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NAE Grand Challenges for Engineering in the 21st Century: Implications for industrial and systems engineering

Waldemar Karwowski[1], Hamid Parsaei[2]

[1]Department of Industrial Engineering & Management Systems, University of Central Florida, Orlando, 32816 Florida, USA
[2]Department of Mechanical Engineering, Texas A&M University at Qatar, 253 Texas A&M Engineering Building, Education City, PO Box 23874, Doha, Qatar

1. INTRODUCTION

On November 11, 2013 a Workshop was held at the University of Central Florida, Orlando, USA to discuss the implications of *NAE Grand Challenges for Engineering in the 21st Century* for industrial and systems engineering discipline with respect to research, education and practice. The attendees of this Workshop included the following researchers and scholars:

- Ben Amaba, Worldwide Executive, IBM Complex Systems – Rational,, Miami, Florida
- Tapas Das, Professor and Chair, Department of Industrial & Management Systems Engineering, University of South Florida
- Waldemar Karwowski (Co-Chair), Professor and Chair Department of Industrial Engineering & Management Systems, University of Central Florida
- Gino Lim, Associate Professor and Chair, Department of Industrial Engineering, University of Houston
- Rakesh Nagi, Professor and Chair, Department of Industrial and Systems Engineering, University of Buffalo
- Hamid Parsaei (Co-Chair), Professor and Associate Dean of Academic Affairs, Texas A&M University – Qatar
- Dylan Schmorrow, Chief Scientist, Soar Technologies, Inc., Michigan.

The main objectives of the Workshop were to define the most important issues facing undergraduate education and curriculum development in industrial and systems engineering, and identify critical areas of engineering challenges and opportunities for the industrial and systems engineering profession over the next 10–15 years.

2. OVERVIEW: NAE CHALLENGES AND OPPORTUNITIES FOR I&SE PROFESSION

In 2008, the National Academy of Engineering defined fourteen *Grand Challenges for Engineering in the 21st Century* (National Academy Press, 2008). These challenges were stated as follows:

1. Make solar energy affordable
2. Provide energy from fusion
3. Develop carbon sequestration methods
4. Manage the nitrogen cycle
5. Provide access to clean water
6. Restore and improve urban infrastructure
7. Advance health informatics

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8. Engineer better medicines
9. Reverse-engineer the brain
10. Prevent nuclear terror
11. Secure cyberspace
12. Enhance virtual reality
13. Advance personalized learning
14. Engineer the tools for scientific discovery

Furthermore, the NAE also created the *Grand Challenges Scholars Program* (2014) and the *Summit Series on the Grand Challenges* (2014) in order to develop the next generation of engineers and revolutionize the engineering education, namely:

1. Enhance student interest in engineering and science.
2. Increase the visibility and importance of engineering and science to society.
3. Underscore the importance of recognizing that engineering education must by coupled to policy, business and law and must be student-focused.
4. Enhance student interest in engineering, science and technology entrepreneurship.
5. Foment future collaborations of interested scientists, engineers, policy makers and researchers in business, law, social sciences and humanities needed to successfully address these complex societal issues.

The Workshop participants discussed which of the above stated grand challenges for engineering are currently addressed in the IE undergraduate curriculum. The potential knowledge deficits that need to be incorporated into future IE curricula were also identified.

3. INDUSTRIAL AND SYSTEMS KNOWLEDGE DOMAINS RELEVANT TO NAE GRAND CHALLENGES

A short term objective of the Workshop was to define and assess relevance of I/SE knowledge domain areas that need to be covered by undergraduate I/SE curriculum to address NAE Grand Challenges. This objective was stated as follows: *What knowledge should our graduating BS industrial/systems engineers have to address the NAE Grand Engineering Challenges?*

Table 1 presents a summary of the consensus reached by the Workshop participants regarding the knowledge domains that were considered as most relevant to the specific Grand Challenges, along with weights of their importance rated on a scale from 1 (lowest) and 5 (highest). In addition, this table identifies the most influential NAE Grand Challenges across the I/ES curriculum. These include: urban infrastructure (total score = 42), health informatics (total score = 38), tools of scientific discovery (total score = 38), and solar energy (total score = 35).

4. KNOWLEDGE DEFICITS AND GAPS IN I/SE CURRICULA

The Workshop participants also identified several knowledge gaps in current I/SE undergraduate curricula. These include additional knowledge needed to address grand engineering challenges in the following major categories:

- Human System Integration: Human in the loop simulation, virtual training and education
- Optimization and OR: A focus on 21st century challenges, complex systems, big data oriented operations research
- Statics/Design of Experiments/Analytics: Big data statistics, prediction modeling, tools for visualizing/manipulating big data, systems science and complex systems
- Quality and Reliability: Healthcare applications
- Manufacturing and Production: Nanomanufacturing (DM/DI), Smart factory of the future, Industry 4.0
- Economics and Management: Multi-criteria decision analysis
- Product Design & Functionality: Additive approach to design
- Computer Simulation: Human in the loop simulation, virtual training and education
- Information technology/systems: Engineering analytics course
- General education consideration: Experiential learning across curriculum.

Table 1. A Summary of I/SE Knowledge Domains Relevant to NAE Grand Challenges (consensus scores: 1-5: 5=most relevant).

I/SE DOMAIN AREA NAE CHALLENGES	HSI HSI HF/ E Safety	Supply chain/ Logistics	Optimization and OR	Stats/ design of exp Analytics	Quality & Reliability	Manufacturing and production	Economics and management	Product design, functionality	Computer simulation	Information technology and systems	SCORE
Solar energy		3	4	4	5	4	5	5		5	35
Energy from fusion	3	2	4		5	2	3				19
Carbon sequestration methods		5	5			2	3		3		18
Managing nitrogen cycle		5	5	5		3	4		3		25
Clean water	3	5	5	5		3	4	4	4		33
Urban infrastructure	3	5	5	5	3	2	5	5	5	4	42
Health Informatics	5		5	5	5		4	4	5	5	38
Better medicines	2		5	4	5	5		4	4	5	35
Reverse- engineer brain	4		4	5					5	5	26
Nuclear energy/terror	2				5				3	5	15
Cyber security	4		3	5	4		3	3	4	5	31
Virtual reality	5		4	4	2	3		5			20
Personal learning	4			5			3		4	4	23
Tools for scientific discovery	4		4	5	3	4	3	5	5	5	38
TOTAL	39	25	53	53	38	27	37	38	45	43	

5. ADDITIONAL ENGINEERING CHALLENGES

The long-term objective of the Workshop was to map future directions for I/SE discipline and profession over the next 15+ years. The Workshop participants identified four additional challenges and opportunities that are specific to the field of industrial and systems engineering. These include the following knowledge and application domains to be considered:

1. Smart digital factory
2. Carbon neutral manufacturing
3. Understanding complexity and complex adaptive systems (i.e. social network applications)
4. Bio-medical/tissue engineering

6. FUTURE PLANS

The Workshop participants have agreed to collect additional input data from other IE chairs and UG industrial engineering program directors, including identification of other current I/SE UG program deficits. In addition, it was agreed to seek feedback from a larger of I/SE community by organizing a follow-up international Workshop on this subject.

SELECTED READING

[1] Clough GW. *The Engineer Of 2020: Visions Of Engineering In The New Century*. Washington D.C. National Academy of Engineering; 2004.
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[3] Grand Challenges Scholars Program. National Academy of Engineers (NAE). 2014, website accessed in October 2014: http://universityinnovation.org/wiki/Grand_Challenges_Scholars_Program,_National_Academy_of_Engineers_(NAE)#Overview.