ESD.84 Doctoral Seminar – Session 10 Notes
Guests Presenting: Richard De Neufville, Yakov Ben-Haim

Session Overview:
- Welcome and Overview and Introductions (5-7 min.)
- Initial Identification of Questions from Readings (7-10 min.)
- Decision Theory and Complex Engineering Systems: Guest Presentation by Yakov Ben-Haim (20-30 min.)
- Discussion (10-15 min.)
- Real Options in the Design and Development of Complex Engineering Systems: Guest Presentation by Richard de Neufville (20-30 min.)
- Discussion (10-15 min.)
- Break (10 min.)
- Critical Decisions in Complex Engineering Systems Not Easily Addressed Through Quantitative Analytic Methods: Student Presentation by Eun Suk Suh (15-20 min.)
- Deeper analysis of results from an exercise on “uncertainty” (15-20 min.)
- Next Steps (10-15 min.)

Questions and comments on info-gap:
- In determining sub-optimal design point – how to make that determination – what are the criteria for backing of off the pareto frontier?
- Info-gap is an approach when you have less information, but how to handle “unknown unknowns” – what are the minimum limits in information needed
- How to understand concepts of convexity of set and abundant properties?
- How does info-gap apply in a management system where you don’t have the luxury of not being able to iterate data collection?
- Where can we find computational illustrations of info-gap and what platforms have they been implemented on?
- Kanaeman and Tversky have show that there are biases in human judgement – how to incorporate these concepts?

Questions and comments on real options:
- Real options sounds powerful, but how to put it into practice?
- To what extent can option theory be used in the design of socio-technical systems – flexibility around services and organizational systems?
- How does real options work across scale – from large systems such as aircraft down to nano-systems?
- How to address issues of sustainability and discount rates?
- In contrast with stock-options and other numerically oriented data sets, how do you collect data on financially oriented factors?
- Can this approach work with subjective factors, such as styling?

Real Options:

- A right, but not an obligation
- A cost or expense in acquiring an option
- Examples:
    - Spare tire in car, insurance policy, a course in a topic you may use in the future
    - Can be a technical design feature built in, a qualitative establishment of relationships, or anything that builds in flexibility
- In financial community – financial community there are many ways to calculate the value associated with options
- Do we design for risk?
    - In building design – the building code has risk built in – same for aircraft design – the regulatory constraints are based on a probabilistic judgment, but the engineer merely designs based on code/regulatory requirements/spec
    - Concept of design to spec – sets the space within which the discussion of options takes place
    - Issues of legal requirements associated with designing to spec
- What is failure?
    - It could be visible cracks or collapse of physical systems – but what about the success or failure of new products
    - Contrast between catastrophic versus minor failure – due to technical factors
    - Issues of failure to generate expected revenue – marketing failure
    - Is it easy to define failure?
    - Failure is multidimensional – contrast in where you sit in the organization – from an executive perspective around implications for the enterprise versus from an engineering perspective around performance to spec – a fuzzy multi-dimensional criteria
- What is the range of risk?
    - Many dimensions – profit, market impact, regulatory response, etc.
    - For any one dimension – such as profit – in principle is unbounded at positive and negative levels, but in practice there may be real constraints (positive and negative)
    - Infrequent but possible outcomes – at tails of distribution – such as the impact of asbestos law suits on ABB
- Where is the "action" around risk?
    - Bridgestone didn't think of their tire design as having the future of the company as a risk
    - Risks – public, private and tort risk
    - There is some distribution on each type of risk – but designers mostly focus within the design spec
    - If we knew distribution for certain than we could calculate the expected value – but we often don't know
    - If you are responsible for system design, you do worry about different types of distributions and some set of events outside of the assumptions built into the specs

- Beyond meeting criteria of not failing, there are still issues around how the system is oriented, what its capacity is, etc.
    - There are assumptions about expected growth or decline in markets
    - Key issue around building a flexible system from the outset
    - Introduction of conditional probability – but there are issues around the establishment of "monuments" that have legacy implications
    - Key issue is the time horizon for design
    - Issue of interacting with environment – to learn and adjust assumed probability distribution
    - Ability to impact distribution through built in flexibility – building in options to grow
    - Deferred expansion of capacity has benefits in terms of net present value
- Options thinking – intentional shaping of distribution
- A nested set of risks which everyone in the design process has in front of them
- How do we deal with the problem of making this work in the real world?
    - A key factor is the use of systems models to represent the design space in multiple ways – a recent expansion in capability
    - Options framework – as a state of mind – a recent domain of increased thinking (financial options, decision-analytic structure, options thinking such as the use of phases)
    - Role of new generations thinking in new ways – and issues of stakeholders who need to be brought along into these new ways of thinking
- This is different from financial options focus on individual contracts – a broader orientation around the full set of pitons in the event space
    - Issues of judgment (evaluation of relative value) versus choice (actions taken or not taken)
    - Contrast micro distinctions on a scale versus qualitative judgments as to whether you are even in the right "ball park"

Info-Gap Theory:

- Issue of convexity of a set and uncertainty
    - Central limit theorem – asymptotic cluster of events tend to be convex
    - Info gap model is a family of nested sets
    - A class of info gap models will be convex
    - In practice an engineer lists a family of sets consistent with known information – which is a convex whole
- Practical implementation
    - French mechanical engineering group analyzing large structure in automotive and aerospace applications – University of French Compute (sp?)
        - Use info-gap buttons in analysis
    - At Los Alamos – use discussed in AIA conference paper
    - Proprietary examples in Israel – in large manufacturing operation
        - Uncertainty in task durations
- Issues around known limits in human judgment – such as come from the work of Kaneman and Tversky
    - Von Neuman and Morganstern game theory is more susceptible to this critique
    - Info-gap is less vulnerable in this regard – different respondents focus on different types of uncertainty and the lack of structure in info-gap theory allows for accommodating these different approaches

- Interval uncertainties have sharp boundaries in contrast to info gap theory
- How to know the smallest set of information needed to launch info-gap theory?
    - This can work with very little and very much information
    - Is there a baseline need for a systems model – there is a need for quantitative analysis
    - This won't work for purely qualitative judgment decisions
    - There is a need for quantitative specification of risk or failure – though there is uncertainty
- Contrast between info-gap and strategic planning gap analysis – one is orientated around ontological states (where we are now, where we want to go, and how we get from here to there) and epistemological states (what we know, etc.)
    - Contrast between satisfying as compared to optimizing
    - Alternative concept of wind-falling
- In context of economic and managerial problems
    - Example of product development case with decisions on quantity, cost, etc. – began seeing this as a scheduling problem and ended up focusing on net present value anticipating impact of future competition and other factors shaping quality of product choice and robustness choice – hard to develop the gap models for these kinds of uncertainties
    - Use of plots of robustness and opportunity spaces – pictures, not equations more accessible to executives
    - Will send a copy of a paper on this
- Modeling is an art – How to turn the verbal and even the sub-verbal descriptions of the properties of a system into a model or representation?
- How to involve people in the process when the numbers are opaque to many people? A key issue – this is also an art
    - Reverse translation – from model in a way that is understandable and true to the underlying model
    - This is the issue around the real utility of info gap modeling
    - Challenge of getting executives or others to understand the concept of immunity to robustness
- There are many cases where there is not available data – especially around future planning
- How to use info gap to choice how sub-optimal a design you want
    - It is easy to explain that more robustness is better than less
    - It is hard to know how far to go up preference ranking – since you can't always choose the option that is least robust
    - This is the same as deciding how sub-optimal you want to be in terms of performance
    - The task that we face is to map from value terms in English to number terms in math
    - Analogical inference – a way of ascribing meaning to a term we don't know – a metaphor ascribes meaning to a term that may have many meanings ("a river of time" – linking the concepts of time to the concepts of river (one direction flow)
- Plot of performance requirement against failure threshold (strict to lenient)
    - Need of linguistic terms to define each axis
    - Consequence severity – labeling the axis in value terms – minor, moderate, severe – as a starting point
    - Analogy – things with some things in common will have other things in common
    - Substantial change in robustness at a point in the curve associated with modest changes in performance (based on the shape of the curve)

Critical Decisions in Complex Engineering Systems Not Easily Addressed Through Quantitative Analytic Methods: Student Presentation by Eun Suk Suh

- Task: Must make Decisions for Complex Engineering Systems.
    - Problem: Not all information required for making decision are known. Also, there might be detrimental consequences (Risks) for making decisions without all the information.
    - Decision Maker must decide with Uncertainty.
    - Decision Maker needs to Quantify Uncertainty to make Critical Decisions, and minimize Risks.
- Key Critical Decisions For Decision Maker in context of new product/platform design
    - Market Trend
    - Styling
    - Competitive Reaction
    - Tradeoff between Loss of Value vs. Commonality
    - Effect of Disruptive Technology
- Implications:
    - Probabilistic Analysis: Need accurate information on probability distribution
    - Information-Gap Theory: Might not work well if there are no "information" available.
    - Real Option Analysis: Works well for scalable factors, such as manufacturing capacity. Would it work well for subjective factors, such as vehicle styling?

Additional observations:

- Even though there are many analytical methods available to quantify uncertainty to help in critical decisions, there are some issues which are hard to apply these methods to.
- Most "Hard to Quantify" factors which makes critical decision hard seem to lie in "unknown unknown" domain.
- Can analytical theory like Information-Gap Theory and Real Options Theory answer the uncertainty in "unknown unknown" domain?
- Some subjective factors, like vehicle styling, are also very hard to quantify analytically.
- Decision Analysis, outlined in the book by Clemen, can be used to rationalize critical decisions, but it faces limits on lack of information, subjectivity, etc…

- **Discussion:**
  - Some use of historical analysis may still focus on known unknowns
  - Dialogue on the concept of known unknowns and unknown unknowns
    - Are these terms sufficiently precise and useful?
    - Frank Knight in 1921 on measurable uncertainty (probability) and unmeasurable "true" uncertainties – a good place to start for a taxonomy on uncertainty: <u>Risk, Uncertainty and Profit</u>
  - Are there uncertainties that just can't be modeled?
  - Kant's distinction between the phenomena (which reaches our senses) that the thing in itself (which we can't really know)
  - Gap between quantitative language and qualitative factors
    - Is there a general theory for the translation between verbal and mathematical?
    - Common observation of guests to this seminar describing "soft" organic problems and attempting to link to "hard" analytical, systematic methods – is there a problem here? Are we using analytic decomposition methods to better understand something that is complex, integrated and not easily decomposed?
    - Epistemologists have focused on what constitutes a good argument – see Susan Haack on Evidence and Inquiry (when do we know that we have warrant for a proposition?)
  - There has to be a mix of qualitative and quantitative – systemic and axiomatic approaches for the issues that concern us in Engineering Systems
  - Issues of exploration, accumulation of knowledge, and other generic strategies for dealing with uncertainty – and link to concept of imagination and progressive modification of decisions
    - Use of info-gap model to modify an info-gap model – an epistemological can of worms
    - Challenge of building your boat while at sea

Additional notes sent subsequently by Yokov Ben-Heim:

Here are a few comments on the discussion of info-gap theory.

CONVEXITY:

The central limit theorem does not imply convexity of event sets. The CLT is a statistical result (first proven by Laplace around 1810) which shows that the normal distribution is the limit distribution for the superposition of i.i.d. random variables, regardless of their distribution. An ANALOGOUS limit theorem, much easier to prove than the CLT, shows that a convex set is the limit of the sets of superpositions of elements of an arbitrary set. This is the mathematical expression of the intuition which relates convexity to uncertainty: complex superpositions tend to cluster convexly. This intuition appears non-mathematically in some philosophical discussions (e.g. C.S. Peirce, quoted in my most recent book). The limit theorem appears in a special form in my first book (Assay of Spatially Random Material, 1985) where it is called the "convexity theorem", and is proved more generally in my second book (Convex Models of Uncertainty in Applied Mechanics, with I. Elishakoff, 1990). The mathematicians have a yet more general form of the theorem.

CONTRAST BETWEEN SATISFYING AS COMPARED TO OPTIMIZING:

I would like to clarify the use of the word SATISFICE. This is related to, but distinct from, SATISFY, though etymologically they are closely related. The Oxford English Dictionary explains the modern use of "satisfice" as "To decide on and pursue a course of action that will satisfy the minimum requirements necessary to achieve a particular goal." They attribute, correctly, the first (and most influential) use of the term with this meaning to Herb Simon.

Concerning the difference between optimizing and satisficing: There are two fundamental points to be made. First, an optimum may be and often is unique, while there are almost invariably an uncountably infinite number of satisficing solutions. The multiplicity of satisficing solutions means that a significant additional degree of freedom is open to the decision maker. In particular, the d.m. can satisfice performance and then optimize something else, like the robustness to info-gaps.

The second distinction between optimizing and satisficing is that the optimum may be unstable or sensitive to uncertainty. Because the satisficing solution can be buttressed by optimizing the robustness to info-gaps, the satisficing solution does not (usually) suffer from that sort of sensitivity. Indeed, the main point which I illustrated in my seminar was that sub-optimal solutions can be reliable when in fact optimal solutions rarely are.

ALTERNATIVE CONCEPT OF WIND-FALLING: Windfalling is a concept of which I am very fond. It is, I believe, not a widely recognize alternative to satisficing, from which it is utterly different. Robust satisficing (in info-gap theory) is the attempt to guarantee "survival" (one's minimal requirements). Opportune windfalling is the attempt to facilitate (but not to guarantee) the exploitation of favorable opportunities which may arise. The trade-off or trade- on between these two strategies is an important axis in the analysis of a decision problem. It is also an important dimension along which to explore risk proclivity or aversion, without any probabilistic underpinning.

Prof. Yakov Ben-Haim