

Thirteenth Vecellio Distinguished Lecture

Abstract

Black Holes, Black Swans, Black Magic

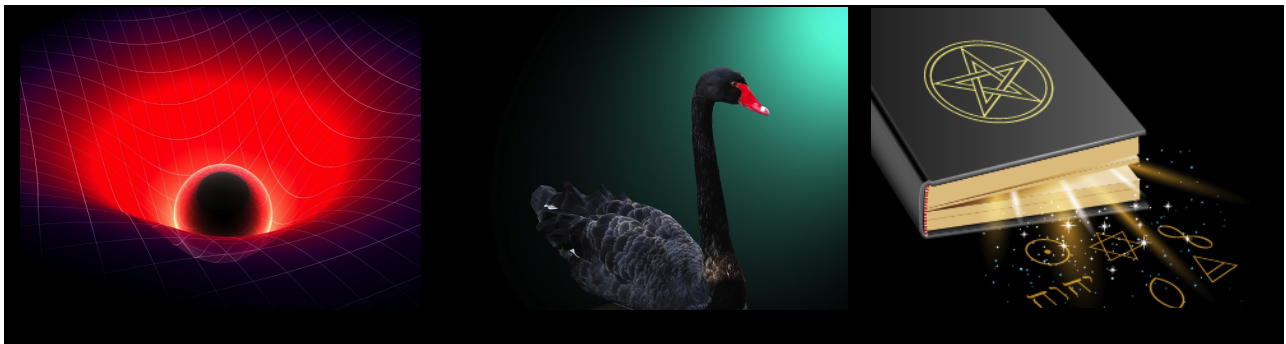
.....the emerging Arts of project execution

By

Bob Prieto

Bob Prieto's 2013 Vecellio Lecture takes the audience on a world-wind tour of some of the growing challenges in project execution and some of the emerging "arts" that may come to the rescue. The lecture looks at three broad challenges represented by black holes, Black Swans and black magic and suggests how our perceptions and tools must change to meet these challenges head on. The laws governing an engineer are recast in a familiar framework harkening back to Isaac Asimov, while parallels are drawn to the pre-Renaissance view of the "arts" and Australia's exploration and discovery.

New territories are both created and explored in the lecture and opportunities and challenges laid out for both Virginia Tech and industry. The lecture remains true to the recognition that we are participants in an "ever-evolving field that needs high quality research, education and well-trained personnel."



In moving through each of the "black" challenges project execution faces, we are introduced to the ESPRIT framework; Kahneman's planning fallacy; reference class forecasting; eigenprojects; knowable unknowns; giga projects; cyclomatic complexity analysis; assumption migration; constraint coupling; and inherent resiliency.

The lecture concludes by asserting that black holes, Black Swans and black magic are not impediments to the successful art of project execution if we only but reach to the future, embracing today's technologies and create the new tools and paradigms that tomorrow requires.

Black Holes, Black Swans, Black Magic

.....the emerging Arts of project execution

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I, Engineer.

Tonight's lecture will not be a reprise of the 2004 film, "I, Robot", but maybe it provides a good analog for the challenges and duties that today's engineer faces in executing increasingly challenging projects in an increasingly uncertain environment.

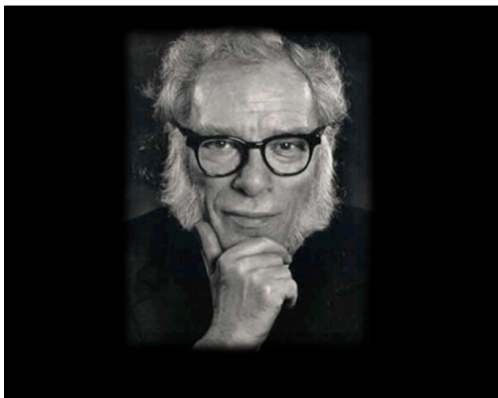
"I, Robot" is set in 2035, only a little over 20 years from now and may not be as much science fiction as the writers of the original screenplay thought in 1995. In the movie anthropomorphic robots enjoy widespread use as servants for various public services. They are programmed with the Three Laws of Robotics directives.

To set the stage let me review those three laws, substituting "engineer" for "robot".



First Law: An engineer must never harm a human being or, through inaction, allow any harm to come to a human.

Second Law: An engineer must obey the orders given to them by human beings, except where such orders violate the First Law.



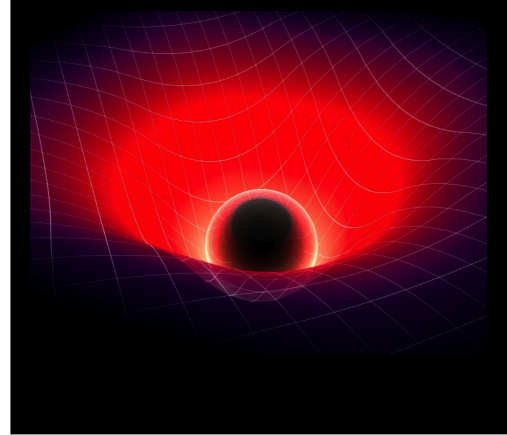
Third Law: An engineer must protect its own existence unless this violates the First or Second Laws.

When first conceived by Isaac Asimov, a Boston University biochemist, these laws might have described the engineers he saw being trained across the Charles River. But even Asimov, with his commitment to science and so called *hard* science fiction (which we might today call hard science prediction) most valued his role as president of the American Humanist

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Association. As a humanist he embraced human reason, ethics, social justice and philosophical naturalism, this later element founded on empirical investigation and reliance on material principles which are a hallmark of engineers.

So that is where my talk tonight will begin, on the human element in project conception, development, execution and utilization. It is the need to better consider and address our needs and behaviors as human beings which so often falls short, creating what might be described as the Black Hole of project execution. Recognizing, understanding and importantly addressing and if possible constraining this black hole are central to the success or failure of project execution.



These black holes undermine the foundations required in our project universe and if not recognized and addressed, they grow over time, consuming all of our good works as they plunge, uncontrollably, into this abyss.

So what are black holes? How are they created? And, importantly, what can we do to avoid or limit their destructive effects?

In physics, a black hole is a region of spacetime where gravity prevents anything including light from escaping. In the universe of projects the analogous region is one which prevents a strongly founded project from being initiated. These black holes may manifest themselves as weak or absent project definition processes, with well defined stage gates that ensure a well founded project. Alternately, they may be masked by the perception of a well founded project only to discover later on that the fundamental assumptions underpinning the project suffer from the so called “planning fallacy”.

So this brings me to my first admonishment on the challenges we increasingly face in project execution, namely the need to ensure our projects are well founded. This requires both a changed perspective as well as augmented tools. Let me spend a few minutes discussing each.

Changed perspectives

Projects today require us to adopt expanded perspectives to ensure our project’s foundations are truly well formed. There are many changes in perspective that I could discuss but let me focus on just three points.

First, our project perspective must become increasingly holistic. It is no longer sufficient to be good engineers from across the Charles or from Blacksburg. We must add the broader perspectives of the humanist, not only addressing, in a check the box fashion, the so called environmental and social bottom lines, but rather embracing them as fundamental to a successful project. In a very real sense we must move beyond Asimov’s three laws and embrace what he later added as the so called Zeroth Law. This law would state that “An engineer may not harm humanity, or, by inaction, allow humanity to come

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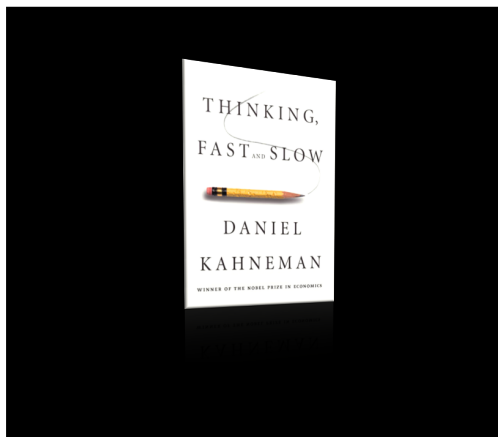
to harm.” This requires us to adopt a perspective more encompassing in scope than perhaps we have been trained for. This is a question not just for this institution but the society that we, as engineers, serve. Must we return to the pre-Renaissance definition of the arts, encompassing both *Artes Liberales* (liberal arts) and *Artes Mechanicae* (mechanical arts)?

Second, our project perspective requires a temporal adjustment. Today we think about planning, design and construction. But that in many ways represents only the initial birthing of a project. Its real value lies in the balance of its lifetime and in many instances, its biggest impacts are in the sometimes even longer societal affecting post lifetime period. Even as major projects grow into what I refer to as “giga” programs with project execution periods often measured in decades, actual project lifetimes are even longer. Today we see projects with design basis lifetimes of a century and we know many of the works of engineers have lasted even longer. Our project foundations must consider these fuller lifecycles across all the broader perspectives of the humanist I previously described.

Importantly, as we consider these longer temporal horizons we must challenge our confidence in knowing or predicting the future. Uncertainty must become a fundamental project planning basis and a key factor in project execution. Things become more uncertain over time, just as a black hole grows over time.

My third point on changed perspectives is quite simple. Consider, look at and challenge a project’s foundations, its very *raison d’être*, from every available perspective. Develop frameworks that help you adopt these different perspectives such as the ESPRIT framework I have used for years in looking at international construction and development projects. ESPRIT, an acronym for economic, social, political, religious, intellectual and technology, has allowed me to better ensure that foundations are strong before we set out to boldly go where no one has gone before.

Let me turn now to the augmented tools we will require to ensure our projects are well founded and that we do not have an undiscovered black hole at the center of our project universe.



Augmented Tools.

Daniel Kahneman’s book, “Thinking, Fast and Slow” returned his concept of the “planning fallacy” to the project management center stage when considering large, complex projects and programs. First coined by Kahneman and Amos Tversky in 1979, the planning fallacy is the tendency of people and organizations to underestimate how long a task will take even when they have experience of similar tasks over running.

Perhaps the poster children for the planning fallacy are large scale public works projects. In a 2006 paper in the *Project Management Journal*, Bent Flyvbjerg describes transportation projects “inaccuracy in cost forecasts in constant prices is on average 44.7% for rail, 33.8% for bridges and tunnels, and 20.4% for roads.”

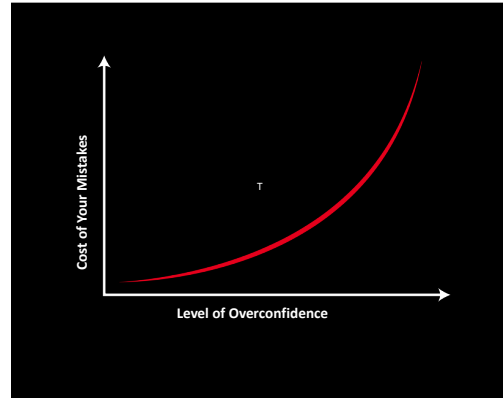
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Work by Kahneman, Tversky, Flyvbjerg and others show that errors of judgment are:

- systematic and predictable
- reflect bias
- persist even when we are aware of, and
- require corrective measures that reflect recognition of this bias

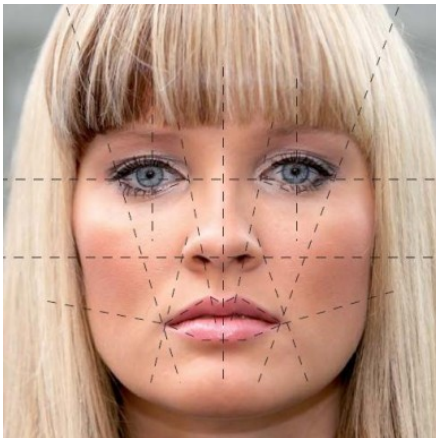
These natural tendencies are further exacerbated when “motivated” individuals frame questions in such a way as to constrain the range of possible answers.

Today’s project execution environment can no longer afford to be held hostage to this “planning fallacy” which deludes us to believe we have a well founded project when reality is very different. We require new tools if we are to observe the Zeroth Law, “An engineer may not harm humanity, or, by inaction, allow humanity to come to harm.”



New tools exist, or perhaps better stated, old tools can be better utilized. Two worth highlighting include reference class forecasting and development and utilization of eigenprojects.

Reference class forecasting is one method for suspending one’s impressions and providing a more critical evaluation of the task at hand. It addresses the natural tendency to underestimate costs, completion times and risks while at the same time overestimating benefits. It squeezes out biases while considering the inevitable “improbable” risks that all projects face. The Association for the Advancement of Cost Engineering (AACE) has recognized the value of estimate validation using separate empirical-based evaluations to benchmark the base estimate, the equivalent of reference class forecasting. This estimate benchmarking process is widely used in the process industries but need not be constrained to them. They must become a standard tool in developing and assessing the very foundations of projects.



The second tool we must develop and deploy relies on so called eigenprojects. So what are eigenprojects?

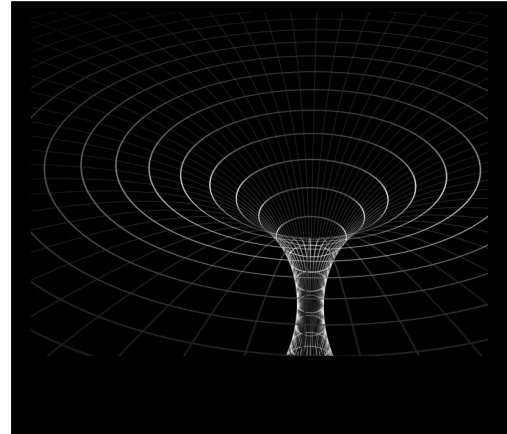
An analogy would be in the area of facial recognition where multivariate statistical techniques are used to create an eigenface. In this analogy we may take 10 pictures of an individual over time and we would expect the 10 images to statistically group. If we took similar sets of photos over time of other individuals we would expect similar images to group. Examples might be Caucasian men, Southeast Asian

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women, Eskimo women and the such. The age of big data opens up the application of pattern recognition to the field of project execution

The tools we require may not be created from whole cloth. Rather they may be adaptation of tools from other areas of endeavor to the field of project execution or in the case of Big Data, old tools on steroids.

Changed perspectives and augmented tools are essential to ensure our projects are well founded and that we can avoid or at least minimize the strong, silent destructive powers of black holes that might otherwise sit at the center of our project universe, a universe with a century long design basis.

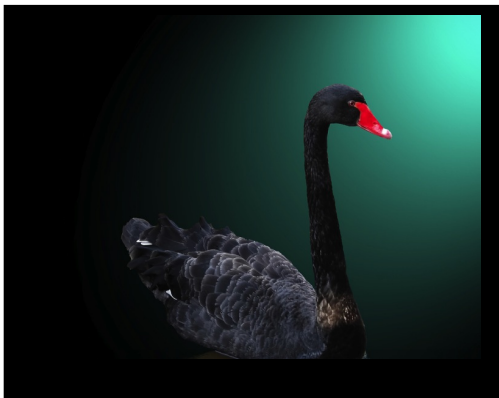


Before I move on to discuss Black Swans there is one last aspect of black holes that I would like to touch upon and that is a changing context in which black holes may form and exist. Historically, a client hired a designer and builder (separately or in an integrated manner) to execute his project. By and large each of these three players was a singular entity. That is less so today, and this introduction of a multi-party entity in each of these three roles is no longer uncommon.

The use of collaborations in accomplishing strategic business objectives has grown considerably over the years with two thirds of the business leaders in a Bank of America Merrill Lynch research survey indicating that they had worked closely in collaboration with at least one other organization and 90% indicating that the future depends on even more collaboration.

This represents not only an added level of execution complexity but in effect new foundational dimensions. Our confirmation of project readiness must now be complemented by an assessment of joint venture readiness, not only within each of the parties to the project but, importantly, between them. A recent survey on joint venture readiness in the engineering and construction industry and the project teams they are part of was not encouraging.

Clarity and communication of strategic business objectives, absent in two thirds of large projects that fail, are even more important and challenging in this joint venture context.



Now onto Black Swans.

Black Swans

All swans were white, until they weren't.

Willem de Vlamingh's sighting of a Black Swan during his 1697 exploration of Australia changed perceptions that all swans were white. It was not that Black Swans had not

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previously existed but rather we hadn't looked in the right place to find them.

Projects, and for that matter all human endeavors, have been victim to unexpected encounters with Black Swans. We know Black Swans or more appropriately Unknown Unknowns, exist and when encountered often produce disastrous outcomes. So what do we do?

A couple of years ago, I had a protracted exchange with a recognized international risk expert commenting on an article I had written on Black Swans. The essence of his point was that Black Swans, at least true Black Swans, were unknowable. I did not then and do not now accept that premise. While Black Swans were unknown to Europeans at least until de Vlamingh's sighting in 1697, clearly they were knowable. What had changed? What allowed us to see a Black Swan?

First and foremost, our perspective of the world in which we lived had changed at that time. Explorers built on chance encounters with various parts of Australia to concertedly seek out the postulated continent of Terra Australis. Herein lies a lesson for those engaged in project execution, seek out the breeding and nesting grounds of Black Swans and other rare "birds" we suspect may exist. I will talk more about these breeding and nesting grounds in a second but remember this – you must look and see before you can find.

Second, we must persevere. Merely sighting a Black Swan is intellectually rewarding but more rewarding would be to be able to hold it in your hands and to control its destiny. I say persevere, since it was almost 30 years before Black Swans had actually been captured. We will require new methods, strategies and tools to capture and control Black Swans but if they are "knowable unknowns" then shame on us if we don't develop and deploy those tools.

Let's talk about the Black Swans of project execution. Today we refer to them as Unknown Unknowns. I believe this is not a sufficient description of what we really mean.

Known Knowns	Known Unknowns
Unknown Knowns	Unknown Unknowns

Let's step back for a second and look at how we categorize risks a project may encounter. We group them into four broad categories – known knowns, unknown knowns, known unknowns and unknown unknowns.

Known knowns we handle in our plan. Unknown knowns are the assumptions we make. Known unknowns are the things we know we don't know, that is to say the knowledge is out there, we just don't have it yet.

Everything that is left over is an unknown unknown or pure risk as others would have you believe.

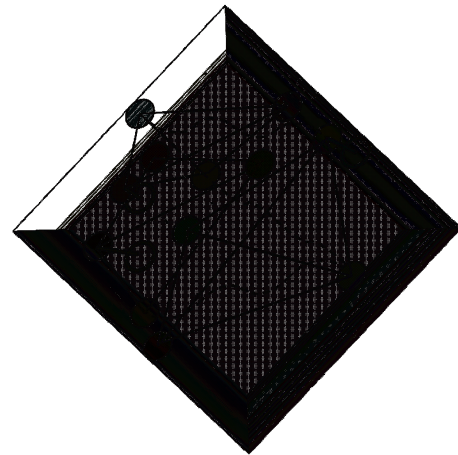
But our world of project execution, especially as it relates to what I refer to as giga projects, is increasingly complex, growing in scale and encompassing extended time periods. What does this new world of project execution suggest? Simply put, more undiscovered

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territory in which Black Swans can nest and breed and longer time frames over which they can make a surprise appearance, again, often with disastrous effect.

Let's examine what we know about this new, risky territory of project execution, let's call it Terra Extremus, and then think about the changes in perception and the new tools we will need to shift many of these unknown unknowns into knowable unknowns and ultimately into known unknowns.

Terra Extremus is a land not often visited and each prior exploration has only touched one small part of it. The results are often akin to the different perceptions of three blind men each touching a different part of an elephant (trunk, tusk, leg). The experiences and findings from all voyages to Terra Extremus have never been adequately compiled and thus our perceptions govern and these by their very nature are not rigorously confirmed or even necessarily fact based. Thus the first tool we require is a common language that recognizes the particular challenges of Terra Extremus and allows us to consolidate our understandings of what makes it different from more familiar territory. Explicitly, today's new giga projects require some new vocabulary or at the very least a recognition that meaning and syntax may have to change even if only in subtle ways. This is not "hokie" but may be something that can be addressed by the "hokies" of Blacksburg.



Terra Extremus is a complex land, but not every approach to executing a project in this land is equally complex. We need to better understand, measure, score and manage project complexity so we can have the best possible outcomes on the projects we undertake there. New tools such as cyclomatic complexity analysis, that provides a measure of relative complexity, need to be an integral part of our project planning and risk toolsets.

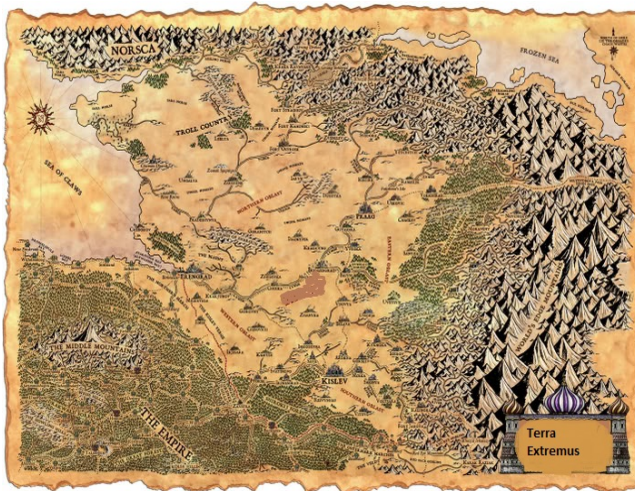
What are the sources of complexity in Terra Extremus?

I count at least five and on a deeper reflection I am sure more are identifiable. These sources of complexity include the global nature of these projects, application of new technologies or significant modifications to existing ones, scaling effects, dynamic project execution environments, and finally, extended time durations. Let me spend a minute discussing each.

Projects in Terra Extremus require mobilization of management, engineering and construction resources from across the globe. They are not typically undertaken by singular companies, adding to institutional complexity as policy, procedures, practices, communication and decision frameworks differ and must be coordinated. All work is not performed at one location as global engineering centers span the continents and more extensive fabrication efforts also are located at multiple locations remote from the final project site. Supply chains similarly tap primary suppliers around the globe with major components coming together for the first time in a mod yard or the final project site. Primary supplier's own supply

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chains are equally global and on one recent project, one primary component arrived at the final project site with items of supply from 80 different countries incorporated. In effect this one component had traveled around the world several times before arriving at the final project site. Project execution in Terra Extremus requires us to be cognizant of not only our own primary supply chain but to have even deeper insights to second and third tier suppliers. This requires radically different tools to manage and maximize the contributions from our supply chains. Unlike the advanced tools used in more traditional



logistical industries, ours will require an ability to deal with a steam of bespoke facilities and a bespoke supplier base, often driven by a complex set of project externalities. Moving a standard shipping box is an easy logistical problem compared to those we increasingly have to wrestle with in real time.

Projects in Terra Extremus often push the limits of technology. Sometimes this is driven by the need to operate in more remote or more extreme environments such as those one often finds in Terra

Extremus. Increasingly this shift in technology is driven by the more holistic perspectives I talked about at the outset of this lecture with considerations around life cycle energy, water, waste, and societal impacts driving project solution sets.

Terra Extremus is a land of scale, I suspect much like the first inland explorers of Australia thought about upon encountering the Outback. The normally small things become big and important and grow as contributors to project risk. Optimization points need to change and change in significant ways. Optimizing steel member sizes or the size of bolts on a flange were great engineering endeavors on smaller, less remote, less complex projects but not so in Terra Extremus. Optimizations will be more holistic, across all three of the bottom lines described, and importantly must happen earlier on, be done on a life cycle basis, and explicitly address uncertainty and risk. Optioneering must begin at the 1% stage of project execution, if not before. “Multivariate options analysis with uncertainty”, now that sounds like the beginning of a good doctoral thesis title.

Global execution, technological complexities and giga scales would be enough to describe the complex environment in which Black Swans can nest and breed, but the picture would not be complete without recognizing the added complexity associated with the dynamic environment that exists in Terra Extremus. Myriad externalities act not only on the various nodes that are encompassed by execution of these giga projects – final site; mod yards; primary, secondary and tertiary manufacturing locations – but importantly on the extensive network linking them. Weather, labor, costs, politics and competition for constrained supplies change through the project life cycle, often shifting what the optimal path forward should be. It is only through skills in all the arts that we even have any hope of achieving good execution performance.

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The final contributor to complexity derives from the extended project durations, whether these are 15 to 20 year project execution time frames, 100 year asset operating lives, or millennial post closure concerns. The longer the time frames we consider, the more likely we will see a Black Swan. Longer time frames are also associated with increased uncertainty around the assumptions we made when looking at unknown knowns. Assumption migration is an important contributor to overall complexity but well within our capabilities to better manage if we choose.

Our perspective on risk and unknown unknowns must change. Black Swans are knowable, if not today then maybe tomorrow. I have suggested some tools and strategies to deal with elements of complexity which provide the breeding and nesting grounds for these rare birds. But let me also suggest that we are using less than our full risk assessment tool set today and that suggests that maybe our dozens of different risk tools need to be assembled and deployed in new more creative ways, addressing concerns such as the thin tails inherent with Monte Carlo analysis.

Similar to black holes, Black Swans do not have to be unmanageable eventualities. Changed perceptions, drawing on all the “arts” and application of new and existing tools in new ways provide the promise of being able to increasingly successfully deliver the most challenging and complex projects of the 21st century.

This brings me to the last element of improving the “art” of project execution, an element that would be the antithesis of Asimov’s philosophical naturalism – black magic!

Black Magic

By now you have come to recognize that project execution is growing ever more challenging driven by



factors such as complexity, scale and duration. Weak foundations have ever more deleterious effects and cannot be sustained. But today’s project execution environment faces added challenges from things which some have individually referred to as being the result of black magic.

Now before I get any further into this part of tonight’s lecture, let me make it clear that I am not a believer and I will not be providing you with any spells to undo the effects some have ascribed to black magic. If only it were that simple.

So what are some examples of black magic acting on projects today and what can we do to bring “arts” other than the dark ones to bear.

The projects of Terra Extremus are often in foggy environments, where every feature cannot be clearly seen. Combined with the complexity previously discussed we find ourselves experiencing risks and realizing execution difficulties where none should have existed. It was as if they were conjured up from thin air.

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Let me use an example to illustrate this apparent black magic at work. A multi-project program includes a project not on the critical path. This project slips in time but is still not on the critical path and will still be done before the original program completion date. It provides no inputs and has no apparent precedences with the critical path project. Yet the program is delayed because of this slippage.

Black magic or something else?

In this case the project drew labor from a constrained labor pool, consuming a critical skill common with the critical path project at exactly the same time. Had it stayed on its original schedule this coupled constraint would never have manifested itself.

Many types of coupled constraints exist such as competition for critical skills, shared logistical choke points and precedences lost in uncertainties and contingencies. Coupled constraints are one example of a broader set of risks that I refer to as white space risks, things that happen between projects, facilities or project activities which have an impact in ways not contemplated and often significant.

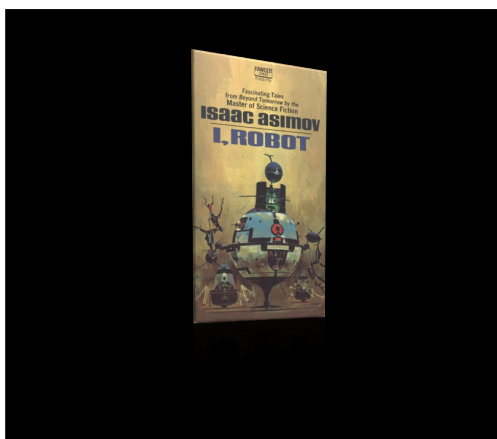
Let's turn to a second example of black magic at work. Two options exist for executing a particular type of project, each with equal cost, duration and apparent project delivery risk. Certain features of the plant are different but plant nameplate ratings are identical. Two owners each build a plant, next to each other but choosing opposite alternatives. Both projects start at the same time, cost the same and open the same day. Did their choices matter?

If you believe in black magic the answer is yes. Subsequently, both plants experienced a Black Swan type event at exactly the same time and experienced identical damage. One plant restarted in 30 days the other in 6 months. It turns out that those slightly different features in the otherwise identically performing projects resulted in dramatically different inherent resiliency. Black magic can play havoc on system level properties such as resiliency, business continuity and inherent flexibility but only if we let it.

As designers, builders, operators and owners of today's projects and tomorrow's capital assets we have the obligation and opportunity to bring a fresh perspective and new tools to bear to improve project

execution. In these two examples of black magic at work new tools focused on deeper probing of possible white space risks, such as constraint coupling, or better assessment of system level properties, such as resilience, would have made a difference back at our earliest optioneering stages.

Understanding the efficiency of project execution alternatives and deploying new metrics to assess and measure relative project disruptions from planned and unplanned changes would similarly improve our performance.

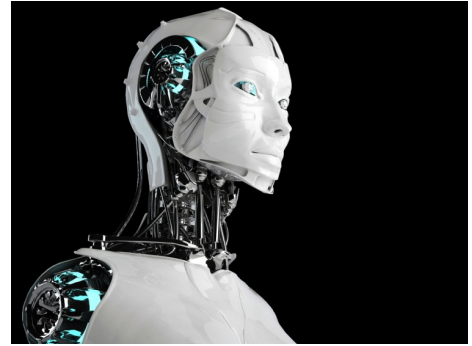


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The Future is Now

“I, Robot” was set in 2035. “I, Engineer” can be set in 2014, if we choose to do so.

Many of the changes essential to improved project execution revolve around changed perspectives including more strongly embracing arts other than just Artes Mechanicae. Perceptions can be changed but only if we broaden our perspectives and adopt a more holistic approach to project execution truly considering the entirety of the life cycle.



The balance of the changes largely build on new and better tools or at the very least applying the ones we have in different and more created ways. Institutions, such as Virginia Tech, are essential, and echoing the words of Leo Vecellio Jr, project execution is an “ever-evolving field that needs high quality research, education and well-trained personnel”.

Black holes, Black Swans and black magic are not impediments to the successful art of project execution if we only but reach to the future, embracing today’s technologies and create the new tools and paradigms that tomorrow requires.

Like Sonny in “I, Robot” we can fulfill our purpose perhaps best summed up in the Zeroth Law, “An engineer may not harm humanity, or, by inaction, allow humanity to come to harm.”

