THE STATE OF GRADUATE SYSTEMS ENGINEERING EDUCATION

PRESENTATION TO INCOSE, CHESAPEAKE CHAPTER

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DISCLOSURE

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The views and recommendations offered in this presentation are solely those of the author and does not necessarily represent the views or policies of UMBC.

OUTLINE

- Current and Prospective Need for SE's
- What Employers Want
- Undergraduate Universities Favored By Employers vs. Top 10 Engr. Schools
- USN&WR Engineering School Assessment Methodology
- Profiles of the "Common Set" of Favored and Best Engr. Schools
- Some Observations
- Potential impediments to Professional SE Education
- Can We Overcome the Impediments?
- Some Schools Offering Professional Masters in SE
- Hoch's Folk Theorem
- A Reference Curriculum for a Professional Program in SE
- Attributes of a Model Program for the Future
- Selected References

CURRENT AND PROSPECTIVE NEED FOR SE's

- **DOD Imperative**
  - Levin –McCain Acquisition Reform Law
  - Significant Emphasis on Robust Systems Engineering in DoD Acquisition Reform Directive
  - DoD to Hire 20,000 Professionals by 2015 Starting With 4,100 by Oct. 1, 2009 (Skills Needed are Experienced Professional SE's, Logistics and Contracting Specialists and Program Mangers)
  - Challenging Environment (38% of Aerospace and Defense Workforce Over 50 and 17% Engineering Population Eligible to Retire by 2013)
- **NAS- USAF STUDIES BOARD 2008 REPORT**

  Pre-Milestone A and Early-Phase Systems Engineering: A Retrospective Review and Benefits for Future Air Force Acquisition , http://www.nap.edu/catalog/12065.html
  - A Common View Is That Better Systems Engineering (SE) Could Help Shorten The Time Required For Development, Making It More Like What It Was 30 Years Ago
  - Tailored SE Processes Are Critical But They Do Not Replace Domain Expertise -
  - SE Tools Assist Management of System Engineering – Not To Be Confused With the Practice of SE
  - Many Other Often Recognized Findings With Recommendations

CURRENT AND PROSPECTIVE NEED FOR SE's -2

- **AVIATION WEEK AND SPACE TECHNOLOGY , Aug. 24, 2009**
  - Aviation Week 2009 Aerospace and Defense (A&D) Workforce Study
  - 1990 Layoffs Fell Disproportionately on Younger A&D Professionals –Led to Demographic Gap of Mid-Career Professionals Needed to Fill Current Gap of Key Leadership
  - Competition Among Companies Causing 16% Attrition Among Employees With Less Than 5 Years Experience
  - Large Companies are Maintaining Internship Programs Through the Recession
  - Conflicting Picture: Three Year Forecasts Counter Warnings of Engineer Shortage – Forecast Show Hesitance to Hire Systems Engineers Due to Uncertain Development Contracts
  - A&D Companies are Hiring 3x as Many Contract Workers (relative to 5 Years Ago) to Address "Surge Requirements"
  - A&D Employee Retirement Eligibility Forecast to Rise to 20% by 2013

WHAT EMPLOYERS WANT
(SEE: AW&ST 8/24/2009)

TOP SKILLS REQUIRED BY A&D

- SYSTEMS ENGINEERS
- AEROSPACE ENGINEERS
- MECHANICAL ENGINEERS
- PROGRAMMING/ SW ENGINEERS
- PROGRAM MGMT

WHAT DRIVES THEIR HIRING

- CONTRACT AWARDS
- PROGRAM EXECUTION
- NEW MARKET ENTRY
- STRATEGIC R&D
- ATTRACTION OF WORLD CLASS TALENT/ATTRITION

U/G UNIVERSITIES FAVORED BY CORP. RECRUITERS COMPARED TO TOP 10 U/G ENGINEERING SCHOOLS FOR 2010 (SEE: AW&ST 8/24/2009 AND USW&NR)

WHERE COMPANIES PREFER TO RECRUIT

- Arizona State- Tempe
- RIT- Rochester
- Georgia Instit. of Tech.- Atlanta
- Purdue- West Lafayette
- Rose Hulman Instit. Of Tech. Terra Haute
- Iowa State- Ames
- Univ. of Central FL.- Orlando
- U. of Colorado- Boulder
- U. of Puerto Rico – Mayaguez
- U. of Texas – Austin
- U. of Arizona- Tucson
- USC- LA
- Cal Tech – Pasadena
- Auburn- Auburn
- Bowling Green- Bowling Green
- Cal Poly
- Central Washington U.
- Cornell, Drexel, Emb.-Riddle, UMCP

TOP TEN ENGINEERING SCHOOLS-2010

1. Cal Tech
   MIT
3. Stanford
   Georgia Instit. Of Tech.
   Purdue
   Univ. of Michigan
7. Univ. of Illinois-Urbana
8. Univ. Of Texas – Austin
9. Princeton
   UMCP

USW&NR ENGINEERING ASSESSMENT METHODOLOGY

- Peer Assessment Score (.25) ★
- Recruiter Assessment Score (.15) ★
- Mean GRE Quantitative Scores (.0675)
- Acceptance Rate (.0325)
- Student to Faculty Ratio (.1125) ★
- Percent of Faculty who are members of the National Academy of Engineering (.075)
- Doctoral Degrees Awarded (.0625)
- Total Research Expenditures (.15) ★
- Average Research Expenditures Per Faculty Member (.10) ★

Peer assessors include school deans, program directors and senior faculty ☺

None of the criteria is based upon educational outcomes. Some of these criteria for ranking are not especially useful for modeling a Professional Degree. Nevertheless, identification of the top ranked Institutions are useful, if only to permit focus for understanding their Programs and course content.

CLASSIFICATION OF SYSTEMS ENGINEERING DEGREE PROGRAMS

From: W. Fabrycky, " Understanding and Influencing Systems Engineering in Academia" INSIGHT (INCOSE), Vol. 10, Issue 3, July 2007

- **Systems Engineering Centric Programs**
  - Leading to a Bachelors or Higher Degree as a Distinct Category with a Discipline-Like Focus
  - The Designated Concentration in Systems Engineering is the Major Area of Study

    Number of Programs: BS- 11, MS- 27, PhD- 10 = 48 (from 31 Institutions)
- **Domain Centric Systems Engineering Programs**
  - Leading to a Bachelors or Higher Degree with a Major Indicating the Application of Systems Engineering to a Specific Domain

  SE with Biological Engineering: BS:16, MS:5, PhD:3 = 24

  SE with Computer Engineering:1 4 2 = 7

  SE with Electrical Engineering: MS:1 =1

  SE with Industrial Engineering: 14 15 7 =36

  SE with Management Engineering: MS: 3, PhD: 1 =4

  SE with Manufacturing Engineering 1 8 1 =10
- **Not All SE Programs are Organized and Administered by a Traditional Departmental Structure. You must Review and Assess the Programs Themselves to Understand their Characteristics and Focus**

CAL TECH PROFILE
(BASED UPON EE DEPARTMENT)

- Does Not Offer a Systems Engineering Curriculum Per Se
- EE Objectives: Train Creative Engineers Urgently Needed by Government and Industrial Labs
- Emphasize Systems: Closely Allied With Computation and Neural Systems; Applied Physics; Computer Science, and Control and Dynamical Systems
- Sixteen FTE Faculty; about 80 Graduate Students, Mostly in PhD. Program
- Masters Completed In 1 Yr., 5 Approved Courses in Each of Three Academic Terms
- Work Study Program: Completed in 2 Years
- Academic Courses Match Other Universities in Breadth and Depth
- An Academic Home for 3-5 Years

GEORGIA INSTITUTE OF TECHNOLOGY PROFILE (H.M. STEWART SCHOOL OF INDUSTRIAL AND SYSTEMS ENGINEERING- ISyE)

- Does Not Offer an SE Centric Curriculum
- Areas of Systems Emphasis (BS in IE): Manufacturing; Supply Chain Logistics; Economic Decision Analysis (Incorporating Financial Issues into Models; OR and Statistics (Optimization); Quality Engineering (think 6-Sigma)
- Masters In: IE, OR, Statistics, Health Systems, Quantitative and Computational Finance, and Science
- ISyE Objectives: Prepare Students, Alumni, Practitioners, Managers For The Practice Of Industrial And Systems Engineering For The Solution Of Engineering And Management Problems
- Sixty Tenure-Track Faculty; about 350 Graduate Students, 35% in PhD. Program
- Academic Courses Highly Theoretical Matching Areas of Stated Emphasis
- Masters Requires 30 hrs of Courses Specified as to Level

UNIVERSITY OF TEXAS- AUSTIN PROFILE (COCKRELL SCHOOL OF ENGINEERING)

- Does Not Offer a Systems Engineering Curriculum
- Areas of Nearest Specialization: Aerospace Engineering and Engineering Mechanics
- Masters and PhD In: Aerospace Engineering and Engineering Mechanics
- Objectives: Emphasis Is Placed On The Knowledge, Methods, And Skills Needed For Scholarly Teaching, Original Research And Problem Solving, Intellectual Leadership, Creative Expression, And Other Modes Of Achievement In The Student's Discipline
- Two Hundred Fifty Five (255) Tenure-Track Faculty; about 7200 Total Students
- Traditional Academic Courses in Matching Areas of Stated Specialization
- Masters Requires 30 hrs of Courses Specified as to Level and Specialization

UNIVERSITY OF MARYLAND COLLEGE PARK (CLARK SCHOOL OF ENGINEERING)

- Offers an SE Centric Curriculum Within the Institute for Systems Research (a Multi-College Graduate Program)
- Breadth Areas Covering: Topics in Systems Definition, Requirements, and Specifications, to Systems Design, Implementation, and Operation, in Addition to the Technical Management of Systems Projects. Students Specialize in Software, Computer, Information, Distributed, Control, Manufacturing, and Process Systems, or in Operations Research.
- Masters Degree: Masters of Science in Systems Engineering
- Objectives: Provide a Home to Cross Disciplinary Research and Education Programs in Systems Engineering and Sciences, and Committed to Developing Basic Solution Methodologies and Tools for Systems Problems in a Variety of Application Domains
- Two Hundred (200) Tenure-Track Faculty; about 4500 Total Students in Clark School
- Traditional Core Academic Courses in Matching Areas of Stated Breadth
- Masters Requires 30 hrs of Courses Specified as to Level and Specialization including Thesis

SOME OBSERVATIONS

- Five of the Top Ten Engineering Schools are Top for Recruiting Engineers (business needs differ from those of University Dean's and Senior Faculty)
- Notable academic SE Programs do not comport with traditional SE skill needs (Ex: UMCP does not have a Systems Architecture course)
- None of the Top Schools made any claims re: educational outcomes (most asserted their robust research programs)
- UMCP has an Industrial Affiliates Program (also, an attractive Patent portfolio available for license)
- Of the reviewed Top Schools, only GIT offers a declared (Professional) Masters degree in Systems Engineering
- None of the reviewed Top Schools offered a Certificate in SE

Key Point from Industry Representatives and Personal Experience:

Working professionals require flexibility of choice guided by preferences regarding work-life balance, career aspirations and employer need.

POTENTIAL IMPEDIMENTS TO PROFESSIONAL SE EDUCATION

- **Value of Measurement Criteria -- Graduate program evaluations are based largely upon academic accomplishments -- See USN&WR Criteria: total and per faculty research expenditures account for 25% of weighting**
- **Targeted Accreditation -- while undergraduate engineering programs are accredited based upon ABET (outcomes based), graduate programs are not required accreditation. Does INCOSE wish to step up to the need?**
- **University Internal Assessments -- how can we prevent bias toward academic measurements without balanced consideration to professional practice program criteria? Assessment criteria likely reflects the values and style of the institution vs. the needs of the profession**
- **Source of Educational Content -- who decides how the training of professionals shall be constituted? Academics vs. Technical Business Leaders vs. Professional Societies?**
- **Faculty Training and Relevance -- many SE Programs emphasize theoretical training based upon their full time faculty competence. This can cause tension between teaching Applied Science and Engineering Practice. See GIT profile.**

CAN WE OVERCOME THE IMPEDIMENTS?

- **Value of Measurement Criteria – We can't prevent a journal from engaging in ratings of Academic Institutions. But an engineering professional society has the obligation to respond to the consequences of distortion that confers quality status absent the imposition of professional value based criteria**
- **Targeted Accreditation – INCOSE needs to consider whether it is the society's responsibility to perform accreditation of SE Programs. The current policy position is one of *laissez-faire***
- **University Internal Assessments – We cannot control internal assessments**
- **Source of Educational Content – Isn't it time that Academic Institutions take seriously and act on the recommendations of a balanced Visiting Committee's? Balance implies industry and academic representation. Professional societies can and should perform assessments.**
- **Faculty Training and Relevance – Once again, it is in the interest of the profession to steer graduate professionals toward institutions that provide instructional currency and relevance in the training of professionals. There is a benefit to membership and the profession as a whole to establish clear criteria for quality, currency and relevance in educational content.**

SOME SCHOOLS OFFERING PROFESSIONAL MASTERS IN SE

- Univ. of Washington
- Penn State Univ.
- George Washington Univ.
- Univ. of California San Diego
- Univ. of Michigan (Energy Systems)
- Cornell Univ.
- UMBC
- Stevens Institute of Tech.
- Colorado State Univ.
- Johns Hopkins Univ.
- University of New South Wales
- Northeastern Univ. (Energy Systems)
- Rensselaer Polytechnic Institute
- University of Texas El Paso

There are additional noteworthy Institutions offering attractive programs

HOCH'S FOLK THEOREM

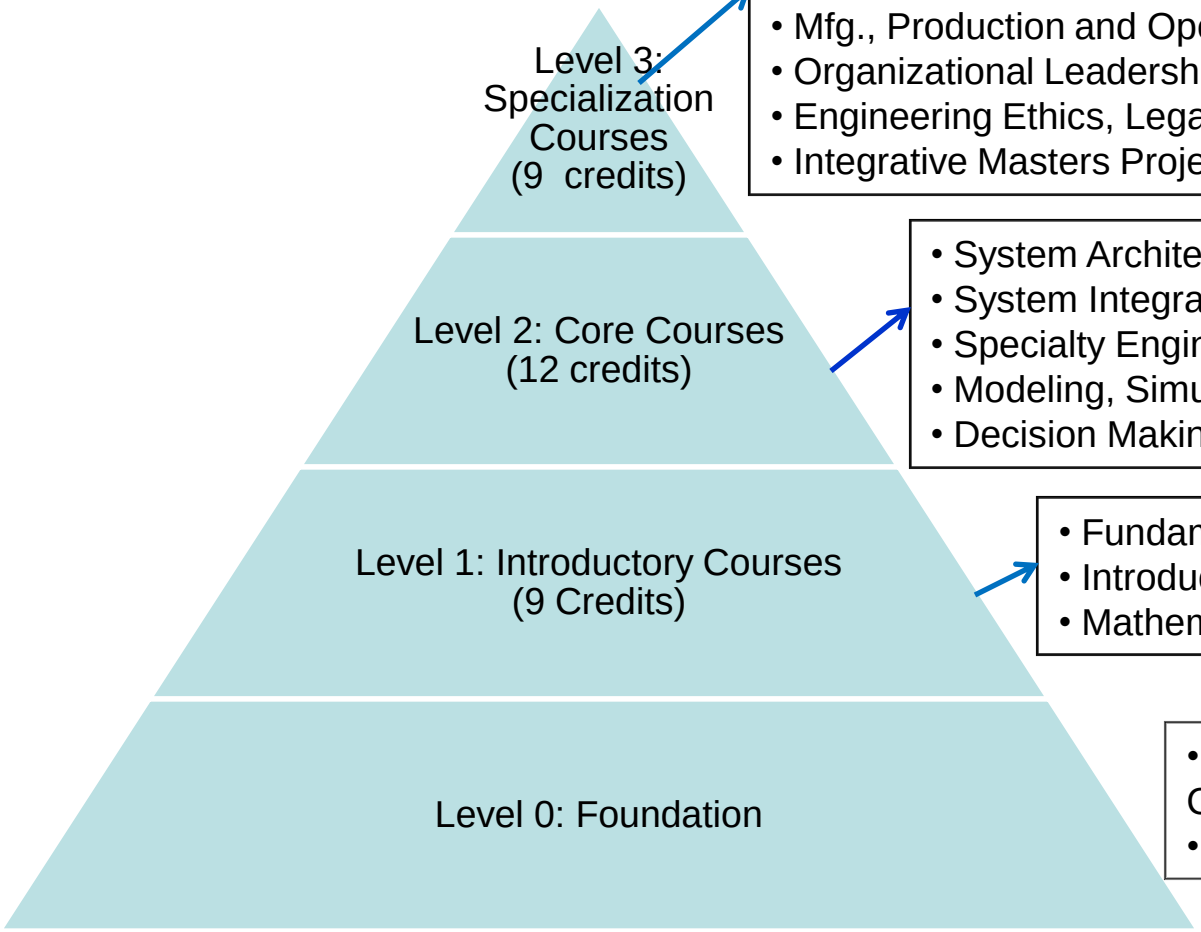
Theorem: A committed graduate engineer with a preparation in advanced calculus, probability and statistics and at least one area of technical specialization can combine a well selected (professional) graduate systems engineering curriculum and professional practice to accelerate professional development of an entry level SE by as much as 50%.

Lemma: It takes the combination of an enlightened employer and a collaborative, insightful academic institution to accomplish this.

Constraints: There are relatively few enlightened employers and fewer highly collaborative, insightful academic institutions in close geographic proximity.

A REFERENCE CURRICULUM FOR A PROFESSIONAL GRADUATE PROGRAM IN SYSTEMS ENGINEERING*

*** ADAPTED FROM JAIN, ET. AL., INCOSE INSIGHT JULY 2007**



- Software Systems Engineering
- Project/ Program Management
- Finance, Economics and Cost Estimation
- Mfg., Production and Operations
- Organizational Leadership
- Engineering Ethics, Legal and Contract Law
- Integrative Masters Project

- System Architecture/Model Based Design
- System Integration and Verification
- Specialty Engineering (RAM, Safety, Quality,..)
- Modeling, Simulation and Optimization
- Decision Making Under Risk and Uncertainty

- Fundamentals of Systems Engineering
- Introduction to SE Mgmt. and Governance
- Mathematics of Simulation and Optimization

- Linear Algebra and Multivariable Calculus
- Probability and Statistics

BEST CURRENT MATCH OF MODEL CURRICULUM TO SCHOOLS OFFERING PROFESSIONAL MASTERS IN SE

1. Stevens Institute of Technology
2. UMBC

Reasons:

Stevens created the School of Systems and Enterprises (SSE) with the mission to provide interdisciplinary and trans-disciplinary education and research rooted in systems thinking. They apply a "systems approach" to conceive novel concepts and solutions that achieve results across a wide range of domains, including : defense, homeland security, intelligence, nuclear weapons, communications, space, infrastructure, finance and business solutions. Stevens emphasizes technical systems, with attention to the interplay between these systems and the human enterprises that design and develop them, operate and use them, and sustain and maintain them. Research and education is grounded in a deep understanding of the state of practice in real-world applications and they are committed to transferring new knowledge that can be utilized by practitioners to enhance their effectiveness.

UMBC has a young, growing program without a research component within the Continuing and Professional Studies Organization with similar Objectives.

ATTRIBUTES OF A MODEL PROGRAM FOR THE FUTURE (WITH A TIP OF MY HAT TO STEVENS INSTITUTE))

- Eliminate the boundary between the academic setting and the industrial/ government reality in instruction and research approach – provide industry and government executable products, and
- Bring the industry and government reality into academia in a usable form -- meaningful problems and challenges, heuristics, and case studies
- Develop alliances with academic partners to create and leverage thought leadership and competencies for instructional and research initiatives motivated by the greatest benefit to students and sponsors
- Create integrative alliances to develop programs connecting Systems Engineering, Software Engineering, Engineering Management, the Intelligent Enterprise with Infrastructure underpinned by Financial Engineering discipline
- Establish a laboratory environment to evolve to a science of Systems with analytics, tools and measurement used in the pursuit of: Systems Architecture; Enterprise and Services Optimization; Systems and Enterprise Management; Systems and Software Engineering, Architecting and Testing.

SELECTED REFERENCES

1. ***Sheppard, et. al., Educating Engineers: Designing for the Future of the Field,*** **Carnegie/Jossey-Bass *(Winter 2008)***

   "ALTHOUGH ENGINEERING SCHOOLS AIM TO PREPARE STUDENTS FOR THE PROFESSION, THEY ARE HEAVILY INFLUENCED BY ACADEMIC TRADITIONS THAT DO NOT ALWAYS SUPPORT THE PROFESSION'S NEEDS"

2. ***Basken, P. , Why Engineering Schools Are Slow to Change , Chronicle of Higher Education, Jan. 2009***

   ***"*COLLEGES AREN'T SATISFYING EITHER STUDENTS OR EMPLOYERS WHO WANT A MORE RELEVANT CURRICULUM", L.J. Jacobs, Assoc. Dean, Georgia Instit. Of Technology**

TOP RATED GRADUATE ENGINEERING SCHOOLS (ELECTRICAL/ELECTRONICS/COMMUNICATIONS) (USN&WR 2010)

1. MIT
2. Stanford Univ.
3. Univ. Calif., Berkley
4. Georgia Institute of Technology
5. Univ. Of Illinois-Urbana-Champaign
6. Carnegie- Mellon
7. California Institute of Technology
   USC
9. Univ. of Michigan- Ann Arbor
10. University of Texas

- Schools that are tied, achieve the same score on the ranking model
- Surveys performed in 2009, published in 2010
- Peer assessors include school deans, program directors and senior faculty