ESD.84 Doctoral Seminar – Session 9 Notes
Guests Presenting: Thomas Hughes

Session Design:

- Welcome and Overview and Introductions (5-7 min.)
- Dialogue on Melanie Mitchell's review of Wolfram's *A New Kind of Science* (5-7 min.)
- Mid-Point Review
    - Focus on "Emerging Themes" (15-20 min.)
    - Preview of the ESD Faculty Presentation (7-10 min.)
    - Uncertainty, Complexity, Fragility, and Robustness Exercise (30-45 min.)
- An "Engineering Systems" View of "Systems Engineering" and "Systems Architecture," C. L. Magee (20-30 min.)
- Break (10 min.)
- Book Review:
    - Galbraith on *Organizational Design – Review by* Jeroen Struben (5-7 min.)
- Socio-Technical Systems, Joel Cutcher-Gerschenfeld (30-45 min.)
- Concluding Observations – Thomas Hughes (15-20 min.)
- Next Steps (10-15 min.)

Discussion of Worfram book review:

- A useful balance between book summary and book critique
- Demonstration of author expertise and perspective is important
- A nice job of situating the book relative to the literature and situating the author relative to the book and the field
- The life skill of writing a book review is a sub-set of the larger task of becoming a critical reader

Discussion of emerging themes:

- Robustness, fragility, and complexity are common themes – with key questions around how to link to the field of engineering systems
    - Do you start from the interesting topics or from the field as a whole?
- What do you need to know to teach engineering systems – this should be part of education much earlier – also it is hard to master so many domains in order to do the field justice
- How to learn all that is associated with each topic area – any one class could be (and is) an entire course or field of study
- Yet the diversity of topics allows you to challenge existing assumptions, ways of thinking and belief systems
- More on the topic reviews by students
- There are many definitions and a great deal of nomenclature – this course accomplishes a great deal in just spanning these many terms
- It is hard to see how all the disparate perspectives fit within engineering systems – a common framework to place or locate the materials that we are covering
- You can always tell when a course is not based on science but when it is instead based on guest lectures – in this sense we are still in the early innovation phase of the field – definition of terms is analogous to the establishment of architectural standards
- There is no guarantee that this approach will become the dominant paradigm
- The importance of ESD succeeding in the domain of field practice
- Historians tend not to give definitions – they give examples – reflecting the complexity of the subject materials
    - Consider the challenge of defining the term “technology”
- “The first step toward knowledge is calling things by their right name”
- The debates on the various Ph.D. programs in ESD have these issues embedded in them
- Contrast between engineering faculties and humanities faculties in the degree to which there is a push for definition versus discussion of issues – too early a rush to definition may close of the field

Faculty Seminar Advance Briefing

- Network perspective to add among emerging themes
- Is the term “complex” redundant in the context of engineering systems
- A need to have more chances to apply learning – in addition to the book reviews and presentation topics – especially ability to look across multiple interdependent systems

Class Exercise

- Step 1:
    - Form four groups – focusing on “uncertainty,” “complexity,” “fragility,” and “robustness” respectively
- Step 2:
    - Brainstorm different metrics and methods for assessing different degrees of your assigned concept
- Step 3:
    - Assess the list – here are sample assessment questions:
        - Are the metrics and methods idiosyncratic to specific systems?
        - Are the metrics and methods easy or difficult to apply?
        - Where are these methods and metrics used and where could they be used?
- Step 4:
    - Be prepared to report out our findings for full group discussion

Uncertainty – Methods and Metrics:

- Known Unknowns
    - Probabilistic analysis – metrics: percent likelihood
        - Supply chain inventory and logistics analysis (concepts of safety stock levels, for example)
        - Tools for analysis at the tails of distributions (infrequent but cataclysmic events)
    - Risk assessment/Insurance analysis – metrics: percent likelihood
        - Risk identification
        - Risk analysis
        - Risk management
        - All involving a mix of scenario analysis, probabilistic assessment and cost-benefit/expected value analysis
    - Fault tree analysis – metrics: identified failure modes with percent likelihood
    - Real option analysis – metrics: multivariate choice options with cost estimates
    - Prevention and mitigation methods -- metrics: cost/consequence estimates and intervention resources required
    - Options and portfolio risk analysis – metrics:
    - Cost/benefit analysis – metrics: cost/consequence estimates
    - Adjusted optimization methods
        - "Backing off" Pareto frontier in order to account for uncertainty
    - Designed in redundancy
    - Targeting uncertainty into observable or addressable failure modes (circuit breaker concept)
    - Attitude surveys on perceptions of uncertainty and around uncertain events
- Unknown Unknowns
    - Historical analysis – metric: capture of historical trends
    - Event history analysis – metric: event clusters
    - Root cause analysis – metric: problems resolved
    - Designed in redundancy – metric: number of redundant options
    - Checking your "gut" -- bivariate choice points

Complexity – Methods and Metrics:

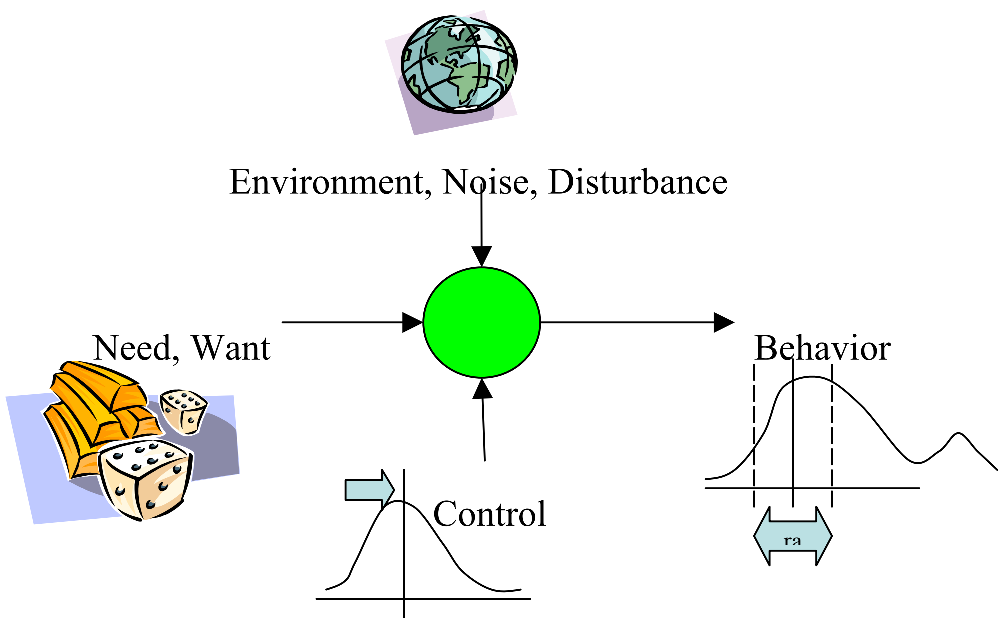
- From Joel Moses – structure of complex systems and by implication the number of illities can measure compleity that must be considered. Also, he pointed to Kalmagoroff and other complexity measures that Lloyd,Doyle and others referred to.
- Measurement of structural complexity – Doyle, Moses
- Dynamic complexity – Sterman – by implication, time delays,visibility and feedback loops could serve as metrics
- Interactions and network, but not a clear path to a metric – Whitney
- Logical depth – Lloyd, Sussman, and others – information content and processing including the key role of constraints in increasing complexity
- Major teaching is that complexity metrics are context dependent and that this is a good thing – Lloyd. Our challenge is to pick the best one for the problems we are interested in: example Ali-structure is critical and measures that allow comparison across programs are not clear-semantic and understanding issues are critical
- THERE ARE INTERESTING LIMITS ON UTILITY OF COMPEXITY METRICS IN DESIGN BECAUSE EVEN IF STRUCTURE IS SIMILAR OR WE KNOW ITS COMPLEXITY WE NEED DEEPER UNDERSTANDING IN ORDER TO DESIGN

Fragility – Methods and Metrics:

- Metrics for assessing different metrics assessing different degrees of your assigned concept:
    - Probability of failure of system (how system is designed)
    - Hazard probability (exogenous)
    - Types of failure modes (dramatic vs. graceful)
    - Impact of potential hazard (implications of failure)
    - Measure of self-containment (airplane crash vs. poisoning water system)
    - Recovery potential and rate
- Methods
    - Methods for assessing different metrics assessing different degrees of your assigned concept:
    - Models and simulation of system, test distortions/sensitivity analysis
    - Historical analyses
    - Brainstorm risk and future scenarios (changes in behavior modes)
- Assess the List
    - Metrics not idiosyncratic to specific systems
    - When using methods need to have specific system in mind
    - Both metrics and methods difficult to apply, almost always a paucity of data, often a lack of deep understanding of how system works
    - Must be creative in utilizing these methods
    - Examples: developing country mega-cities (Mexico City project, large capital acquisition systems, eCommerce system)

Robustness – Methods and Metrics:

- Key initial thoughts
    - The ability to “self-heal”
    - Spontaneity
- Definition of Robustness: Functions as intended despite disturbances (environmental, internal)
    - Duration
    - Evolving context
    - The interpretation of robustness evolves with its context
- P diagram from Tagushi



- Metrics
    - “Gap” between goal and actual
    - Qualitative
        - What disturbances have been considered?
            - Environmental covariance
        - Constraints
            - Economic, social, psychological
        - What are the weak links in the system -- vulnerabilty points
            - Human operators (“idiot” proof)
        - What will happen for each combination of disturbance and vulnerability
    - Quantitative
        - Taguchi, Doyle. . .
- Methods
    - Design
    - Evaluation

Discussion:

- Task of getting to methods and metrics is difficult – challenge of operationalizing concepts
- Abstract thinking process is needed at front end – but then translation into practice could be very powerful

"Engineering Systems" View of "Systems Engineering" and "Systems Architecture" – Presentation by Chris Magee

- Systems Engineering: Tools, methods and processes (enablers) for dealing with complexity (and uncertainty) in engineering design projects.
  - The integrative aspect of systems engineering is problem and domain dependent but USUALLY involves some TOP-DOWN analysis, decomposition efforts, requirements analysis, etc.
  - Systems engineering attempts to enable COMMUNICATION among specialties necessary for the effective design of complex systems
- Systems Engineering 1
  - Specifications, Function and Design are represented at several linked levels of abstraction (multi-level SE)
  - Linking and traceability of detailed requirements before design begins
  - Functional analysis follow specifications and also precedes design
  - Quantitative requirements available at component level
  - Integrated analytical results often guide subsystem and component requirements (functional analysis precedes embodiment)
- Systems Engineering 2
  - Integrative analytical simulations help understand emergent behavior and help determine verification (and validation) procedure
  - Systems engineering has an essential management or leadership aspect.
  - Systems engineering emphasizes process discipline
  - A disciplined process is used for doing trade studies/decisions thus achieving balanced system solutions
  - Status of design vs. requirements first tracked and reported by analysis and other tools rather than just "testing"
- Concept of fast prototyping as opposite to systems engineering
- Factors in shaping when and in what degree to use systems engineering tools and principles – as they increase the need for systems engineering increases
  - Scale
  - Number of attributes / "ilities"
  - Attribute refinement
  - complex interactions and attribute tradeoffs
  - User understanding and predictability
  - Lack of radical technology
  - Partitioning clarity – known interactions
  - Operand and process mix
  - Integration simulation capability
  - Prototype and testing cost and timing
  - Re-Use
  - Long use life
  - Focused or single customer
  - Commercial vs. Government customer
  - System component supplier strength

Discussion:

- Add to the definition the concept of identifying and solving problems
- Issue around whether systems engineering is the whole process or the sub-set of the project or program that concerns the way you operate
- Tools, methods and processes are a useful characterization of systems engineering

"Socio-Technical Systems," presentation by Joel Cutcher-Gershenfeld

The "Big Picture"

	Social Systems	**Technical Systems**
Craft Production	• Decentralized Enterprises • Mastery of Craft	• Custom Manufacture • Specialized Tools
Mass Production	• Vertical Hierarchies • Scientific management	• Assembly Line • Interchangeable Parts
Knowledge-Driven Work	• Network Alliances • Team-Based Work Systems	• Flexible Specialization • Information Systems

"The socio-technical concept arose in conjunction with . . . several projects undertaken by the Tavistock Institute in the British Coal Mining Industry. The time (1949) was that of the postwar reconstruction of industry. . . The second project . . . Include(d) the technical as well as the social system in the factors to be considered and to postulate that the relations between them should constitute a new field of inquiry."

Source: Eric Trist, The Evolution of Socio-Technical Systems: A Conceptual Framework and an Action Research Program, (Toronto, Ontario: Ontario Quality of Working Life Centre, 1981) (original italics)

"The Concept of a production system as a socio-technical system designates a general field of study concerned with the interrelations of the technical and socio-psychological organization of industrial production systems. . . The concept of a socio-technical system arose from the consideration that any production system requires both a technological organization – equipment and process layout – and a work organization relating to each other those who carry out the necessary tasks. The technological demands place limits on the type of work organization possible, but a work organization has social and psychological properties of its own that are independent of technology . . . A socio-technical system must also satisfy the financial conditions of the industry of which it is a part. It much have economic validity. It has in fact social, technological and economic dimensions, all of which are interdependent but which have independent values of their own."

Source: A.K. Rice. Productivity and Social Organization: The Ahmedabad Experiment (London: Tavistock Publications, 1958) – cited in E.L. Trist, G.W. Higgin, H. Murray, and A.B. Pollock, Organizational Choice: Capabilities of Groups at the Coal Face Under Changing Technologies – The Loss, Re-Discovery and Transformation of a Work Tradition. (London: Tavistock Publications, 1963)

Sample Socio-Technical Design Principles:

Self-Design
Minimum Critical Specifications
Open-Ended Design Process

Technical Subsystem – Locate capability to control variances where they occur

Tools and techniques
Variances
Transmitted variances
Boundary variances

Social Subsystem – Division of Labor and Methods of Coordination

Autonomy and discretion
Opportunity to learn
Optimal variety
Opportunity to exchange help and respect
Sense of a meaningful contribution
Prospect of a meaningful future

Source: Calvin Pava. Managing New Office Technology: An Organizational Strategy (New York: The Free Press, 1983)

A Comparison of Three Types of Team Systems:

	Lean Production Teams	**Socio-Technical Systems Teams**	**Off-Line Teams**
Origins:	• Japan (Toyota Pull System, 1960s)	• Scandinavia (Volvo Kalmar, 1970s) and England (coal mines, 1940s)	• U.S. (Harmon and GM/UAW QWL groups, 1970s) and Japan (Quality Circles, 1980s)
System Optimizes:	• Continuous improvement in work operations	• Mix of social and technical sub-systems	• Ad hoc problem solving
Expected Yield:	• Systematic gains in quality and productivity	• Increased worker commitment and targeted gains in quality and safety	• Increased worker commitment and reactive response to quality problems
Success Constrained by:	• High expectations of team autonomy; Low labor/management support for continuous improvement	• High levels of team interdependence; Limited resources for technical redesign	• Separation from daily operations
Typically Found in:	• Assembly operations (high interdependency among teams)	• Continuous production operations (high autonomy among teams)	• Broad range of workplaces
Leadership:	• Depends on strong team leader	• Depends on self-managing group	• Depends on group facilitator
Membership:	• Common work area	• Common work area	• May draw on multiple work areas
Organization Structure:	• Core building block	• Core building block	• Adjunct to the structure
Links to Other Teams:	• Tightly linked to internal customers and suppliers	• Tightly linked across shifts; loosely linked with other teams	• Little or no links among teams

Source: Knowledge-Driven Work: Unexpected Lessons from Japanese and United States Work Practices, Cutcher-Gershenfeld, et. al., 1998.

Comments from Thomas Hughes:

- Appreciate the chance to better understand this seminar and its participants
- I live in a house designed by the architect Robert Venturi – one of the first post-modern houses – his "mother's house" which has a widely read manifesto entitled "Complexity and Contradiction" written in 1963
    - A reaction against the international style of architecture which is geometrical – often "bastardized" for cost cutting purposes – with flat surfaces, high rise buildings
    - A move to complexity rather than clarity and simplicity – young people need clarity to cope with an incomprehensible world – this may have been right for the early years of modernity, but now we are more mature and better able to deal with complexity
- Is this an analogy to what we are doing in engineering – from Henry Ford and Frederick Taylor into a more complex approach
- Think of socio-technical systems in relation to Networks of Power – the socio-technical system is everything involved in producing power for the consumer – much broader than the focus just within organizations as discussed in the readings
    - For example the willingness of banks to loan to utilities and the role of regulatory bodies are all part of the socio-technical system
- A need to think more about the political systems in the concept of engineering systems – contrasting roles of regulatory systems in the U.S. and British cases with electric power – enabling or constraining growth (the countries were comparable with respect to the engineering schools, the quality of the hardware, and other dimensions – but very different on the political dimension)
- A lesson on the need to take into account the "irrational" – such as the respect for local government overriding the importance of system efficiency in the British case