Improbability of Large Project Success

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In his book, “The Improbability Principle” (1), David Hand, former president of the Royal Statistical Society provides a tour de force treatment of uncertainty and how improbable events happen, over and over again. For those who have not read it I highly recommend it.

In this paper I will attempt to use the lenses described by David Hand and look at the world of large projects and their unacceptably high failure rates. Application of “best practices” would suggest these failures should be improbable or at least less frequent than reported failure rates suggest. If we are to repeatedly experience the improbable it is perhaps better that we understand it.

The Lenses

The lenses developed by Hand can best be described as comprising a set of “laws” he has compiled to describe why seemingly improbable outcomes may not be as improbable as they first seem. These laws include:

- **Law of inevitability** – something must happen
- **Law of truly large numbers** – with a large enough number of opportunities, any outrageous thing is likely to happen
- **Law of selection –** you can make probabilities as high as you like if you choose after the event
- **Law of the Probability Lever** – slight change in circumstances can have a huge impact on probabilities
- **Law of near enough –** events that are sufficiently similar are regarded as identical

Let us consider each in turn and how they shape our views on the failure of large projects.

Law of inevitability

The Law of Inevitability, in its simplest terms, says that something must happen. Perhaps, as a corollary to that law, we have Borel’s[1] Law which says that sufficiently unlikely events are impossible.

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[1] Félix Édouard Justin Émile Borel was a French mathematician known for his work in probability and measure theory.

In our evaluation of the risks large projects face we seek to identify and manage top risks. In the process we ignore events that appear sufficiently unlikely, treating them as Borel would, as impossible. But are these ignored events truly as unlikely as we perceive them to be.

Let's consider several highly impactful events that on first consideration might seem sufficiently unlikely as to consider them impossible within a project's context and time frame.

100 Year Storm

A 100 year storm is a weather event with a return period of 100 years. This does not mean that such a storm occurs regularly at 100 year intervals or that it will only occur once in a given 100 year period. Rather, a 100 year storm means that in any given year the probability of such a storm occurring is 1%. As project gestation and delivery times have grown, the cumulative probability of encountering such a storm during the project execution period has similarly grown. This is perhaps one of the underappreciated aspects of large project development, namely, that the **extended project periods are risk aggregating**. When these periods are subject to delays, whether from permitting, agency approvals, design or construction, the cumulative probability of observing this and many other risks during the project period similarly grows.

Let's look at this 1% risk more closely.

In that rare 1 year project our probability of experiencing the risks during project execution (damaged equipment; destroyed work in progress; extended resulting project delays) is 1%, independent of when such an event last occurred. But on larger projects with say 10 year project periods that risk has climbed for simplicity to 10%[2].

A 10% risk of significant project impact is not a risk we would typically ignore in our risk analysis but in our risk assessment we may consider such an event as improbable.

Let's look at another example, one that we underestimate every day, namely the extended risk consequences of disruption.

Extended Risk Consequence of Disruption

No activity is perfectly executed every time. ***Something must happen****.*

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[2] The cumulative probability of this risk materializing exactly once in the 10 year period is actually calculated as the probability of it not occurring in a given year raised to the nth power where n is the number of years. In this example $(1.00 - 0.01)^{10}$ or 90.44%

Even the smallest "off normal" performance has the ability to impact (directly and indirectly) coupled project execution activities. This disruptive impact may have a range of values, and while the mean disruption may be infinitesimally small, it won't be in every case. Let's consider that a significant disruption from just "off normal" performance of an activity is extremely rare, so improbable that Borel would have us treat it as impossible. Let's say such extensive disruptions from mere "off normal" performance happens only once out of every million executions of an activity.

Now think about large projects with 100,000 or more activities. The probability of experiencing measurable disruptions in the course of "normal" project execution grows measurably, even without a significant "event" risk which we may have considered in our risk assessments. At a simplistic level, there is now a 10% chance of one activity's "off normal" performance leading to a significant disruption. This ignores the cascading impacts from consistent "off normal" performance which may be the result of poor planning and estimates (optimism bias as we see in Kahneman's[3] planning fallacy) or more systemic underlying issues (inadequate project alignment, labor skill levels or relations; general environmental conditions). It also ignores indirect coupling of constraints that can greatly exacerbate the impacts of seemingly inconsequential "off normal" performance.

As I discuss some of the other laws that Hand describes, you will see that it is not unusual for one or more of these laws to be acting on project performance simultaneously.

Law of Truly Large Numbers

With a large enough number of opportunities, any outrageous thing is likely to happen. Large projects provide myriads of large pools of opportunities for outrageous things to happen. And they do. Let's look at some of these scaled opportunities we find in large projects:

- Total project durations (from planning through commissioning) sometimes measured in decades (a 30 year planning, permitting, development , design and construction project is not unusual for many large scale public works projects)[4]
- Project schedules with tens of thousands to a 100,000 or more activities
- Workforces that number from the thousands to tens of thousands to 50,000 or more

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[3] Daniel Kahneman is a psychologist and won the Nobel Prize in Economics. Author of Thinking, Fast and Slow

[4] Perhaps this is a key driver in why large public projects seem to be particularly prone to large overruns and project delays in construction

- Miles of welds
- Thousands of field connections
- Thousands of tons of modules and pre-fabricated assemblies moved, collectively, tens of thousands of miles
- Countless thousands of inspections

The improbable is not impossible and as we saw in the Law of Inevitability, something must happen…things go wrong. The Law of Truly Large Numbers makes the opportunity for a risk to be realized a lot less improbable and in fact almost assures its occurrence. Even the possibility that the realized risk will be severe in its impacts grows as we scale large projects into the realm of the Law of Truly Large Numbers.

Let’s look at a couple examples, first a rare event and then one less rare in the world of large projects.

Lost Shipping Container

Large projects focus on increasing logistical efficiency, using barcodes and RFID tags to provide better end to end tracking of cargo required at the project site. Additionally, shipment efficiencies are being sought through the efficient use of standard shipping containers. Much of these containerized shipments will travel by ship at some point in their journey to the project.

But containers get lost at sea. This happens through both routine losses (container over board) and catastrophic losses (ship sinks). What if one of these containers was for your project? Is this a risk we have considered and provided for? Is it something we really need to concern ourselves with?

During the period from 2008 – 2013, annual shipping container losses at sea from all causes averaged 1,679 containers per year. This must be viewed in perspective, in 2013 there were approximately 120 million container shipments, resulting in a probability of a container being lost of 0.0014%. Not a high probability risk?

Now let's put that in perspective and consider a large construction project where one might expect 1000 containers. What is the probability one is lost at sea?

0.0014%		Probability that a shipping container will be lost at sea
99.9986%		Probability that a Given Container will not be lost
98.6097%		Probability that none of the containers is lost
1.3903%		Probability that one container is lost

1.39% is not a large risk but much more measurable than we might first believe. One large ongoing military project will involve the shipment of 80,000 containers. The probability of losing at least one at sea is a virtual certainty.

Now let's look at a more likely scenario and think about how well we provide for its risks.

Delayed Critical Component

In the previous example our container was lost at sea (1.4% of the time). In this example we will consider the significantly delayed availability of a critical component required for a work activity. Its delayed availability will impact project sequence and will add to disruption and work around costs.

Let's consider the case where one in a thousand critical components on a project is significantly delayed as we have defined it. To put this in context for a large project with 100,000 activities it means that one in a hundred of those activities include a component critical to undertaking and completing the activity.

This means the probability that a critical component is delayed is 0.1% or conversely that the probability that a given critical component is not delayed of 99.9%. On the project where we have 1000 critical components (1 out of 100 activities requires a critical component) we see the following:

0.10%		Probability that critical component is significantly delayed
99.90%		Probability that a given critical components is not significantly delayed
36.77%		Probability that none of the critical components is significantly delayed
63.23%		Probability that critical component is significantly delayed

We have a probability that at least one critical component is significantly delayed of over 63%.

If instead, one out of ten project activities requires a critical component (there are now 10,000 on the project) our probability that at least one is delayed rises to essentially 100%.

Law of Selection

The Law of Selection says you can make probabilities as high (or low) as you like if you **choose after the event**. Large projects are characterized by tens of thousands of assumptions, most never written down. We make many of these assumptions based on perceptions of values or their trajectory. Our sources for many other values we assume are mean values but tell us nothing about extremes or distribution of values. In yet other cases, our assumptions are based on adjusted performance, where extremes are thrown out. (We could have ignored the sinking of a container ship to arrive at a lower average number of containers lost annually in the earlier example). Let's look at a couple of examples of how the law of selection can come into play and impact large projects recognizing that these sometimes unconscious selections can come from multiple sources, combining for truly significant impacts on large projects.

Folly of Averages

In our planning of large projects we often use average values which we treat as constant throughout the project period. One of these constant average values often encountered is general inflation or other similar escalation factors. For simplicity we may select our best estimate of what an average value may be over a project period and utilize that value constantly over the planned project duration. Let’s look at how even such a simple selection can impact the outcome of a large project by considering three simple inflation cases. In each the real rate of work performed is assumed to be constant in each and every year of a ten year project and in all three cases the average annual inflation rate over the 10 year period is exactly 3%. The three cases include:

- Constant 3% annual inflation rate
- Growing annual inflation rate; average of annual rates 3%
- Declining annual inflation rate; average of annual rates 3%

Effect of Inflation					
Average Annual = 3%					
Zero variability					
Year	**Real Balance**	**Annual Amt.**	**Remaining**	**Annual Rate**	**Inflation**
1	1.0000	0.1000	0.9000	0.030	0.0270
2	0.9270	0.1030	0.8240	0.030	0.0247
3	0.8487	0.1061	0.7426	0.030	0.0223
4	0.7649	0.1093	0.6556	0.030	0.0197
5	0.6753	0.1126	0.5628	0.030	0.0169
6	0.5796	0.1159	0.4637	0.030	0.0139
7	0.4776	0.1194	0.3582	0.030	0.0107
8	0.3690	0.1230	0.2460	0.030	0.0074
9	0.2534	0.1267	0.1267	0.030	0.0038
10	0.1305	0.1305	0.0000	0.030	0.0000
	Total	1.1464	Average	0.030	

Effect of Inflation					
Average Annual = 3%					
Growing					
Year	**Real Balance**	**Annual Amt.**	**Remaining**	**Annual Rate**	**Inflation**
1	1.0000	0.1000	0.9000	0.010	0.0090
2	0.9090	0.1010	0.8080	0.015	0.0121
3	0.8201	0.1025	0.7176	0.020	0.0144
4	0.7320	0.1046	0.6274	0.025	0.0157
5	0.6431	0.1072	0.5359	0.030	0.0161
6	0.5520	0.1104	0.4416	0.030	0.0155
7	0.4570	0.1143	0.3428	0.035	0.0137
8	0.3565	0.1188	0.2377	0.040	0.0107
9	0.2484	0.1242	0.1242	0.045	0.0062
10	0.1304	0.1304	0.0000	0.050	0.0000
	Total	1.1133	Average	0.030	

Effect of Inflation					
Average Annual = 3%					
Declining					
Year	**Real Balance**	**Annual Amt.**	**Remaining**	**Annual Rate**	**Inflation**
1	1.0000	0.1000	0.9000	0.050	0.0450
2	0.9450	0.1050	0.8400	0.045	0.0378
3	0.8778	0.1097	0.7681	0.040	0.0307
4	0.7988	0.1141	0.6847	0.035	0.0240
5	0.7086	0.1181	0.5905	0.030	0.0177
6	0.6083	0.1217	0.4866	0.030	0.0122
7	0.4988	0.1247	0.3741	0.025	0.0075
8	0.3816	0.1272	0.2544	0.020	0.0038
9	0.2582	0.1291	0.1291	0.015	0.0013
10	0.1304	0.1304	0.0000	0.010	0.0000
	Total	1.1800	Average	0.030	

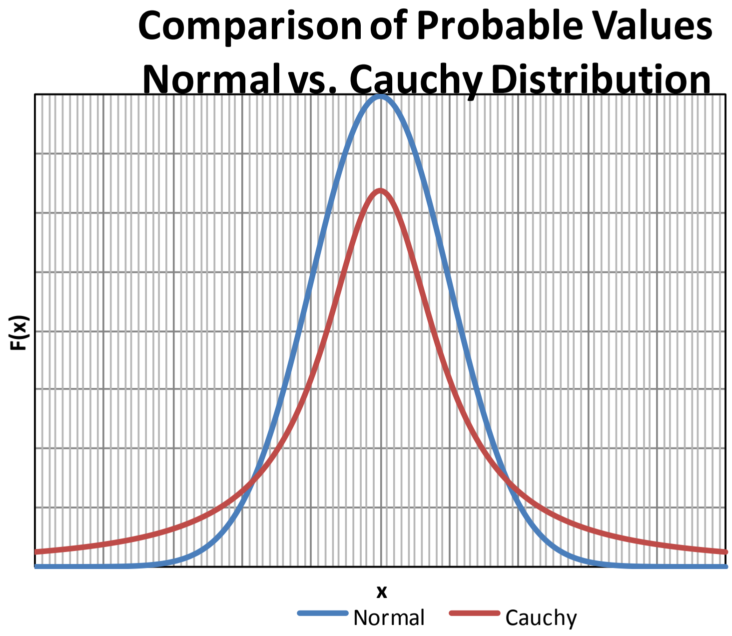
Taking timing of inflation rates into account can change our expected project cost by 3.3% in this simple example, just one of many selection decisions we make focused on simplifying analysis.

Fat Tails

Large projects are complicated and often sophisticated endeavors and we seek to improve the quality of our time and cost estimates by accounting for certain quantitative uncertainties in our estimates. Clearly a step in the right direction but as the results of large project performance would suggest, not good enough. This paper begins to suggest that perhaps we are unwitting victims to some of the laws of improbability and maybe the Law of Selection even impacts our best efforts to address uncertainty of estimates in our own risk analysis.

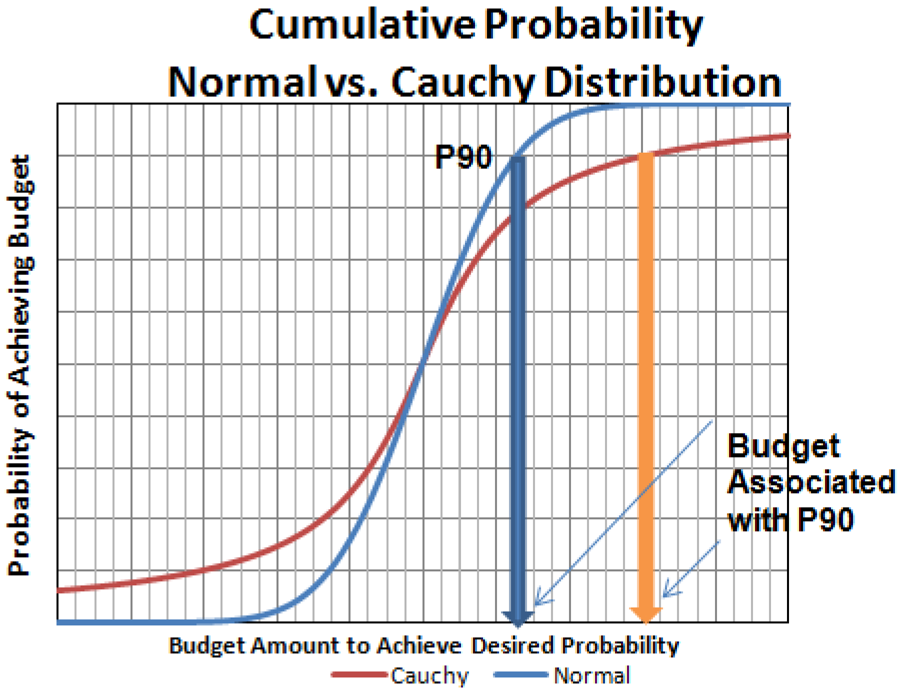
Let's consider a given estimated value where we have assumed a normal distribution around a mean value. Have we selected the data set for calculating the mean in such a way as to dismiss so called outliers? Or potentially more common, have we utilized a distribution around a mean which dismisses these outliers without any direct action on our part other than the selection of the probability distribution itself. One place where these distribution assumptions come together with direct impact on our perception of likely (vs. actual) project performance is in our project risk analysis.

Let's consider the very typical case where a Monte Carlo analysis is run utilizing a normal distribution. Implicit is an assumption that extreme outliers are so improbable as to be impossible under Borel's Law.



We see the normal distribution's characteristic thin tails as contrasted with the thicker tails associated with the Cauchy[5] distribution. It is in these thicker tails that we might expected to see Black Swans or even less exotic but extremely significant "off normal" events that combine for project failure in large projects.

Let's consider these distributions from a slightly different perspective by looking at the cumulative probabilities. We can see that in order to achieve higher confidence levels (say P90), the Cauchy distribution and its inherent inclusion of the possibility of off normal events, would have us include a significantly higher budget amount.



Finally, we see the results of the various improbabilities discussed in this paper in the "failed" performance of large projects. The following figure shows the distribution of project schedule overruns for a sample of large industry projects[6]. Note the better fit of the Cauchy distribution for overruns larger than the mean overrun. The fatter overrun tail better describes the "failed" project performance we see in large projects.

The stark difference in the views of the two distributions as it relates to improbable events should cause us to reconsider the choice of distributions for select parameters in

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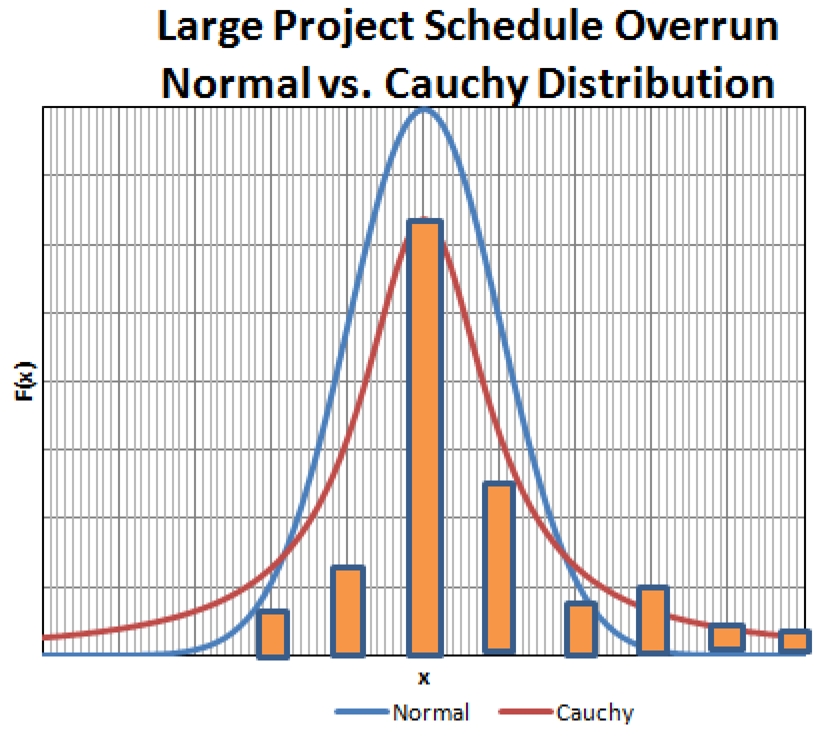
[5] Baron Augustin-Louis Cauchy was a French mathematician who almost singlehandedly founded complex analysis

[6] Data reflects number of projects within an overrun range from a sample of over 50 billion dollar plus engineering & construction industry projects. Overruns were calculated based on final cost and originally approved budgets.

our overall Monte Carlo risk assessments or at the very least confirm that the parameters we are modeling actually vary as the normal (or other assumed) distribution would suggest.

Probability of the Improbable		
	Normal	**Cauchy**
5 sigma event	1 in 3.5 million	1 in 16
10 sigma event	1 in 1.3 x 10^{23}	1 in 32
20 sigma event	1 in 3.6 x 10^{88}	1 in 63
30 sigma event	1 in 2.0 x 10^{197}	1 in 94



Law of the Probability Lever

The Law of the Probability Lever says that a **slight change in circumstances can have a huge impact** on probabilities. Today's focus on unconventional oil and gas development has its roots in hydraulic fracturing (1940's) and horizontal drilling using mud motors (1970's). It was the combination of these two technologies, and their progressive improvement that have led to the boom in unconventional oil and gas. The rapid advancement in shale development has had a tremendous impact on large scale oil and gas projects:

- Shifting the need for LNG terminals from import oriented to export oriented in the US, causing some projects to be canceled, new ones to move ahead and impacting capital efficiency in a broad portion of the market
- Shifting the nature of facilities to be constructed to handle these unconventional energy supplies and the locations and required supporting infrastructure for these projects
- Indirectly influencing CAPEX costs of new oil and gas projects as energy, a significant cost component in new construction, dropped in price within the US.

More recently, sharp global oil price drops driven by both supply and demand challenges, have had significant impacts on large oil and gas projects, with upwards 0f 30% of the final project decisions expected in 2015 likely to be either cancelled or deferred.

In the first instance, the rapid adoption of a combination of two existing technologies fundamentally shifted a major portion of the large project market while in the second instance policy decisions by OPEC had similarly extreme impacts. Preceding each event the probability of energy independence by the US or dramatically lower global oil prices were viewed as highly unlikely scenarios.

We see the probability lever come into play in catastrophes, where a slight change leads to a broader dramatic change (Katrina levy overtopping leads to flooding of New Orleans); in observed domino effects (construction delays) or cascading failures (key supplier or subcontractor fails and brings down the prime); and our tendency to overestimate probabilities when we can think of examples (estimating a project risk based on our prior experiencing of it; conversely underestimating those we have not experienced).

Some other examples of how a small change can have an extensive impact can be seen in “Details Matter” and “Nuts & Bolts”.

Details Matter

Today’s large projects often require extensive welding and other highly specialized construction operations. These specialized operations often result in miles of welds or other large sets of highly specialized results. Specifications for these specialized operations are often referenced in contract documents but it is not unusual for the supporting documents, incorporated by reference, to not be similarly defined.

On one large project involving highly specialized operations, the base specification and version was referenced in the contract but the acceptance test incorporated by reference did not contain a revision number or date. During construction the acceptance criteria in the referenced document changed significantly such that the resultant construction which would have passed the earlier acceptance test could not meet the revised, more stringent testing and acceptance regime.

This small change contributed to extensive cost and schedule overruns.

Nuts & Bolts

On a large project the drive for capital efficiency resulted in a blanket policy for design optimization. It became a stated project goal. The result of a good idea out of control was a dramatic increase in the number of sku's best represented by one hopper that contained eight different size nuts & bolts. The optimization by the design engineer to use smaller bolts wherever possible (since smaller bolts cost less than larger bolts) resulted in $157 in bolt savings on the hopper and over $30,000 in added labor and supply chain costs in this labor-short, extreme environment. Similarly, optimization of structural steels shapes to reduce steel tonnage resulted in 30% of major structural members being custom shapes with significant net addition to project costs despite the steel tonnage savings.

Law of Near Enough

The Law of Near Enough states that events that are **sufficiently similar are regarded as identical.** This presents a challenge when ascertaining the root causes of near miss safety events on large projects. While the near miss of a hand injury may be ascribed to putting one's hand into a tight space which can move on us, it is important to understand why the hand needed to be there (is it a design issue or a means & methods issue?); what causes the movement which puts the hand at risk (is the worker in an unsteady position or does the construction approach cause the movement or other?)

We see the Law of Near Enough impact large projects where inadequate float exists in tightly coupled activities. While we may record durations in actual performance as near enough to be consistent with planned durations, late starts or completions can create a disruptive ripple effect through the project.

Coupled Constraints

Consider the situation where an activity not on the critical path begins late but near enough to the original plan to stay off the critical path. No problem? It won't be if that key resource it uses doesn't arrive on time for a critical path activity. The complexity of large programs masks a raft of hidden, coupled constraints that can then cascade. Near enough is not good enough and the complexity of large programs needs to consider the probability of disruption when the Law of Near Enough seems to have governed in assessing project risks.

Conclusion

We focus on the probable and make best efforts to account for the uncertainties we are likely to encounter in our project planning and risk provisions. But in planning for dealing with the probable we underestimate the possibility of what we believe to be improbable. Our risk lens is somewhat opaque and perhaps even the models we use are not well chosen. The results of large projects tell us that near enough is not good enough. We must ask ourselves whether the world of complex projects is more like complex financial markets, catastrophic events or analysis of fuzzy data, all of which benefit from fatter tails and consideration of the improbable. Large projects may not live in a neat Gaussian world.

The improbable is not impossible and the performance of large engineering and construction projects suggests that we revisit not only execution of projects but our planning and risk basis as well.

References

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