Flexibility in Engineering Design

Using Flexibility to Creating Value

CRAG-IRGC Symposium 2013

Uncertainty: from Insight to Action

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From Insight… to Action

- Insight: Future is uncertain – therefore, we do not, cannot know the actual design requirements
- Action: Design Systems Flexibly – for range of possibilities. Strategy for Managing Uncertainty:
  - Learning about developments
  - Taking advantage of new opportunities
  - Exiting from unfavorable situations

Theme for Flexibility

A Change in Paradigm from designing to

- a specified requirements;
- to actual conditions using flexibility!

Flexibility:

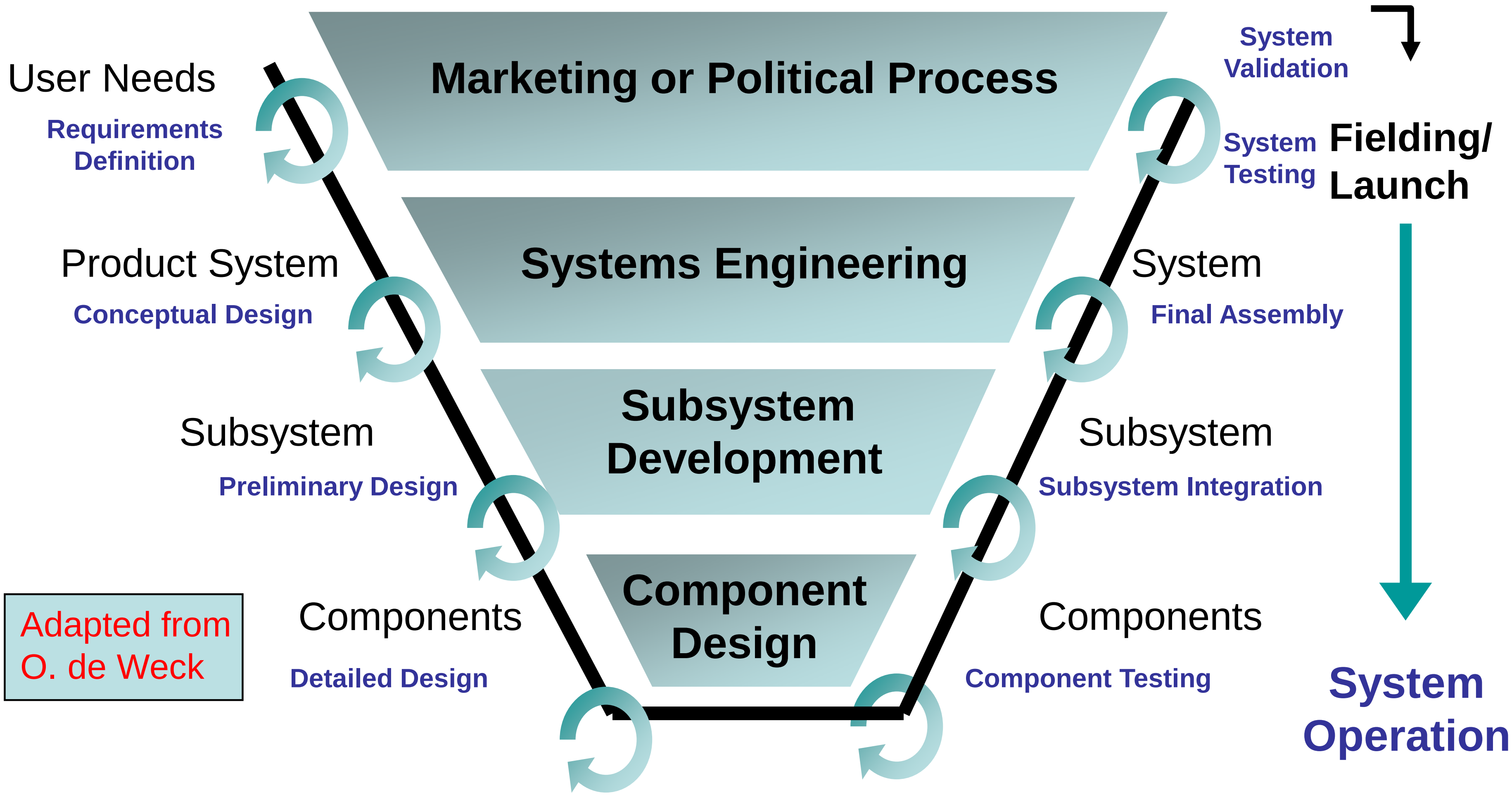
- Leads to 20 to 30% increase in value
- Using a win-win approach
- Mitigates risk (downside) – a win
- Opens opportunities (upside) – more win

Outline of Presentation

1. Standard System Design Procedure
2. Flaw of Averages
3. Concept of Alternative Paradigm
4. Contrast with Robust Design
5. Analytic Procedure
6. Example Application

Standard Procedure for Design of Engineering Systems

Traditional Systems Paradigm



Implicit Assumptions of TSE

- Companies, public know what the needs are
- These requirements are time-invariant
- The product or facility can be designed as one coherent whole and is built and deployed in one step
- Only one plant or mine designed at a time
- The system will operate in a stable environment as far as regulations, technologies, demographics and usage patterns are concerned

Assumptions of TSE – not Realistic!

- Companies know the needs? New ones emerge!
- The requirements are fixed ?
  No change with new needs and regulations, etc.
- The system can be designed as a coherent whole and built and deployed in one step? Often not
- Only one system being designed? Families likely
- The system will operate in a stable environment as far as regulations, technologies, demographics and usage patterns are concerned? We wish…

Traditional (Systems) Engineering

- Has been very successful, delivering highly complex systems of all sorts
- However, it can now do better…
- If we step outside its "box" of assumptions
- … which are unrealistic!

- **The Reality is**

- Our plants, facilities face great uncertainties
- Outcomes risky
- We need to deal with this

The Flaw of Averages

Flaw of Averages

- Named by Sam Savage ("Flaw of Averages, Wiley, New York, 2009)

It is a pun. It integrates two concepts:

- A mistake => a "flaw"
- The concept of the "law of averages", that that things balance out "on average"

- Flaw consists of assuming that evaluation based on "average" or "most likely" conditions give correct answers **NOT SO!**

In Words

- **Average of all the possible outcomes associated with uncertain parameters,**

- **does not equal** (except if system linear)

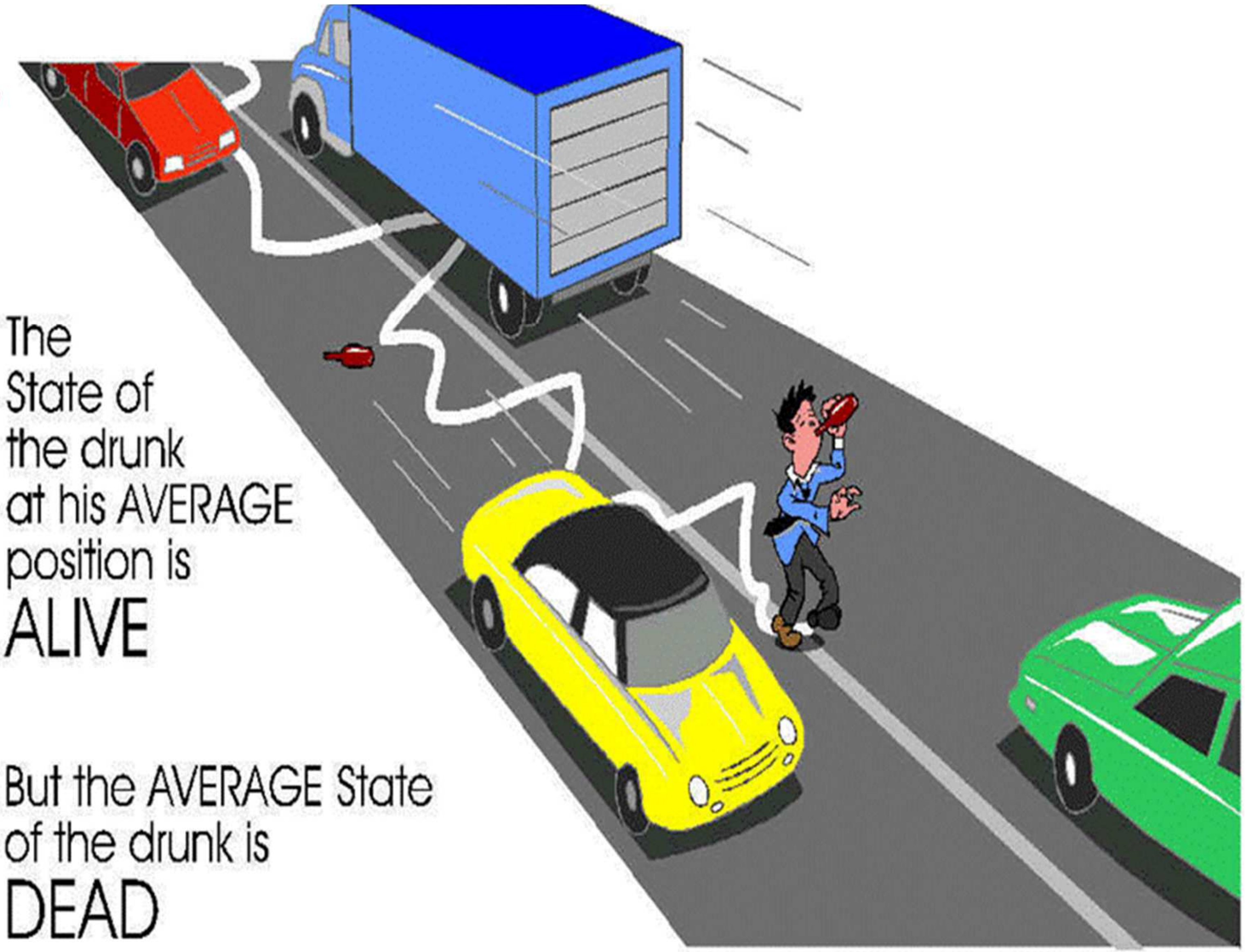
- **the value obtained from using the average value of the parameters**

Example

Given: $f(x) = \sqrt{x} + 2$

And: x = 1, 4, or 7 with equal probability

- The average: $E(x) = (1 + 4 + 7) / 3 = 4$
- System Value based on average $f[E(x)] = \sqrt{4} + 2 = 4$
- Actual possible values of system: $f(x) = 3, 4,$ or $[\sqrt{7} + 2] \sim 4.65$ with equal probability
- Actual System Value: $E[f(x)] = (3 + 4 + 4.65)/ 3 \sim 3.88$ This is not equal to $f[E(x)] = 4$


The
State of
the drunk
at his AVERAGE
position is
ALIVE
But the AVERAGE State
of the drunk is
DEAD

Concept
of
Alternative Paradigm

The Concept

- Flexible design recognizes future uncertainty. The economy, technology, regulations all change.
- Flexible design creates systems easily adaptable to actual futures. It differs from the traditional approach, which defines a future and creates a design for that situation – which has little chance of occurring!
- Traditional design often leaves us with plants and operations poorly suited to actual conditions, and thus inefficient..

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Flexible Approach to Design

- Recognizes Uncertainty
- Analyses Possible Outcomes of Designs
- Chooses Flexible Designs to
  - Reduce, eliminate downside risks (in general, less ambitious initial projects – less to lose)
  - Maximize Upside opportunities (that can expand or change function, when, if, and how seems desirable given future circumstances)

20 to 30 % Increases in Expected Value Routine!

Great increase in Expected Value

- systems with flexibility to adapt to new conditions can greatly increase expected value.
- With flexibility we can
  - avoid future downside risks (by building smaller with confidence that can expand as needed)
  - profit from new opportunities by appropriate actions
- Reduce initial capital expenditure (CAPEX).
  - Lower initial CAPEX because less complex at start
  - Lower Present Values, because costs deferred many years (and maybe even avoided)

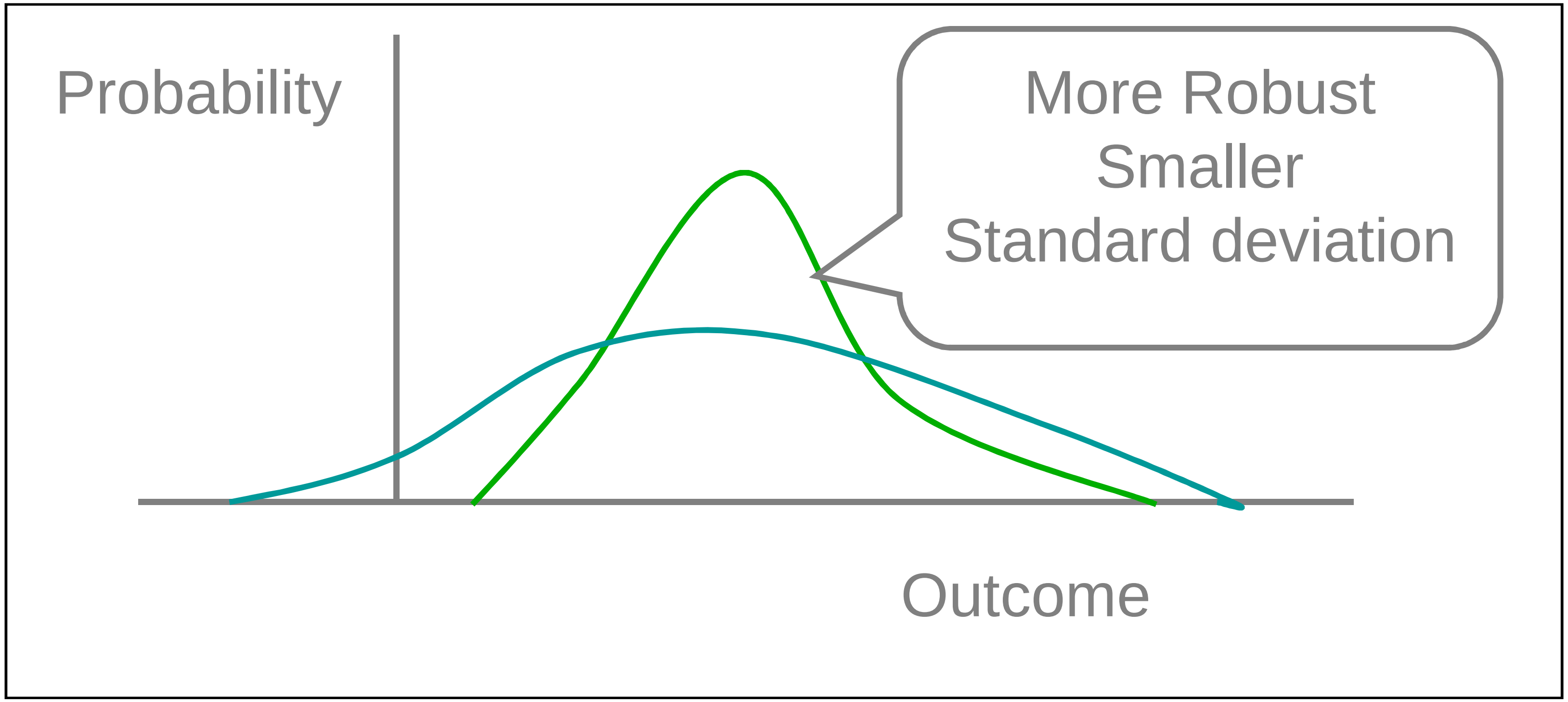
Higher returns, lower cost = A Great Formula

Contrast with Robust Design

Concept of "Robustness"

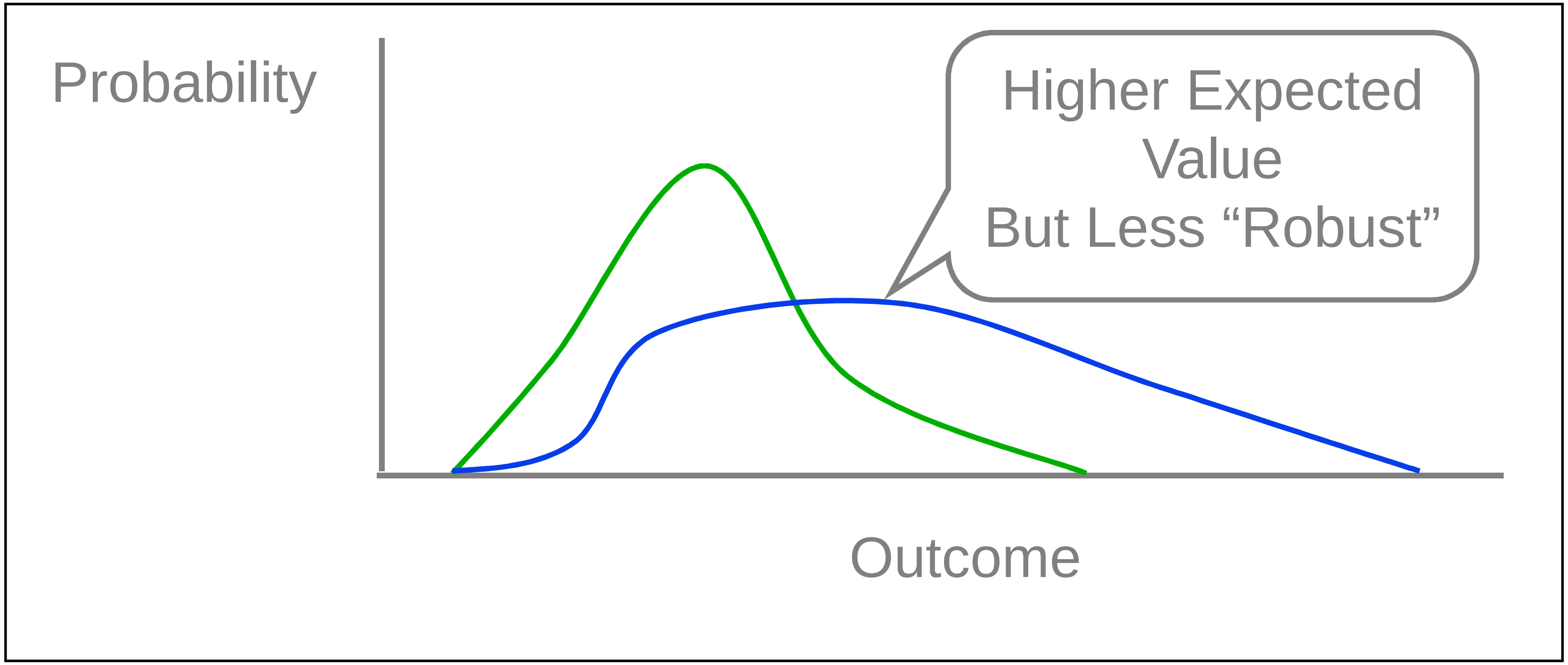
- Robust design ≡ "a product whose performance is <u>minimally sensitive</u> to factors causing variability…"
- Robustness thus can be measured by standard deviation of distribution of outcomes

Illustration of Robustness



Maximizing expected value

ADAPTABLE contrast to BUNKER



Analytic Procedure

Main Elements of Procedure

1. Recognition of Uncertainty …
   and its characterization

2. Simulation of Performance for Range of Scenarios

3. Evaluation… necessarily multi-dimensional, one number not enough to describe a distribution

4. Implementation … needs planning

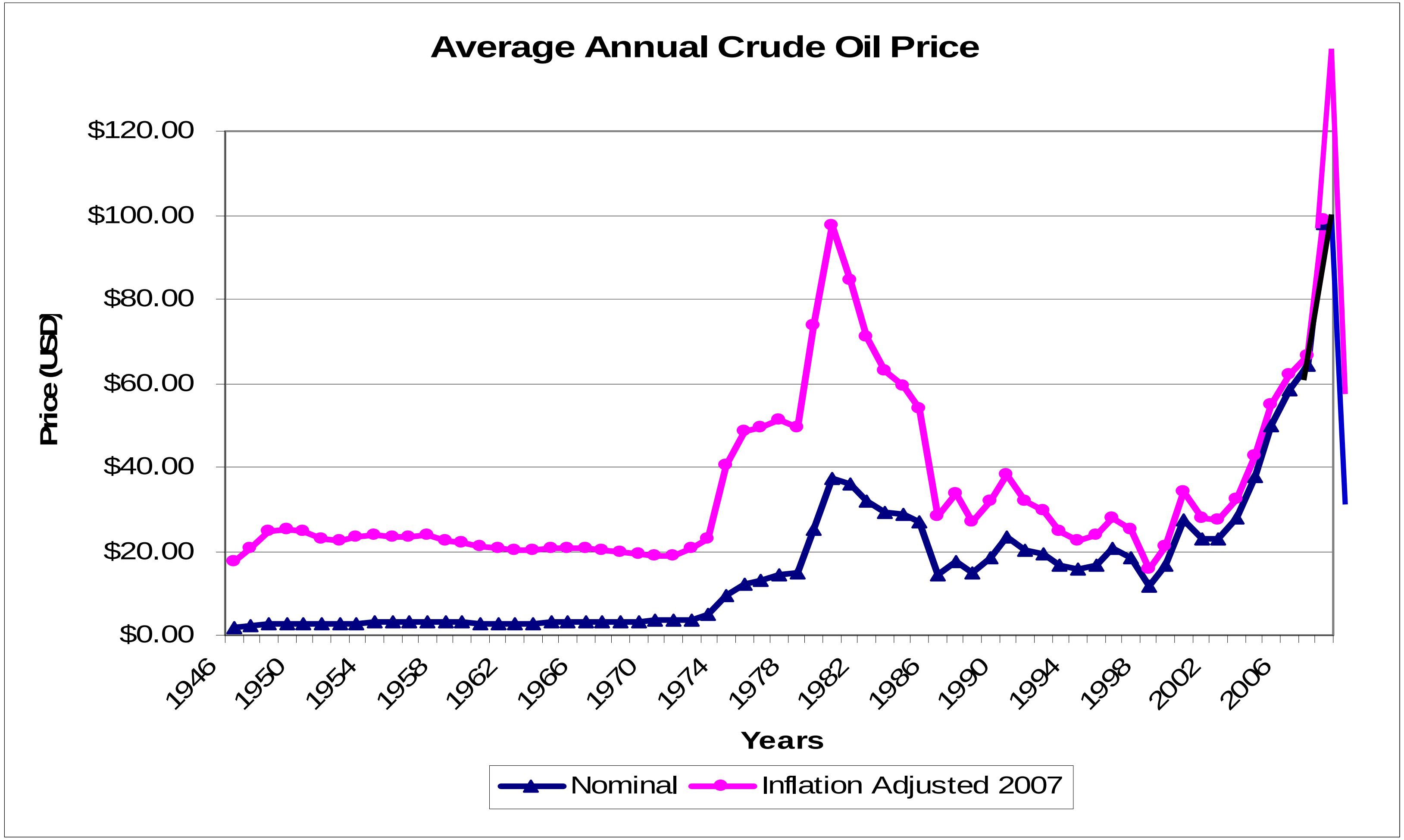
Example Application:
Deep Water Oil Platform

Example: Deep Water Oil Platform

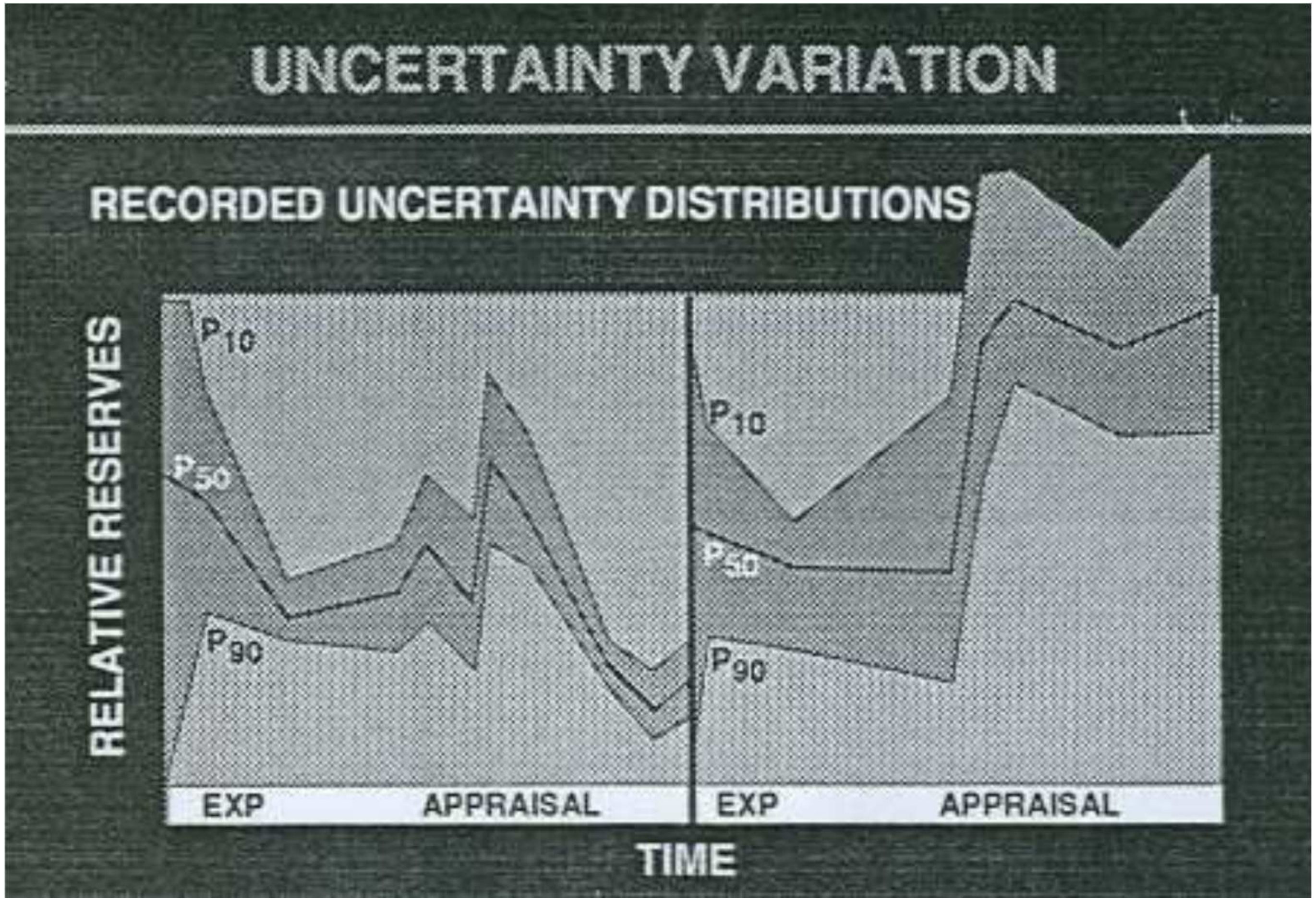
Details of Case

- Deep water reservoirs, off-shore Country ***
- Design team taking traditional approach – optimizing for "best estimates of conditions"
- Preliminary design: **Single large facility**
- Note Uncertainties:
  – Price of Crude Oil highly volatile
  – Recoverable quantities of oil and gas difficult to determine during design stage – will only be known after more wells sunk and production begins.

Historical Prices of Crude Oil



Example Uncertainty in Oil Recovery



Source: Lin, 2009 (from BP sources)

Flexible Approaches to Design

- Platform concept
  – Not a single large platform, smaller modular initial platform that can be expanded as, and when needed, even beyond traditional design
  – Much less invested, much lower risk of losses
  – Much greater profit if quantity high
- Sub-sea concept
  – Multiple "tie-back" interconnections, to adjust flow depending on size of fields, viscosity of crude, need for pressure injections
  – Flexibility to manage range of flows maximizes quantity

Cumulative Effect of Flexible Design

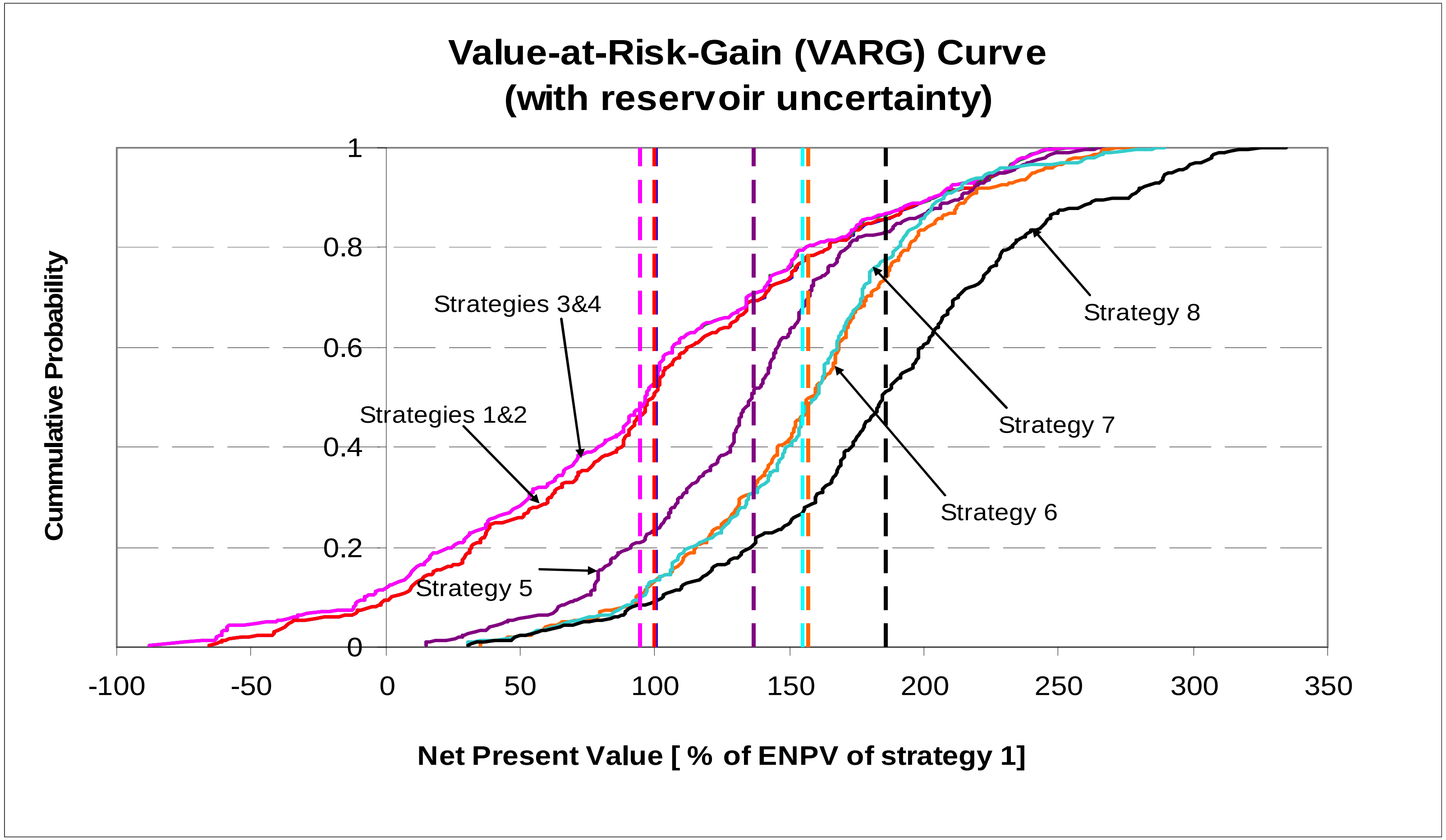
- Great advantages compared to traditional design around "most likely" scenario

- Fixed design subject to
  - large losses if extractable quantity and price of oil is low
  - Cannot expand production economically if reservoirs larger and richer than "best estimate" (likely half the time!) and thus misses out on good opportunities.

- Flexible design improves
  - Much lower exposure to losses
  - Ability to take advantage of good conditions

Moves Cumulative distribution of outcomes higher

Analysis Results



Source: Lin et al, 2009

Bottom Line Improvement

Flexible design for oil platform

- increased expected value 78%,
- lowered CAPEX about 20%

- These were real results

Flexible design more realistic and profitable

Summary

Insight:

•Recognize Requirement Uncertainty

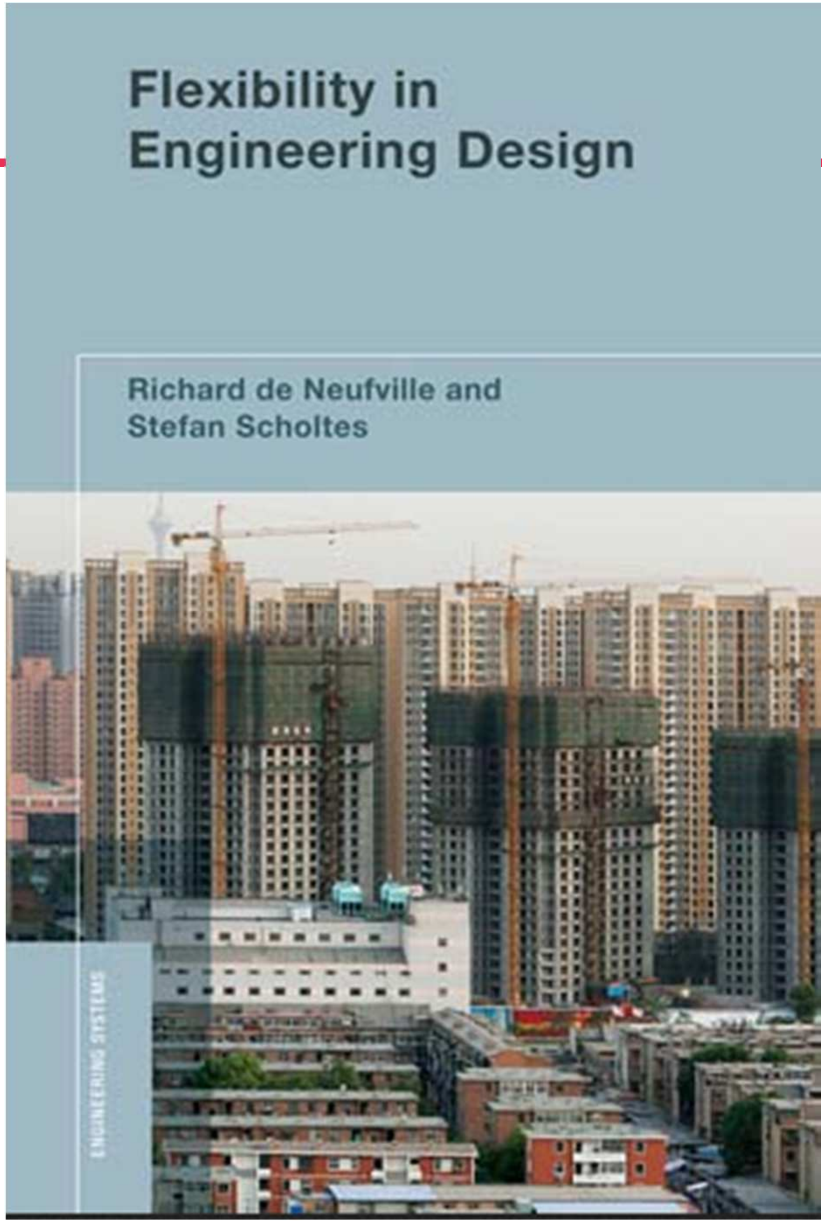
Action:

•Flexible thinking can greatly increase expected value from projects

•New paradigm -- Not traditional way

•A “must” for future system designers and managers!

Thanks for your attention! Questions?



This is the book

MIT Press 2011

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