Developing Engineers to be Leaders in a World of Growing Complexity

Seminar in Lahore University of Management Sciences

Ebad Jahangir, Ph.D.
Pratt & Whitney, United Technologies Corporation

August 8, 2005

Any opinions, findings, conclusions, or recommendations are those of the author and do not necessarily reflect the views of the author's employer or any academic institutions. The material presented draws mostly from the discussions within P&W on the directions of systems engineering, the NAE publications, and the MIT ESD symposium.

I Made Some Love; I Did Some Work   کچ عشق ک ا، کچ کام ک ا

Ah, those fortunate people
who considered their lifework to be love,
and those who were in love with their work.
I kept busy all my life;
I made some love, I did some work.
Work kept interfering with love;
love got in the way of work.
At last I got fed up with it all
and left both half-finished.

Faiz Ahmed Faiz

و لوگ بہت خوش قسمت ت ة
جو عشق کو کام سمج تة ت ة
ا کام سة عاشقی کرتة ت ة
ج تة جی مصروف ر
کچ عشق ک ا، کچ کام ک ا،
کام عشق کة آڑ آتا ر
اور عشق سة کام الج تا ر
پ ر آخر تنگ آ کر Ŭ
دونوں کو ا ورا چ وڑ د ا

ف ض احمد ف ض

I Did Some Engineering; I Improved Some Lives (with apologies to Faiz)

Ah, those fortunate people
who lived to be engineers,
and those who wanted to engineer lives.
I kept busy all my life;
I did some engineering, I improved some lives.
Leading kept interfering with engineering;
engineering got in the way of leading.
At last I became a Systems Engineer
and found there is no optimum in this complex world.

Questions

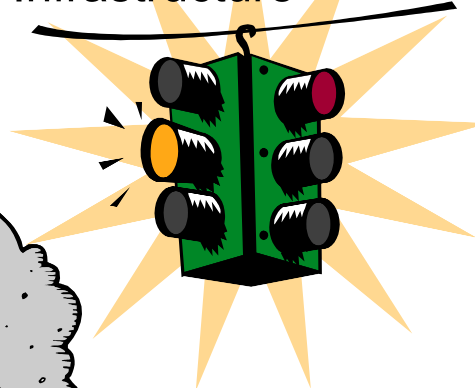
- **What's different between engineering of yesterday and today?**
  - **Technologies Progress and Overlap**
  - **More people spread in time and space**
  - **Societal, ethical and policy issues at the forefront**
- **What characterizes Engineering Systems?**
  - **Engineering Systems instead of Engineering Products**
- **What attributes are required of engineers and what attributes need increased focus?**
  - **Traditional Engineering**
  - **Traditional Business / Management / Policy Curriculum**
  - **Confluence of Both**
- **How do we develop future engineers who are leaders?**

Engineering Systems

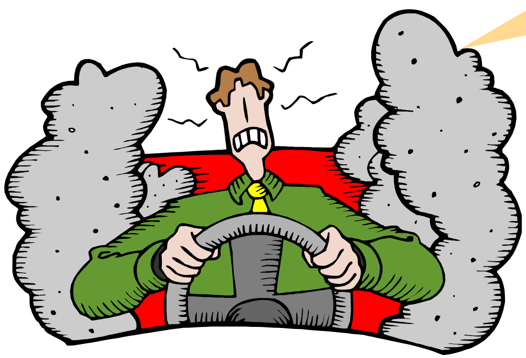
Automobiles / Transportation

Urban Environment

Infrastructure



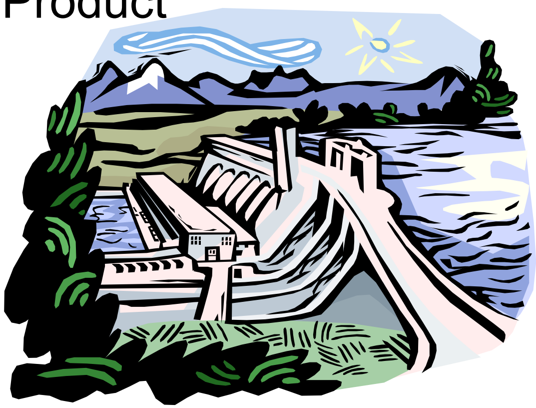
Human Factors



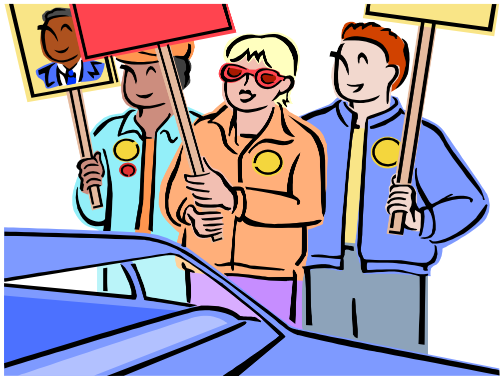
Affordability

Kalabagh Dam

Product

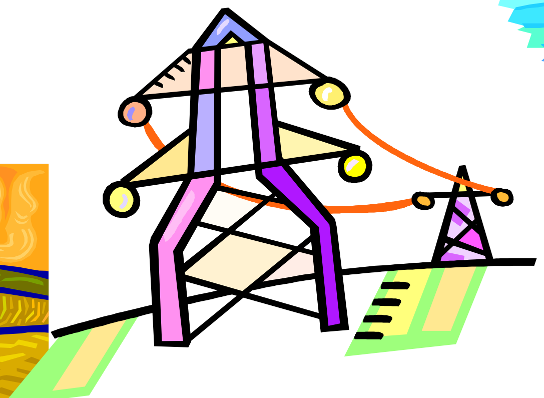


Politics / Society



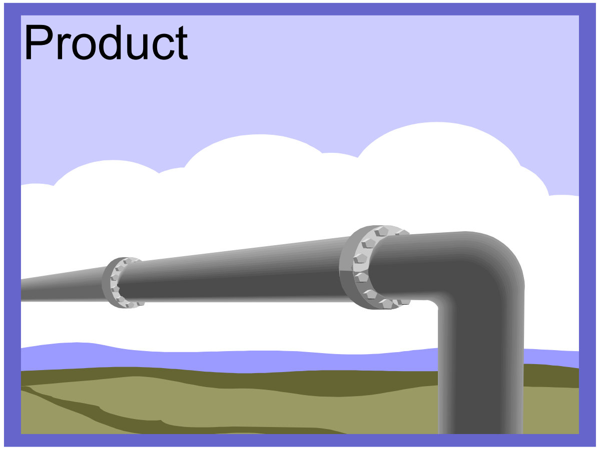
Environment

Infrastructure

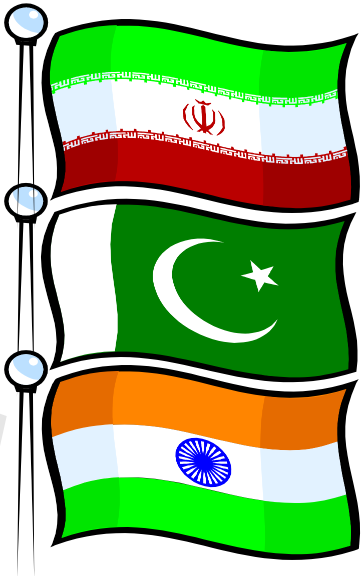


Economy

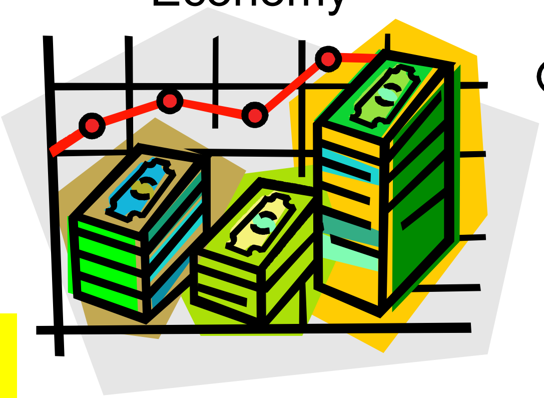
Iran-Pakistan-India Pipeline



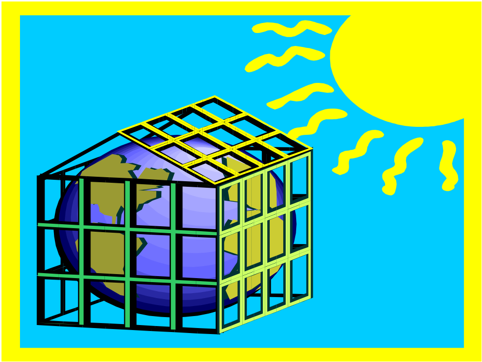
Global Politics



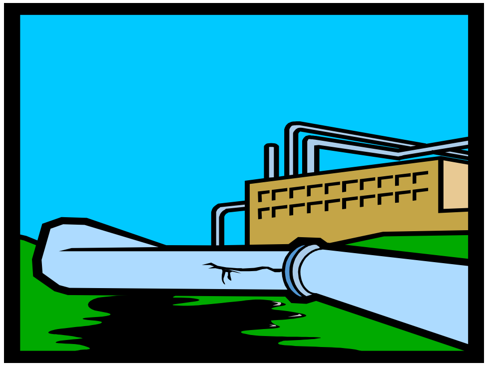
Economy



Sustainability



Environment



Security

What's New in Engineering?

- Traditional goals of function, performance, cost
- Integration of multiple overlapping technologies
- Technologies progress and are being transformed repeatedly by new knowledge
- Organizational complexity: more people spread in time and space
- A world linked globally: where differences can mean progress but divisions can destroy it
- Economic and social prosperity
- Safe environment
- Environment and life-cycle issues
- National and global security

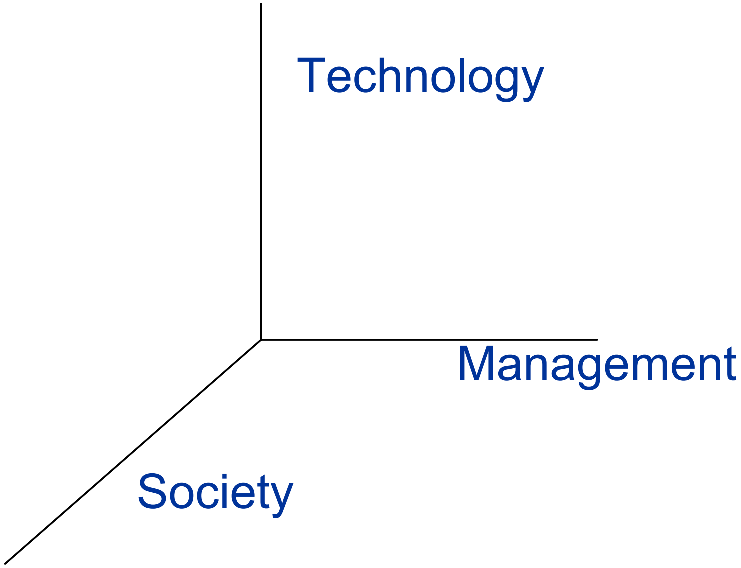
- Non-traditional goals ("ilities") such as flexibility, sustainability, safety, robustness, maintainability, durability, scalability, quality… involving long time spans and life-cycle issues

- Change and complexity are the rule; a world evolving at an accelerating pace due to leaps in knowledge and technology

Engineering Systems Perspective

- **Engineering systems deals with large scale, complex products, the wider processes of design, manufacturing, and operation and even wider context of management and policy**

- **Engineering systems fundamentals attempt to get at the "essence" of certain issues in large scale, complex engineering systems, such as flexibility, sustainability, and safety**



3 Dimensions of Engineering Systems

Holistic perspective – system architecture is the starting point

Industry Directions

- **Started with Civil and Military Engineering**
- **Spawned and continues to spawn new engineering fields based on new areas of application**
  - **One example is aerospace engineering combining elements of mechanical and electrical engineering**
- **Engineers being asked to lead complex technology spanning projects**
  - **Typical practitioners are aerospace engineers and civil engineers and some software engineers**
- **Industry practice of new engineering disciplines generally precedes formation of academic engineering departments**
  - **Engineering Systems one of the new emerging disciplines**

Academic Perspective

The Definition of Engineering Systems

- **Engineering Systems are "technologically enabled" complex systems that have a management or social dimension as well as a technical one.***

- **Good design is central to Engineering Systems which requires a *holistic view* (Product, Process and Context)**
  - **"Always design a thing by considering it in its next larger context -- a chair in a room, a room in a house, a house in an environment, an environment in a city plan."**

    Eliel Saarinen, quoted by his son Eero, Time 2 June 1977

- **The context becomes a *design variable* rather than a *constraint***

* Adapted from ESD Terms and Definitions (Version 13)

How Quantitative is the Study of Engineering Systems?

- **Traditional engineering disciplines, such as EE and ME, are based on a Mathematics based approach**
  - **Mathematics provides great rigor and trustworthy generalizability**
  - **The aim is arrive at optimal decisions for an imaginary simplified world approximating the real world instead of arriving at good enough decisions for the complex real world**
- **The traditional way of engineering is to exclude social constraints from problems so they can be mathematically modeled and solved**
  - **Often the problems that can be solved are not the ones that society most needs solved**
  - **Excluding social constraints reduces the societal relevance of the problem**

Engineering Systems Expands Upon Systems Engineering

- **The spirit of systems engineering is to strive for *completeness***
- **Not one best solution for complex problems**
  - **All problems cannot be completely solved**
  - **Satisfactory solutions instead of optimal ones**
- **Why not use a mix of quantitative-qualitative methods**
- **Is engineering systems the <u>union</u> of the following?**

• System Modeling and Simulation	• Industrial Engineering
• <u>Decision Analysis</u>	• Specification Writing
• Project Management and Control	• <u>Risk Management</u>
• Requirements Development	• Interpersonal Relations
• Software Engineering	• Liaison Engineering
• Specialty Engineering	• <u>Operations Analysis</u>
• <u>Risk-Cost-Benefit Analysis</u>	• Cost Estimation
• Organizational Processes	• <u>Technology and Policy</u>
• Human Factors Engineering	• Political Analysis

Engineering systems deals with issues involving large scale complex systems, such as architecture and uncertainty, at a higher level of <u>abstraction</u> than the above interdisciplinary fields

Why Engineering Systems?

"Today, many large-scale, extraordinarily complicated systems call out for a systems driven engineering approach. Just consider a few of these critical systems challenges:

- redesigning transportation systems such as airline, rail, and urban highway systems that have increasingly reached their capacity and created enormous delays;
- using information technologies to create products that are more timely, less expensive and increasingly responsive to consumer needs;
- reconciling the inevitable growth in world-wide energy demand with potential environmental costs;
- creating product development systems that address the full spectrum of conceiving, designing, and developing a new product; and
- developing manufacturing systems that are more attuned to the human impacts they generate, from wage attenuation and job losses to dislocations linked to globalization.

We believe that the converging forces of increased system complexity and the social impact of technology -- combined with a need for increased leadership by engineers -- create opportunities for new directions in engineering education and practice.

The most successful engineers must possess superb professional skills as engineers, including a keen understanding of social, regulatory, environmental, cultural, and other forces.

In short . . . we need Engineering Systems"

Thomas L. Magnanti – Dean of MIT School of Engineering

Engineering Systems Leaders

Engineering Systems
Implications for Engineering

- **Complex large-scale systems require leaders that understand technology**
- **Engineering leaders need broader understanding of organizations and context**
- **An opportunity for engineers in new leadership roles developing engineering systems**
- **The challenge for engineering schools – offer new engineering systems programs to *educate future leaders who can operate at the interface of technology and society****

* Dan Hastings – Co-Director, The MIT Engineering Systems Division

Aspirations for the Engineer of 2020

(National Academy of Engineering – The Engineer of 2020)

- **Our Image and the Profession**
  - **We aspire to engineers in 2020 who will remain *well grounded in the basics of mathematics and science*, and who will expand their vision of design through a *solid grounding in the humanities, social sciences, and economics*. Emphasis on the creative process will allow more effective leadership in the development and application of next-generation technologies to problems of the future.**
- **Engineering Without Boundaries**
  - **We aspire to an engineering profession that will rapidly embrace the potentialities offered by *creativity, invention, and cross-disciplinary fertilization* to create and accommodate new fields of endeavor, including those that require *openness to interdisciplinary efforts with non-engineering* disciplines such as science, social science, and business.**

The Need – LUMS SSE Website

- Pakistan continues to lose talent, while our industry remains technologically dependent and our universities remain intellectually barren. Almost exclusively, our industry manufactures products licensed from foreign companies. To be globally competitive, or even to survive, we need to start producing high-value-added products and services. **This requires scientists and engineers who are technically competent, innovative, entrepreneurial, have leadership qualities and broad problem solving skills.** **Our universities are not equipped for this responsibility. Their graduates are narrowly specialized and are unable to create knowledge at the boundary between multiple disciplines, increasingly the domain of true technological breakthroughs. Further, they have ineffective linkages with industry, an acute shortage of qualified faculty and no internal faculty pipeline to sustain academic or corporate entities. If we are to compete internationally or even survive, we need to produce a cadre of scientists and engineers who can not only develop technologies suitable for local conditions but also create entirely new economic and social opportunities for the country.**

Attributes of Engineers

Change agents

Knowledge handlers

Leadership

Lifelong Learners

Creativity

Anticipate the future

Enterprise enablers

Understanding the large context

Master integrators

Communication

Dynamism, Agility, Resilience, Flexibility

Flexibility to make course corrections

Strong Analytical Skills

Harm avoiders

Practical Ingenuity

Shift from one context to another with agility

Holistic designers

Entrepreneurial

Leadership Qualities

Astute makers

Innovative

Technology stewards

Tolerance for ambiguity

Broad Problem Solving Skills

Trusted inventors

Technically Competent

High Ethical Standards / Professionalism

Business & Management

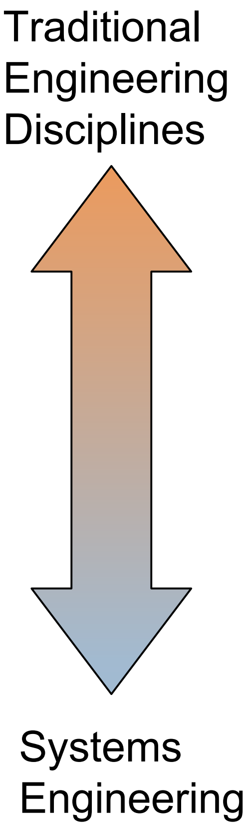
Key Attributes

LUMS: Attributes Required of Engineers

- **Technically Competent**
- **Innovative**
- **Entrepreneurial**
- **Leadership Qualities**
- **Broad Problem Solving Skills**

NAE: Attributes of Engineers in 2020

- **Strong Analytical Skills**
- **Practical Ingenuity**
- **Creativity**
- **Communication**
- **Business & Management**
- **Leadership**
- **High Ethical Standards / Professionalism**
- **Dynamism, Agility, Resilience, Flexibility**
- **Lifelong Learners**



Aspirations for the Engineer of 2020

(National Academy of Engineering – The Engineer of 2020)

- **Education of the Engineer of 2020**
  - **It is our aspiration that engineering educators and practicing engineers together undertake a proactive effort to prepare engineering education to *address the technology and societal challenges and opportunities for the future*. With appropriate thought and consideration, and using new strategic planning tools, we should *reconstitute engineering curricula* and related educational programs to prepare today's engineers for the careers of the future, with due recognition of the rapid pace of change in the world and its intrinsic lack of predictability.**

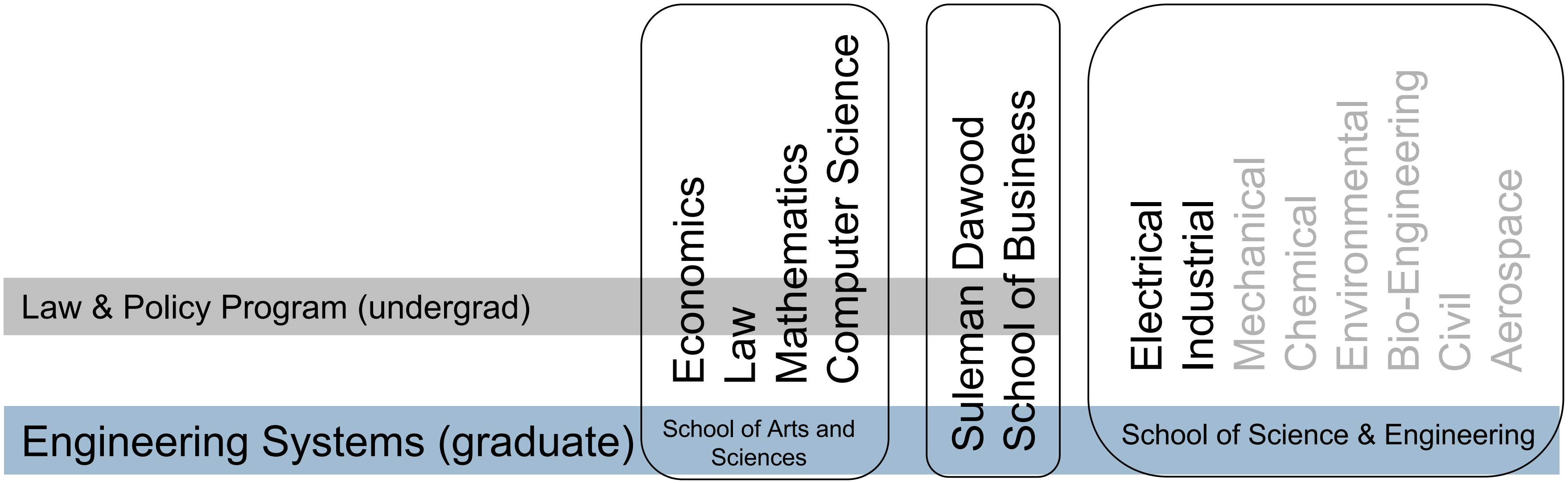
A Model of Systems Engineering Education

- **Engineering is broadening – leadership opportunities for engineering profession in engineering systems**

- **Pros:**
  - **Intellectual challenge**
  - **School of Management connection**
  - **Track record of successful implemented programs**
  - **Industry / government involvement**
- **Cons:**
  - **Too soft – not real engineering**
  - **Lacks intellectual content – not a discipline**
  - **Departments already doing systems – different systems perspectives**
  - **Use of scarce resources**

A Possible Inter-Disciplinary Model of Systems Engineering in LUMS

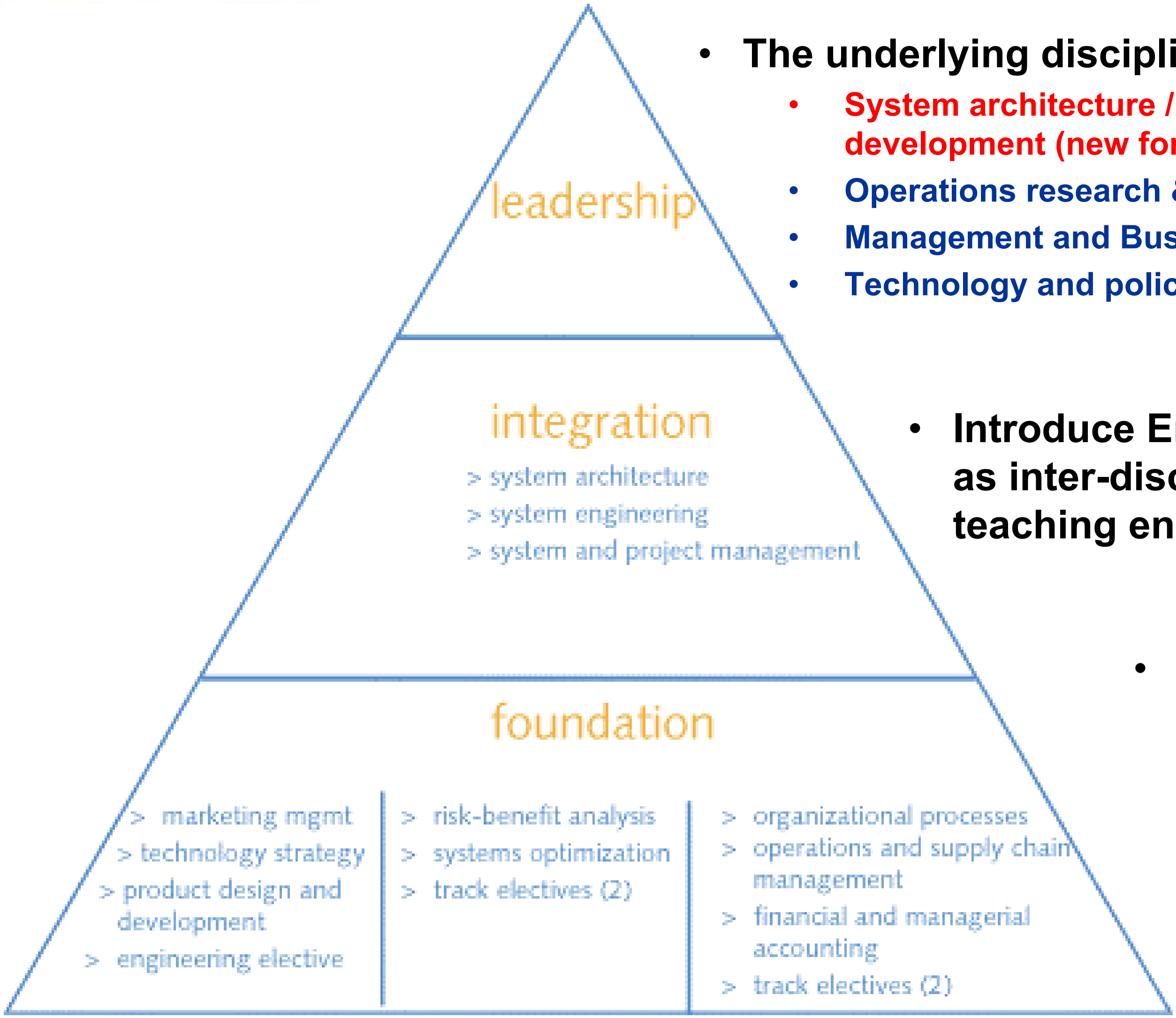
- **Educate future technical leaders, whether currently in industry or academia, to focus on theory and methods in architecting and designing complex products and systems**
  - ***The pre-requisite is technical / engineering depth***



- **Give them the leadership and management skills necessary to do that successfully across organizations**
  - ***The deliverable is management / policy breadth***

Curriculum Models

MIT Systems Design & Management / Engineering Systems Division



- **The underlying disciplines are**
  - **System architecture / system engineering and product development (new for LUMS)**
  - **Operations research & system analysis (exists in LUMS)**
  - **Management and Business Practices (exists in LUMS)**
  - **Technology and policy (partially exists in LUMS)**

- **Introduce Engineering Systems Studies as inter-disciplinary exercises for teaching engineering systems**

- **Combine traditional "case study" methods with technical models and data sets to teach students how to analyze and develop solutions for complex engineering systems**

Summary

- **Engineering Systems deal with diverse, complex, physical design problems that may include components from several engineering disciplines, as well as economics, public policy, and other sciences**

- **Inter-disciplinary programs spanning social sciences and management with foundations in systems engineering are needed to grow future Engineering Leaders**

Conclusion
(A Poem by A. R. Ammons)

don’t establish the
boundaries
first,
the squares, triangles,
boxes
of preconceived
possibility,
and then
pour
life into them, trimming
off left-over edges,
ending potential: