	x	x	x
	Temporal	x	x	x	x	x	x	x	x	x
	Uncoupling	x		x	x		x			x

	Table 2								
	Ranking of Coupling Class Contribution to Disruption								
	# Incoming	# Outgoing	Total	Instability	Stability	I/O		Least to **Most** Impactful	
	(I)	(O)		Outgoing/Total	Incoming/Total				
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	

Cohesion, by contrast, looks at the range of actions that occur within a given activity and makes a judgement to how related they are. For example if a given activity required painting all east facing walls blue and changing washers in all 4" valves we would describe its cohesion as low. By contrast an activity that required welding flanges and making all connections in a particular fluid system would be viewed as having higher cohesion.

By definition modules as previously described should be expected to have high cohesion.

In my book, *Theory of Management of Large Complex Projects*, I suggest three areas where current project management theory falls short at scale. In simple terms I suggest the need for stronger foundations; a focus on flows, the arrows, not just the activities; and recognize a need for a strengthened approach to stakeholder engagement. This work on complexity is intended to begin to address the areas this new theory highlights and to suggest another foundational activity to strengthen project performance through its increased focus on flows and couplings, including most notably, stakeholder coupling. Assessment of complexity is intended to help evaluate alternative execution

PM World **Journal**
Vol. VI, Issue XI – November 2017
www.pmworldjournal.net   Featured Paper

Complexity in Large Engineering &
Construction Programs
by Bob Prieto

approaches and perhaps provide guidance on the confidence we should have in planned or predicted results.

Improving large complex project execution remains a journey which I feel compelled to continue.

Appendix 1
Constraint Coupling Example
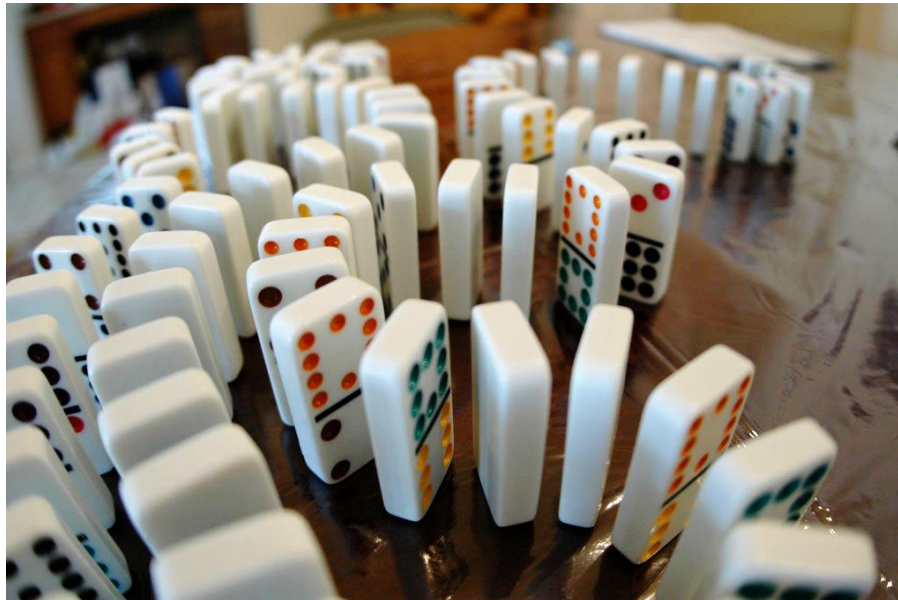
Today, constraint identification is based on the original execution plan and rarely updated. But, original program execution plans change and even impacts off the critical path can have significant impacts on overall program performance because of constraint coupling.

Let's look at a simple example for a four project program:

- **Project 1** is an enabling project, not on the critical path with a 12 month duration. Its sequencing does not lend itself to acceleration.
- **Project 2** is interdependent with Project 1 and cannot be initiated until Project 1 is substantively complete. The baseline plan shows it not starting until after Project 1 complete but it could start 2 months earlier when Project 1 substantively complete.
- **Project 3** represents the critical path effort and project labor is constrained at 600 as a condition of permitting.

PM World *Journal*
Vol. VI, Issue XI – November 2017
www.pmworldjournal.net   Featured Paper

Complexity in Large Engineering &
Construction Programs
by Bob Prieto

- **Project 4** is seasonal work which cannot be rescheduled but is generally independent of other project linkages except constraints related to overall labor availability.

Total labor available to program is capped at 1200 as labor is in short supply and multi-owner labor agreements executed to eliminate poaching and an uncontrolled wage spiral.

This is what the baseline program manpower loading looked like.
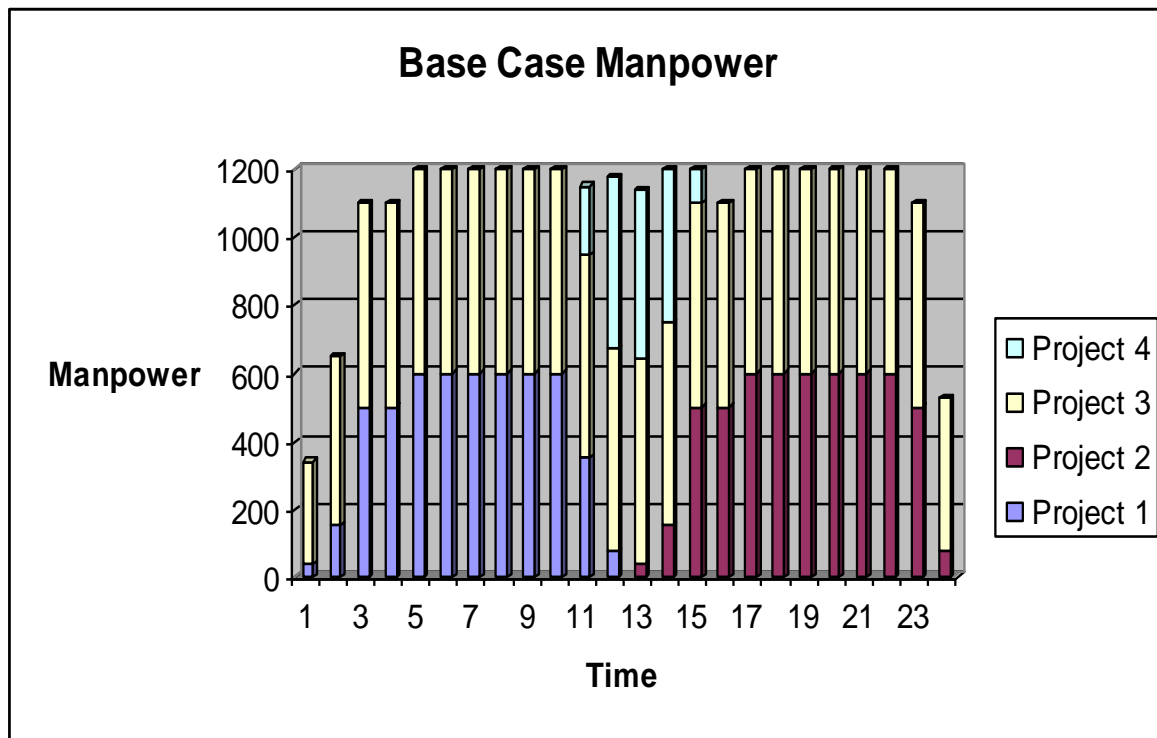
Like all programs, something changed in Project 1 that causes suspension of construction and other activities at the end of month 4. The hiatus lasts for 2 months; Project 1 not on critical path and the PM has indicated he can control costs so no cost increase; no increased labor requirement; but project schedule is 2 months longer.

PM for Project 2 indicates he can accommodate 2 month slippage in Project 1 since precedent work would be completed in time for him to begin.

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From a "direct" project interface perspective neither Projects 3 nor 4 were dependent on Project 1.

The PM for project 1 submits a new manpower forecast and the other 3 PMs continue without updating their forecasts since no direct impact.
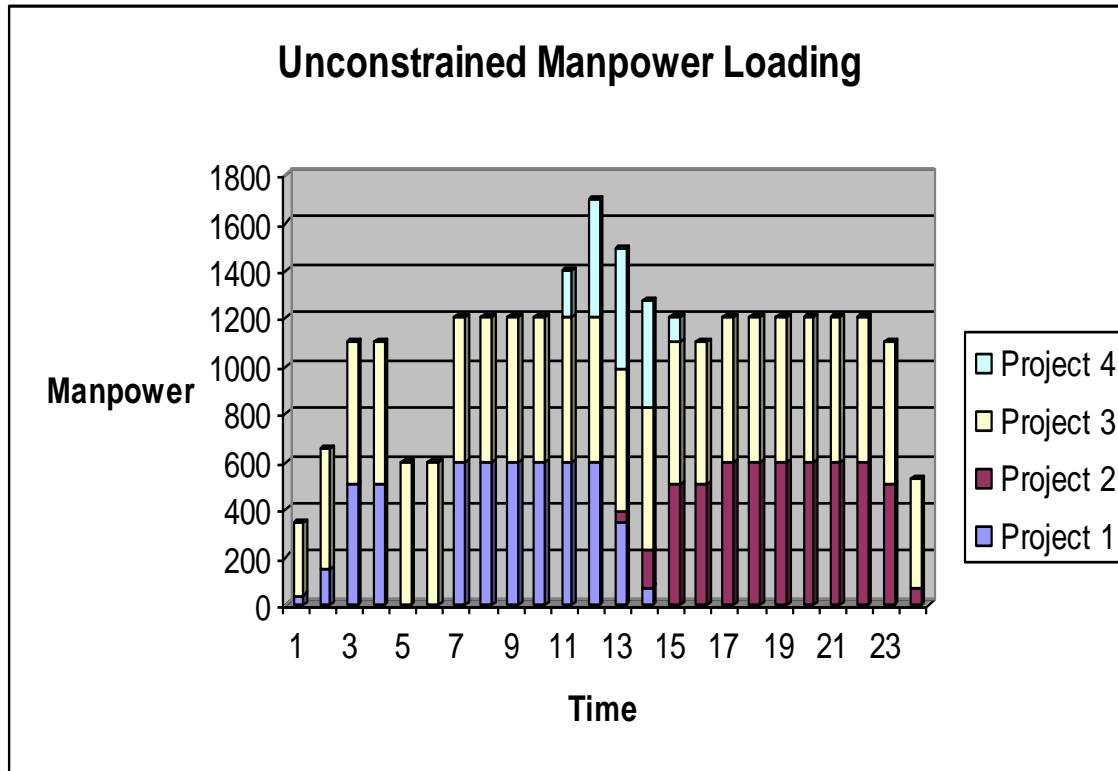

Initial look shows the overall critical path end date maintained but manpower loading at the program level is in excess of the overall 1200 constraint placed on the program. Without such a programmatic viewpoint it may not be self evident that the change proposed for Project 1 would cause the program to violate one of its constraints.

Attention now turns to executing the changed program while still meeting both the overall program 1200 person constraint and Project 3's 600 person constraint.

Program completion is delayed by 2 months despite the fact that Project 1 is not on the critical path.

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Granted a simple example but others exist with respect to limited supply of key trades, such as welding; limited camp accommodations; constrained import facility capacity and so on. Each of those an example from a recent giga program.

Manpower Loading Reflecting Labor Constraints
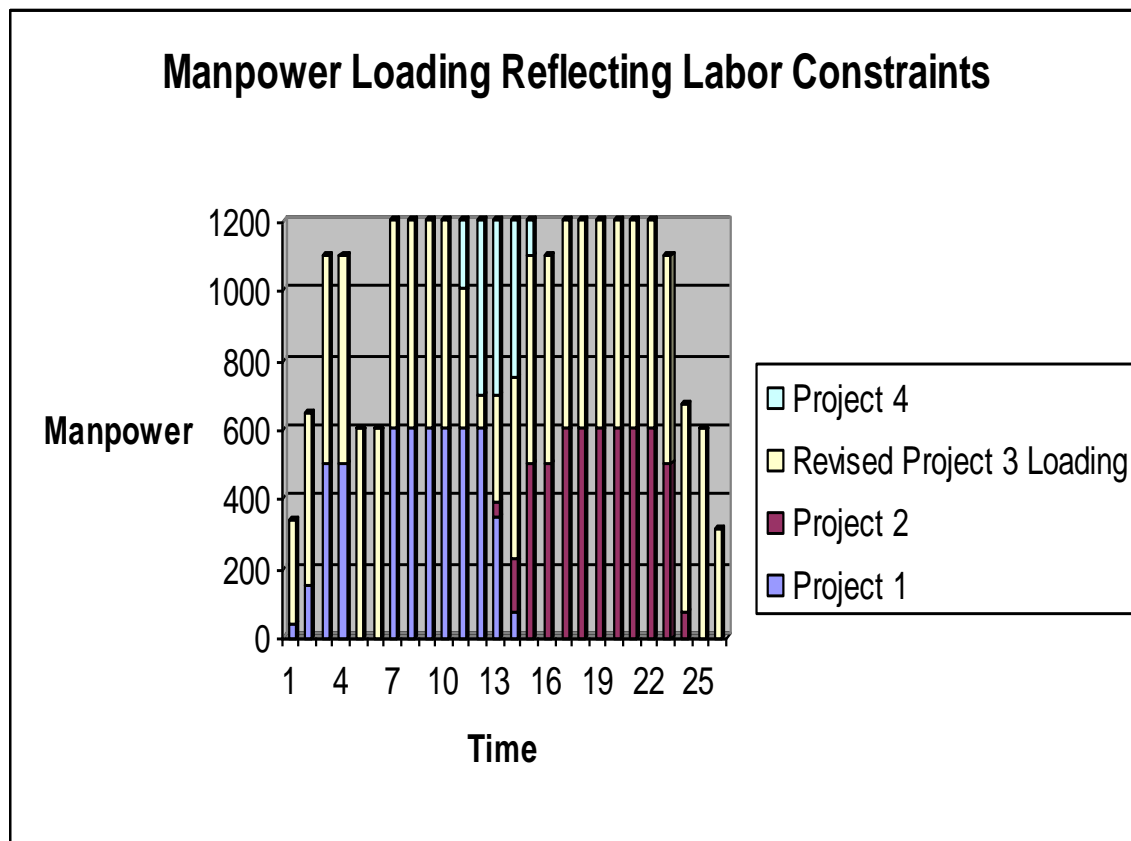
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i.   The importance of being modular; Marta Sales-Pardo; Science Vol 357, Issue 6347

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About the Author

Bob Prieto

Chairman & CEO
Strategic Program Management LLC
Jupiter, Florida, USA

Bob Prieto is a senior executive effective in shaping and executing business strategy and a recognized leader within the infrastructure, engineering and construction industries. Currently Bob heads his own management consulting practice, Strategic Program Management LLC. He previously served as a senior vice president of Fluor, one of the largest engineering and construction companies in the world. He focuses on the development and delivery of large, complex projects worldwide and consults with owners across all market sectors in the development of programmatic delivery strategies. He is author of eight books including "Strategic Program Management", "The Giga Factor: Program Management in the Engineering and Construction Industry", "Application of Life Cycle Analysis in the Capital Assets Industry", "Capital Efficiency: Pull All the Levers" and, most recently, "Theory of Management of Large Complex Projects" published by the Construction Management Association of America (CMAA) as well as over 600 other papers and presentations.

Bob is a non-executive director of Cardno (ASX) and an Independent Member of the Shareholder Committee of Mott MacDonald. He serves on the Millennium Challenge Corporation Advisory Board and a member of the ASCE Industry Leaders Council, National Academy of Construction, a Fellow of the Construction Management Association of America and member of several university departmental and campus advisory boards. Bob served until 2006 as a U.S. presidential appointee to the Asia Pacific Economic Cooperation (APEC) Business Advisory Council (ABAC), working with U.S. and Asia-Pacific business leaders to shape the framework for trade and economic growth. He had previously served as both as Chairman of the Engineering and Construction Governors of the World Economic Forum and co-chair of the infrastructure task force formed after September 11th by the New York City Chamber of Commerce. Previously, he served as Chairman at Parsons Brinckerhoff (PB).

Bob can be contacted at rpstrategic@comcast.net.