# Risk Analysis at the Edge of Chaos

John K. Hollmann PE CEP DRMP

AACE International

www.aacei.org

aace International
The Authority for Total Cost Management™

# PLEASE USE MICROPHONE FOR ALL QUESTIONS AND COMMENTS!

AACE International

www.aacei.org

aace International

The Authority for Total Cost Management™

# BIO of John K. Hollmann

- Owner: Validation Estimating LLC (since 2005)
  - **Help owner companies improve their Cost Engineering capabilities, review strategic project estimates and conduct risk analyses**
  - **35 years experience: engineering, project control, estimating, research, benchmarking, and consulting**
  - **AACE Approved Education Provider: CEP Exam Prep Course**
  - **Previous employers include: Battelle, Fluor, Kodak, IPA**
- Education and Certification:
  - **BS Mining Eng - Penn State Univ.; MBA - Indiana University of PA**
  - **Registered PE, CEP, DRMP**
- Associations:
  - **AACE Life Member & Award of Merit**
  - **Editor/Lead Author of the AACE's TCM Framework**
  - **Led development of AACE's DRMP Certification (and many RPs)**
  - **Have served on AACE Board and Technical Board**
  - **Society of Mining Engineers**
- Something you do not know about me
  - **Top Senior Art Student in High School Class**

# SUMMARY

AACE International

www.aacei.org

aace International®
The Authority for Total Cost Management™

# Summary

- Problem:
  - **Research shows that project cost accuracy distributions (actual/estimate) are bimodal with a very long tail on the high side**
  - **Our risk analyses fail to predict this; we are not even close (actual p90 values are about 3X the values we are estimating)**
- Hypothesis and Proposed Resolution
  - **Hypothesis: Bimodality reflects the cost outcome of project chaos**
  - **Resolution: Use chaos and complex systems theory to develop a method to warn management when a project's risks threaten to push it over the edge of chaos; i.e., the tipping point to disaster**
- Scope of the Presentation:
  - **Review chaos and complex systems theory and how they relate to project cost uncertainty**
  - **Present a "tipping point indicator" that brings theoretical findings into a practical risk quantification toolset**
  - **Demonstrate a model that replicates bimodality and the long tail**

# THE PROBLEM

AACE International

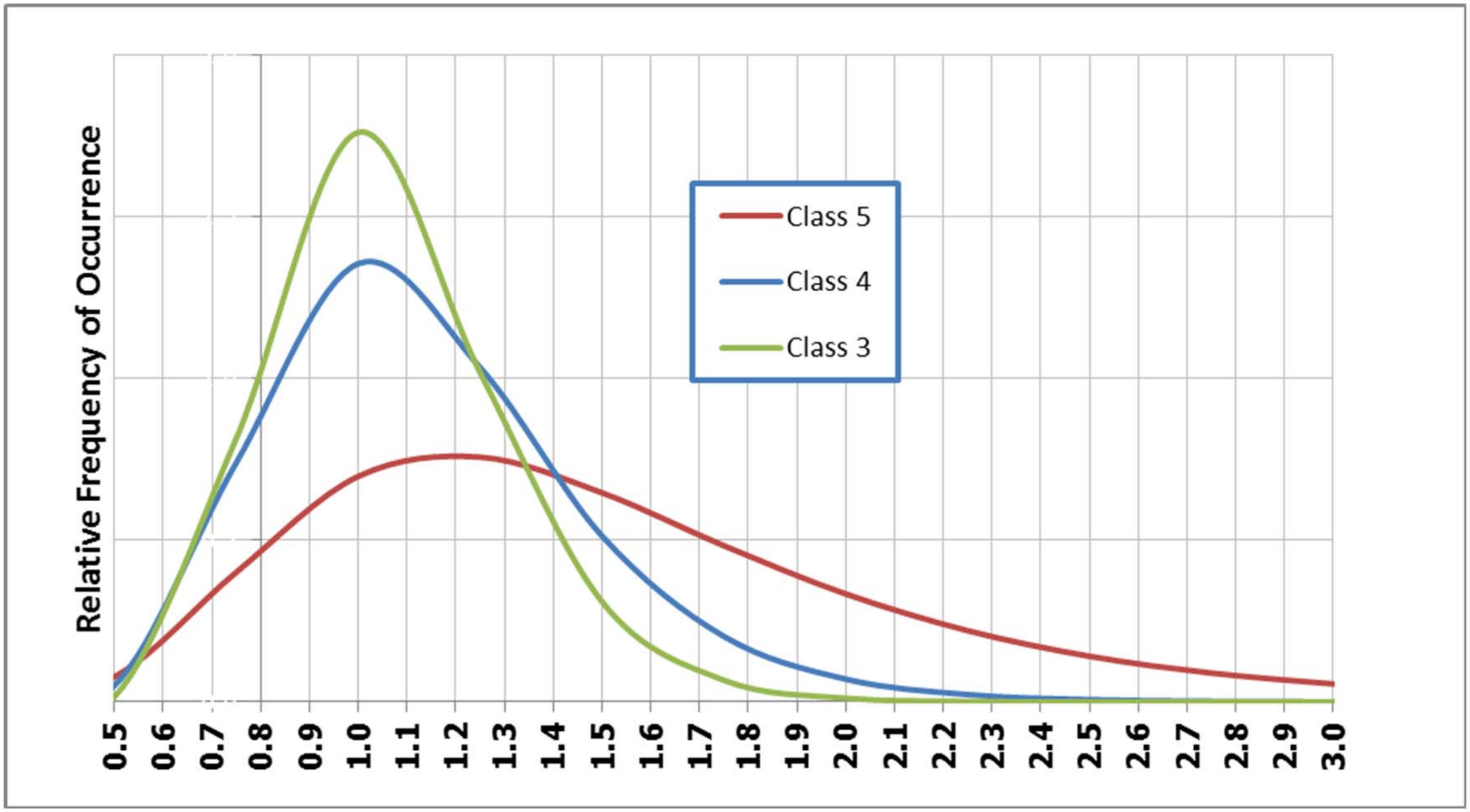
www.aacei.org

aace International

The Authority for Total Cost Management™

# The Reality of Estimate Accuracy: Long Tails

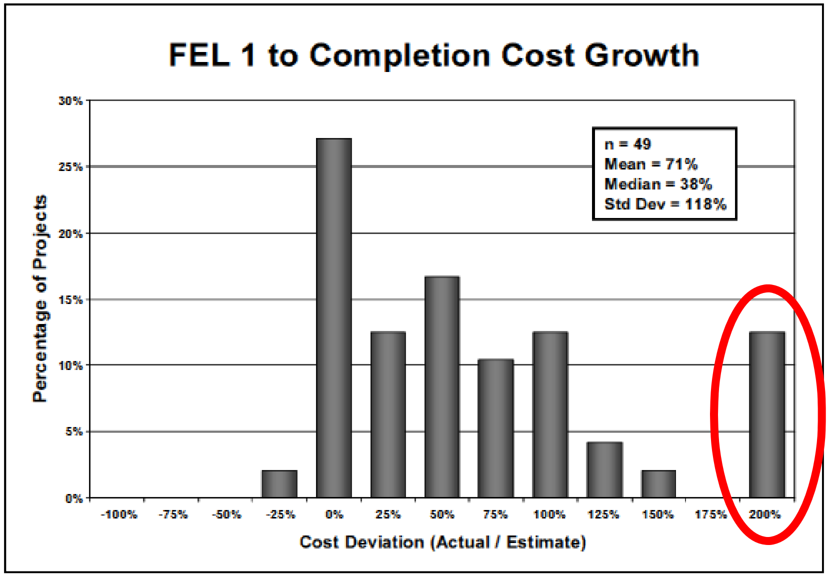
- Research shows that cost accuracy distributions (actual/estimate) have a very long tail on the high side



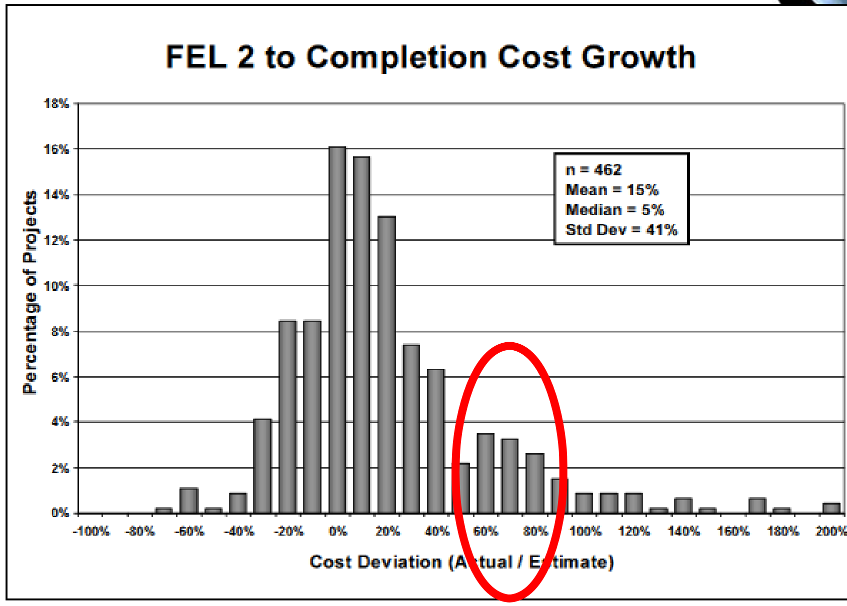

Log-normal replications of figures 7,8 and 9 from Ogilvie, Alexander, Robert A. Brown Jr., Fredrick P. Biery and Paul Barshop, "Quantifying Estimate Accuracy and Precision for the Process Industries: A Review of Industry Data", Cost Engineering Magazine, AACE International, Nov/Dec 2012.

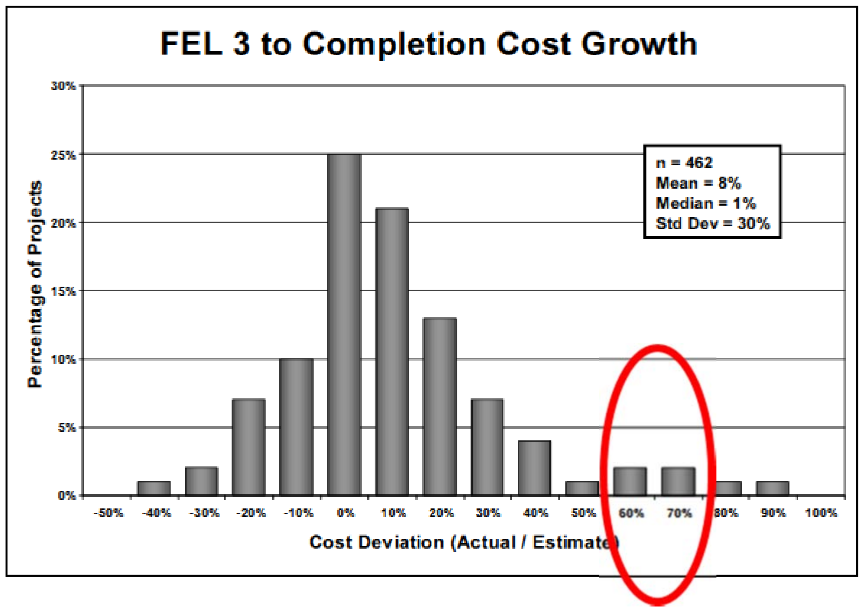
# The Reality of Estimate Accuracy: Bimodality

- Further, the actual accuracy distributions are *bimodal*



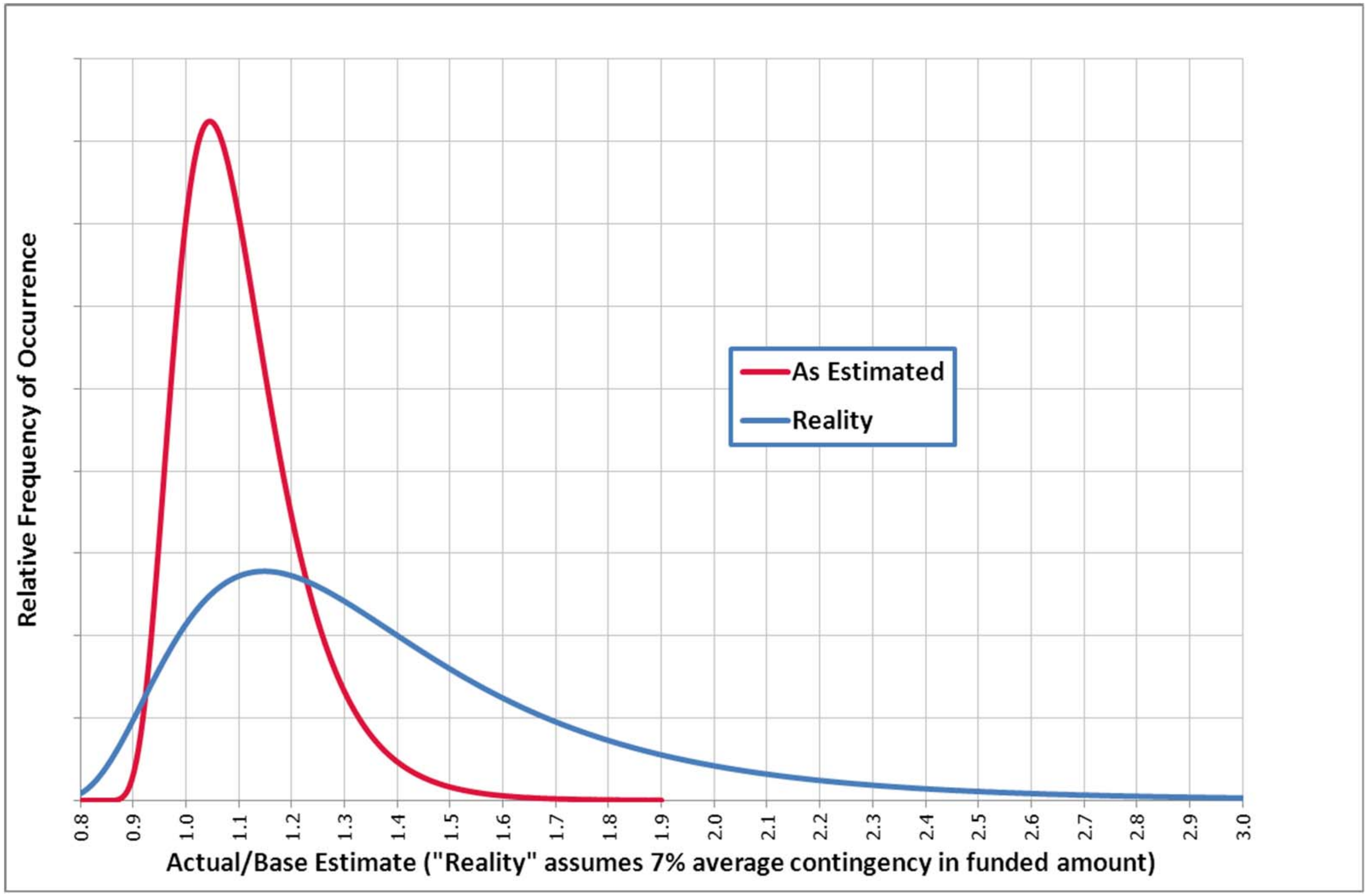

Used with permission: re: Ogilvie, et. al.



# Our Predications Are Nowhere Close

- Our risk analyses fail to predict the long tails or bimodality---actual p90s are 3X what we estimate!




From: Hollmann, John K., "Estimate Accuracy; Dealing with Reality", Cost Engineering Magazine, AACE International, Nov/Dec 2012.

# The Questions Raised By This Research

- What *causes* the long tails and bimodality?
- Can we *measure* the causal elements?
- If we identify the causes and measures, can we use this information in risk quantification…
  - **so that it predicts reality**
  - **in a way that helps us address the causes (i.e., manage the risks)?**

# HYPOTHESIS AND SOLUTION

AACE International

www.aacei.org

aace International The Authority for Total Cost Management™

# The Hypothesis

- In my years at IPA Inc. and later, I saw the bi-modality of outcomes in many empirical studies (obviously, the huge cost overruns were capital disasters for the clients)
  - **If one asks a team member what the project was like during its execution, they'd often reply "*it was chaos*."**
- But, we all tend to discount the disasters; we call them *outliers* or *unknown-unknowns* and for the most part make no attempt to predict them.
- My hypothesis is that these outcomes do reflect chaos
  - **Can we predict it? Can we use what is known about chaos in our methods? .....I think the answer is Yes!**

# System Dynamics, Chaos, and Complex Systems

- In searching for practical risk analysis methods to model and address the real cost accuracy distributions, my learning path went from:
  - **system dynamics,**
  - **through chaos theory,**
  - **to complex system theory.**
- This is a logical progression of inquiry and I hope the next few slides will adequately explain what I learned and how these learnings were used as the basis of the risk quantification methods I developed.

# Projects as Systems

- Projects are *systems* (a thing with parts that interact to form an integrated functioning whole); Some say *cost engineering* is a type of *systems engineering.*
- Project systems are dynamic; they change over time. *Systems dynamics* (SD) studies how complex systems behave over time.
- SD has evolved models using feedback loops (e.g., rework) that demonstrate nonlinear behavior which looks more like reality than CPM-based and other risk models.
- Unfortunately, SD models are too difficult for everyday use and they are based on the premise of orderly systems when *disorder* is the reality that we often see.
- The next step is to look at the study of disorder.

# Disorder, Non-Linearity and Chaos

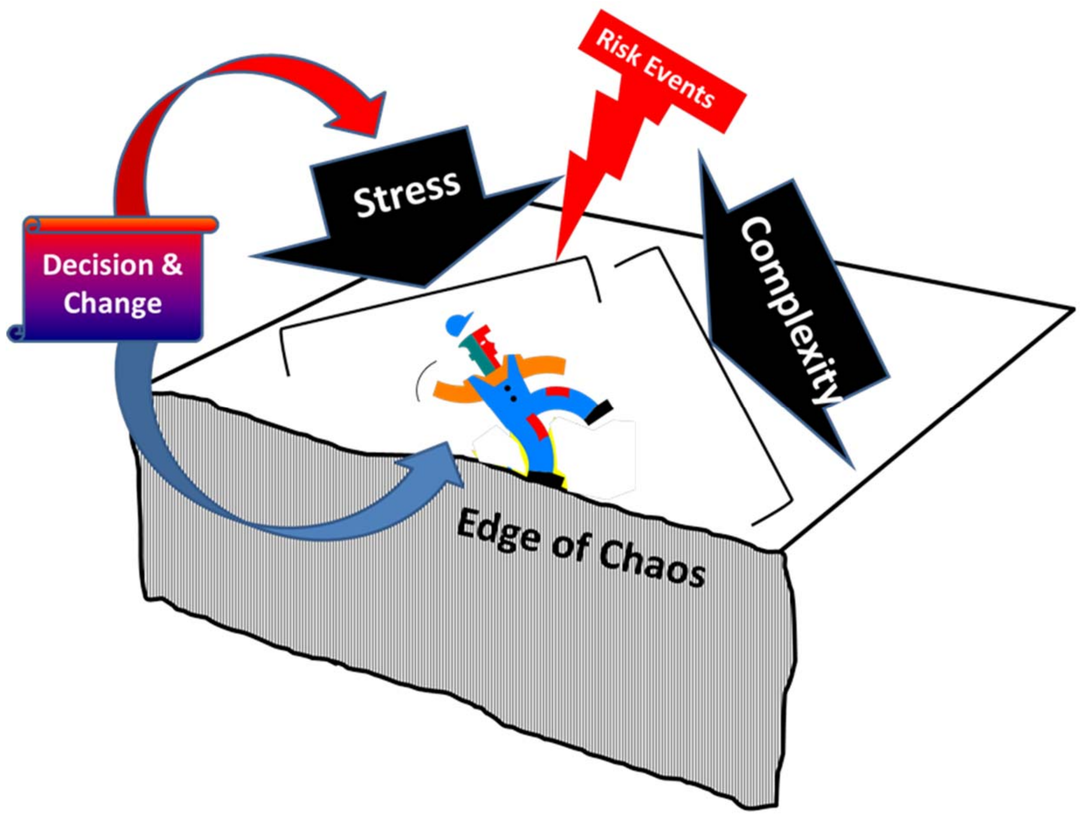
- A search for disorderly/non-linear models leads to *chaos theory* (luckily, one does not need math to understand it.)
- Simply put, chaos is the state of a disordered and unpredictable system; it is *out of control*.
- Chaotic systems are *non-linear* which for projects means *progress is not proportional to the work effort*; i.e., we spend lots of hours but make little progress.
- In chaos theory, the *edge of chaos* is where a project teeters between order and chaos; i.e., *a tipping point*.
- If we knew the key attributes of projects at the edge of chaos, we would have the start of a risk analysis method. So, *what are the attributes and how do we measure them*?

# Complexity and Complex Systems Theory

- One finds that *complexity* is the key focus of systems and chaos research; it’s a hot and unsettled topic.
- Complexity focuses on *interaction* of a system’s parts as opposed to the number of parts or size of the system (i.e., *complicated* is not synonymous with *complex*)
- *Complex* systems are more likely to be disorderly and non-linear (complicated systems respond better to reductive control than complex ones.)
- Aggravating the complexity are *stresses* put on a system by management, the market or environment.
- The good news is that we can *measure* complexity and stress (albeit a contentious topic among researchers)

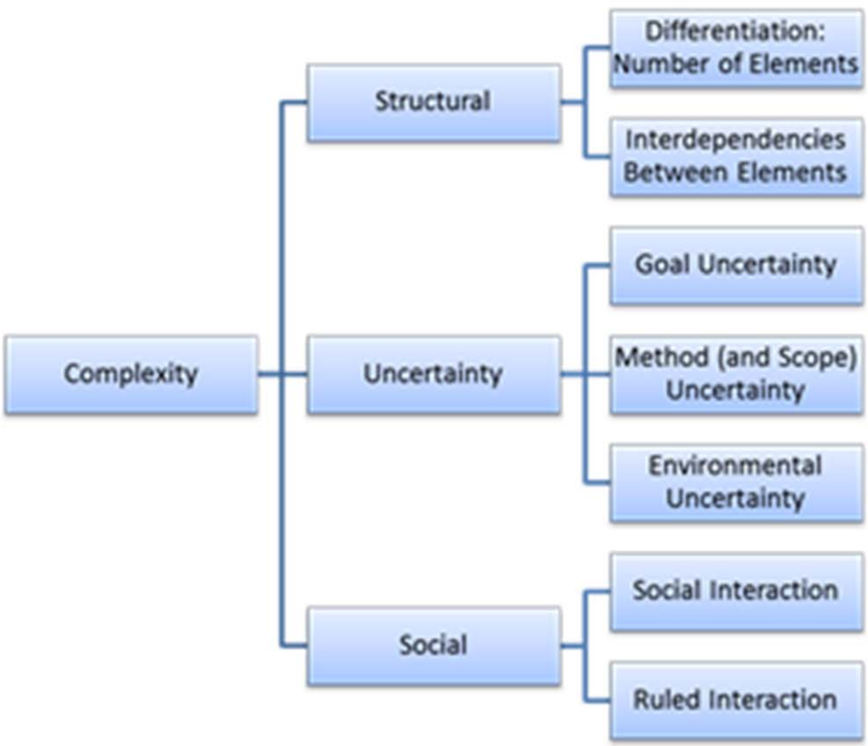
# Complexity and Stress and the Edge of Chaos

- Complexity and stress tend to push a project system from order towards chaos
- Stress can be a positive push; i.e., a management decision or change to help restore order
- Risk events are an added stressor
- General uncertainty adds a fog to the whole system



# Complexity in a Project System

- The following is a conceptual model of the elements of ***complexity*** and its attributes in a project system




**Project size, number of WBS elements, number of block flow steps, number of contracts, etc.**

**Ventures, partnerships, alliances, batch or continuous process, process variability, etc.**

**Clarity of objectives, bias, decision making policy, cost/schedule tradeoff understanding, etc.**

**Status or scope development, new technology, quality of estimate, reliability of assumptions, etc.**

**Uncertainty in marketplaces, communication with stakeholders and authorities, politics, etc.**

**Team building, Communication, Respect, Motivation, Commitment, etc.**

**Organizational structures, hiring policies, contract types and terms, process and procedures, etc.**

# Stressors on a Project System

- The following is a conceptual model of the elements of ***stress*** and its attributes in a project system


**Schedule pressure, acceleration, fast tracking, short durations, production rates, resource congestion, etc.**

**Resources, hours, budgets, equipment, tools, skills, etc.**

**Level of quality, productivity, safety, efficiency, environmental, KPIs, etc.**

**Level of lag and delay, responsiveness, decisiveness, agreement, communicativeness, etc.**

**Appropriateness, directness, sensitivity, robustness, alignment, confusion of authority, interference, etc.**

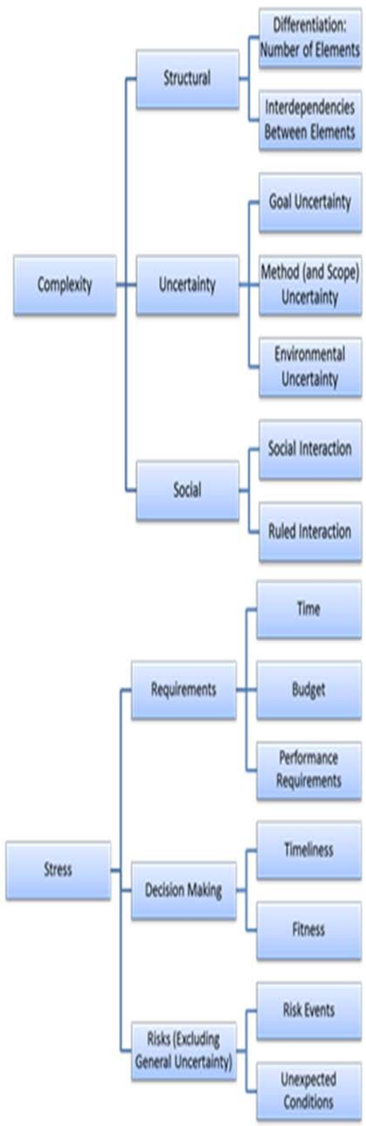
**Labor disputes, damages, losses, material delays, accidents, permit delays, floods, etc.**

**Poor soils, adverse weather conditions, shortages of skilled labor, etc.**

# Measuring Complexity and Stress: AACE's RPs

- AACE has defined a *methodological* risk breakdown:
  - **Systemic: artifacts or attributes of the system or strategy**
  - **Project-Specific: risk affecting the specific project and plan**
  - **Escalation: driven by economics**
    - analogies for the above include: strategic (enterprise), operational (project), and contextual (global) risks respectively.
- AACE RPs for quantifying these risk types include:
  - **Systemic: RPs 42R-08 and 43R-08 cover Parametric Models**
    - **these are based in large part on research by RAND. Since the RAND research, IPA, Inc. has added a "Team Development Index (TDI)" factor as a major systemic risk driver.**
  - **Project-Specific: RP 65R-11 covers Expected Value with Monte Carlo Simulation (MCS).**
  - **Escalation: RP 68R-11 covers Escalation methods using Indices and MCS.**

# Complexity & Stress "Risks" Using AACE RPs




AACE International

| Complexity Attributes | AACE Measures of Those Attributes |
|---|---|
| Project size, # of WBS elements, # of block flow steps, number of contracts, etc. | Systemic: 42/43R-08 |
| Ventures, partnerships, alliances, batch or continuous process, process variability, etc. | Systemic: 42/43R-08 |
| Clarity of objectives, biases, decision policy, cost/schedule tradeoff clarity, etc. | Systemic: 42/43R-08 (with TDI) |
| Scope development, quality of estimate, reliability of plan assumptions, etc. | Systemic: 42/43R-08 |
| Uncertainty in marketplaces, regulatory biases and policies, politics, etc. | Systemic: 42/43R-08<br>Escalation: 68R-11 |
| Team building, Communication, Respect, Motivation, Commitment, Conflict, etc. | Systemic: 42/43R-08 (with TDI) |
| Organizational structure, HR policies, contract terms, procedures, regulation, etc. | |
| Aggressive schedules, acceleration, fast tracking, production rates, resource congestion, etc. | Systemic: 42/43R-08 (with TDI) |
| Reduced resources, hours, costs, equipment, tools, etc. | |
| Challenging level of quality, productivity, safety, efficiency, environmental, KPIs, etc. | |
| Lag and delay, unresponsiveness, indecisiveness, disagreement, uncommunicative, etc. | |
| Appropriateness, directness, sensitivity, robustness, alignment, etc. | |
| Labor disputes, damages, losses, material delays, accidents, permit delays, floods, etc. | Project-Specific: 65R-11<br>Escalation: 68R-11 |
| Poor soils, adverse weather conditions, shortages of skilled labor, etc. | |

# Complexity Risk in a Non-Linear Model

- We have identified the hypothesized causes of chaos (i.e., complexity and stress) and practical ways to measure them (i.e., AACE's RPs)
- So, how to apply the measures in a non-linear model?
  - **Note: the AACE RP methods (and supporting research such as RAND's) presume order and linearity**
- A risk quantification model that considers complexity and stress in a way that the "whole is not equal to the sum of the parts" in terms of risk impact (non-linearity)

# Hypothesis: Non-Linearity Driven by Stressors

- The total risk impact as one approaches the *edge of chaos* is not (x+y) but $\mathbf{(x+y)}^{e}$ where *e* is greater than 1.
- So, what is *e* ? My hypothesis is that the drivers of non-linearity and disorder are the stressors:
  - **aggressiveness of requirements**
  - **team/stakeholder management**
  - **quality of decision making (recognizing authority & responsibility)**
  - **risk events and conditions that occur**
- Each stress can be a positive or negative influence on *e* depending on whether it is aggravating the complexity and uncertainty or mitigating it

# The Tipping Point Indicator

- I applied the stress measures in a *tipping point indicator*

| | |
|---|---|
| Aggressiveness of Requirements | 🔴 |
| Team/Stakeholder Management | 🟡 |
| Decision Making | 🟢 |
| Risk Events and Conditions | 🔴 |
| Overall; Threat of Chaotic Outcomes | 🔴 |

- This warns management that the project may be near the *edge of chaos*
- Why do we need this?
  - it is well reported that financiers (who ignore sponsor risk assessments) see contingency of even 25% as “modest”
  - something more than just a high contingency value is needed to tell the “disorder” story

# Tipping Point Indicator: Criteria and Responses

- The following are general indicator criteria and typical risk treatments for or

| Stress Factor | Criteria | Typical Risk Treatment |
|---|---|---|
| Aggressiveness of Requirements | Based on quantitative estimate and schedule validation/benchmarking which shows if the plans are more or less aggressive then industry norms. Green is > norm. | Ease off cost and/or schedule "savings" not resulting from real value improvements or scope changes, etc. |
| Team and Stakeholder Management | Based on systemic ratings of the team resourcing, alignment, competency, etc. Green is best practice. | Add resources, provide training, perform team building, improve communication, etc. |
| Decision Making | Based on systemic ratings of clarity of goals, engagement, responsiveness, buy-in, etc. Green is best practice. | Clarify and communicate goals, expedite, lead, minimize gaming, clarify authority, etc. |
| Risk Events and Conditions | Based on project-specific and escalation tool risk outcomes compared to industry norms. Green is < norm. | Increase focus on the risk treatments identified in risk management. Make changes as needed. |

# Similar Indicator/Filter Approaches

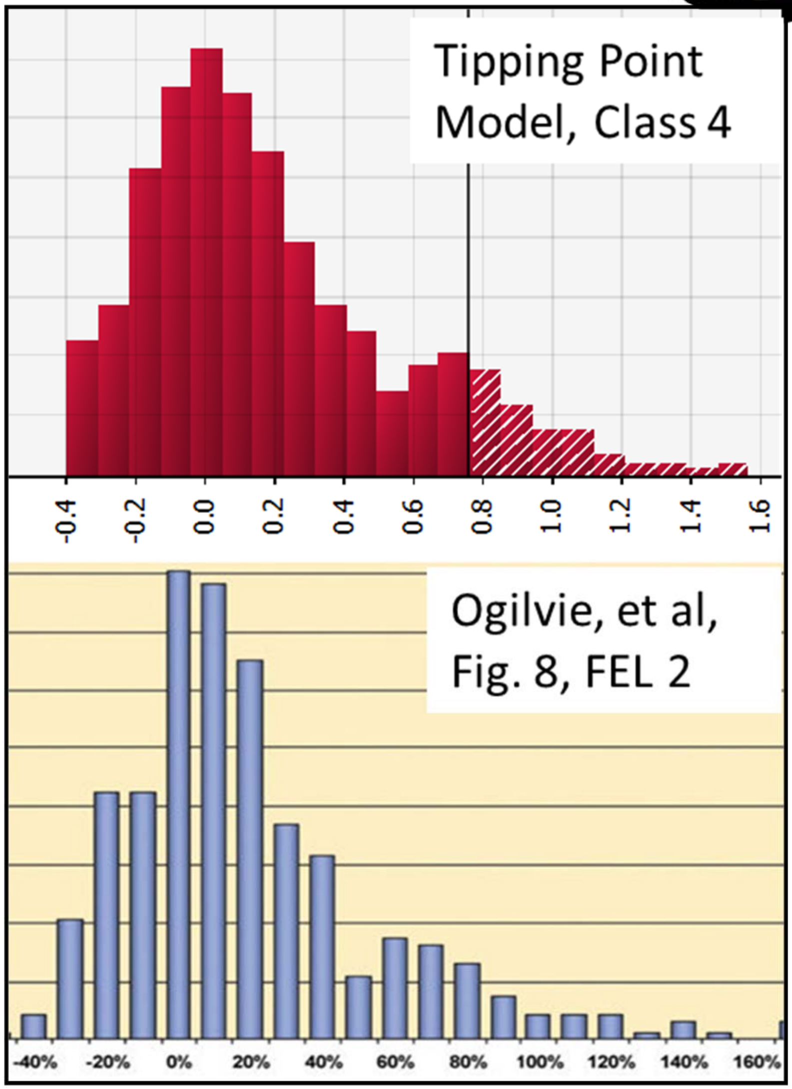
- My research found 3 comparable methods that flag projects for increase management attention:
  - **Ackermann's "*Risk Filter*" is based on a systemic risk questionnaire (2006)**
  - **Maidment & Gough's "*Project Stability Index*" uses a ratio of positive over negative stressors (2006)**
  - **Canadian Treasury's "*complexity and risk assessment*" tool considers a sponsor department's capacity to handle projects of a given risk level (2012)**
- While not reporting a theoretical or empirical basis, these indicate a building consensus of experts as to the need for raising awareness of these "special" risks

# Predicting the Long Tail and Bimodality

- The tipping point indicator alone helps, but how does one convince stakeholders that it matters?
- Can the *e* stress metric be used in a risk model that results in 70% cost growth at p90 and bimodality?
  - **The answer is "yes". To test this, I modified my existing Expected Value with Monte Carlo Simulation model to…**
    - **add an *alternate* risk impact distribution that reflects the observed outcomes IF chaos results (the "chaos penalty")**
    - **incorporate a variable for the % of MCS iterations to cross the edge of chaos based on the "tipping point factor" (*e*).**
    - **Incorporate a random number generator to develop a merged, bimodal distribution.**

# Hypothesis Proven?

- The similarity of the tipping point model outcome and reality is remarkable!
- I am reluctant to use this in practice because it is reductionist; implying that the outcome of chaos is predictable and that my assumptions reflect reality.
- More empirical research is needed to validate this.
- In any case, this presents a dramatic picture and it is useful for illustrating the tipping point concept.



# Assumptions in the Tipping Point Model

- The model outcome reflects 2 key input assumptions

**how do these compare to your experience?**

1. **The alternate *chaos distribution* is the same as the base (linear) distribution but shifted right by about 5 to 6X the base contingency set at p50 (i.e., the "chaos penalty")**
   - **e.g., if base contingency at p50 is $100M, then the chaotic distribution would be shifted by $500M (5X) to the right.**
2. **The impact of the stress factor (*e*) resulted in 15% of the MCS iterations using the alternate chaos distribution.**
   - **i.e., 1 in every 6 or 7 major projects funded at Class 4 experience chaos (the hypothesis being that this proportion of projects was highly complex and stressed.)**

# Risk Treatment For Chaos

- Apply the tipping point indicator at decision gates, key milestones during execution, and as risks occur.
- 🟡 calls for stress reduction, e.g.:
  - **slowing a schedule or**
  - **reducing work on overtime, etc.**
- 🔴 calls for "containment": i.e., swift, decisive actions, e.g.:
  - **assign a "swat team" of experts to help the team,**
  - **rebaseline the control system from scratch,**
  - **replace the PM, ineffective contractors, and/or vendors, etc.**
- These add stress, but directed towards restoring order.
- Reductive "control" only works in an ordered project; *recovery from chaos requires timely and decisive* ***change****.*

# Conclusions

- The tipping point indicator is a simple tool (like others).
- It is well grounded in theory (chaos and complex systems) and empiricism (applied in an Expected Value risk model with MCS, it replicates bimodal behavior and the long tail).
- We need such predictive risk analyses if we are to really make a difference in project systems and improve outcomes
  - **Those who do *realistic risk analysis* will face the enormous headwind of management optimism bias; but, we must stop promulgating the myth of narrow ranges and recognize that the "unknown-unknowns" excuse is largely a cop-out.**
- Complex systems theory is evolving and fairly new to most people and companies. The methods here are just a start.
- Many variations of analyzing and dealing with potential chaos are possible and it is hoped that other methods will be developed and reported.

# QUESTIONS/COMMENTS?
# (PLEASE USE MICROPHONE)

AACE International

www.aacei.org

aace International®
The Authority for Total Cost Management™