ESD.84 Doctoral Seminar – Session 15 Notes

Session Overview:

- Welcome and Overview and Introductions (5-7 min.)
- Collective Brainstorming and Dialogue on Engineering Systems as a Field of Study (30-45 min.)
  - Promising Aspects of Engineering Systems as a Field
  - Troubling Aspects of Engineering Systems as a Field
- Comments and Dialogue with Thomas Hughes and Peter Senge (60-75 min.)
- Architecting Engineering Systems as a Field of Study (20-30 min.)
- Lunch (15 min.)
- Book Review and Syllabus Presentations (7-10 min.)
- Construction of the Curriculum for a Ph.D. in Engineering Systems (30-45 min.)
  - Architecture for a Ph.D. program in Engineering Systems
  - Course options associated with various architectures
- Concluding Comments (10-15 min.)

Promising Aspects of Engineering Systems as a Field:

- Instructor's Thought Starters:
  - A real need exists – this is not just a fad and there is the potential to have a significant impact in society
  - A range of exciting developments in various fields offer significant promise for development to the stage that they will really be useful in *design* (what engineering is all about)
  - We are attempting to give concurrent attention to social, technical and contextual aspects of complex engineered systems
  - There is strong interest at MIT to take engineering to a new level – with beneficial impacts on society, while remaking engineering education
  - Multi-disciplinary programs and communities of practice seem to be emerging in engineering schools and field settings around the world
- Summary of Submissions:
  - Recognition of importance of vocabulary/definitions and frameworks
  - Opportunity to develop new ways of addressing problems
  - Lots to learn from network theory, biology, etc.
  - Opportunity to develop goals for field
  - ESD is open to various stakeholder inputs
  - Interdisciplinary engineering is a real need
  - Rigorous theories from existing engineering disciplines can serve as "building blocks"
  - Rigorous Engineering Systems theory is needed in many application areas
  - ESD is appropriately broad and timely
  - Inter-related domains such as Complexity Theory, Systems Dynamics, and Agent-Based Modeling are particularly promising
  - Continued/accelerated development through increased productivity as better tools (no sledgehammers) are used by engineers/managers
  - New differentiation between "intuitive" and "real"
  - Avoidance of societal catastrophes
  - Appealing ***huge opportunity*** and perhaps only way to attack issues now seen as dualities
  - Complexity Theories of various kinds now winning prestigious prizes- these accomplishments have opened up an opportunity to develop real and applicable tools/frameworks/methods that have very important impact on tangible industrial products (and society)
  - The Engineering Systems Field is Integrative
  - The Study of Engineering Systems is Novel, Useful and Needed

Troubling Aspects of Engineering Systems as a Field:

- Instructor's Thought Starters:
  - Many of these ideas are not new and have not taken hold before
  - Qualitative, case-study based methods are still the most useful for practice but these do not have sufficient power to rapidly improve our design capability
  - Measuring and understanding of complex engineering systems is so difficult that quantitative theories and methods may be slow to develop because of their lack of quantitative feedback from the real systems of interest
  - Many engineering systems are one-of-a-kind, making it hard to investigate alternative paths or options
  - University and industry institutions (especially around career paths) and demographics of the field pose many challenges
- Summary of Submissions:
  - Disjointed nature of ESD and non-dedicated faculty
  - Potential lack of balance towards quantitative modeling
  - Possible lack of acceptance by other fields
  - It will take a long time to succeed-do we have the time?
  - Fit of ESD graduates in industry and academia
  - Boundaries- technical and social to what degree??
  - Tendency to academic-centric
  - Humans are unpredictable
  - Generalization and not "sloganeering" is needed
  - How much will be "provable"; limitations of simulation
  - Lack of balance between more formal quantitative and more instinctive qualitative approaches – the foundation areas are thus far divorced from application
  - Acceptance in multiple disciplines for the "simply" brilliant
  - Real "glue" needed – perhaps micro/macro beak-down
  - Limits on growth of field (or it self-destructs)
  - Common language focus has potential negatives
  - Disaster if stay at theoretical/ philosophical level and lack of ESD research centers in the area is a concern
  - The Engineering Systems Field is Poorly Defined

Initial Observations:

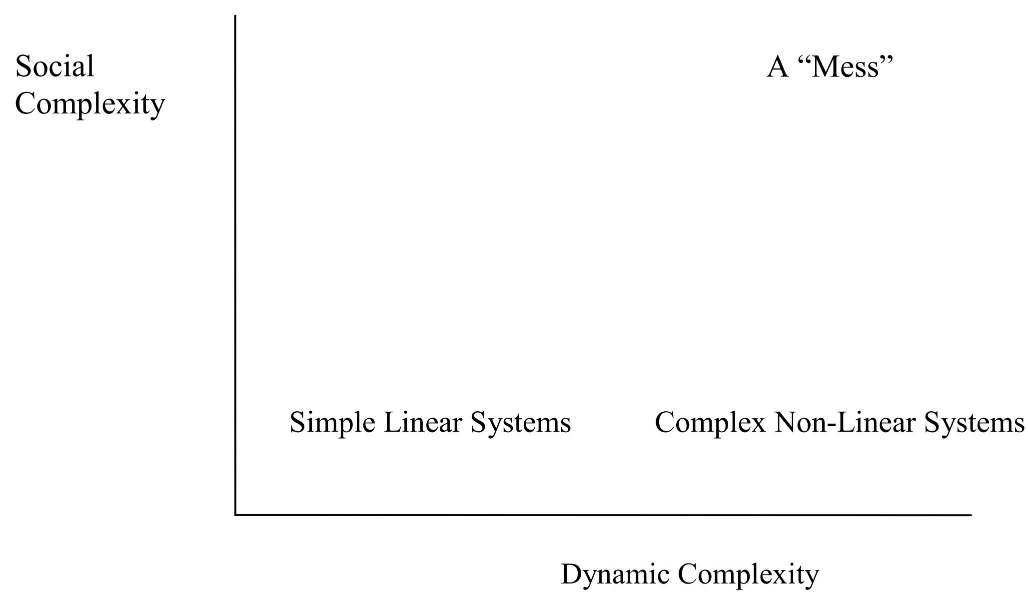
- We discussed many historical and theoretical ideas – less on current events and future opportunities (for example, global warming)
- We may not know enough historically – where are the galvanizing events that will drive this effort forward (consider the impact of WWII on MIT)
- An impressive range of fields sharing elements that are of interest – a question around more diverse representation of students in different fields such as mathematics, system biology, control theory

Comments by Thomas Hughes:

- Three key themes:
  - A definition of the systems approach – drawing on history
  - Past challenges comparable to global warming – look at the way a systems approach was used around what were termed "urban problems" in the 1960s
  - Concluding comments from Russell Akoff
- A historical definition:
  - Look at how operations research, systems engineering, and the development of systems analysis emerged in the past
  - Operations research goes back before WWII when left-leaning social scientists in Great Britain introduced these concepts to the British Navy and Air Force – a mix from Biology, Social Science, Mathematics, Material Science – often meeting over dinner
  - It was initially termed Operational Research – one group was termed a "circus" because of the many clowns involved – they would gather data on bombing missions such as darkness, distance, height, etc. to construct a history of the given operation in order to identify patterns in the quantitative data – the same was done with submarine missions – this is the roots
  - Systems engineering took shape during the Atlas project – the first intercontinental ballistic missile – under the Air Force during the 1950s – with a tea pot committee including professors and researchers from MIT, ATT, Bell Labs, etc. under John Van Neumann – which urged no more prime contractors (with the low trust environment in the air frame contractors) and instead all the best specialty companies – to be coordinated by the Systems Engineers
  - Did not use consultants from academia – they were seen as experts about the past, not helping to shape the future – instead turned to the Rand Corporation (a California think tank known for its trans-disciplinary approach – focusing on the problem)
  - Economists were effective in that they took in big issues and spoke a common language centered on mathematics that was seen as relevant by others
- A word on a great failure
  - Hubert Humphrey as VP in 1968 spoke on the promise of the systems approach: The techniques that are going to put a man on the moon are going to be exactly the techniques needed to clean up our cities – management techniques, coordination of scientists and engineers – the approach modern cities will need – pioneering in space to solve problems as home
  - Four star general Bernie Shriever leaves the Air Force to solve the problems of the cities – sets up a consortium company called Urban, Inc. to plan transportation, housing, waste disposal, etc. – for two years does not get a single regional contract – blamed on "politics"
  - Cities are so much messier than aerospace projects or life at MIT
- Concluding comments from Russell Akoff
  - Came to University of Pennsylvania in Operations Research but shifted since OR was too "thing" oriented
  - We can no longer take a mechanistic approach – we can no longer focus on cause and effect
  - Only focus on simultaneous interactions – a systems approach
  - The only approach is how to manage a "mess"

Comments by Peter Senge:

- So much of this history has been in my life – beginning as a masters, doctoral student and faculty member here
- I had a course in Systems Engineering at Stanford as an undergrad with a retired chief engineer from Boeing and operations research from Dansig and then to work with Jay Foerster here at MIT – who comes from these domains and took on the urban challenges (since the "war" on poverty was such a failure)
- Most popular urban policies were focused on symptoms (such as building housing) not systems – a simple observation: The cities with the best programs drew more people with more challenges
- Began with a big interest in environmental issues and migrated into Systems Dynamics
- Developed a core concern – the realizing of the potential for Systems Dynamics was miniscule – despite many successful projects, not a systemic impact and no enduring shift in practice
- The challenge was how to foster different ways of thinking
- The process starts with the question – what is the problem? A narrowly posed problem will preclude systems approaches – most problem statements are actually solutions posing a problems (for example: how do we solve the housing crisis?)
- System engineering brought a project management focus, but that was still not attending to the long-term implications for the corporation
- By the end of the 1970s it was clear that the analytic tools were vital, simulation was needed understand non-linear systems – but the impact was not being felt – interdependent, complex domains were not functioning for the well-being of people
- Consider the definition of engineering – notice the focus on just on serving human activity will undercut even our own needs since it doesn't fully encompass natural environment – the thoughtless imposition of boundaries
- Bucky Fuller used to say "start with the universe and then go from there"



- Dynamic Complexity: Causal relationships are not close in time and place
    - Our institutions are terrible at this given out fragmented they are, and humans may or may not be able to do this (a question of innate capability) – not even knowing about the delays that can happen with stocks and flows
- Social Complexity: A common realization – the problem with so many systems is that they are populated by human beings
- System is not just a bunch of biographies or a bunch of models – the two extremes on this model
- Would like the spirit of systems engineering applied to systems analysis – as a negotiated point of view
- Conclusions:
    - The importance of aspirations – people have to really care
    - The importance of time – with a short enough time horizon you can ignore many feedback loops
        - Our society has worked hard to create a culture of not caring
    - Umberto Moteranta – a biologist who has worked for 30 years around what is termed the Santiago theory of cognition – a biology based theory of perception
        - There is only one way to escape our history is through the capacity to reflect
        - What Buddhists call the awareness of thought
        - We only perceive our thoughts, not reality
        - Awareness is the next step from reflection
    - Ultimately this is about our becoming more human

Discussion:

- We live in a world of a continuous thought stream – a 2000 year tradition in Buddhism – the challenge of quieting the mind and slowing down the thought stream
- Anthropology gets at some of this through ethnography – awareness of how we are trying to know what we are seeing
- Consider Gerte as a scientist – his theory of light is very different in approach from Newton – not a focus on the discovery of hidden laws – theory comes from the Greek for seeing – all science should be about the seer, not just what is seen (he is seen as a great literary figure, but he thought of himself mostly as a scientist) – he would wonder why botanist would primarily study dead plants
- The personal challenge of changing ourselves
- Discussion of agent-based modeling involved example of multi-player computer simulations – where key strokes represent people (but there are people behind it so it doesn't count as a systems model)
- This all comes home when people have very different views – the central role of reflection in action – that people have different views is not new – can they interact in ways that deepen their view of each other or do they interact in ways that polarize their views
- The contrast between core assumptions about common interests, competing interests or a mixed-motive approach assuming both common and competing interests
- Is there really a duality between dynamic complexity and social complexity
- There is this distinction between the qualitative and quantitative that falsely concludes the qualitative is not rigorous
- 21st Century engineering systems can be different than 20th Century systems engineering along these lines – attending to both the skills needed for social complexity and the skills needed for dynamic complexity

- Dynamic skills and social skills are conceptually distinct
- Difficulty of finding people who simultaneously excel in both dimensions – more common with women, it turns out
- Consider the example of Taichi Ohno as someone who integrated technical principles such as reduced in-process inventory with social principles such as the way knowledge drives continuous improvement
- Consider moving beyond individuals to ask about networks and institutions that embody this principle
- In a project in Gloucester with the local fishing community – initial focus was on competing nearby communities and then expanded to regulatory issues and then larger
- How to define the boundaries of a system
- When Deep Blue beat Kasperoff – he interpreted an aggressive "personality" and then build his strategy in response – like pilots referring to different models of the same plane having different personalities
- Consider Jay Forester's work now at the end of his career in educating school children – including using systems dynamics to analyze Shakespeare and other domains
- Is this too late in our lives – are we captive to not having been trained in this way at a young age?
- We studies a 2,000 year old irrigation systems in Sri Lanka and brought together farmers, engineers and others – a key dimension was trust among the people – a necessary pre-condition for any meaningful impact
- The interconnections between academia (what we are doing here), industry, government, and the larger eco-system is possible – it takes efforts such as what we are doing here to really build these needed bridges – example of the aerospace systems course taught by Earll Murman with a focus on a real problem such as building a super large aircraft
- How to get beyond the duality even as we talk about eco-systems
- We know the strong leadership required for systems engineering and there is a contrast in the leadership needed in a church committee, for example
- Issue of the human genome project – this is just code that presents a huge opportunity in learning how it works – issues of cause and effect
- Modeling is a wide open space
- The very understanding of engineering systems is critical – by the stakeholders within the system – reflection in action
- The power of the systems ideas to get people to focus on important issues
- Every technical systems is also a social system, even if every social system is not a technical system
- The language that we develop as boundary objects – getting beyond the mechanistic lens so characteristic of engineering is the potential of engineering systems
- Concern about continual bias to focus on dynamic systems in way that is not balanced by social systems

Concluding Observations:

- People who defined the foundations – Alkoff, Forester, Moss and others all had physics backgrounds – the future of this approach may involve using a foundation in biologists – consider too medical systems (the mix of machines and values)
- Understanding machine systems is a key foundation for engineering systems
- The very language of engineering systems is important
- Early definition of engineering was – do you believe in tools and do you want to solve practical problems – that is may still be true, but there is more

- Contrast autopoetic (self created) and alopoetic (created by an other) – the boundary is becoming fuzzy – such as machines that create themselves
- Problem domains will be key for Engineering Systems – it will provide a needed anchor – the machine understanding is so far advanced in relation to the understanding of living systems
- Consider the new work now taking place on intelligent materials pooling and the implications for living systems – this is not being seen systemically but it involves links across complex supply chains that can have a large impact
- Thank for the chance to be with you in exploring these important matters

Dialogue on Engineering Systems Ph.D.

- Anticipate that next semester's course will build on what has taken place this semester.
- Next semester may be more of a reading course – with a deep focus on a single book for some sessions
- Next semester may also involve some work with simulation
- Have a discussion publishing in different types of journals and how to communicate more broadly to key target audiences
- Engineers don't actually design systems to meet human needs – they design systems that they are excited about and it may or may not meet intended human needs
- Explore what to expect from a field of study – how disciplines form, how fields form, how approaches form

Dialogue on Overall ESD Ph.D. Architecture:

- This Ph.D. seminar should be a full 24 credit immersion with parallel 24 credit for research
- Consider moving to more of a major and minor structure
- Important to have specific Ph.D. classes – marking the movement from consumer of knowledge to producer of knowledge
- Consider the interaction between social systems and technical systems – moving beyond the term socio-technical systems
- Do we need two capstones – an introductory seminar and another one a year and a half later as we launch into dissertation
- A need to bring into the sequence a field application oriented course
- There should be a few core course requirements – in addition to this seminar – consider the systems dynamics intro course and the systems architecture course and a mathematical requirement
- A research focus in ESD can cut across many faculty members working with a range of different research methods – remember that there are 900 faculty members here each of whom are individual entrepreneurs
- Research graduate students is one of the key ways that faculty are linked together
- We need to send a broader meta message that ESD can integrate people doing work across a broad scope of methods – requires a different way of operating
- Requirement to be a TA – this should be an expectation – the pedagogical learning that is important for students and it is also a form of "giving back" to the community by students
- Where there are funding restrictions on taking on a TA role consider at least the chance to teach a few modular units
- Consider career paths in industry and government, not just in the university
- Does the context in the curriculum cover transition processes – not just the system and the methods, but issues of implementation, failures, interactions, etc.

- Discussions of ESD Ph.D. and the TPM – there was never enough commonality of courses in TPM to build community – it mostly happened during the generals, with primary attachments tied to projects, labs and other activities – a challenge for the pilot ESD students – the forces that pull people apart
- This course has overlap with TMP, but the emphasis is distinct – this course is frustrating in that it opens up whole new domains that I want to pursue
- In linking with Cambridge University on Technology and Policy – there is this image of competence on legal, regulatory, organizational, technology and other dimensions – which pulls some people more strongly into domains of law and regulation that may or may not be part of the conception of ESD
- What is the role of law in ESD? Research issues around knowing the legal context and being able to operate effectively when called to testify in court
- Looking across LFM, SDM, MLOG, Transportation, and TPP – perhaps there is a way to respect the diversity of students at that level and still allow some continuing diversity at the doctoral level while still building a common culture – ESD should allow people to grow but not impose a single approach on them

Course Recommendations for ESD Ph.D.:

- More coursework on systems architecture and design
- More coursework on systems theory
- More mathematical rigor suited to our needs – different from what is offered in mathematics and from traditional engineering math
- 15.347 in methods is excellent
- Probability around social distributions involves different thinking than probability in engineering that we might have had as undergraduates
- Complex systems will bump into AI limits – pointing to computational mathematics
- Organizational theory
- Course work on institutional issues around regulation, sustainability and trade
- ESD Visiting Committee was pushing for more on probability – but this is built into other course work such as on risk and real options – it may be as or more important to use the tools in other courses
- Get people like Nick Ashford and Ken Oye to co-teach a class on regulatory and legal issues