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TSDS as an Educational Tool for Non-S&H Majors

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Abstract

Chemical hazards and methods to relate these hazards to workers, managers, and designers have puzzled safety scientists for decades. In 1984, a major catastrophic event in Bhopal, India, caused a strong push for what is now known as the “Right-to-know” move. In that incident, a Union Carbide unit was a source for a significant release of a Methyl-Iso-Cyanate (MIC) cloud that resulted in around 3,000 fatalities, and over 80,000 mild to severe reactions due to the exposure. As a result, the Occupational Safety & Health Administration (OSHA) introduced the Hazard Communication (HAZCOM) as an emergency standard. Under that, then, new standard (29 CFR 1910.1200) OSHA mandated that all users of chemicals should maintain what is now called the Material Safety Data Sheets (MSDS). MSDSs gave workers and safety managers’ valuable information to deal with chemicals. Hence, MSDS became a valuable tool to a variety of personnel.

Like chemicals, man-machine interaction tools have become complex due to technological advances. Even with training aimed at satisfying compliance requirements, this complexity has increased the level of risk to which workers are being exposed. As a result, identification and assessment of associated hazards has also been increasing in complexity. In an attempt to manage these safety concerns, information sheets simulating MSDS were first introduced. These are called Technology Safety Data Sheets (TSDS). Their aim is to capture and relate a concise abstract of technical information and provides it in a user-friendly format to workers, technology, equipment, or processes designers, as well as safety manager.

If mandated, TSDS development can be taught at engineering schools to familiarize and educate non-safety professionals on safety issues at an early stage of their careers. These non-safety majors typically graduate without any knowledge or formal training in safety and health issues. If trained on the development of TSDS, these new engineers can set the stage for the understanding of safety and health concerns as they take on bigger and more important responsibilities.

Introduction

The manner by which we view technologies have changed dramatically in the past centuries. From the invention of the wheel to airplanes and space flights, engineers have been a crucial and integral part of these technologies. These inventions, while advanced the human race, it came at a price that has been paid in blood.

Speed of travel have changed from mere walking to horse pulled carts then to cars, and finally to the space shuttle that can travel at a speed of up to 17,500 miles per hour (NASA Archive, 2004). Weight limits of transportation have changed from a fraction of a ton pulled by a horse to thousands of tons being flown over large bodies of water. Transfer of information increased from a few words sent by pigeons to extended messages sent in an instant across email. Most of our day-to-day activities have now become more and more automated. People can now live 50 miles away from work and still make it on time every morning.

These technologies gave us time, speed, convenience, an enormous mass of production, and a lot of information. The past few decades, especially, saw technologies improve in leaps and bounds (Brauer, 2006). Computers have made our inventions much more useful, and a lot more frequent. This, however, took away our patience. People no longer have the patience to wait for a file to download at a speed of 56 KB/s, we want our downloaded material at the speed of light. This gave way for the invention of fiber optics. Other inventions came as a result of our impatience.

Inventions, while advanced the human race, it came at a price that has been paid in blood. This is partially because engineers and designers are being taught and trained to focus on the vision of a final outcome or approach, but not the process. It is not because of lack of ethics on behalf of engineers or designers, but because of lack on knowledge of essential safety and health information.

Causes of accidents are divided into three major categories: (a) unsafe acts of people; (b) unsafe physical or mechanical conditions; and (c) acts of God (floods, hurricanes, etc.). While accidents caused by unsafe acts of people are considered the majority of all accidents, 10% of all accidents are caused by unsafe conditions, while only 2% are considered acts of God (Heinrich, 1980). Unsafe conditions include:

1. Defective, inferior, or unsuitable tools, machinery, equipment, or materials.
2. Hazards of surroundings (poor housekeeping).
3. Hazardous methods or procedures.
4. Placement hazards (person not mentally or physically compatible with job requirements).
5. Inadequate guarding of machinery, equipment, work areas, etc.

Accidents caused by unsafe conditions are considered preventable if processes or equipment were designed and implemented probably. This falls on the designing engineer. In addition, failure to recognize these unsafe conditions also falls on engineers who lack the safety knowledge. Currently, there are a few people practicing safety in this country, only a small portion of them have an engineering background. Furthermore, a smaller group of engineers have any formal education in safety (Talty, 1985).

While this problem was widely recognized, there were few attempts by efforts by organizations such as the National Institute for Occupational Safety & Health (NIOSH). NIOSH, in 1980, developed a project called SHAPE for Safety and Health Awareness for Preventive Engineering (NIOSH). Other attempts were carried out by Universities around the country such as Ohio State University, Tufts University, Purdue University, Georgia Institute of Technology, however, these attempts were lacking due to the lack of interest of faculty and the already over crowding of engineering curricula. NIOSH has also attempted to contract with the American Society for Engineering Education (ASEE), the American Society of Mechanical Engineers (ASME), and the Accreditation Board for Engineering & Technology (ABET). Furthermore, they also attempted to contract authors of engineering books to add some safety material into their books, and engineering faculty to provide them with some level of safety backgrounds (Talty, 1985). While these efforts are commendable, their fruits are yet to be reaped.

We live in a civilized society where almost everything is governed by rules. To function in society, one must abide by these sets of rules. Where rules lack, codes and society expectations take over. However, we still fail to recognize root causes of certain problems. We continue to attempt to fix a given problem by promulgating and implementing more rules. However, in a profession such as engineering, providing safety should be an ethical issue. According to the fundamental canons of the code of ethics of professional engineers, engineers should "…*hold paramount the safety, health, and welfare of the public…*" (NSPE). While engineers strongly believe in this, they fall short of complying with safety rules due to lack of knowledge.

It wasn't until 1984 that OSHA focused its attention on chemical hazards. It took a major catastrophic event in Bhopal, India to start the push for the "Right-to-know" move. In this incident, a Union Carbide unit was a source for a significant release of a Methyl-Iso-Cyanate (MIC) cloud that resulted in around 3,000 fatalities, and over 80,000 mild to severe reactions due to the exposure. OSHA's resolve was to introduce the Hazard Communication (HAZCOM) standard (29 CFR 1910.1200). According to this standard, OSHA mandated that all users of chemicals should maintain what is now called the Material Safety Data Sheets (MSDS) (Akladios, et al, 2007).

OSHA defines MSDS as a tool to *"… provide comprehensive technical information, and serve as a reference document for exposed workers as well as health professionals providing services to those workers..."* (OSHA). These documents are produced by chemical manufacturers and importers to give workers and safety managers valuable information while handling these chemicals. Hence, MSDS became a valuable tool to a variety of personnel.

Information provided by a typical MSDS includes manufacturer information, hazardous ingredients, physical data, fire and explosion hazard data, health hazard data, reactivity (instability) data, spill or leak procedures, special protection information, and special precautions. Therefore, in order for MSDS users to understand the document, they would have had to have some training or education on other safety and health terms and limitations such as TLV's (Threshold Values that are provided by the American Conference for Governmental Industrial Hygienists-ACGIH), PEL's (Permissible Exposure Levels that are mandated by OSHA), LC50/LD50 (Lethal Dose/Lethal Concentrations that killed 50% of the animals tested in the lab), etc. Other terms and safety-related expressions such as Carcinogenic, Routes of Entry, Inhalation, Chemical Reactivity, PPE (Personal Protective Equipment and clothing), EPA regulations (Environmental Protection Agency as they relate to disposal procedures), Flammability, Flash Point, etc.

Likewise, a tool that teaches engineers and users about safety during the design phase is a must. But first, one must gauge the amount of knowledge and safety information that is being taught to undergraduate engineering students in our schools.

Method

To gauge the amount of safety information that engineers need to learn, we need to better understand what these engineers are being taught exactly. Therefore, curriculum from around the country is collected. Due to practicality reasons, a representative sample of curriculum from the top three colleges in the US offering the top five most popular (highly demanded) programs graduating the most number of students in these disciplines were considered using the following assumptions:

1. Demand for a particular type of engineers is indicated by the number of programs offering this type of education
2. Supply of engineers in a particular field is indicated by the number of students graduating with a BS degree in that field
3. Curriculum at top demanded and top supplied disciplines are representative to all other disciplines
4. The curriculum that is being taught at engineering schools in the US is an indication of what's being taught around the world
5. Curriculum from the top 3-5 colleges in the US offering a particular program of engineering is representative to all other programs within the same discipline around the country
6. Curriculum from the top 5 most popular disciplines of engineering is representative to all other programs within the same discipline around the country
7. Curriculum available online is a true representation of the actual topics discussed in these courses. In other words, if the curriculum of a particular course doesn't specifically indicate "Safety" or "Health", it is not assumed that these topics are handled or discussed
8. If curriculum from the above mentioned colleges indicates discussions of "Safety" or "Health" in a particular course, that these topics are not discussed anywhere else in other courses.
9. The top 5 colleges offering an undergraduate program in engineering (not specified by a particular field) in the county is also a true representation of the rest of the country. These colleges were picked based on the highest peer assessment score.
10. Computer engineering has low or no relationship to safety and health issues, hence, is not considered in this study

Findings and Results

The United States alone graduates a large number of engineers in close to 300 disciplines. Some of which are closely related to each other. According to the National Center for Education Statistics (NCES), in 2004, there were 1.4 million graduates in all fields, out of which 64,680 were engineers (4.6%) graduating with a BS degree (Table 1). There were seven disciplines that were most prominent (highest number of BS graduates). For the purpose of this study, only the top five disciplines will be considered. These are I. Electrical Engineering, II. Mechanical Engineering, III. Civil Engineering, IV. Chemical Engineering, and V. Industrial Engineering. These disciplines are responsible for graduating 84% of all engineers in the US.

Table 1: Number of Graduating Engineers in 2004

Discipline	Bachelor's Degrees
I. Electrical Engineering	21,374
II. Mechanical Engineering	14,342
III. Civil Engineering	9,400
IV. Chemical Engineering	5,185
V. Industrial Engineering	3,808
Total	**54,109**

Source: National Center for Education Statistics

Other statistics showing the number of engineers graduating with a doctorate degree, Master's degree, Associates degree, or professional certification roughly showed the same percentage (3.4%) of engineers (108,332) to the total graduating population in the US (3,200,812).

The Accreditation Board for Engineering and Technology (ABET) data showed that there is a total of 1,624 engineering programs in the US. The top five of these disciplines were I. Electrical Engineering, II. Mechanical Engineering, III. Civil Engineering, IV. Chemical Engineering, and V. Industrial Engineering (Table 2). These five had 985 programs, or 61% of all the engineering programs in the US.

Table 2: Number of Engineering Programs by Discipline

Type of Program	#
I. Electrical Engineering	259
II. Mechanical Engineering	249
III. Civil Engineering	211
IV. Chemical Engineering	149
V. Industrial/Manufacturing Engineering	117
Total	**985**

Source: Accreditation Board for Engineering and Technology

Statistical calculations showed that there is a positive correlation (r = 0.174) between number of students graduating with a BS in a particular discipline of engineering and the number programs offering these disciplines.

According to the U.S.News, the following colleges were ranked as the 2006 top three colleges in each of the top five most demanded and supplied fields of engineering. Curricula from these schools were studied for indications of teaching safety and health-related topics as follows:

I. Electrical/Electronic/Communications Engineering

1. Massachusetts Institute of Technology: None.
2. Stanford University: Only one word in the entire curriculum that is part of the ABET objectives under "Preparation for the Profession"
3. University of California, Berkeley: None.

II. Mechanical Engineering

1. Massachusetts Institute of Technology: : None.
2. Stanford University: None.
3. University of California, Berkeley: Safety was part of the following course:
    - Combustion Processes (as part of fire safety)

III. Civil Engineering

1. University of California, Berkeley: Safety was part of the following courses:
    - Transportation Facility Design
    - Design, Construction, Maintenance of Civil and Environmental Engineered Systems
    - Traffic Safety and Injury Control
    - Geotechnical Earthquake Engineering
2. University of Illinois, Urbana-Champaign: Safety was mentioned in the following courses:
    - Transportation Engineering
    - Probabilistic Loads and Design
3. Stanford University: Safety was part of the following courses:
    - Managing Sustainable Building Projects
    - Design for a Sustainable World
    - Structural Reliability
    - Design and Management of Construction Operations
    - Managing Engineering and Construction Companies

IV. Chemical Engineering

1. Rose-Hulman Institute of Technology: Safety was part of the following courses:
    - Safety, Health, and Loss Prevention
2. Cooper Union: None.
3. Rowan University: Safety was part of the following courses:
    - Chemical Process Component Design
    - Process Safety

- Principles of Bioseparation Processes

V. Industrial Engineering

1. Lehigh University: None.
2. Hofstra University: None.
3. Kettering University: Safety was part of the following course:
    - Work Design: Safety & Human Factors

In addition, to further determine the level of safety-related education to engineering disciplines in the US, the top 5 colleges with the "Best Undergraduate Engineering Programs" in 2007 (in all engineering disciplines at these Universities) were also considered (U.S. News, 2006). The following table indicates these schools and the safety-related education.

Table 3: 2007 Best Undergraduate Engineering Programs

Rank	**School**	**# of Under Graduate Safety-related courses**
1.	Harvey Mudd College (CA)	None
2.	Rose-Hulman Institute of Technology (IN)	-One mention of safety in the capstone for Biomedical & Mechanical Engineering Program (only handles safety in terms of ethics, and not knowledge) -One course in Chemical Engineering Program -No safety in Civil, Computer, or Electrical Engineering Programs
3.	Cooper Union (NY)	-No mention of safety in any of their Engineering programs
4.	United States Military Academy (NY): West Point	-1 credit seminar in Mechanical & Electrical Engineering Programs that may handle safety among other topics, and not as a separate topic
5.	United States Naval Academy (MD)	-Out of 5 engineering programs, only 1 (Electrical Engineering) has a project course with safety as a factor in design (Factor of Safety)

From the above list, in addition to others, only military schools had some curriculum related to safety in their "cap-stone" requirements (Jenkins, 2002).

Furthermore, while the Code of Ethics for Engineers and the Accreditation Board of Engineering & Technology (ABET) schools criteria for accreditation of engineering programs (2007-2008) includes safety and health as part of their objectives, it doesn't specify how these engineers should gain that knowledge about safety.

As part of its criteria objectives, ABET has the following sentence about Safety and Health:

- Engineering programs must demonstrate that their students attain an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, <u>*health and safety*</u>, manufacturability, and sustainability.

Most of the safety-related courses were found in Civil Engineering. A few had some in Chemical engineering. This is due in part to OSHA's Process Safety Management standards (29 CFR 1910.119). Other mention of safety came as part of the general cap stone projects, or part of ABET objectives, but not in the curriculum.

While Mechanical and Electrical Engineering schools are among the top engineering disciplines in terms of design, their curriculum had no or very little mention of safety. Similarly, Industrial Engineering curriculum also lacked safety except in Human Factors-related courses.

European universities have already started to integrate safety- and health-related material into their curriculum. This was done in collaboration with industry and college (Lemkowitz, 1992).

The Solution

Many attempts have been made to introduce safety- and health-related material to engineering students. These attempts included requiring an added course to engineering students, but the overcrowding of their curricula prevented that from happening. Another attempt was to add a safety and health course to the curriculum as an elective. However, according to Tufts University, only a few students were found to have taken the course. Finally, it was found that the best attempt was to inject safety and health as a topic into existing courses. This seemed to have had the best result (Rossignol, et al, 1990). A tool that can do this must include enough interest, yet simple enough to follow should be used.

Just like an MSDS, a similar analytical document attached to each technology should be mandated. These documents have been in development for emerging technologies and have been supported by the Department of Defense and the Department of Energy. These sheets are called the "Technology Safety Data Sheets" or TSDS.

A typical TSDS should include nice sections as follows (IUOE, 2002):

<u>SECTION 1</u>: TECHNOLOGY IDENTITY (Manufacturer's Name and Address, Emergency Contact, Information Contact, Date Prepared, and Prepared by, etc.)
<u>SECTION 2</u>: PROCESS DESCRIPTION
<u>SECTION 3</u>: TECHNOLOGY DIAGRAMS OR PICTURES
<u>SECTION 4</u>: CONTAMINANTS AND MEDIA
<u>SECTION 5</u>: ASSOCIATED SAFETY HAZARDS (this includes, A. ELECTRICAL--LOCKOUT/TAGOUT, B. FIRE AND EXPLOSION, C. CONFINED SPACE ENTRY, D. MECHANICAL HAZARDS, E. PRESSURE HAZARDS, F. TRIPPING AND FALLING, G. LADDERS AND PLATFORMS, H. MOVING VEHICLES, I. BURIED UTILITIES, DRUMS, AND TANKS, J. PROTRUDING OBJECTS, K. GAS CYLINDERS, L. TRENCHING AND EXCAVATIONS, M. OVERHEAD LIFTS, and N. OVERHEAD HAZARDS
<u>SECTION 6</u>: ASSOCIATED HEALTH HAZARDS. This includes, A. INHALATION HAZARD, B. SKIN ABSORPTION, C. HEAT STRESS, D. NOISE, E. NON-IONIZING RADIATION, F. IONIZING RADIATION, G. COLD STRESS, H. ERGONOMIC HAZARDS, and I. OTHER.

SECTION 7: PHASE ANALYSIS. This includes, A. CONSTRUCTION/START-UP, B. OPERATION, C. MAINTENANCE, and D. DECOMMISSIONING.

SECTION 8: HEALTH AND SAFETY PLAN REQUIRED ELEMENTS. This includes, A. AIR MONITORING, B. WORKER TRAINING, C. EMERGENCY RESPONSE, D. MEDICAL SURVEILLANCE, and E. INFORMATIONAL PROGRAM.

SECTION 9: COMMENTS AND SPECIAL CONSIDERATIONS

Other sections may be added to include:

1. Technology Description
2. System Operation
3. Safety & Health concerns
4. Job Hazard Analysis
5. Failure Mode and Effects Analysis
6. Emergency Response/Preparedness
7. Applicable Standards/Regulations
8. Applicable Training
9. Considerations and Recommendations
10. References

While OSHA's intention was to educate chemical users on the effects of overexposure, the resulting side benefit was to also educate them on all these other safety issues, hence expanding their horizons to think in terms of safety.

Likewise, engineers need to be educated in terms of technological safety with a resulting side benefit of expanding their horizons to understand other safety related facts. Other benefits include catching the unsafe design and making the necessary changes or adding the safety features during the design phase not after production where a recall may be necessary, or after a major accident has occurred.

TSDS is an excellent tool to utilize because of the following reasons (Lippy, 2001):

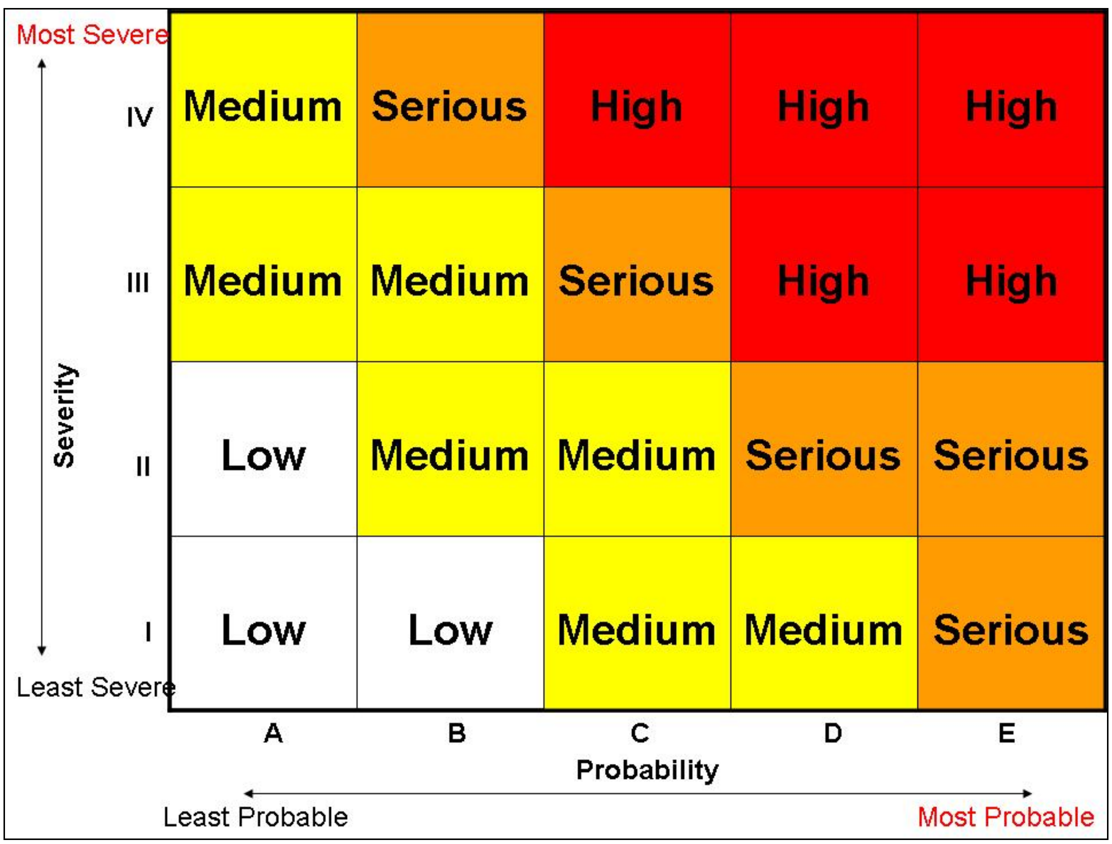
1. It uses multiple approaches to hazard identification which can reveal different hazards
2. TSDS is the most thorough and comprehensive format of identification, evaluation, and control of hazards in a single document. Therefore, not only it is of extreme value to the technology designer, but also, to the safety manager and the end user.
3. TSDS allows a quantitative risk value and hazard rating to be calculated based on Risk, which is the multiplication of the Probability into the Severity. This resulting Risk rating typically ranges from 0 – 4, with 0 being "No Hazard" and 4 being the highest level of hazard. The later is where there is a potential for imminent danger to life or health
4. Acts as a checklist for designers, engineers, safety professionals, workers, and other personnel on the different risks associated with the technology
5. Educates non-safety professionals on safety issues
6. Acts as a legal document that safety measures has been dealt with and accounted for
7. A vital element of fore-see-ability of risks, and the reasonable measures for mitigating these risks
8. Describes the responsibilities of each person coming in contact of a particular technology
9. Holds designers, engineers accountable for unsafe designs

10. Acts as a reference for users of similar technologies to follow

The latest addition to TSDS was conducted by the Indiana University of Pennsylvania in the form of hazard color-coding. This latest addition is an excellent enhancement since it directs the reader to focus on the most important hazards first. Less hazardous situations are also summarized on the same sheet, but are rather placed on secondary importance, as opposed to high-hazard situations.

This quantitative risk valuation and hazard rating is calculated based on Risk = Probability of occurrence (5 possible probabilities: A-Improbable, B-Remote, C-Occasional, D-Probable, and E-Frequent) X Severity (5 possible levels of severity: I-Negligible, II-Marginal, III-Critical, and IV-Catastrophic). The resulting four possible levels of Risk are Low (indicated by White), Medium (indicated by Yellow), Serious (indicated by Orange), and High, indicated by Red (Figure 1).

Figure 1: Color Coded Hazards by Severity and Probability



Source: IUP's TSDS for a Thermal Desorption technology

Recommendations

While engineering curricula is extremely condensed, injecting some level of safety- and health-related topics is a much needed task. The following topics should be taught to undergraduate engineers (Bryan, 1999):

- Where to find safety and health rules, regulations, and standards
- Employer and employee rights and responsibilities under the law
- Record keeping and reporting requirements
- Ergonomic considerations in equipment and job design
- Fire prevention and fire protection
- Mechanical and machine hazards and protection
- The hazards of working in a noisy environment
- Protecting workers from electrical hazards
- Dealing with chemical hazards, toxic materials and hazardous wastes
- The HAZCOM standards, 29 CFR 1910.1200
- Indoor air quality and “sick building syndrome”
- Bloodborne pathogens
- Confined space entry
- Responding to hazardous material emergencies and the community “right to know” requirements
- Managing safety programs
- Environmental protection requirements

Using the proposed tool, the TSDS, in a simple way to teach to engineers or at least given as a short class project will force them to research and learn the above mentioned topics just to be able to fill out the TSDS forms. This learning process may be conducted on their own as a research topic, or formally discussed in a class. It may also be taught by an online deliver method. This way, their exhaustive curriculum is not overburdened to make way for safety and health, yet they still capture the idea and the thought process of a safety professional.

In addition, engineering faculty administration should require their faculty to start to learn this tool and require them to teach it in their courses. Furthermore, ABET should consider adding this requirement as part of their accreditation procedures (Farwell, et al, 1995).

Conclusions

We don’t have to wait for a significant engineering-related disaster to mandate better safety education for engineers. Like MSDS is to chemicals, a tool needs to be implemented to educate technology designers and users of the potential hazards that these users maybe exposed to. During their undergraduate education, engineers need to learn these safety terms, and open their horizons to understanding safety in general.

A TSDS is a comprehensive hazard analysis tool that can be utilized at various stages of a technology, but most importantly, at the design phase. Engineering students in various disciplines must be taught the basics of analyzing a system or a technology in terms of safety using TSDS. Not only will this teach them design safely, but also will give them a broad range of knowledge and understanding of basic safety issues.

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