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THE TECHNOLOGY INTERFACE INTERNATIONAL JOURNAL EDITORS

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A COMPREHENSIVE AND OPEN FRAMEWORK FOR CLASSIFYING INCIDENTS INVOLVING CYBER-PHYSICAL SYSTEMS

Philip Weinsier, TIIJ Editor-in-Chief

Cyber Security! Kinetic Cyber-attacks! Cyber-physical Systems! Computer Worms! Unless you've been living under a rock, these terms will at least be familiar to you, and at most be involved in your livelihood. And while it's less likely that you'll be worrying about related problems for your own personal system, this is becoming a concern for the general safety of us all. But, before we can muster a viable response to cyber threats, or incidents, we first need to understand, identify, and develop a framework for classifying them, which is the topic of the featured article in this issue.

In 2010, the Stuxnet computer worm was introduced. It was designed to attack programmable logic controllers (PLCs) in industry. Early on, this particular worm affected mostly Indonesia, India, and Iran—where it affected more than half of the country's computers as well as its centrifuges for separating nuclear material. But there's more to it than just a worm, which simply executes the routines related to the payload of the attacking entity. There is also a linking file that automatically copies and disseminates the copies of the worm, and then the rootkit for hiding all malicious files and processes. But this is just one configuration; the diversity of the attacking entities is the reason why a framework is necessary so that a concerted war on kinetic cyber incidents can be developed.

The average cyber-attack involves, by implication, malicious actions to be inflicted on computer systems; some barely annoying, others catastrophic, but virtually all designed to cause the manipulation or destruction of electronic data. For the average person, this doesn't yet seem relevant or concerning. But consider that since the mid-1960s PLCs have all but taken over the automation of most industrial processes such as those used to control machinery on assembly lines. PLCs are part of the more comprehensive cyber-physical system (CPS), often referred to as embedded systems. Now consider the following physical entities controlled by cyber-physical systems: aerospace/avionics, automotive, civil infrastructure (smart structures), energy (electric power, water resources), healthcare (medical devices), manufacturing, transportation (traffic control and safety), environmental control, communication systems, robotics, military/defense systems, entertainment, even consumer appliances.

Kinetic cyber incidents are those that cause, directly or indirectly, physical damage to the computer or the machinery it controls. By extension, they can also cause injury or even death to humans. Thus far, it may be safe to say that such attacks have been statistically insignificant and out of the mainstream. Digging a little deeper, though, we find the utilization of supervisory control and data acquisition (SCADA) systems, which facilitate the management of remote access to station control devices (field devices) that control our national infrastructure through real-time data and operator-driven supervisory commands. As the authors of this featured article point out, the environments surrounding industrial control systems (ICS/SCADA) are known for being well-prepared for physical safety issues, such as fires or explosions. But the foresight typically stops at physical events caused by random hardware malfunction or failures, leaving the proverbial door ajar to cyber-attacks such as the following:

A 2007 experiment conducted by the Department of Homeland Security in which security researchers hacked into a replica of a power plant's control system and changed the operating cycle of the generator, which sent it out of control, resulting in catastrophic damage to the system. A 2008 announcement by security researchers at Harvard Medical School's Beth Israel Deaconess Medical Center in Boston, and others, that implantable cardioverter defibrillators (e.g., pacemakers) could be vulnerable to hacking.

The authors of this featured article suggest that the classification of incidents focus on the technology that is compromised in an incident and the application that is involved. Existing databases could be modified to record and classify CPS incidents but, of the ones reviewed, none were deemed suitable for adaptation, due to issues related to proprietary ownership, access being tied to paid subscriptions, and design scope. For example, the Repository of Industrial Security Incidents (RISI) is an industry-focused database of incidents, but cost thousands of dollars per year and does not take into account CPS utilization (e.g., communications or healthcare industries) outside of industrial control systems. The advantage of the system being proffered in this current article is that it allows for detailed analyses of the types, frequency, and impact of incidents, with significant contextual information.

Editorial Review Board Members

AUTOMATION OF A BIODIESEL REACTOR FOR THE PRODUCTION OF BIODIESEL FROM WVO USING A PLC AND A SMALL-SCALE CONTINUOUS ULTRASONIC PROCESSOR

Chase Malone, Tennessee Technological University; Matthew Holman, Tennessee Technological University;
Brian Katz, Tennessee Technological University; Ahmed ElSawy, Tennessee Technological University

Abstract

There is a need in the U.S. to decrease dependency on fossil fuels and reduce our carbon footprint. One alternative fuel that has gained much popularity in the past few years is biodiesel. Biodiesel can be produced using vegetable oil, waste vegetable oil (WVO), animal fat, and yellow grease as raw materials. However, the process of converting a batch of WVO into usable biodiesel is time consuming, requires a human operator to run the system, and necessitates the performance of a chemical titration for each batch of biodiesel produced. The ultimate goal of this research project was to design and produce an automated biodiesel processor to minimize the processing time and increase the biodiesel yield.

In the first phase of this project, an automated biodiesel processor was designed and built utilizing a programmable logic controller (PLC) in conjunction with pumps, valves, temperature sensors, etc. to minimize operator interaction. Also, a two-step processing method was used to eliminate the titration process. In the second phase of this project, a small Hielscher ultrasound continuous processing unit was integrated into the automated system to expedite the mixing and reaction processes. In this paper, the authors describe the system and demonstrate the design aspects of the automated biodiesel production processor using a PLC and ultrasonication (continuous processing) as well as how the chemical titration procedure for each batch is eliminated.

Introduction

With our desire to recycle and reuse solid waste, many people are looking for alternative ways to power vehicles and equipment using biofuel. One alternative fuel for diesel engines is biodiesel. The primary ingredient, waste vegetable oil (WVO) is available and inexpensive. However, the current processors available to produce batch biodiesel are time-consuming; they require an operator to run and monitor the system, and a chemical titration procedure for each batch to be produced. In order to reduce the processing time, a more advanced system is needed. Therefore, the main objective of this current project was to explore potential alternatives to the current biodiesel production methods, thus contributing to biodiesel commercialization. This main objective was to develop a small-scale, continuous biodiesel process through the reduction of operator interaction time, eliminating the titration process, moving the fluid throughout the system using solenoid valves and a PLC, using the ultrasonic reactor, and presenting the end-user with biodiesel upon completion of a full cycle.

Objectives

The ultimate goal of this project was to significantly increase the production capacity and product quality, while reducing cost and human interaction. Therefore, this project was divided into two phases:

a. In the first phase [1], an automated, continuous-flow system was designed that would limit operator interaction of depositing waste vegetable oil into the processor. The system had to automatically take care of moving fluids throughout the system, all chemical reactions, draining of waste glycerol byproduct, and, upon completion of a full cycle, the system had to present the operator with finished biodiesel that would meet ASTM standards.

b. In the second phase, a small Hielscher industrial ultrasonic continuous biodiesel processor (UIP500-500W) was integrated into the system. This technology creates nano-sized vacuum bubbles (i.e., cavitation) that help to overcome the cohesion and adhesion of the liquid being mixed [2]. This introduction of cavitation to the reaction process was intended to reduce the processing time from ~1-4 hours for batch processing to less than ~30 seconds. Also, it would reduce the separation time from ~10 hours to ~1 hour.

Biodiesel Chemistry

Biodiesel has several advantages: 1) being biodegradable; 2) being non-toxic; 3) having low emissions of carbon monoxide; 4) having a relatively high flash point (150°C), which makes it less volatile and safer to handle and transport than petro-diesel; and, 5) having good lubricating properties that can reduce engine wear and extend engine life [3]. Transesterification is the most common way to produce biodiesel. It is a catalyzed chemical reaction involving vegetable oil and an alcohol to yield fatty acid alkyl esters (i.e., biodiesel) and glycerol (see Figure 1).

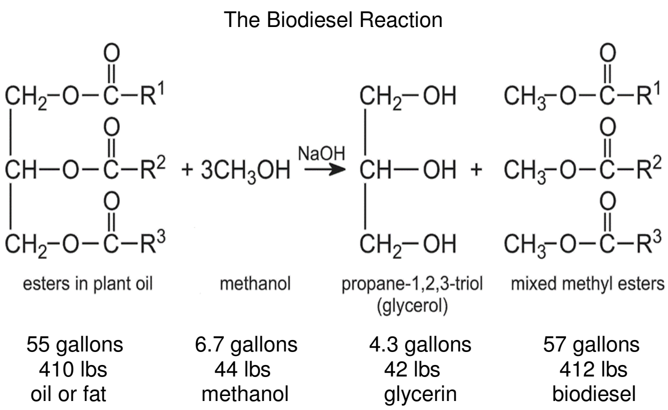

Figure 1. Schematic Representation of the Transesterification of Triglycerides (vegetable oil) with Methanol to Produce Fatty Acid Methyl Esters (biodiesel)

Triglycerides are the main component of vegetable oil and consist of three long-chain fatty acids esterified to a glycerol backbone. When the triglycerides react with methanol, the three fatty acid chains are released from the glycerol skeleton and combine with the alcohol to produce fatty acid methyl esters (biodiesel) and glycerol as the byproduct. R1, R2, and R3 represent alkyl groups present in the WVO and in which the carbon atoms are attached to each other in an unbranched chain. The catalyst is NaOH (lye). In general, a large excess of methanol is used to shift the equilibrium far to the right (see Figure 1).

WVO Filtration System

The system was designed to remove impurities from the WVO and moisture before future processing into biodiesel. It consisted of taking the heated, strained oil and pumping it through two filters. The first filter was a 15-micron water block that was designed remove water from the oil, while the second filter was a 10-micron filter that was designed to take out dirt and impurities from the oil (see Figure 2). This process was run twice in order to produce a better overall biodiesel.

Figure 2. WVO Filtration

Automated Biodiesel Processing Description

Elimination of the Titration Process

To fully automate the process, the first step was eliminating the titration process that was needed before transesterification. This is because each batch of oil has a slightly different composition. The titration process consists of taking a small sample of WVO and mixing it with lye, water, phenolphthalein solution, and alcohol to determine both the pH level of a sample from each batch of oil and the correct lye-to-methanol ratio required for a particular batch. The process itself is not that difficult, but it does require careful measurement and operator knowledge of the process. To eliminate this procedure, a certain volume of WVO, a given volume of CH_3OH (methanol), and a given weight of NaOH (lye) were combined to produce sodium methoxide, which was used for the transesterification reaction. Typically, when an operator performs the titration process on a batch, the batch requires between six and seven grams of lye per liter of oil [4]. If fully reacted using 6.7 gallons of methanol and a potassium hydroxide catalyst, 55 gallons of WVO will produce 4.3 gallons of glycerin and 57 gallons of pure biodiesel.

The transesterification process chosen for this project consisted of three steps to eliminate the titration from the process. It is because most oils have a similar composition that standard amounts of chemicals per volume of oil can be used (see Figure 1). Additionally, this method has the benefit of more completely reacting the oil with the sodium methoxide, thus producing more biodiesel than other methods. When the oil reacts all at once, it will reach an equilibrium stage at which point the reaction completely stops, even though more glycerin could be removed from the oil. Reacting the oil in two steps restarts the reaction at the second stage, allowing more glycerin to be split out of the waste vegetable oil. However, a drawback to this method is an increase in processing time. For this current project, this was acceptable, as the length of the process was not a critical factor.

Biodiesel Processor

Figure 3 illustrates the backside of the automated biodiesel processor. Before the actual reaction begins, it is important to preheat the WVO to reduce the viscosity and evaporate any water existing in the oil from cooking. The next step is to pre-filter the WVO in order to remove any food particles remaining in the oil so that the oil is clean and ready for the chemical reactions. To achieve this step, the WVO was poured through a series of progressively finer filtering screens. The finest filtering screen should be around 50 to 75 microns. After the pre-filtering stage, the oil is ready to be added to the 60-gallon tank for processing.

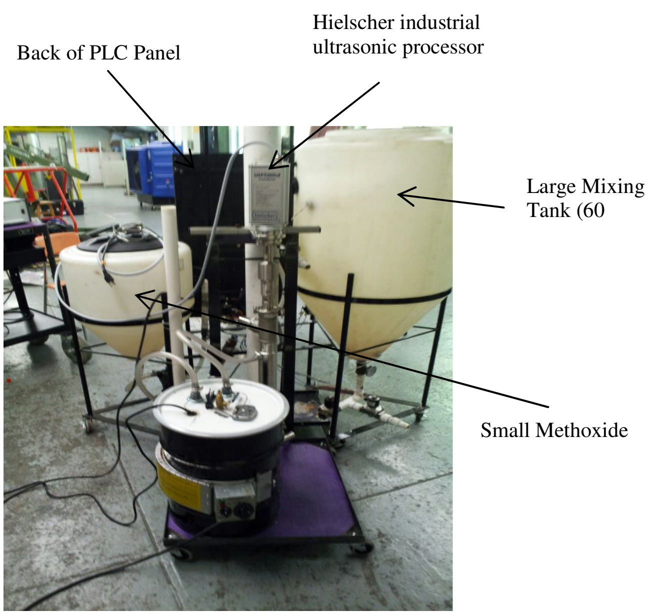

Figure 3. Modified Processor with Ultrasonictransducer (back of the processor with the ultrasonic unit assembled)

Ultrasonic Transducer for Mixing WVO

Mixing WVO is a lengthy process, as can be seen in prior research. A mixing aid was needed to alleviate some of this time and make it a more continuous process. The Hielscher industrial ultrasonic processor (UIP500-500 W) was used for this project. The ultrasonic transducer uses cavitation or nano-sized vacuum bubbles that locally produce high temperatures and extreme pressures when the cavity implodes on itself.

This creates jets of liquid that help to overcome the cohesion and adhesion of the WVO and sodium methoxide. This aids in the transesterification and allows for a better and more thorough reaction. Reaction rates can be examined by using a 27/3 test. This test shows how thoroughly the methanol and WVO have reacted with each other. It is done by mixing three parts biodiesel and 27 parts methanol. When mixed together, the solution should have a single-phase clear look, signifying a pass. However, if the solution is cloudy and has more than one phase, the biodiesel needs to be reacted again (see Figure 4). This test correlates well with the ASTM equivalent (ASTM D6584) [5].

Figure 4. A Passed 27/3 Test Using Ultrasonication (left) and a Failed Test using Conventional Stirring (right)

In the 20-gallon chemical tank, the methanol and lye were mixed to produce the sodium methoxide. This reaction is exothermic, which produces heat, and results in the formation of sodium methoxide. In the first step, the sodium methoxide was added to the WVO in two stages. First, the oil was reheated to between 118-126°F (120°F is optimum), and 80% of the sodium methoxide was added. The mixture was maintained at this temperature and mixed for one hour using a circulating pump and the ultrasonic transducer.

Biodiesel Filtration and Soap/Glycerol Removal

The mixture was then allowed to cool to room temperature for approximately two hours, during which time the glycerin separated and settled onto the bottom of the conical

60-gallon reactor tank where it could be drained off. In the second stage, the partially reacted biodiesel was re-heated to an average temperature of 120°F. The remaining 20% of the sodium methoxide was then added and allowed to circulate/mix for another hour and then cooled for another 12 hours before draining off any final glycerin that formed.

The final step in the biodiesel process was to remove any soap, water, methanol, and other contaminants from the biodiesel that were inadvertently created during the processing. Traditionally, a wet wash system is used for this process. It requires several wash cycles with water, and each cycle requires 12+ hours of settling/separation time. It is also common practice then to test the pH of the resulting biodiesel and add an acid, such as vinegar, as necessary in order to balance the biodiesel's pH level. Then the contaminated water must be properly disposed of, adding cost and time to the process.

In this project, a dry wash tower was designed specifically for this purpose. Initially, the cost was greater, but the return on investment will be much higher because biodiesel can be produced faster and the end-product will be of higher quality. Using a dry wash system with ion exchange media eliminated the step of having to balance the biodiesel pH by adding an acid. In this project, a two-step dry wash process with Purolite PD 206 filtering media [6] was planned. Before removing the biodiesel from the 60-gallon reactor, it had to be at, or very close to, room temperature. This is because the higher temperatures can damage the filtering media and accelerate the degradation of the PVC pipe. The biodiesel was pumped through the tower at a rate of seven gallons per hour. The plan was to have two dry wash filtration towers to ensure that the maximum amount of contaminants was removed in a shorter period of time. From the towers, the biodiesel was pumped into an airtight and sealed holding tank, where it would then be ready to use in virtually any diesel engine.

PLC Programming

The last step was writing a PLC program to control the two-phase process and incorporate the dry wash towers. The biodiesel processor used an Allen Bradley (AB) SLC-503 PLC controller. The AB SLC-503 PLC controller was selected because it is currently widely used in industry, has multiple input/output (I/O) capabilities, and is easy to program (see Figure 5). In addition, the PLC allows the operator to easily add a vast array of items to the process, such as flow meters, temperature gauges, timers, solenoid valves, and pumps. The processor works on an input/output basis for each action to occur. Once an input signal is received (a given temperature, elapsed time, etc.), the controller delivers an output signal (begin mixing, turn heater on, etc.).

Figure 5. The AB SLC-503 Controller

The PLC controller has 16 inputs (I:1/0-I:1/15) and 16 outputs split between two output cards (O:2/0-O:2/7 and O:3/0-O:3/7) (see Table 1). There are three buttons on the PLC panel: a green start button, a red stop button, and a black reset button. The red stop button can be pressed at any time to stop the processor. The reset button can also be used to stop the program, and it must be pressed after the stop button is pressed in order to reset the counters in the program.

The overall process happens in two phases. To start, the operator adds the desired amount of WVO oil into the larger 60-gallon tank. For the reactants, the operator measures out a volume of 22% methanol for the amount of oil and 6.25 grams of lye for every liter of oil used. During the first phase, the operator adds 80% of the measured reactants (the remaining 20% of lye should be kept in an airtight container until it is needed). The methanol and lye are added to the smaller 20-gallon tank.

The operator then presses the Start button on the PLC panel to open valve #1 on the small 20-gallon tank, valves #3 and #5 on the large tank, and turn on both pumps and the heater. Once the oil in the 60-gallon tank reaches 120°F (~49°C, via a thermometer attached to the tank), a 15-minute timer begins counting to ensure that all of the oil is thoroughly heated. After15 minutes, valve #2 on the small tank opens and begins pumping the sodium methoxide from the small tank into the 60-gallon reactor. Valve #1 closes five seconds later, while the large tank continues to circulate and stir the mixture. Once fluid level sensor #1 (located in the bottom of the small sodium methoxide tank) reads empty, a 5-second timer begins counting to ensure that the tank is empty before turning off pump #2. The ultrasonic transducer then runs for one hour, as the large tank is circulated.

Table 1. The Input/Output for the AB SLC-503 PLC

Inputs	
I:1/0	Thermostat
I:1/1	Fluid Level Sensor 1 (bottom of small tank)
I:1/2	Fluid Level Sensor 2 (top of large tank)
I:1/3	Fluid Level Sensor 3 (bottom of large tank)
I:1/4	Stop Button (red)
I:1/5	Start Button (green, bottom button) (NOTE: press to start 1st and 2nd phase)
I:1/6	Reset Button (black, middle button) (NOTE: press and release to stop processor)
Outputs	
O:2/0	Pump 2 (pump 2 for small tank.)
O:2/1	Valve 1 (for circulating small tank)
O:2/2	Valve 2 (for pumping contents of small tank into large tank)
O:2/3	Valve 3 (for circulating large tank)
O:2/4	Valve 4 (for final draining of biodiesel into dry wash towers)
O:2/5	Valve 5 (for circulating large tank)
O:2/6	Valve 6 (for glycerin draining)
O:2/7	Pump 1 (on large tank)
O:3/0	Ultrasonic (for mixing)
O:3/1	LED (signal ultrasonic on)
O:3/7	Heater (inline heater)

After one hour, both valves, the ultrasonic transducer and pump #1, shut off. A 1-hour timer then starts. After one hour, valve #6 automatically opens to drain the glycerin from the 60-gallon reactor. It closes when sensor #2, indicating fluid level, goes false (sensor #2 is on the top of the large 60-gallon reactor). The program now waits for the operator to add in the remaining 20% of the reactants and press the reset and then the start button. Once the start button is pressed, the processor carries out the same steps as in phase one.

Heating Large Quantities of WVO

Heat is required to speed up the chemical reaction and reduce the oil viscosity as well as remove the remaining water content from the oil. For this current system, an inline water heating element was plumbed into the circulation piping. The heating element was a standard inline water heater with 1500W of power and 120 AC voltage requirement. This heater was regulated by the thermometer sensor. This fit perfectly with the designed power scheme and PLC program.

Conclusions

The ultimate goal of this project was to design and produce an automated biodiesel processor to minimize the processing time and increase the biodiesel yield. This goal was successfully achieved in two phases. In the first phase, an automated processor was built and was capable of producing biodiesel with very limited operator interaction. The biodiesel produced was analyzed and met ASTM standards. It was used successfully in running an AMICO diesel engine AD 186FE. In the second phase, the results showed a great reduction in the reaction time to approximately one hour using ultrasonication compared with four hours by using traditional means. Also, the settling or separation time was reduced from 12 hours to less than two. Small batches were titrated and reacted by traditional means for comparison, and 27/3 tests were performed on both these and the ultrasonified fuel. The use of sonochemistry provided B100 of even greater quality with more yield quantities than all previous tests and by using less methoxide.

Acknowledgments

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Construction of a Recycled Brick Masonry Aggregate Concrete Test Pavement

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Abstract

Use of recycled aggregates in Portland cement concrete (PCC) can offer benefits associated with both economy and sustainability. Recycled brick masonry aggregate (RBMA) can be used as a 100% replacement for conventional coarse aggregate in concrete that exhibits acceptable mechanical properties for use in structural and pavement elements. Recycled brick masonry aggregate concrete (RBMAC) is currently not used in any type of construction in the U.S. However, its use could become a viable construction strategy, as the popularity of sustainable building practices increases. Although some researchers have studied RBMAC in the laboratory, minimal research on full-scale installations has been performed to evaluate the constructability concerns associated with its use, the performance of which is highly influenced by the relatively low unit weight and high absorption of the RBMA.

In this study, RBMA from a demolition site was used in RBMAC mixtures designed for use in a test pavement. The RBMAC test pavement, along with a control section of conventional PCC to facilitate performance comparison, was constructed within the access roadway of a local industry in order to allow researchers to identify and address construction concerns, and to evaluate both early age and long-term performance of RBMAC in a full-scale pavement installation. Due to the novelty of RBMA and the associated risk and expense related to its use in a traditional batch plant, mobile volumetric concrete mixing trucks were used to facilitate construction of the test pavement. In this paper, the authors present the challenges encountered during pre-construction and construction of the test pavement. Pre-construction challenges included handling, transporting, and stockpiling of the RBMA, as well as calibration of the truck in order to achieve the desired mixture proportions. Experience with placing and finishing the RBMAC and control PCC pavement is also presented, along with fresh property and early-age test results for both concrete mixtures.

Introduction and Background

The construction industry is currently facing a significant problem in the accumulation and management of construction and demolition (C&D) waste. According to the Environmental Protection Agency, conservation of landfill space, reduction of the environmental impact of producing new materials, and the reduction of overall project expenses can all be realized by recycling C&D waste [1]. Increasing costs and decreasing availability of landfill options to dispose of C&D waste has created an economic incentive to market recycled aggregate materials [2]. Additionally, a market for increased aggregate supply has been created by the long-term and continuously increasing demand for aggregate in many urban areas of the U.S. [3]. Incentives for use of recycled materials in building construction have been provided by several sustainable construction rating systems, including the Leadership in Energy and Environmental Design building rating system, Green Globes, and others. Ongoing efforts to promote sustainable construction practices in roadway construction include the development of similar rating systems, such as Greenroads and the Green Highways Partnership. The incentives for use of recycled materials in each of these sustainable construction-rating systems tend to change as performance requirements are continually enhanced, and the reader is encouraged to review the most current literature on individual rating systems for details on specific incentives.

The use of recycled concrete aggregate (RCA) in a variety of new construction applications including temporary roads, as a suitable fill material, and as a replacement of virgin concrete aggregates (fine and coarse), has been extensively studied in academia and successfully implemented in the field. However, using RBMA in new concrete construction has not been extensively researched, particularly in the U.S. When used in new concrete construction, the resulting mixture can be referred to as RBMAC. Through recycling demolished brick masonry rubble as aggregate in new construction applications such as pavements, the construction industry can divert brick rubble from landfills [4]. Several researchers have published findings relating to the use of recycled crushed brick as a base course material used in pavement applications [5-7]. As the widespread acceptance of recycled materials in new construction continues to grow, research and use of different types of recycled materials obtained from different sources progressively increases. Particularly in the U.S., the production and use of RBMAC could offer stakeholders in sustainable construction a new material that could be viable in a number of applications, including pavements.

Several impediments to the widespread use of recycled materials in new concrete construction exist, including intrinsic mechanical properties and external factors [3]. The source of each recycled aggregate is unique. Therefore, the variability of mechanical properties of recycled aggregates could present a challenge to the mixture designers [8], [9]. Characteristics of recycled aggregates that affect the quality of concrete have been identified as aggregate strength, shape and texture, absorption, and size and grading [10]. Physical and mechanical properties that must be accounted for when using recycled aggregates include a lower specific gravity, higher absorption, possibly reduced soundness (resistance to chemical and physical weathering), more variable gradation, contaminant solubility and the potential for groundwater contamination [11], particle shape (angularity) [3], and a higher porosity [12]. The presence of attached cement paste (mortar) contributes to a lower particle density, higher porosity, variation in the quality, and higher water absorption of recycled concrete aggregates [13]. Recycled aggregates can also be viewed as undesirable, due to the possibility of contaminants [14].

Since different processes are involved in the manufacture of brick, there is inherent variability in physical, mechanical, thermal, and chemical properties related to brick aggregates. The high absorption of recycled aggregates, including RBMA, can affect the workability of RCA concrete mixtures [4]. Without accommodating this additional absorption, RCA mixtures can be stiffer and can lose workability faster than conventional mixes. Other impediments affecting the widespread use of recycled aggregates in new concrete mixtures include lack of performance history [15] and availability of material in large quantities [9], [16]. External factors such as cost, state specifications, and environmental regulations can also limit the use of recycled aggregates [11]. In the U.S., impediments to the widespread use of recycled materials also include lack of standard specifications to provide guidance for use and the local regulatory environment [17].

RBMAC is currently not used in the U.S. for any type of construction. Testing performed as part of previous work [4], [16], [18] has indicated that pavement applications may be a viable use of RBMAC. In this study, RBMA from a demolition site was used in RBMAC mixtures designed for use in a test pavement. The RBMAC test pavement, along with a control section of conventional PCC to facilitate performance comparison, was constructed within the access roadway of a local industry in order to allow researchers to identify and address construction concerns and to evaluate both early age and long-term performance of RBMAC in a full-scale pavement installation. This approach allowed researchers to identify and address challenges to the use of this product associated with the procurement, production, and placement of RBMAC. Therefore, the viability of RBMAC for use in pavement applications was explored.

Design of Test Pavement

The RBMAC test pavement and control section of PCC were constructed at a crushing and grading facility in Charlotte, North Carolina. The planned dimensions of each pavement were approximately 60 ft (18.3 m) wide by 200 ft (61.0 m) long, although the as-constructed pavement was smaller, due to restrictions of the mobile volumetric concrete mixer (discussed later). Both pavement sections were constructed in a single travel lane, in line with the weigh scales that serve the crushing and grading facility. A photograph of the site prior to construction of the test pavement is shown in Figure 1. Prior to construction of the test pavement and control section, a deteriorated, undoweled jointed plain concrete pavement (JPCP) of varying thicknesses and composition was present at the site. The existing pavement was severely distressed, exhibiting extensive cracking and deflection at the joints. Moisture ingress into the subgrade has likely resulted in its substantial weakening. Additional information on this site is presented in another publication [19].

Figure 1. Overview of the Test Pavement Site

Many states, including North Carolina, have implemented the Mechanistic-Empirical Pavement Design Guide (M-EPDG) procedure for pavement design [20], now utilized in the commercially available AASHTOWare Pavement ME Design software. M-EPDG was determined to be a particularly useful tool for evaluating RBMAC pavements because of the level of detail that can be incorporated into M-EPDG design and analysis. Properties of RBMAC that differ from conventional PCC can be inputted into the software, allowing for the difference in predicted performance between these two types of concrete to be explored [19]. The M-EPDG process is an iterative approach to pavement design. The performance of trial pavement sections is compared to design performance criteria that are selected to “ensure that a pavement design will perform satisfactorily over its design life” [20]. Performance criteria for JPCP include joint faulting, transverse slab cracking, and smoothness. Threshold values for performance criteria are selected by agencies based on a number of considerations including pavement characteristics that trigger major rehabilitation efforts, impact safety, and require other maintenance. Characteristics of a trial pavement section are inputted into the software program, along with site conditions including climate, traffic, and subgrade characteristics. Pavement responses such as stresses, strains, and deflections are then computed over the design life, along with incremental damage. Cumulative damage over the design life of the pavement is compared to empirical performance data collected on existing pavement sections. The trial pavement section is evaluated based upon the reliability values specified by the pavement designer, which are based on the desired confidence levels. If the proposed design does not meet the desired performance criteria, it can be revised by the designer and the analysis rerun until an optimal design is identified [20].

The test pavement and the control pavement were designed using M-EPDG. A discussion of the inputs and threshold values for performance criteria used in the design of the RBMAC and conventional PCC pavements was presented in a previous publication [19]. A design life of 30 years was selected for the test pavement. Personnel at the site provided information to be used in the pavement design, including truck weights, axle configurations, and trip counts. Trucks entering the facility carry loads of demolition rubble headed to the crushing and grading operations. Trucks leaving the facility typically contain crushed, graded recycled aggregate material or are empty. Facility personnel indicated that the one-day maximum traffic loading experienced by the entrance drive, where the proposed test pavement was to be constructed, was 293 tri-axle trucks at approximately 78,060 lbs each. A growth rate of 2% per year was assumed. For the subject site, climatic data for the Charlotte-Douglas airport was downloaded from the M-EPDG website and utilized in the analysis. The depth to the water table was assumed to be 10 ft (3.05 m).

The North Carolina Department of Transportation (NCDOT) performance criteria for concrete pavements were used as limits and reliability levels for the international roughness index (IRI), transverse cracking, and mean joint faulting. Level 1 input values (site specific) were utilized wherever possible, including the input values for the RBMAC. Level 2 input values (correlated data) then Level 3 inputs (default values) were used when Level 1 input values were not available. When appropriate, the M-EPDG input values used by NCDOT [19] were used in the design. The M-EPDG input data used for the RBMAC test pavement, along with the reliability summary (output), are shown in a previous publication by Cavalline [19].

Testing indicated that RBMAC exhibits several properties that differ from those of conventional natural aggregate concrete, including unit weight and Poisson’s ratio [19]. Additionally, the thermal properties of RBMAC differ from those typically exhibited by concrete using natural coarse aggregates [19]. Therefore, the use of RBMAC in M-EPDG pavement design results in design thicknesses that differ slightly from those obtained using conventional concrete. A summary of M-EPDG inputs used for the RBMAC and conventional concrete pavements is shown in Table 1.

Table 1. M-EPDG Inputs for the RBMAC and Conventional Concrete Pavements

PCC input value	Value used for control section (PCC with natural aggregate)	Value used for RBMAC test section
Aggregate type	granite	rhyolite*
Unit weight (pcf)	150	130
Poisson’s ratio	0.20	0.18
Coefficient of thermal Expansion (in/in/°F)	5.6×10^{-6}	4.4×10^{-6}
Thermal conductivity (BTU/(hr•ft•°F))	1.25	0.533
Heat capacity (BTU/(ft•°F))	0.28	0.20

*Since brick is not an aggregate type listed in M-EPDG, rhyolite was selected due to its fine-grained structure (which was assumed to be most similar to brick).

The proposed RBMAC test pavement and the control pavement were designed using an unbound crushed stone base, 12 in. (0.305 m) thick, with an elastic modulus of 30,000 psi (206.8 MPa). Poisson’s ratio was specified as 0.35, with the coefficient of lateral pressure allowed to remain at the default value of 0.5. Based on information on the characteristics of the soils underlying the subject site obtained from the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service Web Soil Survey (WSS), the characteristics of an A-4 soil was used in the analysis. Based on experience with local soils, M-EPDG suggested values of resilient modulus that are quite high and could result in an unconservative pavement section, falsely indicating successful performance against the M-EPDG performance criteria. It was decided that a more conservative (lower) value of resilient modulus should be used in these designs. A resilient modulus of 6,000 psi was thus used for the subgrade resilient modulus input.

Based upon the input values and assumptions previously described, M-EPDG analyses indicated that the proposed RBMAC and the conventional PCC (control) pavement sections, summarized in Table 2, should perform satisfactorily over the 30-year design life [19]. Predicted reliabilities for both the RBMAC pavement and the control pavement are provided in previous publications [19]. It should be noted that the required thickness of the control pavement section, which was to be comprised of concrete with natural aggregates, needed to be slightly thicker than the RBMAC pavement in order to provide a similar reliability in M-EPDG distress modeling. However, for practical considerations, it was decided that both pavement sections would be constructed to the same thickness (10 in. or 254 mm) for constructability reasons.

Table 2. Pavement Layer Thicknesses Based on M-EPDG Analyses

Layer	Control pavement (PCC with natural aggregate)		RBMAC test pavement	
JPCP	PCC with locally available natural aggregate (granite)	10.5 in	RBMAC	9.25 in
Base	Crushed stone base	12 in	Crushed stone base	12 in
Subgrade	Subgrade soils, A-4, with 6,000 psi resilient modulus	Infinite	Subgrade soils, A-4, with 6,000 psi resilient modulus	Infinite

RBMAC and Control PCC Mixture Designs

Demolished brick masonry from a single demolition site was crushed and graded to create RBMA. Although the crushing and grading processes produced RBMA in several AASHTO M43 gradations (#4, #57, #78, and fines), the #57 material was used for this project. Physical properties, including the gradation, specific gravity, absorption, unit weight, and abrasion resistance were determined in order to compare RBMA to other conventional and recycled aggregates. A summary of the properties of the RBMA produced from the case study site is provided in Table 3, along with the values for a locally available natural granite coarse aggregate used in the control PCC pavement. NCDOT requirements for aggregates are outlined in a previous publication [19].

Table 3. Characterization of RBMA Produced from the Subject Demolition Site and a Locally Available Granite Coarse Aggregate used in the Control PCC Pavement

Property (Test Method)	RBMA	Locally available granite coarse aggregate
Gradation (ASTM C136)	AASHTO M43 #57	AASHTO M43 #57/#67 blend
Specific Gravity (ASTM C127)	2.46	2.62
Absorption (ASTM C127)	9.2%	0.5%
Unit Weight, rodded (ASTM C29)	68.6 pcf (1099 kg/m^3)	95.1 pcf (1523 kg/m^3)
Abrasion Resistance (ASTM C131)	38.4 %	36%

Four preliminary RBMAC mixtures were batched prior to identifying the RBMAC mixture to be used in the test pavement section. Each mixture was proportioned in accordance with ACI 211.2, Method 1: Weight Method [21]. This method was used due to the high absorption of the RBMA. After the baseline mixture FL.57.1 was proportioned, subsequent variations with different cement contents were developed, batched and tested. The volume of coarse aggregate and the water/cement (w/c) ratio were held constant between Mixtures FL.57.1, FL.57.2, and FL.57.3, as shown in Table 4. Mixture FL.57.1 contained the highest cement content, approximately 800 lbs per cubic yard, which corresponded to the cement content obtained using the ACI 211.2 procedure, resulting in a design with a 28-day compressive strength of 6,200 psi. Mixture FL.57.2 contained the lowest cement content, approximately 550 lbs per cubic yard. Mixture FL.57.3 represented the mid-point, containing approximately 675 lbs of cement per cubic yard. The target slump of each mixture was four inches, and the target air content (ASTM C173) was 5% to 7%. These targets were met for each of the trial mixtures.

To ensure the best odds of achieving the desired strength of pavement using the lowest cement content, Mixture FL.57.4 was designed in which the proportions of FL.57.2 were modified to reduce the w/c ratio from 0.38 to 0.35. The coarse aggregate and cement contents remained the same as Mixture FL.57.2, while the fine aggregate and water contents were modified to keep the total batch volume consistent. A summary of the mixture proportions are provided in Table 4.

Table 4. Preliminary RBMAC Mixture Proportions

	Mixture			
	FL.57.1	FL.57.2	FL.57.3	FL.57.4
Coarse Aggregate, RBMA (pcy)	1553.6	1553.6	1553.6	1553.6
Fine Aggregate, natural sand (pcy)	818.4	1132.1	984.9	1172.8
Cement (pcy)	802.9	550.8	675.0	550.8
Water (pcy)	305.1	209.3	256.5	192.8
w/c Ratio	0.38	0.38	0.38	0.35
High-Range Water Reducer (oz/cy)	10.4	7.3	9.7	7.3
Air Entraining Admixture (oz/cy)	7.8	7.8	9.0	7.8

FL.57.4 was selected as the RBMAC mixture design to be used in the test pavement. This mixture design exhibited desirable mechanical properties and provided the most economical concrete mixture, due to the low cement content. The mixture proportions are shown in Table 5, along with the associated fresh and hardened property test results. Also shown in Table 5 are the proportions used in the conventional concrete pavement section, which utilized a locally available natural coarse aggregate (AASHTO M43 #57 gradation). The contractor selected a previously utilized conventional mixture with proportions similar to the RBMAC section. One notable difference in the two mixtures was in the amount of sand utilized. This was due to the difference in volume occupied by the relatively light RBMA. It should be noted that due to the contractor's experience with the control PCC mixture, laboratory tests were not performed on this mixture prior to construction of the test pavement. Additionally, due to an oversight during construction, the same admixture dosages were utilized for both the RBMAC and control PCC pavement mixtures. However, fresh property tests indicated that acceptable workability and air contents were obtained, even though the same admixture dosages were inadvertently used for both mixtures.

Table 5. Final RBMAC and Control PCC Mixture Proportions and Laboratory Test Results

		Mixture	
		RBMAC Test Pavement	Control PCC Pavement
Mixture Components	Coarse Aggregate, RBMA or granite (pcy)	1554	1554
	Fine Aggregate, natural sand (pcy)	1173	1527
	Cement (pcy)	551	550
	Water (pcy)	192.8	208.5
	w/c Ratio	0.35	0.38
	High-Range Water Reducer (oz/cy)	17.8	17.8
	Air Entraining Admixture (oz/cy)	17.8	17.8
Laboratory Test Results	Slump	4.5 inches	---
	Entrained Air Content	5.5 %	---
	Compressive Strength (28-day)	5240 psi (36.1 MPa)	5000 psi*
	Modulus of Rupture (28-day)	212 psi (1.46 MPa)	---
	Modulus of Elasticity (28-day)	2,990,000 psi (20,615 MPa)	---
	Poisson's Ratio (28-day)	0.18	---

*Typical value obtained via testing of this mixture on other projects constructed using this mixture.
No pre-construction laboratory testing was performed on the PCC mixture.

Pre-Construction Considerations and Preparation

Due to the novelty of RBMA and the associated risk and expense related to its use in a traditional batch plant, two mobile volumetric concrete mixing trucks were used to mix and place the concrete for the pavements. A mobile volumetric batch truck (Figure 2) stores material in three hoppers (coarse aggregate, fine aggregate, and cement) and a water tank. Materials are delivered to the chute for mixing by a series of conveyors. Coarse and fine aggregates were delivered simultaneously to the mixing chute. The coarse and fine aggregate hoppers had individual conveyors to draw material through a screeding gate. The amount of each type of aggregate that was delivered to the chute was controlled using a gate setting (see Figure 3). Cement was introduced to the mixture of aggregates at a constant rate. The amount of water included in the concrete mixture was adjusted by the technician to ensure that the correct mixture proportion was delivered. Chemical admixtures were added into the mixing water in the correct proportions and introduced to the concrete mixture with the water.

Figure 2. Mobile Volumetric Concrete Mixer

RBMA has a lower unit weight than the locally available natural coarse aggregate. Therefore, it was necessary to calibrate the mobile volumetric concrete mixer prior to construction of the test pavement. In order to calibrate the truck, a load of RBMA was delivered to the contractor prior to placement of the test pavement concrete. The specific gravity and absorption of the RBMA was used to help the contractor calibrate the volumetric batch truck. A ratio of coarse-to-fine aggregate was used and the gate settings were determined by batching a known quantity of concrete in a given amount of time. The gate settings were adjusted until a calculated quantity was delivered in a given time.

Figure 3. Volumetric Batch Truck Gate Setting Controls

It was also necessary to calibrate the mobile volumetric concrete mixer to ensure that the proper dosage rates of the concrete admixtures were supplied in the mix water. Admixtures are typically dosed by adding a certain number of ounces of admixture per hundred pounds of cement, per manufacturer recommendations. The slump and entrained air content of the mixture was then tested to verify that a suitable dosage rate was utilized. To calibrate the mixer, the required dose of each admixture was added into a known volume of water. Using this type of volumetric mixing equipment, cement was introduced to the mixture at a constant rate. Therefore, the mix water was also dosed at a constant rate. Since the w/c ratio is a critical parameter, the mixing water was pumped through the system without introducing other components or verifying the flow rate over several iterations.

Once the fine and coarse aggregate gate settings that delivered the proper volumetric proportion of aggregates were identified and the water delivery and admixture dosage rates were calibrated, several trial batches of RBMAC mixtures were produced. A box of known volume (1/2 cubic yard) was used to contain the concrete. A gage located at the rear of the truck helped the operator determine the quantity of concrete that had been delivered. The gate settings were adjusted until the box of known volume and the quantity of concrete delivered (according to the gage) matched, completing the calibration process for volumetric mixing of the RBMAC using the mobile volumetric concrete mixer.

Construction of the Test Pavement

The existing concrete pavement was removed using a small excavator. The subgrade was excavated to a depth of

22 inches below the finished pavement surface, allowing installation of the 12 inches of compacted stone base and the 10 inches of concrete pavement. Prior to installation of the stone base material, soil samples were obtained and returned to the laboratory for testing. Laboratory testing indicated that the subgrade beneath the stone base material had a California Bearing Ratio (CBR) of approximately 2.2, which supports the decision made during design to use the relatively conservative resilient modulus of 6,000 psi.

Crushed stone base material meeting AASHTO M147 was installed to a thickness of 12 inches. Since the adjacent, existing pavement at the subject site was significantly distressed and joints were not doweled, a bituminous-treated fibrous joint filler material was utilized to isolate the new pavements from the surrounding pavement and from each other (see Figure 4). Wood formwork was installed between the RBMAC test section and the control section, and the bituminous-treated fibrous joint filler was also used to separate the two new pavements. The RBMAC test pavement was installed first, utilizing one of the two volumetric concrete mixer trucks. The conventional PCC control pavement was installed second, utilizing the second volumetric concrete mixer truck. Welded wire mesh (6 x 6 – W4.0/W4.0) was installed at mid-depth of each of the two pavement slabs. The surfaces of both pavements were screeded, floated, and received a broom finish (see Figure 5).

Figure 4. Compacted Stone Base, Formwork, and Isolation Joint Material

During placement of the RBMAC slab, issues related to conveyance of the aggregate material through the volumetric mixer truck were encountered. It was suspected that the lighter nature of the RBMA, along with the higher fines content, resulted in an excess of fine material clogging the conveyor belt. Although the RBMA stockpile was washed prior to use, it may not have been washed as thoroughly as typical washed stone. It is suggested that in the future use of RBMA, the aggregate be washed thoroughly using washing procedures typically utilized in preparing other aggregates. Workers tasked with placing and finishing the pavements reported that the RBMAC mixture was harsher than the conventional PCC mixture, and was more difficult to finish. However, a satisfactorily finished surface was achieved on both the RBMAC and conventional PCC pavements.

Figure 5. Finished RBMAC Test Pavement (foreground) and Conventional PCC Control Pavement (background)

Both the RBMAC and conventional PCC pavements were covered with plastic sheeting and allowed to cure for five days (see Figure 6), at which point the sheeting was removed as it exhibited distress from wind. The sheeting was removed, and the pavements were opened to traffic at an age of nine days, a point at which the owner needed to utilize these drive lanes.

Figure 6. Curing of the Finished RBMAC Test Pavement (foreground) and Conventional PCC Control Pavement (background)

Early-Age Test Results and Performance

Testing was performed in order to determine the fresh and hardened properties of the RBMAC and conventional concrete batched, respectively, for the test pavement and control pavement sections. Cylinder and beam specimens cast during placement of the test pavement were allowed to cure for 24 hours on-site, and then returned to the laboratory. Curing was performed in accordance with the methods prescribed in the testing standards listed below. A summary of these test results is presented in Table 6.

Table 6. Test Results for RBMAC and PCC used in Pavement Construction

	Mixture	
	RBMAC Test Pavement	Control PCC Pavement
Slump	3.5 in	5.5 in
Entrained Air	4.5%	6.5%
Yield	136.4 pcf (8.5 kg/m^3)	142.9 pcf (8.9 kg/m^3)
Compressive Strength (28-day)	5195 psi (35.8 MPa)	4200 psi (28.9 MPa)
Modulus of Rupture (28-day)	208 psi (1.4 MPa)	220 psi (1.5 MPa)
Modulus of Elasticity (28-day)	4,040,000 psi (27,854 MPa)	4,045,000 psi (27,887 MPa)
Poisson's Ratio (28-day)	0.20	0.19

It can be seen in Table 6 that the RBMAC and the control PCC exhibited similar fresh and hardened property test results. A key difference between the two is shown in the results for compressive strength. RBMAC had a stronger 28-day compressive strength by approximately 1,000 psi (6.9 MPa). Note that in addition to having a slightly lower w/c ratio, the RBMAC had less fine aggregate than the control concrete. The higher compressive strength of the RBMAC could possibly be attributed to the larger volume of RBMA coarse aggregate used in the RBMAC mixture. Whole brick obtained from the demolition material was tested in accordance with ASTM C67 to determine the compressive strength of 7,260 psi. Additional work is needed to determine the cause(s) of the difference in the observed compressive strengths, but the RBMAC's was likely higher, due to its slightly lower w/c ratio. The entrained air content of the RBMAC was also somewhat lower than the control PCC, which may influence future durability performance.

The test pavement was observed several times during early ages, typically weekly for the first two months in order to monitor the progression of early-age cracking, if it were to occur. Observations were performed using FHWA-recommended procedures during dry conditions and by bending at the waist. To date, no cracks have been observed on either pavement section. Ongoing work is being performed to monitor the performance of the pavement, which is still in service. This work includes removal of cores to evaluate strength gain and other mechanical properties, as well as durability performance. Ultimately, it is of interest to compare distresses observed in the RBMAC to distresses observed in the PCC over the service life of the pavement.

Conclusions

In this study, brick masonry demolition waste from a single site was successfully utilized to develop RBMAC mixture designs suitable for use in a pavement application. An RBMAC test pavement section, as well as a control section of conventional concrete, was constructed at a private industrial complex, and is currently serving up to 300 loaded tri-axle dump trucks per day. Construction challenges, including processing, handling, and staging of the material prior to construction of the test pavement were addressed. A mobile volumetric concrete mixer was shown to be a suitable method of constructing small-scale pavement installations incorporating recycled aggregates that require separate handling. The volumetric concrete mixer truck may also be suitable for similar recycled aggregate concrete construction applications that utilize novel materials in sustainable construction.

Early-age test results indicated that acceptable mechanical properties were achieved for both the RBMAC and control concrete. No early-age cracking was observed in either the test pavement or control pavement during visual surveys performed during the first 11 months of service. Although the test pavement constructed as part of this study was not instrumented, the successful performance of this test pavement has spurred interest in constructing a second, instrumented test pavement at a future time. An instrumentation plan was developed using industry standard technology for use in a future RBMAC pavement [19].

Since RBMA is produced from existing brick masonry construction, variability of material produced from different sources is a concern. This is, however, no different from the potential variability in RCA produced from different sources of waste concrete. Proponents of RCA implemented strategies that promoted understanding and control of the source material. These strategies typically include assessing potentially recyclable concrete for existing materials-related distress such as alkali-silica reaction (ASR) and the reuse of concrete in the same project being reconstructed [22]. Strategies for proper stockpile management also aid in ensuring consistency and minimal contamination [16, 22]. Research and field implementation has shown that, with proper evaluation of the source concrete, RCA concrete exhibiting acceptable performance can be produced. Similar strategies could also be utilized in RBMA production and transport to help ensure adequate performance of RBMAC. Ultimately, it will be the burden of the recycled aggregate supplier to demonstrate that their RBMA product meets the requirements of owners and/or state agencies. Additionally, more research demonstrating successful performance of RBMAC in both laboratory and field installations will be needed to provide agencies and owners a comfort level with this material [23].

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OPEN-SOURCE, MULTILEVEL, INTERACTIVE PROGRAMMABLE LOGIC CONTROLLER SOFTWARE DEVELOPMENT FOR HIGH SCHOOL STUDENTS, TWO- AND FOUR-YEAR COLLEGES, AND DISPLACED WORKERS

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Abstract

Two programs in Electrical Engineering Technology and Computer Science at Michigan Technological University collaborated in a joint effort to develop a set of open-source and online learning modules, which would give students interactive, hands-on experience with programming programmable logic controllers (PLCs) on a standard desktop or laptop computer. Faculty members from both departments led a group of undergraduate and graduate students from both units to effectively work on this joint effort. The three levels of the software were to be built so that future users could select the most appropriate version of the module based on their knowledge of the subject matter. It was to be flexible enough to get high school students interested in programming PLCs, to be used to train displaced workers seeking a certificate, to train technicians enrolled in two-year degree programs, or to teach more advanced concepts of PLC programming in four-year university programs. Each level of the learning modules included multimedia materials such as video, audio, and/or electronic documents, which provided an introduction to the content presented in the module. Upon completion of each level, students took the computerized comprehensive exam, testing all aspects of the introduced material.

The learning system hosted by Michigan Technological University was freely available for anybody around the world to use over the Internet. When the system was used in conjunction with a class, instructors were able to connect with their students and monitor their progress. Learner competency was tested by structuring some of the learning modules as games, where students could work collaboratively or competitively to solve PLC programming challenges. This three-year project devoted to the design and implementation of the software was in its first phase. In this paper, the authors present the preliminary techniques, approaches, and the overall project vision of the effective PLC learning/ gaming system development and implementation.

Introduction

With current advancements and reconfigurability of manufacturing, the programmable logic controller (PLC) has become an integral part of nearly all of today's industrial processes. A PLC is a digital computer used for automation of electromechanical processes and is designed for multiple input and output arrangements, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. There are several major PLC makers such as Allen Bradley (AB), Siemens, Modicon, ABB, Mitsubishi, GE, Omron, Bosch, Fuji, and Toshiba, but AB retains about 80% of the market share in the U.S. For the past 30 years, AB PLC solutions have significantly evolved from PLC-2 all the way to PLC 5000 series with several configurations in-between. The most up-to-date AB PLC has endless functionality, including programming using functional blocks, multitasking, and communication capabilities and, therefore, is the most widely employed by industry. It is also very common that PLC systems integrate with robotic solutions to enhance automation processes. As a result, the skills of newly employed industrial workers must include the knowledge of PLC and robotic systems, as well as how to integrate these two systems together in one efficient automated process suiting the requirements of the modern industrial environment.

In recent years, there have been significant changes in engineering education, especially in electrical and computer engineering education, both in terms of the content and its delivery. With the advent of computers, learning through computer-based environments has dramatically increased [1], [2]. The high demand for engineering professionals equipped with relevant and up-to-date PLC skills drives engineering education to develop an alternative to standard in-class instructional approaches. The traditional approach to teaching PLCs assumes that the training is to be done on actual equipment. Theory and exercises are integrated into a course to improve and perfect student skills. The conventional way of performing an experiment is to be physically present in the laboratory. Students work in groups of two to three in a laboratory and receive help from an instructor. While the traditional way of teaching PLCs is very effective, the disadvantages of traditional labs include the need for a qualified person/teacher, the demand for institutional space, time constraints on the students and on the institution, crowded classes, safety problems, recurring maintenance, etc. [2].

Because of resource limitations and the complexity and importance of the subject matter, there is a great need for instructional technologies and methodologies that can allow greater access to PLC educational resources and communicate complex concepts in ways that help engineering students learn more effectively and pique the interest of prospective students [3]. Web-based presentations of introductory PLC concepts are relatively easy to find [3-5]. There are also several websites that provide free PLC information such as book chapters, programs for download, and online Q&A [3], [6], [7]. Grand Valley State University has a free downloadable e-book [3], [8]. However, tutorials that provide opportunities for practice with feedback are harder to find, and tutorials that adapt practice and feedback to the needs of individual learners appear to be non-existent. Some websites provide ladder logic editors for free download [3], [9]; however, not all of these editors simulate program execution.

A notable non-web-based commercial software system is LogixPro—available at a low cost, provides a good PLC simulation environment, and comes with animations for various processes such as traffic control, batch mixing, and I/O configuration. This well-designed simulation software shows how a ladder logic diagram relates to an automated process [3], [10]. On the other hand, LogixPro does not provide fundamental knowledge such as Boolean algebra, digital gates, ladder notation, wiring, and syntax of individual instructions. Blakley and Irvine [11] reported the development of PLCSIM, a PLC simulator designed to assist in the teaching of ladder diagram programming, and PLCTUT, a multimedia teaching package that uses audio, video, and animations to teach about PLC hardware and programming [3]. The downside of PLCSIM is that it is tightly linked to a particular brand of PLC, the Toshiba EX20PLUS.

The Electrical Engineering Technology (EET) and Computer Science (CS) Departments at Michigan Tech are ready to take the challenge and collaborate with Bay Community College to develop a PLC curriculum to help solve the current shortage and future expected growth in control engineering professionals required to have relevant and up-to-date PLC skills within the state and beyond. This project will develop and implement the open-source, multi-level, interactive PLC software to be used in high schools, two- and four-year colleges, as well as to offer training of the displaced workers wishing to improve their knowledge and expertise in the subject matter and to meet the changing needs of industry. The authors will work with a faculty expert on PLCs and build three levels of the software so that students can select the most appropriate version of the module for their situation. For example, it will be flexible enough to be used to get high school students interested in programming PLCs, could be used to train displaced workers seeking a certificate or two-year degree, or be used in more advanced courses that are part of a four-year degree. Each level of the learning module will include multimedia materials including video, audio, and/or electronic documents, which will provide an introduction to the content presented in the module. This development will focus on implementation of AB PLCs, which are the most commonly used in industry. However, the basic skills that the students learn while completing the learning modules would be easily transferable to other systems.

University Overview

Michigan Technological University is a public university committed to providing a quality education in engineering, science, business, technology, communication, and forestry. In the fall of 2013, there was a total enrollment of 6,979 students, including 1,333 (19.1%) graduate students. Over 65% of Michigan Tech students are enrolled in engineering and technology programs [12]. The School of Technology [13] offers programs covering the entire spectrum of technology. The School of Technology awards bachelor's degrees in Computer Network & System Administration, Construction Management, Electrical Engineering Technology (EET), Mechanical Engineering Technology, and Surveying Engineering. The EET program [14] at Michigan Tech offers a Bachelor of Science in Electrical Engineering Technology. The EET program is application-oriented and focuses on preparing students for entry into the workforce upon graduation. Graduates of the program are electrical engineering technologists with career options in microcontroller applications, robotics, industrial automation, instrumentation, and control.

The Computer Science department [15] at Michigan Tech has had a long-standing reputation of outstanding educational programs enabling students to grow with and adapt to rapidly changing technologies. The diversity of courses offered includes computer science, computer systems science, software engineering, and support for computer-related degree programs across the Michigan Tech campus.

Open-Source Software Development Model

This project aimed to develop a free and open-source website that introduces students to PLCs and SCADA systems. Once complete, anyone interested in learning more about PLCs can learn from the course materials and then complete interactive problems and games. The aim of the website is to both attract the general public and be customizable by instructors wishing to use the website in conjunction with a course at a university or community college. For example, course instructors will be able to log in and customize which curriculum modules are available to the students, monitor the progress of their individual students through the course, and use the system in course labs, where students can cooperate or compete to quickly and accurately complete problems and modules.

Authors also plan to collect feedback about the course and make improvements. Since the idea is to make the software open-source, other institutions will be able to customize the software and convey the changes back to the original authors or create their own version of the website.

The software that powers the website will be developed by a team consisting of a faculty member, a graduate student, and multiple undergraduate students. This project will be a unique learning experience for the students working on the project. Students will learn how to budget time, respond to unforeseen obstacles, and how to satisfy the people who are using their product. The team will also gain experience using agile software development methods so that they can rapidly respond to changes and feedback. The multidisciplinary nature of the overall project involves giving computer science and engineering students the opportunity to work together.

There are many different tools which could be used to develop this web-based learning environment. One of the goals is to make the website flexible enough to run on a variety of computers without the need to install any software. Therefore, the software will be easy for schools to implement on any computer with a modern web browser. The software will be developed using the HTML5 standard recommended by the World Wide Web Consortium as well as JavaScript programming language.

To speed up the development process, the open-source libraries will be utilized. For simple web components like dialog, tab, button, drag-and-drop and widgets, the popular and well-documented jQuery library will be used. Using jsPlumb will provide the ability to connect web components with style lines. This capability is useful when drawing a logic diagram or using ladder logic to program a PLC.

The authors are currently working on the preliminary versions of the first two curriculum modules and are simultaneously developing the more complicated software necessary to implement a PLC simulator. The first two modules introduce students to binary/decimal conversion, logic gates, and truth tables. Some of the software and data structures necessary for the simulator have already been developed. For the simulator core, an adjacency matrix will store the ladder logic information with each cell representing a connection between two nodes. Each node will have a type (switch, relay, I/O, etc.), current state (open or closed), and function parameters (like the amount of time for a timer node).

While simulating the behavior of the ladder logic, the matrix will be updated row by row with an algorithm to simulate the behavior of the PLC. The rate at which the matrix is updated is adjustable to ensure that it results in realistic simulation results. When the simulator is complete, a PLC sandbox will be included, which will allow students to design and code different ladder logic programs. In addition, the students will be presented with a visual representation of the scenario (for example, a garage door opener) for better interaction with the system.

Husky Game Development Enterprise

Many of the students developing the software for this project will come from Husky Game Development (HGD) Enterprise [16]. HGD is a course at Michigan Tech that provides students with an environment that approximates a real-world game development studio. HGD differs significantly from traditional courses. In a typical traditional course, students attend lectures, participate in discussions, and independently complete well-defined assignments. In HGD, students self-organize into teams, develop a video game that they want to create, and then work together to create the video game over the course of two or more semesters.

HGD is managed both by the faculty advisor and five student managers that are elected by their peers or selected by the faculty advisor. Managers are responsible for evaluating the progress of teams, setting deadlines, developing content for lectures, pursuing industry sponsorships, and supporting previously released games. Although this project is not solely a game, Husky Game Development has motivated capable students to find creative ways to add gaming elements to the website that will engage people who use the website.

Three Levels of the PLC Educational Model

To fulfill the knowledge requirements for various layers of education, three levels of the PLC educational model will be developed in the course of this three-year project.
Level 1 (Beginner) will use a game-based approach to target high school students, summer camps, and summer youth programs with the goal of preparing high school students for college-level PLC courses. In this level, students will learn the basic concepts of digital logic and PLC programming using interactive and hands-on game-based approaches. After completing level one, students will have learned the basics of digital logic, Boolean algebra, and game-based basic PLC programming scenarios.

Level 2 (Intermediate) will target community college students, displaced workers, and industry representatives desiring to improve their skill sets. The main course will be devoted to learning the intermediate concepts of PLC programming based on industrial, manufacturing scenarios (pick and place, palletizing, etc.). This level will include several approaches such as Game-based + "Show Me, Guide Me, Test Me, Figure it Out". This level will begin with a short review of Level 1 material via gaming applications. The main course will be conducted utilizing a "Show Me, Guide Me, Test Me, Figure it Out" approach. During the "Show Me" stage, students will observe the demonstration of a learning objective utilizing predefined industrial processes involving PLC programming. During the Guide Me stage, students will be guided to interactively practice the skills learned in the demo of the Guide Me stage. The Test Me stage will be used to test the students' understanding of the learning objectives by having them work with the proposed simulator. After successful completion of the Test Me task, the Figure it Out mode will allow students to check their understanding of the learning objectives by working on an altered scenario which will be introduced in the scenario used during the Test Me stage, requiring the student to modify the PLC program to accommodate for the introduced changes.

Level 3 (Advanced) will target advanced community college students, four-year college students, displaced workers with a background in PLCs, and industry representatives with a background in PLCs desiring to advance their skill sets. Similar to the previous level, Level 3 will use a Show Me, Guide Me, Test Me, Figure it Out approach. At the beginning of the level, all of the material from the previous levels will be available to students to review. Unlike Level 2, this advanced level will cover Program Control Instructions, Data Manipulation Instructions, Math Instruction, Sequencer and Shift Register Instructions, PLC Installation Practices, Editing and Troubleshooting, Process Control, Network Systems, and SCADA.

Module-Development Approach

Scenarios, games, and quizzes are critical aspects of any web-based training program. These items being incorporated into the training solution provide reinforcement to lectures and create a virtual lab environment that can be accessed by geographically separated students. These features are to be integrated into each of the modules described in this paper for web-based training solutions with the goal of enhancing user experience. Included here is a detailed description of currently developed modules and an outline of the approach for the ones to be developed upon evolution of this project.

Module 1 focuses on the binary number system and memory. The interactive aspects of this module focus on teaching the user how to manipulate this number system. The first portion of this set of games helps the student become familiar with converting base ten numbers into base two, binary numbers. The game allows the student to input any four numbers into the program for conversion into binary. The program then checks that at least one number is greater than a pre-determined limit but less than 255. It also checks to be sure that there are no repeats or negative numbers. These checks ensure that the numbers selected are not too complicated or too easy for the student to convert. Once the four numbers are selected, the program moves on to the converting portions of the game. The basis of the conversion from decimal to binary is based on the "Dividing by Two" method. Here the student divides the number by two and records the quotient and the remainder. Next, the quotient is divided by two and, again, the new quotient and remainder are noted. This process continues until the student gets a quotient of zero with a remainder of one.

From there, the student puts the remainder values in the proper order to determine the binary number, adding additional zeroes to make an 8-bit number. When the student gets the correct answers, the process repeats for the remaining numbers. There was some discussion on the method used to teach the students how to convert decimal to binary. A popular method of conversion, especially in the computer science realm, is simply knowing the powers of two and how they go into a number. For individuals familiar with this method, the process of converting a decimal number to binary is quick. This issue is that it can be confusing for students not used to the idea of binary or who do not easily remember the powers of two. The "Dividing by Two" method only requires students to understand how to half numbers and understand when they get a remainder. Once the four numbers are converted, the game will take the converted binary numbers and put them into a randomly sized memory table. Here, the student is asked basic questions on generic memory in order to test his/her general understanding. Through the table, the student determines the size or the number of addresses required for the memory. The student is also asked how many bits, bytes, and words are in the memory. Once the memory portion of the game is completed, the student begins the final portion of module 1.

Here, the student converts the binary form of the selected numbers back into decimal. The general process for this part of the game is determining which powers of two are in the binary number and adding them together to determine the final value. The student starts off with the binary number laid out in a table then drags powers of two over the one's digits. Once the powers of two's are properly laid out, the program converts them into their decimal numbers and asks the student to add the values together and input the correct answers.

Module 2 is an interactive module consisting of two portions: "test your knowledge" and a "logic circuit simulator". The test-your-knowledge portion displays logic circuits to the student and then asks him/her to input the truth table. The circuits are ranked in difficulty and the overall difficulty will have a difficulty weight. The program randomly selects circuits from a pool of circuits and populates the quiz with the circuits selected. The difficulty weight keeps the program from selecting too many easy or hard circuits for the selected difficulty. The second portion of Module 2 is a logic circuit simulator. This simulator has two modes: problem solving and sandbox. In the problem-solving mode, the student has to construct logic circuits from a pre-determined toolbox in order to perform certain tasks. These tasks are determined by "user requirements", essentially word problems. The student has to interpret the description, wire the circuit, test it, and submit it for approval. If the circuit is correct, then the student moves on to the next problem. The sandbox mode allows the student to create logic circuits. This model encourages learning through experimentation. This also allows any instructor utilizing the program a basic program to perform a logic circuits lab.

Module 3 is an interactive module that revolves around the physical parts of the PLC and input/output devices that are typically used with PLCs. Students have to identify the various parts of a PLC, sensors, and output devices. There is also an assignment where the student has to select the proper device based on a description provided.

Module 4 introduces the virtual PLC system. Here the scenarios focus on programming in ladder logic. The module starts off by asking the student to build programs in ladder logic to mimic logic gates and circuits. Once the students have mastered converting logic circuits into ladder logic, they are asked to solve word problems. All of these problems focus on the "examine if open" input, "examine if closed" input, and general outputs. The students learn how to use branches and latch an output on. A very simple sandbox mode is implemented as well.

Future modules will focus on more advanced PLC topics. Concepts of timers and counters will be introduced. Students will learn about SCADA and how PLCs are integrated in an industrial environment. A fully functioning PLC simulator will eventually be added along with a virtual industrial work station and a basic water treatment control simulator. With all of these scenarios and quizzes, the program will provide feedback to both the student and the instructor utilizing the web-based learning module. The program will inform the user when they make incorrect choices in their design or answer a question incorrectly. It will provide hints if needed and eventually show the answer if the students cannot figure out how to fix their mistakes. Correct and incorrect answers, plus "show help" selections, can be sent back to a database for an instructor to review.

Conclusion

Academic programs at Michigan Tech are designed to prepare technical and/or management-oriented professionals for employment in industry, education, government, and business. The Electrical Engineering Technology (EET) and Computer Science (CS) Departments at Michigan Tech are collaborating with Bay Community College to develop a PLC curriculum to help solve the current shortage and future expected growth in control engineering professionals required to have relevant and up-to-date PLC skills within the state and beyond. This project aimed on developing and implementing an open-source, multi-level, interactive PLC software program for use in high schools, two- and four-year colleges, as well as for training displaced workers wishing to improve their knowledge and expertise in the subject matter and to meet the changing needs of industry.

The learning system will be hosted by Michigan Tech and made freely available for anybody around the world to use over the Internet. At Michigan Tech, the authors will integrate the materials into high school outreach programs and into PLC courses. Bay College and other interested instructors or students will be able to use the material independently or in conjunction with a class. When the system is used in conjunction with a class, instructors will be able to connect with their students and monitor their progress. Given the remote location of Michigan Tech, this online PLC education system is expected to reach a much larger audience. To make improvements to the current version of the developed software package, user feedback will be solicited.

Besides the benefits to the students who use the proposed PLC learning system, the project will also give undergraduate and graduate students hands-on experience working on a large-scale project with multiple people that span different disciplines. These hands-on experiences will encourage students to think about how they can use their own skills in an entrepreneurial way to improve the lives of others. Student competency will be enhanced by structuring some of the learning modules as games, where students can work collaboratively or competitively to solve PLC programming challenges. The software developers will use metrics such as the time it takes to solve a particular problem as well as the complexity or efficiency of their solution as game metrics.

This three-year project devoted to the design and implementation of the software is in its first phase. In this paper, the authors present the preliminary techniques, approaches, and overall project vision of the effective PLC learning/gaming system development and implementation, but more work is on the way.

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3D DESIGN PROCESS FOR MANUFACTURING AND ASSEMBLY: TABLE-TOP TOOLS FOR INCREMENTAL CONTINUOUS IMPROVEMENT (KAIZEN)

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Abstract

In this paper, the author proposes a design for manufacturing assemblies of washers, bolts, and nuts, which can be used to illustrate Kaizen as an incremental continuous improvement methodology. Kaizen accomplishes continuous improvement through waste elimination and cycle time minimization. In addition to a compact set of manufactured plastic steel assembly, the corresponding 3D models were generated in order to facilitate non-destructive testing. The suggested Design for Assembly was used as a prototype for several applications of Kaizen tools and techniques through multiple sizes of individual parts and multiple sequences of part arrangements. Incremental continuous improvement has been found as a value added in each step of the assembly process to minimize the cycle time and eliminate waste. In addition, substantial and significant improvements were noted on the final model of each manufactured assembly. Finally, the author demonstrates an incremental improvement in the assembly processing that explains the design process for manufacturing and assembly using 3D visualizations and renderings.

Introduction

In this paper, the author proposes a design for manufacturing assemblies of washers, bolts, and nuts, which can be used to illustrate Kaizen as an incremental continuous improvement methodology. Kaizen accomplishes continuous improvement through waste elimination and cycle time minimization. In addition to a compact set of manufactured plastic steel assembly, the corresponding 3D models were generated in order to facilitate non-destructive testing. The suggested Design for Assembly was used as a prototype for several applications of Kaizen tools and techniques through multiple sizes of individual parts and multiple sequences of part arrangements. Incremental continuous improvement has been found as a value added in each step of the assembly process to minimize the cycle time and eliminate waste. In addition, substantial and significant improvements were noted on the final model of each manufactured assembly. Finally, the author demonstrates an incremental improvement in the assembly processing that explains the design process for manufacturing and assembly using 3D visualizations and renderings. Design for Manufacturing and Assembly is an important technique used to validate incremental improvement through table-top assemblies of washers, bolts, and nuts, especially when the value added improvement is trivial and incremental to the work in process (WIP). Sturges et al. [1] defined design for manufacturability as "designing a product to be produced in the most efficient manner possible (in terms of cost, resources, and time) taking into consideration how the product will be processed, utilizing the existing skill base (and avoiding the learning curve) to achieve the highest yields possible".

Design for Manufacturing and Assembly is a very powerful tool that enhances manufacturing process design and control through Kaizen, which is a common word in Japan. Kaizen means change for the better. Change is deeply ingrained in the mind and behavior of humans and it fluctuates among three states: change for better, change for worse, and change for new paradigm. Leaders, managers, engineers, and workers do not always realize that the trivial changes they introduce could affect the manufacturing process for better or worse, until they face problems with the customers, who feel the propagated variation of trivial changes. In many industries, Kaizen practices are used to eliminate waste and involve employees at minimal cost. Moreover, Kaizen permits industries to manufacture products at low cost and with improved quality and quantity. It is a powerful weapon that helps sustain success in a competitive environment [2].

Research Purpose

This study focused on the impact of trivial design changes of the manufacturing procedure for assembling washers, bolts, and nuts by applying Kaizen. In addition, the author suggests a design for manufacturing washer, bolt, and nut assemblies, which is used to illustrate Kaizen as an incremental continuous improvement methodology through waste elimination and cycle time minimization.

Earlier Work

The earliest known and recognized manufacturing paradigm was product design specification, which involved changing the requirements of the customers into engineering specifications. Later, design engineers used the customer information to introduce new engineering changes. Design for Manufacturing and Assembly was developed before the Second World War, and was used by Chrysler and Ford as a rigorous methodology in their design and manufacturing process of military equipment such as tanks, carts, and weapons. Prior to the 1970s, Boothroyd et al. [3] developed a Design for Manufacturing and Assembly, where the product development was essentially done through the product design and/or the working prototype. After testing and approving the prototype, the manufacturing plan should be constructed along with the lists of required specifications, tools, manpower, methods, and materials.

Many Design for Manufacturing and Assembly paradigms are available. For example, the Lucas Design for Assembly divides the product design procedure into three steps: function analysis, handing analysis, and fitting analysis. This method has been integrated in the engineering analysis software "TeamSet" [3].

CyberCut is another paradigm, which relies on the knowledge-based planner to promote design for manufacturing [4]. The producibility measurement tool paradigm practices Producibility Assessment Worksheets, which are dependent on the familiarity and proficiency of the evaluators. Mathematical/numerical values are used to calculate the producibility factor for the constituent components of the process. The mean value of these provides an estimate of the probability of production success [3]. Gupta and Nau's [5] paradigm involves estimating manufacturing evaluation using a 2-step process:

1) Generation of all the possible features for the design element, wherein the feature elements correspond to a machining operation [5], and elimination of the non -machinable components/parts.

2) Creation of a feature-based model without redundancy.

After that, the same process is repeated. Eventually, the best plan is followed. The Genichi Taguchi paradigm is a statistical procedure intended for estimating the factorial design and experiment design in order to ascertain process unpredictability and to discover the optimal set of parameters or conditions in diverse manufacturing practices. The Taguchi Method is a very successful technique for manufacturing process stability and quality of their products. It is a well-established method for incremental continuous improvement (Kaizen).

Kaizen

The word Kaizen was coined in 1984 by Imai [6] in his book *Gemba Kaizen—A Common Sense Approach For Continues Improvement Strategy*. According to Imai, Kaizen is a continuous improvement process involving everyone, managers and workers alike. In general, Kaizen is typically defined as "a strategy that includes concepts, systems and tools within the larger picture of leadership involving and people culture, all driven by the customer" [7]. It is a comprehensive strategy that covers many continuous improvement techniques such as Poke-Yoke, lean manufacturing, cellular manufacturing, Kanban, total productive maintenance, six sigma, automation, just-in-time, suggestion system, and productivity improvement [8]. Among the very important goals of Kaizen is reducing cost, improving quality, and providing on-time delivery. It is true that Kaizen will generate more income, but without people there is no Kaizen, and without improving people's standards of work life, Kaizen is not sustained.

Methodology

Part One: Hands-On Design Manufacturing and Assembly

The authors designed the Washers, Bolts, and Nuts assembly to facilitate the application of Kaizen at the college of engineering at the University of Hail. Design for Manufacturing and Assembly includes not only assembling the geometric shape of the Washers, Bolts, and Nuts but also the entire tooling activity. Designing the assembly with different sizes of washers, bolts, and nuts requires knowledge about the tooling and materials involved. Since the assembly was designed with pre-knowledge of the downstream manufacturing process, the assembly team had to modify its practices based on the feedback provided by the manufacturing designer. The author designed the manufacturing assembly with robust planned variability in the size of each washer, bolt, and nut to furnish the floor for the following Kaizen measurements:

1. Assembly time improvement
2. Assembly process variability
3. Manufacturing accuracy
4. Value-stream mapping
5. Manufacturing flow
6. Human-factor effect
7. Waste recognition
8. Waste elimination
9. Production system simulation

Materials

The assembly consisted of the following materials:

1. 20x20x8 mm waterproof plastic junction box (see Figure 1)
2. 12x120 mm steel bolt x 24 pieces
3. 10x120 mm steel screw x 24 pieces
4. 8x120 mm steel screw x 24 pieces
5. 6x120 mm steel screw x 24 pieces
6. 6 mm steel nut x 2 kg
7. 8 mm steel nut x 2 kg
8. 10 mm steel nut x 2 kg
9. 12 mm steel nut x 2 kg
10. 6 mm steel washer x 2 kg
11. 8 mm steel washer x 2 kg
12. 10 mm steel washer x 2 kg
13. 12 mm steel washer x 2 kg
14. Multiple quantities of random-sized washers, bolts, and nuts (see Figure 2)
15. Adjustable wrench
16. Nose pliers
17. Drill
18. 12x12 cm marking square
19. Bits (6 mm, 8 mm, 10 mm, and 12 mm)

Figure 1. Waterproof Plastic Junction Box

Figure 2. Random-sized Washers, Bolts, and Nuts

Assembly Procedures

Each assembly consisted of one plastic junction box with one piece of each size of the bolts, nuts, and washers. The process of manufacturing the assembly had the following steps:

1. Marking the drilling points for each bolt using the 12x12 cm marking square.
2. Drilling the corners of the marked square with the appropriate bits starting with a 6 mm hole.
3. Continuing the drilling process clockwise, ascending to 12 mm hole (see Figure 3).

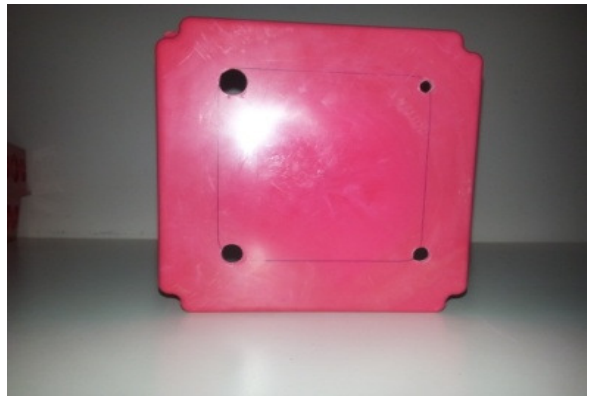


Figure 3. Junction Box Prototype

4. Basic assembly: attaching each bolt to the appropriate hole, as shown in Figure 4.

Figure 4. Basic Assembly

5. Installing the appropriate washer to each bolt.
6. Tightening each nut to the appropriate bolt.
7. Repeating the above steps to manufacture 24 units.

Kaizen Application

The authors developed a set of models to apply Kaizen basics and rules using the Washers, Bolts, and Nuts assembly. The main idea behind each model was to install extra washers and nuts to each unit, according to the instructions, procedures, and measurements of each model in order to perform the planned tasks and goals for that model. Each model mimicked of actual manufacturing processes and production paradigm such as push-pull system, lean manufacturing, visual workplace, inventory control, Poke-Yoke, 5S, etc. The authors designed the Kaizen models based on a teamwork role to achieve the following:

1. Standardize the tasks for each model
2. Identify the value added/non-value-added activities in each task
3. Allocate the bottleneck in sequential models
4. Determine the eight types of waste
5. Evaluate teamwork performance
6. Develop organizational skills
7. Create the culture of working smarter not harder
8. Set high standards to achieve near perfection

Part Two: 3D Design Visualization

Of late, visualization tools are being employed in a wide range of applications [9], [10]. Visualization has innumerable benefits, especially in the areas of design, assembly, and manufacturing. One crucial advantage of visualization in the area of manufacturing design is the ability for non-destructive testing. This refers to the ability to conceive industrial design, create the models in 3D, and then inspect the various aspects of the design and check them for criteria -satisfaction. This greatly reduces waste generation and is extremely time-saving. For instance, Figure 5 shows the rendering of the bottom-view of the model show in Figure 3. By using 3D visual scene renderings, manufacturing designers can identify desirable or undesirable elements within the design and make modifications before the actual implementation. Chandramouli and Bertoline [11] presented some of the important advantages of such VR visualizations. Table 1 highlights few salient features provided by VR settings.

Virtual Environments with Interactive Capabilities

Interactive capabilities are very desirable in virtual environments as they enable the user to interact with the scene components. This can also be useful in the case of teaching manufacturing design process to students via simulation. Such features allow students to visualize a pre-recorded simulation and, with the ability to interact, they can use the tools to gain more experience working with them. The EAI (External Authoring Interface) serves as a channel to access the nodes making up the scene elements in a virtual scene. Typically, a VRML-based virtual environment is constructed using scene elements that can be structured as nodes representing the basic shapes that make up the whole scene. Interaction, at the core, involves a change in the state of the scene objects. Two important functionalities used in this study, from a design perspective, included sensors and EAI. Sensors refer to the ability of a virtual environment to sense and respond to user actions. Using sensors like visibility sensors, touch sensors, etc. the objects in the scene can be programmed with these sensing elements to respond to user events like holding, dragging, etc.

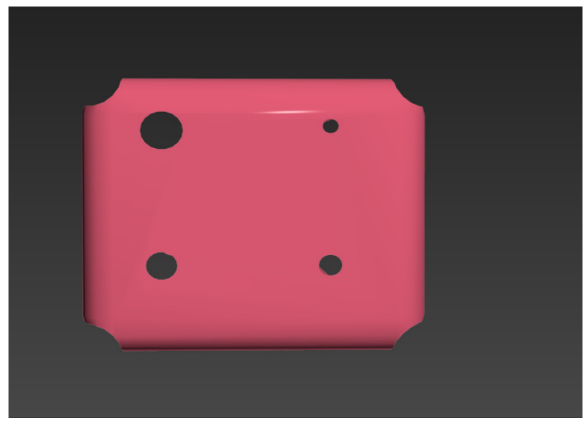


Figure 5. 3D Model Rendering of Junction Box Prototype

Table 1. Important Advantages of the VR Scene Visualization

Feature	Description of the advantages.
Point of View (POV)	The scene can be evaluated from innumerable points of view.
Levels of Detail (LOD)	The same scene can be created and viewed using varying levels of detail.
Navigation	Different browser/plug-in combinations offer various methods of navigation such as study, flying, and walk-through.
Controlling Scene Attributes	The scene attributes and the attributes of the VR scene objects such as geometry and appearance can be controlled in multiple ways.

Figure 6 shows the virtual elements such as bolts, nuts, and washers, which can be selected, grabbed, and moved to new locations. These can be re-positioned, rotated, and even scaled (larger or smaller). This is also useful in aesthetics, where users can try to map different textures and materials to these objects. Various shades of metals and paints can be applied to these objects before finalizing the manufacturing design.

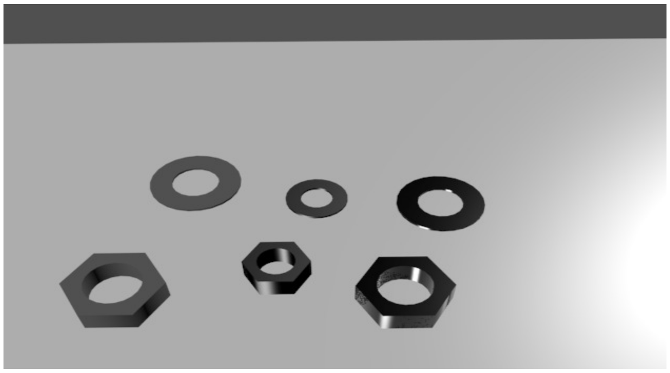


Figure 6. Virtual Elements: Nuts, Bolts, and Washers with Changeable Parameters

Pilot Test: Kaizen Improvement using the 5S Model

The purpose of the 5S Model is to improve the assembly process by organizing the workplace through the following steps:

1. Sort
2. Set in order
3. Shine
4. Standardize
5. Sustain

The model begins with a normal mode, where the assembly process starts randomly. Then, an evaluation session for the count and waste identification is established according to Tables 2 and 3. The results of the pilot test are illustrated in the graphs of Figures 7-9.

Pilot-Test Results

The data collected from the pilot test show an incremental improvement in the assembly processing, as shown in Figure 7. The measurement during the pilot test focused on the cycle time of each assembly and counted the repetition of the non-valued-added activities (waste). The differences of the measured values between the normal mode and the Kaizen mode are shown in Figure 8. Figure 9 illustrates a decreasing level of inventory in each team activity.

Table 2. Waste Identification Sheet

	Team 1	Team 2	Team 3	Team 4
Inventory				
Waiting				
Rework				
Motion				
Overproduction				
Over processing				
Transportation				
Unutilized skill				

Table 3. Parts Count

	Team 1	Team 2	Team 3	Team 4
Washers				
Nuts				

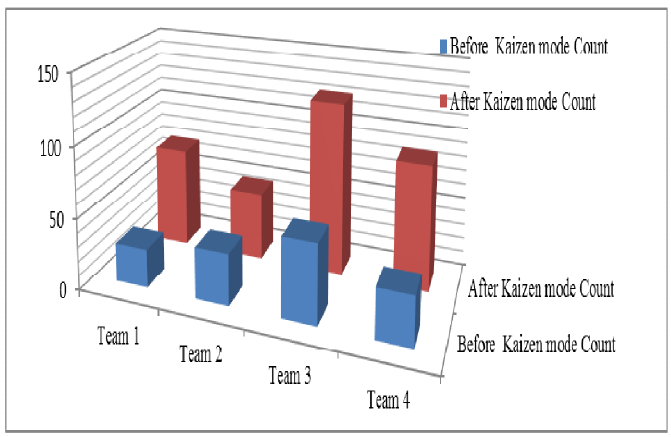


Figure 7. Before and After Kaizen Mode Washer, Bolts, and Nuts Count

Conclusion

Design for Manufacturing and Assembly is a methodology that works well in facilitating Kaizen through waste elimination and cycle-time minimization. The Washers, Bolts, and Nuts assembly was found to be efficient and easy to use for Kaizen models in order to measure the level of improvement in manufacturing processing.

Recommendations

The authors recommend that each Kaizen model be visualized through VRML before hands-on practice. Also, they recommend team-based projects to perform each exercise focusing on one type of waste in order to be able to determine the incremental improvement that is associated with each model.

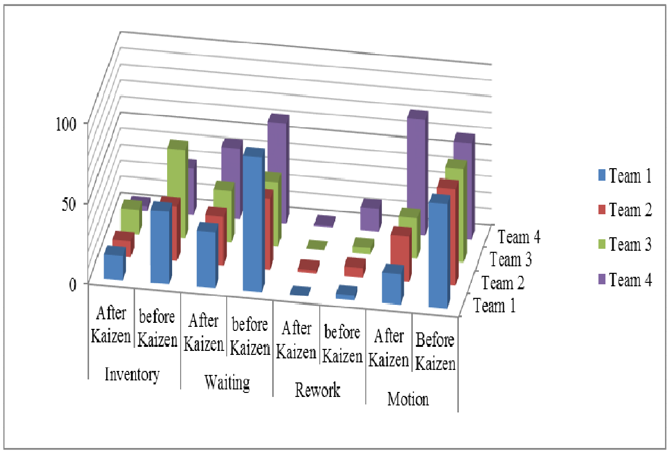
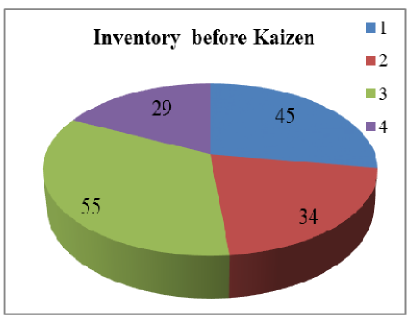
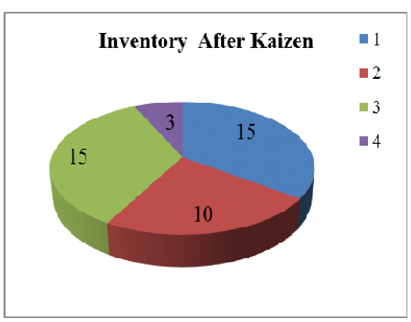


Figure 8. Before and After Kaizen Mode Washer, Bolts, and Nuts Count



(a) Before Kaizen



(b) After Kaizen

Figure 9. Before and After Kaizen Mode Waste Identification

Acknowledgment

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Biographies

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A Comprehensive and Open Framework for Classifying Incidents Involving Cyber-Physical Systems

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Abstract

In recent years, events such as the Stuxnet nuclear plant cyber-attack have brought the security of industrial control systems under scrutiny. Most of this focus has been on supervisory control and data acquisition (SCADA) systems, more generically known as ICS or industrial control systems. While these systems play a major role in our daily lives, this focus tends to overlook the broader scope of cyber-physical systems (CPS) and the impact they have on human lives (e.g., vehicles, mobile devices, agriculture, etc.). There are currently no open databases to record and classify CPS incidents that include systems outside of ICS. While it may be possible to adapt existing databases, we have found that those suitable for adaptation have multiple drawbacks, including proprietary ownership, requirement of a paid subscription and/or limited access, and design scope.

In this paper, the authors propose an open-standards framework for classifying a wide variety of CPS incidents. As part of this framework, a new taxonomy is introduced that facilitates the rapid categorization of such incidents by a variety of criteria. An important new parameter of this taxonomy is a hierarchy of market sector classifications, allowing incidents to be evaluated in their application of context. Other factors of the taxonomy include source profile, impact (both direct and indirect), method, and a comprehensive victim profile. This framework is compared to other existing approaches by classifying several incidents occurring over the last twenty years and demonstrated the wide capabilities of the method by including incidents outside of industrial control systems. It is also noted that the flexibility of the framework caters to multiple CPU types and provides a context-rich description of incidents. Also considered is that the system allows multiple classifications so an incident can be identified in multiple relevant contexts.

An online implementation of this framework is available. This system is intended to be free and cater to an international audience. It is hoped that this will enable researchers to rapidly identify and correlate key incidents involving CPS systems and that, in turn, this will lead to an increased overall awareness of risk management options for these types of systems. Also discussed here are the security risks involved with making such a framework available and the associated countermeasures that have been taken.

Introduction

Incidents such as the SQL Slammer infection at the Davis-Besse nuclear power plant and the Stuxnet attack on the Iranian nuclear facility at Natanz have alerted the industrial community to the need to pay more attention to the security of their critical infrastructure. Most of this focus has been on industrial control systems (ICS), particularly supervisory control and data acquisition (SCADA) systems. In 2012, an attempt was made to classify several incidents involving SCADA [1]. In this process, it was discovered that these types of incidents apply to the broader scope of cyber-physical systems and that a standardized incident classification system is needed. Such a system will afford the study of how incidents happen and what their ultimate effect is.

In this paper, the authors propose an open-standards framework for classifying a wide variety of incidents within cyber-physical systems (CPS). As part of this framework, a new taxonomy has been developed, which facilitates the rapid categorization of incidents by a variety of criteria. The utility of this framework was demonstrated by classifying several incidents from ICS and from the broader realm of CPS.

Literature Review

There have been many attempts to define a system for classifying cyber-attacks or incidents. These began as attempts to identify software vulnerabilities that could be compromised to form an attack. In 1998, Howard and Longstaff [2] presented the first attempt at a unified security taxonomy. This taxonomy attempted to define an attack based on the tool used, the vulnerability exploited, the action taken, the target, and the unauthorized result. Several attempts to modify or expand on their taxonomy have been made. Kjaerland [3] proposed a taxonomy that included the source and target sectors along with the method of operations and the impact to the target. Blackwell [4] focused on the defensive posture of the victim of an attack. Where Howard and Longstaff focused on the objectives of the attacker, Blackwell attempted to understand the ultimate effect on the target.

Other taxonomies include the four dimensions of an attack defined by Hansman and Hunt [5] and the AVOIDIT taxonomy [6]. Each of these taxonomies provides a valuable methodology for looking at an attack. However, none of these taxonomies considers the unique characteristics of CPS. Existing taxonomies do not provide a comprehensive method for analyzing an incident in the context of the market sectors that are impacted. They also do not provide a means of analyzing incidents in the view of their impact on the physical world.

Cyber-Physical Systems

The first challenge in classifying incidents in CPS is that there is no clear definition of what a CPS is. In this study, the authors found that, in the context of security, the definition of CPS has generally been limited to ICS and SCADA systems [7]. This view is narrowly focused and omits other system types that extend beyond critical infrastructure. A broader definition would be any system that combines computers, networks, and physical interactions [8]. CPS has also been defined as systems that bridge the world of computing and communication with the physical world [9]. A more accurate definition, and the one that the authors of this current study believe to be the most fitting for this framework, is that a CPS is a system that embeds the capabilities of cyber-systems in the physical world. This type of system would operate on humans, infrastructure, or platforms in order to modify interactions with the physical world [10]. The term "cyber-physical" itself is intended to denote the interactions between computer systems and the real world [11]. Security should be of greater concern to this larger scope of cyber-physical systems. For instance, the healthcare industry should be more concerned with the rampant malware on medical equipment [12] or the ability for non-medical personnel (or attackers) to access or change information on implanted medical devices [13]. There are also vulnerabilities within the automotive industry that could be the source of incidents in the future [14], [15].

Just as there are many definitions of what CPS is, there is also confusion about how to classify cyber-attacks on these systems. There are two basic approaches to classifying incidents: 1) focusing on the technology that is compromised in an incident, and 2) focusing on the application that is involved. The taxonomy used in this current study was applications-focused. In CPS, an incident tends to be more focused on the application of the system rather than which technologies are being utilized. The value of assets and mechanisms designed to protect them also tend to be application specific. This current classification system included a variety of categories to describe an incident but was primarily focused on the market sector of the entity where the incident occurred.

CPS Market Sectors

There are many ways to classify the market sector in which a CPS functions. In developing the following list, multiple approaches were combined. Considered were government sources, lists created by other researchers, this current evolving list, and, as a cross-check, the input of a large focus group. The North American Industry Classification System [16] is a useful starting place; however, this classification system was developed in the 1930s for use by the U.S. government [17]. Others have included short lists of areas where CPS might be used [8], [10]. What is needed is a comprehensive list of market sectors where CPS is used. With this goal in mind, the following is a list of market sectors that currently utilize CPS in their operations. This list was developed through several iterations of looking at industries and how they might be using CPS. Next, a group of senior students studying Information Assurance and Security was invited to develop their own list without input from the authors. Finally, the results of these exercises were integrated to form the list presented in Table 1.

Table 1. Market Sectors Utilizing Cyber-physical Systems

Market Sectors
Utilities
Industrial Process Control
Health Care
Transportation
Aerospace
Military
Consumer Electronics
Facilities Infrastructure
Agriculture
Physical Access Control
Communications
Construction
Media Creation and Distribution

Incident Taxonomy

With the limitations of the existing taxonomies in mind, this new taxonomy was developed. This taxonomy expands on the work that has already been done and addresses the key missing features of the alternative choices. Incidents are classified based on several factors: market sector, source, means, impact, and victim. Accounting for the market sector has already been considered. The impact classification accounts for the physical aspects of an incident along with the information aspects. The possibility that an incident can be classified in multiple categories was also allowed for.

Source Type

The source type describes the entity where an incident was initiated. The list in Table 2 attempts to comprehensively address the spectrum of possible sources. It should also be noted that an incident may include a single source or it may have multiple sources. A non-profit organization (NPO) classification is assigned when an incident originates with a recognized NPO. The identified group classification is used in the case of a group that is not officially organized and has no legal recognition, such as anonymous. The unknown classification is used when the source of an incident has not been identified.

Table 2. Incident Sources

Source Type
Commercial
Government
Educational
Non-Profit Organization
Individual
Identified Group
Unknown

Means

The means of an incident (see Table 3) denote how the incident occurred. This could be the methods used if the incident was a deliberate attack or the things that went wrong in the case of an unintentional failure. Note that a single incident can involve multiple means. While almost any incident could be classified as a misuse of resources, this classification is reserved for those cases in which an authorized user of the system used it in a manner that was not authorized or intended.

Impact

The impact of an incident describes the effect of the incident. The description of the impact needs to address all the affected entities; these include the computer system, the physical system that the CPS interacts with, and the broader impact on the organization and community, too. There are both direct and indirect impacts of any incident. The direct impacts of an incident are typically those that are easily seen. These are the impacts that may be discovered immediately or within a short time-frame. The classifications for direct impact are presented in Table 4.

Table 3. Incident Means

Means
Misuse of Resources
User-level Resource Compromise
Root-level Resource Compromise
Social Engineering
Virus
Web-site Compromise
Trojan
Worm
Recon
Denial of Service
Other System Failure

Table 4. Direct Impacts

Direct Impact
Service Disruption
Information Distortion
Physical Destruction
Environmental Destruction
Information Destruction
Information Disclosure
Death/Serious Injury
Unknown

Indirect or intangible impacts are sometimes harder to quantify. The indirect impacts may not be seen for several years following an incident. In many cases, the indirect impacts are more costly than the direct impacts. When these indirect impacts are combined, the costs of an incident increase significantly. The indirect impacts are listed in Table 5.

Table 5. Indirect Impact

Indirect Impact
Loss of Reputation
Loss of Trust
Lost Business
Political Repercussions
Public Response

When determining the full impact of an incident, it is necessary to account for the level of severity of the impact. The severity is a modifier to the impact as already defined. In this current study, the authors modified a typical low-, medium-, high-severity scale to account for the unique nature of CPS. This scale is shown in Table 6.

Table 6. Impact Severity

Severity of Impact
Inconvenience
Secondary Operations Degraded
Secondary Operations Halted
Primary Operations Degraded
Primary Operations Halted

Other factors in the impact of an incident include how long it takes for the impacts to be recognized, the time to recover from an incident, and the cost of the incident. The immediacy of an impact describes how long it takes after an incident for the impact to be recognized. This could be seconds, minutes, hours, days, or even longer. This is not necessarily an increasing or decreasing scale of impact. The immediacy is a modifier that allows one to understand the context of the impact better. The time it takes to recover from an incident is another indication of the impact of the incident. The longer it takes to recover from an incident, the greater the impact is. A component of the impact of an incident is also the cost of the incident to the victim. This cost could be hard costs such as the cost to repair the system, or soft costs like lost revenues due to system down time.

Victim

The victim describes the entity where an incident took place. In this study, the victim was classified in two ways. First, the victim type was identified (see Table 7). The types are the same as for the source and the same rules apply. Second, the victim of an incident was described based on this classification of CPS market sectors (see Table 8). A hierarchy tree was developed for each market sector to show how the sector breaks down into various industries and activities. Although the classification scheme shown is strictly hierarchical, it was recognized that some incidents can fall within multiple sectors. Therefore, this strict hierarchy was not imposed on the classification of incidents. It is possible for a victim to be classified under multiple market sectors. This provides further flexibility and utility in the system, as incidents may be classified and found in the multiple contexts where they are important.

Table 7. Victim Type

Victim Type
Commercial
Government
Educational
Non-Profit Organization
Individual
Identified Group
Unknown

Table 8. Victim Market Sectors

Victim Market Sectors
Utilities
Industrial Process Control
Health Care
Transportation
Aerospace
Military
Consumer Electronics
Facilities Infrastructure
Agriculture
Physical Access Control
Communications
Construction
Entertainment Media Creation and Distribution

Utilizing this taxonomy allows for analysis of incidents based on the vertical market sector along with the impact of an incident and other factors that are overlooked in many incident taxonomies. The complete taxonomy can be seen in Figure 1.

Incident Classification Examples

Some experimental scenarios of incidents involving CPS and some real examples of these types of incidents are presented here and demonstrated how they would be classified within the current system. Several recent incidents and security failure demonstrations have shown how systems can be compromised through cyber-attacks. Two examples are presented to show how they can be classified with this incident classification system. Also presented are several other types of incidents, both actual and theoretical, and shown how these can also be classified in this system.

In 2010, researchers from the University of South Carolina and Rutgers University [18] demonstrated several vulnerabilities within vehicle tire pressure sensors. These researchers were able to track a vehicle using the unique identifiers broadcast by the tire pressure sensors as well as spoof low-pressure warning signals to the vehicle. *Source Type*: educational; *Means*: misuse of resources, recon; *Direct Impact*: service disruption, information distortion, information disclosure; *Indirect Impact*: none at this time, but a real-life attack could result in loss of reputation, loss of trust, political repercussions, and public response; *Severity of Impact*: inconvenience; *Victim Type*: individual; *Victim Market Sector*: transportation.

Researchers from the University of Washington [15] and the University of California San Diego were able to demonstrate the capability of using the cellular network to attack

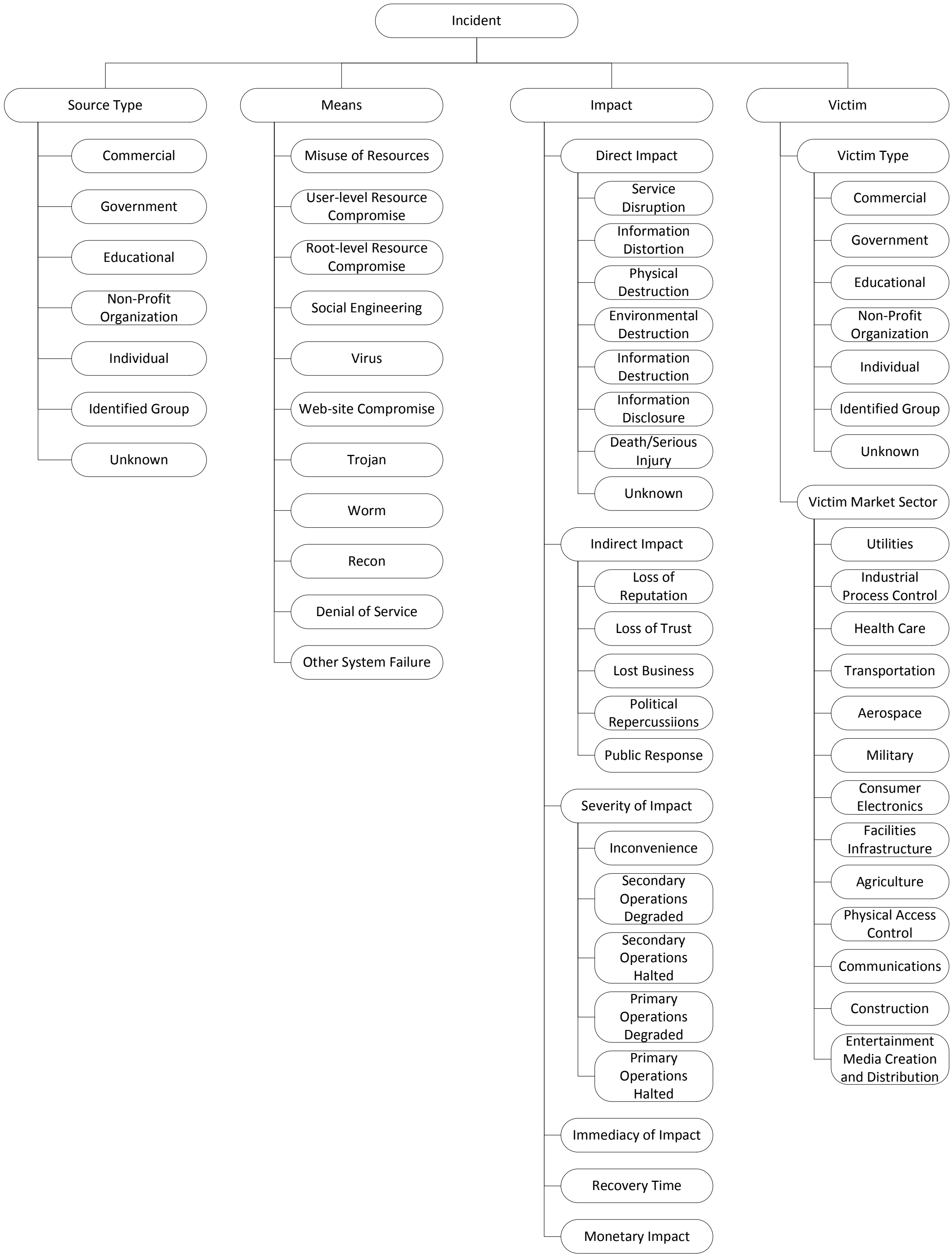

Figure 1. CPS Incident Taxonomy

vehicle telematics systems such as GM's OnStar or Ford's Sync. *Source Type*: educational; *Means*: misuse of resources; *Direct Impact*: service disruption, information distortion; *Indirect impact*: loss of reputation, loss of trust, lost business, political repercussions, public response; *Impact Severity*: secondary operations degraded, primary operations degraded, primary operations halted; *Victim Type*: individual; *Victim Market Sector*: transportation.

Beth Israel Deaconess Medical Center [12] in Boston has 664 pieces of medical equipment that run on older versions of the Microsoft Windows Operating System. The manufacturers of this equipment will not allow the hospital to modify the systems even to install anti-virus software, due to certification requirements. This equipment is often infected with malware, and one or two devices have to be taken out of service each week to be cleaned. *Source Type:* unknown; *Means:* misuse of resources, virus; *Direct Impact:* service disruption, death/serious injury; *Indirect Impact*: loss of reputation, loss of trust, public response; *Severity of Impact*: primary operations degraded; *Victim Type*: non-profit organization; *Victim Market Sector:* health care.

In June of 1999, 237,000 gallons of gasoline leaked from a 16" pipeline into a creek that flowed through Whatcom Falls Park in Bellingham, Washington. About 1½ hours after the rupture, the gasoline ignited and burned approximately 1½ miles along the creek causing three deaths and eight documented injuries. The pipeline failure was exacerbated by control systems not able to perform control and monitoring functions. The National Transportation Safety Board report [19], issued in October of 2002, cited that one of the five key causes of the accident was the Olympic Pipeline Company's practice of performing database development work on the SCADA system, while the system was being used to operate the pipeline. *Source Type:* user; *Means:* misuse of resources; *Direct Impact:* service disruption, physical destruction, environmental destruction, death/serious injury; *Indirect Impact*: loss of reputation, lost business, political repercussions, public response; *Impact Severity*: primary operations halted *Victim Type*: commercial; *Victim Market Sector:* utilities.

This example shows that an attack can be multi-classified. In March of 1997, one hacker penetrated and disabled a telephone company computer that serviced Worcester Airport in Massachusetts. As a result, the telephone service to the Federal Aviation Administration control tower, the airport fire department, airport security, the weather service, and various private airfreight companies were cut off for six hours. Later in the day, the juvenile disabled another telephone company computer, this time causing an outage in the Rutland area. The outage caused financial losses and threatened public health and public safety [20]. *Source Type*: individual; *Direct Impact*: service disruption; *Indirect Impact*: public response; *Impact Severity*: secondary operations degraded, primary operations degraded; *Victim Type*: government, commercial; *Victim Market Sector*: transportation, communications, physical access control.

In February of 2013, the Emergency Alert System for television station KRTV in Montana broadcast a warning that "The bodies of the dead are rising from their graves and are attacking the living" [21]. *Source Type*: unknown; *Means*: user-level resource compromise; *Direct Impact*: service disruption, information distortion; *Indirect Impact*: loss of trust; *Impact Severity*: inconvenience; *Victim Type*: commercial; *Victim Market Sector*: communications.

In January of 2003, the SQL Slammer worm infected the Davis-Besse nuclear power plant in Ohio. As a result of the worm's activity, the plant's safety parameter display system and plant process computer were disabled for several hours [22]. *Source Type*: unknown; *Means*: worm; *Direct Impact*: service disruption, information distortion; *Indirect Impact*: loss of trust, political repercussions; *Impact Severity*: secondary operations halted *Victim Type*: commercial; *Victim Market Sector*: utilities.

In June of 2010, it was discovered that a worm, dubbed Stuxnet, had struck the Iranian nuclear facility at Natanz. Stuxnet used four "zero-day vulnerabilities" (vulnerabilities previously unknown, so there had been no time to develop and distribute patches). The worm employed Siemens' default passwords to access Windows operating systems that run WinCC and PCS7 programs. The worm identified and attacked frequency-converter drives made by Fararo Paya in Iran and Vacon in Finland. These drives were used to power centrifuges used in the concentration of the uranium-235 isotope. Stuxnet altered the frequency of the electrical current to the drives causing them to switch between high and low speeds for which they were not designed. This switching caused the centrifuges to fail at a higher than normal rate [23]. *Source Type*: government; *Means*: worm; *Direct Impact*: service disruption, physical destruction; *Indirect Impact*: political repercussions; *Impact Severity*: primary operations degraded; *Victim Type*: government; *Market Sector*: utilities, military.

In a similar case to the SQL Slammer worm, also in 2003, a computer virus named Sobig was reported to have shut down train signaling systems in Florida. The virus was reported to have been one of the fastest spreading e-mail attachment viruses at the time. It shut down signaling, dispatching, and other systems at CSX Corporation, one of the largest transportation suppliers in the U.S. While there were no major incidents caused by this case, trains were delayed [24]. *Source Type*: unknown; *Means*: virus; *Direct Impact*: service disruption, information distortion; *Indirect Impact*: lost business; *Impact Severity*: primary operations degraded; *Victim Type*: commercial; *Victim Market Sector*: transportation.

In Maroochy Shire, Queensland, Australia, in 2000, a disgruntled ex-employee hacked into a water control system and flooded the grounds of a hotel and a nearby river with a million liters of sewage. The Maroochy Shire attack was not one attack but a whole series of attacks over a prolonged period [25]. *Source Type*: individual; *Means*: user-level resource compromise; *Direct Impact*: service disruption, information distortion, environmental destruction; *Indirect Impact*: loss of trust, political repercussions, public response; *Impact Severity*: primary operations degraded; *Victim Type*: government *Victim Market Sector*: utilities.

In 1999, hackers broke into Gazprom, a gas company in Russia. The attack was collaborated with a Gazprom insider (disgruntled employee). The hackers were said to have used a Trojan horse to gain control of the central switchboard, which controls gas flow in pipelines [22]. *Source Type*: unknown; *Means*: user-level resource compromise, Trojan; *Direct Impact*: service disruption, physical destruction; *Indirect Impact*: loss of reputation, lost business, political repercussions; *Impact Severity*: primary operations degraded; *Victim Type*: commercial; *Victim Market Sector*: utilities.

Cyber-Physical Systems Incident Database

Just as there are multiple incident taxonomies available, there are also different incident databases available. The Repository of Industrial Security Incidents (RISI), available at http://www.securityincdents.net, is an industry-focused database of incidents. This database costs thousands of dollars per year for access and does not factor utilizations of CPS outside of industrial control systems. For example, there is no consideration for the communications or healthcare industries within RISI. The US-CERT database, available at http://www.us-cert.gov, is another example. This database focuses on vulnerabilities rather than incidents, has no consideration for CPS, is U.S.-focused, considers a limited range of sectors, and is not updated for more recent developments in platforms.

The framework presented here was used to develop an incident database. This database was designed to be a repository of incidents along with their classifications. Information about incidents was gathered from available sources and compiled into a single repository. This database may be used for academic research into CPS incidents and is freely available to researchers in this area. The database is hosted by the Brigham Young University Cyber Security Research Lab and may be accessed at http://cpsid.et.byu.edu by the time of this publication.

Unfortunately, due to the malicious intent of a relative few, it is necessary to perform some sanitization of the public incident database to help minimize the risk of misuse. Two levels of protection are implemented in the online database. The first is the sanitization of records; this removes sensitive information and details from recorded incidents that may be misused. The second level of protection implemented is access control and a requirement to register for complete unsanitized access. Users will be required to register with a valid institutional, organizational, governmental, or recognized corporate domain. They will then be granted access subject to a basic verification of their request.

Future Work

The initial goal of this work was to develop the taxonomy, complete the CPSID, and make it publicly available. No attempt was made to analyze the contents of the database. A methodology for analyzing the contents of the database needs to be developed. This analysis should focus on identifying trends, commonalities, and differences in these incidents. This analysis should provide understanding into how CPS incidents happen and how they can be prevented. Understanding that it is impossible to prevent all possible incidents, steps need to be taken to minimize the occurrence of incidents and the impact these incidents have. The analysis of incidents included in this database should be used to develop these methodologies for minimizing both the occurrence and impact of CPS incidents. Above all, these methodologies should focus on protecting the people and the environment that surround these systems.

Conclusions

Presented here is a detailed yet highly adaptable CPS security incident taxonomy. The classification system allows for precise and flexible classification of security incidents. As the system is adopted and the database is populated, it allows for detailed analysis of the types, frequency, and impact of incidents, which in turn enables a directed approach to mitigating the consequences of incidents and will also lead to improved risk management and design approaches for future systems. A significant benefit of the approach is that each incident is recorded with significant contextual information. A malicious break-in that causes inconvenience in an entertainment context is of less concern than an accidental error in healthcare leading to potential loss of life, although they could both employ the same means in the attack execution (for example, the SQL Slammer worm). Permitting cross-classification also allows related incidents to be identified in different areas.

The field of CPS security is young but growing very rapidly. It is anticipated that research and development of the system will continue in several possible directions. Some possible future developments include combining the information with comprehensive design approaches for CPS, tracking and updating incident records as further information emerges, and analyzing the types and frequency of incident occurrences. Further detail of the technologies used in the incidents could also be added as supplementary information. The openness and free cost of the database is intended to encourage adoption and rapid growth.

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DESIGN AND IMPLEMENTATION OF A HYBRID POWER SYSTEM USING WIND AND SOLAR PHOTOVOLTAICS

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Abstract

In 2002, a 1.5-kW grid-connected, wind-solar hybrid energy system was installed as a teaching and research tool. Since then, increased enrollment at the University of Northern Iowa (UNI) caused a marked interest in renewable energy (RE) systems and related projects. As a result, there was a demand to increase the capacity and size of the existing wind-solar energy system as well as laboratory activities in renewable energy technologies. The capacity of the existing wind-solar hybrid power system was improved and increased to a 12-kW system by the students and faculty. This system was used as an educational and research demonstration module on a smart grid for STEM (Science, Technology, Engineering, and Math) education and for purposes of energy efficiency. Also, a real-time data generation system was implemented and made available for online systems. A goal of this project was to save a total estimated annual energy amount of 13 MWh. This estimated savings was calculated according to local utility company rates.

Introduction

Education and training in applications of renewable energy for the nation's workforce have become significant. The integration of green concepts in technology and engineering curricula for workforce development is very common among colleges. The University of Texas (integration of green concepts in the technology curriculum), Sinclair Community College (Center for Energy Education Laboratory), Drexel University (RE-based capstone design projects), Illinois State University (residential RE case studies), Southeast Missouri State University (development of a green technology curriculum), and York College of Pennsylvania -based RE course development) are examples of recent renewable energy curriculum development for the future workforce [1-7].

Hiring technicians with Associate of Applied Science (AAS) degrees in the areas of electromechanical, solar photovoltaic, and wind technologies may address the needs of the industrial workforce in wind and solar energy in the short term. Having a skilled technical workforce with degrees in electrical engineering technology (EET), with an emphasis on advanced wind and solar power, and having been engaged in projects such as variable wind speed and frequency issues, turbine generator testing, troubleshooting, data acquisition, monitoring, and advances in grid-tie technologies, together with knowledge in liberal arts courses, fosters more productive and efficient energy employees who can advance wind and solar power development. For example, some of the programs at educational institutions build their own laboratory equipment to use in RE-related courses and laboratories using student participation. Students gain experience with hands-on projects by designing, developing, and utilizing custom-built training equipment. There have been a variety of recent projects [8-10] in which students were heavily involved in RE projects. Students helped to develop two RE courses, portable solar-thermal lab equipment, solar photovoltaic training units, wind-power training infrastructure, and a solar photovoltaic tracking system. According to the authors, student feedback was very positive in regards to hands-on learning projects. They gained an understanding of solar and wind energy systems in addition to the theory they learned in the classroom.

An upsurge in the wind-power market has been the result of several concurrent factors, according to Sesto [11]. The first factor is the continuous progress of turbine technology, which has led to a cost drop in wind machines. A second factor is improved energy conversion efficiency and reliability of the turbines. Yet another factor is increasing government support and a variety of funds available for wind research and deployment. Recent academic projects attracted many young minds to the wind energy field. Sarkar et al. [12] reported a project completed at the University of Texas at Pan American in which faculty and students developed small wind turbines for isolated Colonia homes of south Texas with the help of the Texas State Energy Conservation Office. This project was a hands-on engineering project where 22 senior high school students were involved in building the wind turbines.

The 1.5-kW wind-solar hybrid energy system at the UNI campus that was built in 2002 was not sufficient due to growing student numbers, increasing interest in wind-solar projects, the growing need for more advanced laboratory activities on renewable energy systems, and emerging requirements for a larger testbed with grid inter-tie and smart grid features [13]. To address the shortcomings of existing instructional techniques for electrical power systems, controls, wired and wireless instrumentation, and data acquisition, a larger-scale hybrid wind-solar power system with grid-tie features was constructed in the EET program at UNI. The system was designed and implemented with the following technological and educational goals:

a) To be completely different from conventional electrical power labs and to be fresh and interesting by using wired and wireless sensors that provide communication among the existing 1.5-kW wind and solar power system, the proposed 12-kW wind turbine and solar panel system, and the main computer that provides data acquisition and monitoring through wireless sensors, LabView software, and a NI FPGA data acquisition module.
b) To show a complex, interrelated system that is closer to those existing in the real world than the common, simpler systems covered in educational labs.
c) To motivate learning by introducing elements such as energy, environmental, and economic concerns of wind and solar power systems that are of practical interest to students and workshop attendees.

The main objective of this project was to design and build a 12-kW wind-solar hybrid energy system with associated wireless sensors and a graphics-based monitoring instrumentation system to provide a teaching and research facility on renewable energy for students and faculty members in Electrical and Manufacturing Engineering Technology programs at the University of Northern Iowa (UNI).

This project required the purchase of a 10-kW Bergey Excel-S wind turbine with a Power Sink II utility inter-tie module (208 V/240V AC, 60 Hz), eight BP SX175B 175W solar photovoltaic (PV) panels, and related power and instrumentation/data acquisition hardware through major funding from the Iowa Alliance for Wind Innovation and Novel Development. The electricity generated by this energy system is used as a renewable energy input for a smart-grid-based greenhouse educational project to aid in the teaching and research of wind-power systems development, wind turbine and tower selection, smart grids, and energy efficiency issues.

The following classes used this proposed testbed as a laboratory and for demonstration activities: Introduction to Electrical Power/Machinery, Advanced Electrical Power Systems, Wind Energy Applications, Wind Energy Management, and Solar Energy Applications and Issues. There were also workshops planned for the region's STEM teachers as well as for education and training for local farmers on wind-power systems. Previous workshops organized by the UNI Continuing and Distance Education program have been very successful.

Design and Construction Phases

The unit contained a 10-kW Bergey Excel-S wind turbine installed on a 100 ft. (30.48 m) tower at the UNI campus. It was connected and synchronized in parallel to the UNI power grid as part of laboratory activities on wind-power systems and grid-tie interactions. The overall project block diagram is presented in Figure 1.

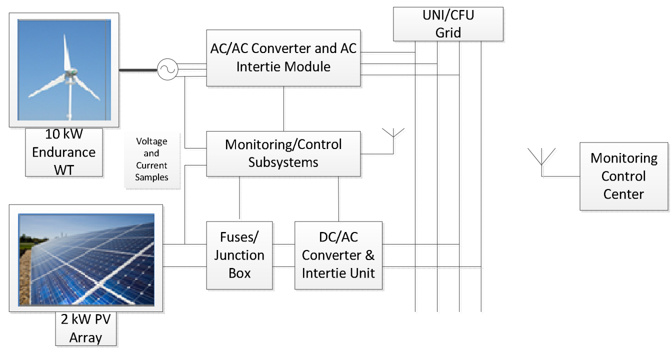


Figure 1. 12-kW Wind-Solar Power System at the UNI Campus

The wind turbine was installed at the top of a new steel tower at a height of approximately 100 feet. The wind turbine depicted in Figure 1 was a 10-kW Bergey Excel-S with a grid-tie inter-tie module called Power Sink II; there were twelve solar panels with a capacity of 175 W each. A best-case scenario of 12x175 W (for a total DC power of 2100 W) was hypothetically available from the PV panels, although this would have been equal to or less than 2000 W, due to the location of the solar panels.

A 10-kW wind turbine was selected because of its strong features, low maintenance, and safety features. The output power of the selected wind turbine was 10 kW, based on its rated speed of 13 m/s, or 29 mph. One of the important features of the fiberglass wind blades was its blade deformation as the turbine reached its rated output. This feature allowed the blade to change its shape, causing the blades to go into a stall mode. This shape change limited the speed of the generator and prevented damage in strong winds. An internal regulator in the wind turbine periodically checked the line voltage and corrected for low voltage conditions. The photovoltaic modules selected for this system were ultra-clear tempered glass and were manufactured for long-term durability. The power quality of the inverters was very important, due to sinusoidal waveform output distortions that cause problems such as harmonic contaminations and poor voltage regulation. The Institute of Electrical and Electronics Engineers (IEEE) explains and publishes standards on inverter efficiencies.

The Standard states that a maximum of 3% to 4% total harmonic distortion is allowed from inverter outputs. However, many inverter outputs—commonly ones not approved by standardization agencies such as UL (underwriter laboratories)—may exceed the allowed harmonic distortion. An inverter with a power rating of 2.5 kVA was selected for this energy system. For the PV system, there were twelve lead-acid AGM batteries available that were connected in series and parallel combinations. Figures 2 and 3 show block diagrams with illustrative pictorials.

For purposes of data acquisition, interfacing, and instrumentation, two Fluke power quality analyzers and permanently mounted AC and DC digital panel meters were used to monitor and record power values including voltage, current, power, and harmonic contamination data.

A functional, pictorial block diagram of the existing 1.5-kW hybrid wind-solar energy system is depicted in Figure 4. This system interacts with the new system. The major differences between the existing and the new energy systems are a larger output of wind power and wireless communication integration including wireless sensor nodes deployed for data acquisition. The wireless system establishes a communication between the wind turbines, the main computer, the PV array, the inverter, and the charge controller. The advantage of this hybrid system is that the reliability of power output for the overall system, due to the solar array, generates power during the summer season when less wind is available to reach the expected power output from the overall system.

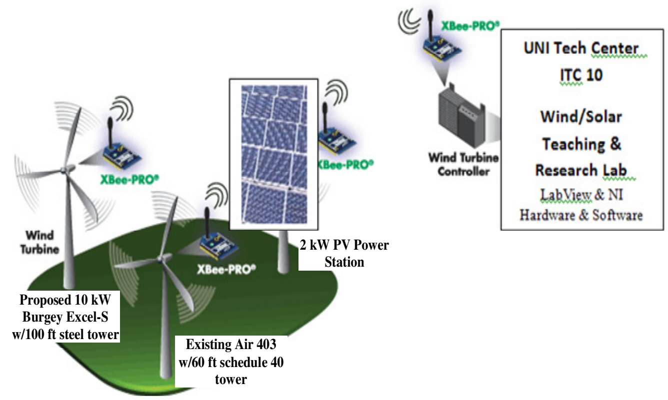


Figure 2. Illustrative Pictorial of the New System

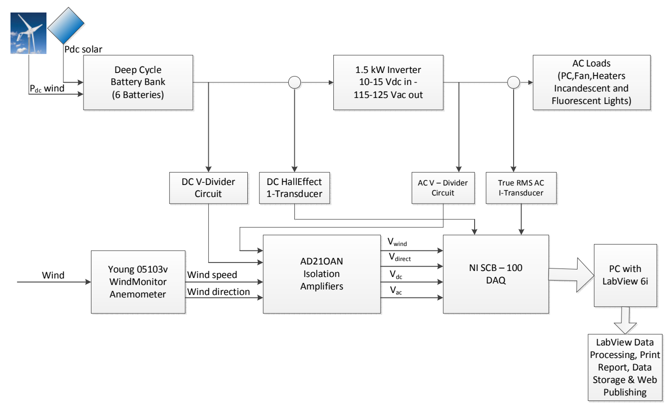


Figure 4. Functional Block Diagram for Instrumentation and Data Acquisition Purposes

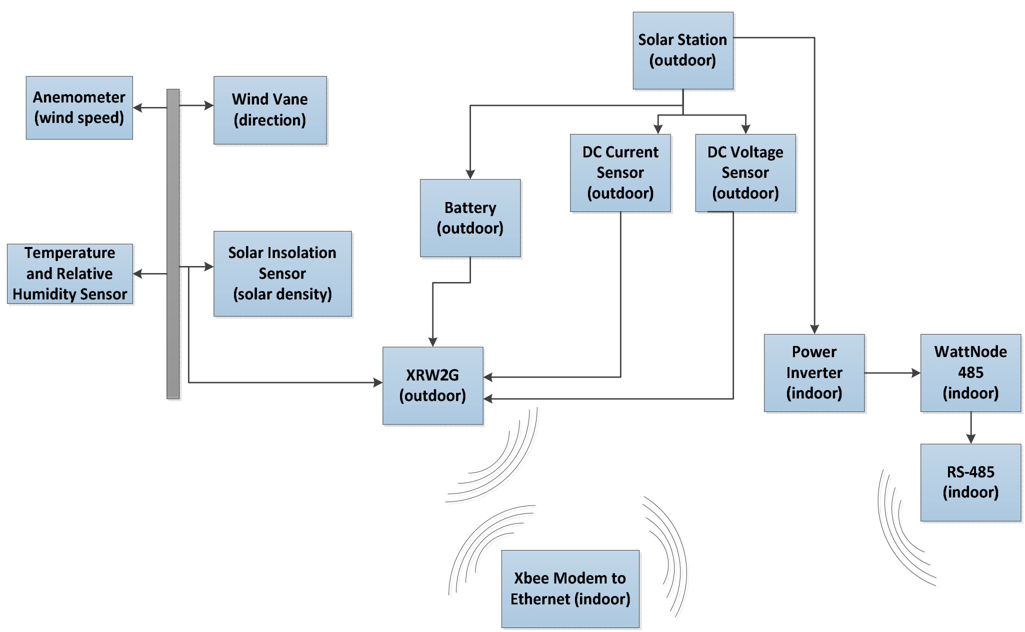


Figure 3. Functional Block Diagram of PV Array Wireless Monitoring

Initial Study on Wind Capacity

Using Iowa Energy Center's wind assessment study [14], [15], information was provided on average wind speed and estimated annual energy output (kWh). An estimated energy amount of 18,835 kWh of wind power was expected to be harnessed from the hybrid wind-solar energy system, as shown in Table 1. Based on an initial study, an estimated 3,325 kWh of electrical energy would be available from 2 kW PV arrays that were part of the wind-solar hybrid power system.

Table 1. Estimated output from a 10-kW Bergey Excel-S Wind Turbine at Cedar Falls, IA

Period	Average Speed (mph)	Air Density (kg/m^3)	Average Wind-power Density (W/m^2)	Capacity Factor (%)	Estimated Output for Period (kWh)
Annual	13.50	1.233	229	21.65	18,835
Jan	14.62	1.291	278	26.45	1,867
Feb	14.35	1.286	276	25.65	1,642
Mar	15.00	1.252	295	27.27	1,985
Apr	15.16	1.222	316	27.45	1,981
May	13.58	1.193	223	21.15	1,616
Jun	12.63	1.174	175	17.39	1,306
Jul	11.51	1.163	124	12.97	1,017
Aug	11.13	1.168	110	11.63	907
Sep	12.07	1.182	144	14.99	1,119
Oct	13.21	1.216	192	19.45	1,458
Nov	14.14	1.252	268	24.40	1,718
Dec	14.31	1.285	275	25.49	1,808

The following lab activities were completed.

- Power curve determination of the 10-kW Bergey Excel-S;
- Annual average energy production using data from an anemometer;
- Measurements of transient phenomena due to sudden load changes;
- Voltage, current, and power (V, I, P) measurements at both DC and AC buses;
- Measurements of V, I, and P transients due to sudden load changes at the AC power grid;
- Measurement and monitoring of overall system efficiency;
- Vibration monitoring using a NI9234 sensor module that included monitor vibrations on the turbine structure at the base and on the nacelle;
- Calculations of yearly wind speed, direction, temperature monitoring, and data storage;
- Strain monitoring, which is a common technique for determining the structural health of the energy system—information is becoming increasingly more important in the wind turbine industry;
- Wind turbine noise impact measurements using NI sound and vibration analysis software. Data that are commonly used to ensure that the wind system complies with standards such as IEC 61400-11:2002;
- Temperature measurements used for preventive and predictive maintenance;
- Power quality monitoring: The system can degrade as a result of wind speed, turbulence, and switching events. Therefore, power quality monitoring included peak power output, reactive power, voltage fluctuations, and harmonics;
- Assessments of AC and DC power system interactions in case of sudden source and load changes;
- Measurements of the impact of temperature changes to overall system efficiency; and,
- Measurements of the impact of the wireless sensor network on the overall system response during source and load fluctuations and sudden wind changes. Any new control schemes developed as a part of advanced senior (capstone) design projects can be used to monitor and control the frequency and voltage of the AC grid.

The subjects taught as part of the objectives of a typical wind-power education project such as this, as they apply to a Baccalaureate degree program, should include:

- basic mathematics
- physics
- statistical analysis
- computer programming
- electrical circuits
- analog devices
- digital electronics
- conventional and renewable energy fundamentals
- electrical machines
- power electronics
- programmable logic controllers (PLCs)
- electro-mechanics

- measurement and protection fundamentals
- power transmission lines
- power system interactions
- instrumentation interface using wired and wireless sensors and networks

This proposed wind testbed was intended to foster an excellent learning experience for undergraduate and graduate students. UNI is Iowa's first and only state institution offering a BS degree in EET. Almost 40% of incoming students transfer from Iowa community colleges with AAS degrees in EET and similar fields of study. The program was recently reviewed for ABET-TAC accreditation, and findings from the visiting ABET team were very promising. One of the reported observations about the program was that students were exposed to hands-on training and curricula in renewable energy and the applications of wind power [15]. The testbed strengthens Iowa's efforts with renewable energy education and provides a major resource for workshops to be arranged for area STEM teachers and for local farmers. One STEM workshop organized by the PI in 2008, to promote math and science education in using limited renewable energy equipment, was very successful. Twenty area teachers completed the workshop in 2008, which was followed by school visits and real-time project demonstrations into the spring of 2009 [16].

Project Implementation

Undergraduate and graduate students from electrical engineering technology, manufacturing technology, and metallurgy were involved in this project from its beginning to its completion. Pictures of the different levels of construction and installation process are shown in Figures 5-9.

Figure 5. Solar Panel Installation on a Frame

Figure 6. Wind Turbine (WT) Foundation Construction with E-bars and Grounding Equipment

Figure 7. 10 kW Bergey WT Installation on the Tower

Figure 8. WT Blades are Attached and Inspected

Figure 9. Final Installation of 100 foot Wind Tower and 10-kW Bergey WT

Student Outcomes

Energy knowledge and renewable energy-based projects are important in preparing students to be competitive for careers in the growing fields of energy-related engineering, science, and technology for the future. Preliminary projections from the Bureau of Labor Statistics state that the number of energy-related green jobs is expected to increase by 11% by 2016, and most of that growth is expected to be in the environmental or energy-related sectors [17], [18]. Edgar Dale's cone of learning shows that participating in discussions or other active experiences may increase retention of material by up to 90% [19]. Felder and Silverman [20] recommended several teaching techniques to address all learning styles, one of which was to provide demonstrations for students with sensing and visual learning styles and hands-on experiments for students with active learning styles. According to Moore [21], there is a direct correlation between in-class performance, laboratory attendance, and performance. In renewable energy courses, active learning can be achieved through a variety of activities including lab and project experiments with hands-on projects and hands-on laboratory experiments [22-25].

Student involvement and outcomes of the project included:

- Power and economy outcomes:
    - The 10-kW wind turbine project saved an estimated annual total energy of 13 MWh between January, 2011, and January, 2012.
    - Economy savings were estimated according to the Cedar Falls Utility rate charge, which was: 13,000 kWh x $0.1/kWh = $1,300 per year.
- Environmental outcomes:
    - The proposed project helped reduce CO_2 emissions at a rate of 1,416 lbs/kWh.
    - 13,000 kWh x 1,416 lbs/kWh = 18,408 lbs of CO_2 emissions saved at the UNI campus.
- The educational outcomes and community outreach program:
    - Provided a hands-on and a remote laboratory application through a dynamic website.
    - Generated several lab activities in wind-solar technology that were used for educational and research purposes.
    - Promoted wind and solar energy for middle school and high school students.
    - Promoted Science, Technology, Engineering, and Math (STEM) education at UNI.
    - Supported five senior undergraduate EET students to work on the project for about one academic year and one additional summer semester. Their varying responsibilities were in the areas of electrical, mechanical, and instrumentation for the successful completion of three separate senior design projects in the EET program.

Course Development

Additionally, these types of projects are being used in undergraduate courses on renewable energy and electronics as hands-on labs and for training. There are currently two renewable energy-related courses available for students. One is a traditional course with lab requirements (Solar and Wind Energy Systems) and the other is an online hybrid course (Alternative Energy Technology). The topics of the course include, but are not limited to: (a) photovoltaic systems; (b) hydrogen fuel cell systems; (c) measurement of temperature, speed, solar insolation, voltage, current, gas flow, and regulation; (d) motor control systems; (e) battery technology; (f) circuit analysis; (g) energy harvesting and conversion circuits; and, (h) wind-power technology. Students who enroll in related classes will advance the project, implement more alternative energy systems, and increase the viability of the project.

A new senior/graduate-level class, entitled Wind Energy Engineering, was developed at UNI to help Iowa's demand for the future wind energy technical workforce. The class includes an understanding of wind energy with respect to environmental, economic, technical, and political issues. It also promotes the value of increased use of wind energy and related research, development, and manufacturing for Iowa's efforts in energy independence. The class website is open to other educational institutions through Google Learn.

This new wind-power system was facilitated as a laboratory tool in the course. Student interest and involvement was very positive. Students could analyze wind and power monitoring data from their own home computers by accessing the wind turbine output in real time. Figure 10 shows the interface of real-time data monitoring through the website. A basic wind-power equation is given in Equation (1) [26]:

$$P = 1/2\rho Av3 \qquad (1)$$

where, P is the electrical power (W), ρ is the air density (kg/m^3), A is the wind-swept area (m^2), and v is the wind velocity (m/s).

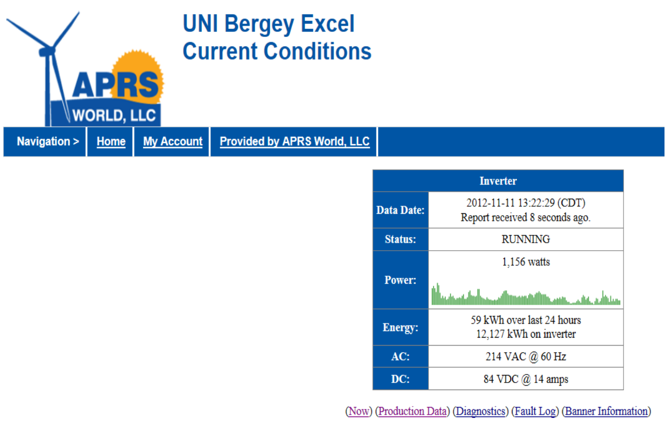


Figure 10. Real-time Data Monitoring of the 10-kW Wind-power System

For example, a wind turbine with a radius of 2 m, giving a swept area of A = 12.6 m^2, would have approximately 100 kW of wind power across that area, due to a 25 m/s wind speed. Students observed that the maximum theoretical efficiency for the wind turbine was 59% [27]. Additionally, Figure 11 shows a graph of the amount of generated green energy. As of March 30, 2012, 2,118 kWh of green energy had been generated, which would be approximately 1,298 kg of the CO_2 emissions saved at the UNI campus if the same amount of energy was produced from a coal-fired power plant.

The graphs shown in Figure 12 (a,b,c) indicate the monthly energy production. A random selection of three months is also depicted in the figure.

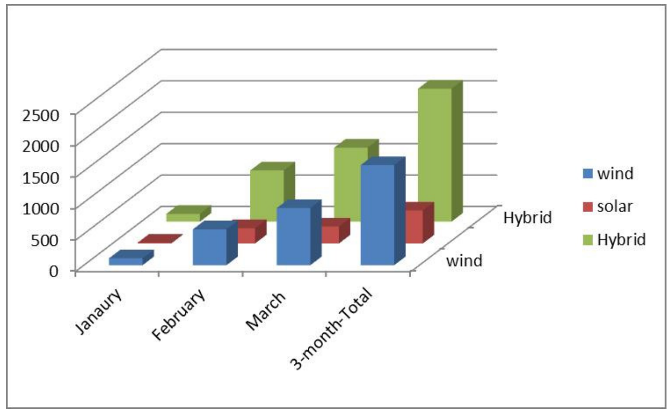
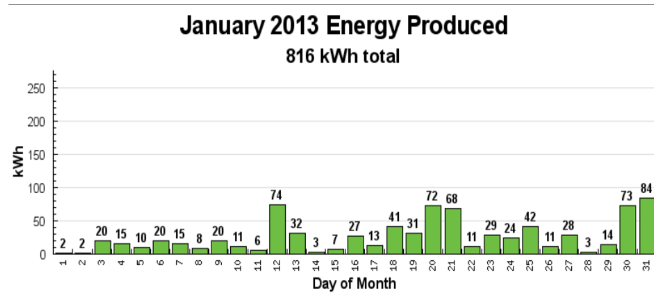
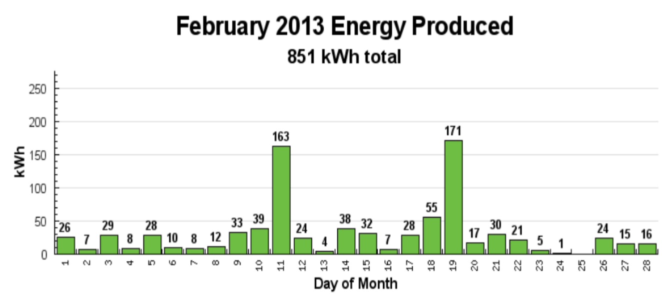


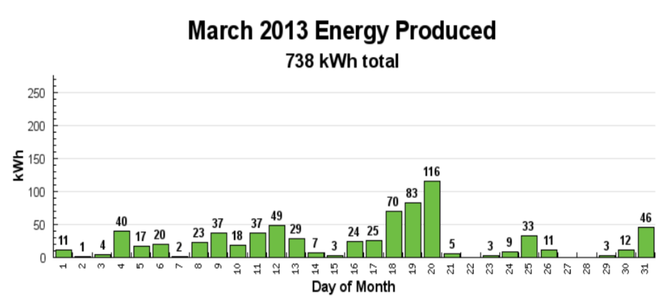
Figure 11. Amount of Energy Generated



(a) January 2013



(b) February 2013



(c) March 2013

Figure 12. Wind Power Generation in the Three Selected Months

Conclusion

A complete 12-kW wind-solar power and instrumentation/ data acquisition system was completed and synchronized with the AC power grid with faculty, graduate, and undergraduate student involvement. The wireless sensors collecting data on wind, temperature, vibration, sound, voltage, current, power, and load changes at both wind and solar power systems communicate with NI data acquisition hardware and the main computer. A graphics-based instrumentation and data acquisition system provided data to a dynamic website in real time. The website provided remote access to the wind-power system by all permitted institutions requesting real-time data.

In addition to curriculum development in the courses Introduction to Electrical Power/Machinery, Advanced Electrical Power Systems, Wind Energy Engineering, and Windpower Applications, workshops were planned for Cedar Valley area STEM teachers and local farmers interested in establishing small-scale wind-power systems. The equipment was part of a program initiative to improve laboratory facilities to better reflect current and future renewable energy technologies. The testbed allowed students to become educated and trained in using real-time electrical power systems and allowed them to gain valuable hands-on experience in setting up a real-time data acquisition system, specifically in grid-tied wind-power systems. In terms of student learning and satisfaction, the project was a success. With the increasing importance of renewable energy resources in present and future energy scenarios, an ability to design and analyze renewable energy systems is essential for educators and students in engineering and technology. All students in the project showed improved learning and understanding of concepts about renewable energy sources by complementing theory-based lectures with hands-on experimentation.

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INTEGRATING ETHICS BY USING CASES

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Abstract

In this paper, the author examines integrating ethics into technical classes using a case approach; specifically, information on the background and efficacy of the case method, suggestions for appropriate cases and classroom activities, and resources for instructors.

Introduction

Since ABET introduced outcomes-based criteria in 2000, ethics has received a much-needed boost. Criterion 3f, which requires that students display "an understanding of professional and ethical responsibility" [1], translates into the need to either require an ethics class or include ethics instruction in technical classes. However, many technical curricula are already very crowded, and squeezing in an extra class may prove difficult. Using an ethics-across-the-curriculum approach can effectively impress upon students the need for understanding and following professional behavior expectations. In this paper, the author focuses on this approach, specifically addressing background on cases and efficacy, cases and activities for various engineering disciplines, and resources for instructors.

Of course, there are more compelling reasons for introducing ethics than simply meeting ABET requirements: As students evolve intellectually and transition into professional life, ethics assumes a more prominent role. Instructors can arm students with technical knowledge for their future careers. But giving sufficient attention to the "soft" skills, which include the values of honesty and integrity that so often appear on those lists of desirable employee characteristics, is also essential.

Background and Efficacy

Using cases as a primary teaching methodology has roots dating back to antiquity. Indeed, for Socrates, cases provided a way to "sting" his students into deeper thought, as noted in the often-quoted gadfly paragraph in "The Apology of Socrates", where Socrates describes himself as a gadfly stinging the flanks of the lethargic horse of society [2]. All of the problems presented to students, as recounted in Plato's *Dialogues*, constitute cases of various sorts, although Socrates dealt with lofty metaphysical principles such as the nature of truth or virtue or reality, in his goal of training the philosopher-king.

Cases also capture an inherent fascination with narratives. People, notes Gottschall [3], author of *The Storytelling Animal*, are as much *Homo fictus* as they are *Homo sapiens*:

> Humans live in a storm of stories. We live in stories all day long, and dream in stories all night long. We communicate through stories and learn from them. We collapse gratefully into stories after a long day at work. Without personal life stories to organize our experience, our own lives would lack coherence and meaning. (p.1)

Given the human penchant for narratives, it is natural that students would find them engaging. In the educational arena, Christopher Columbus Langdell, dean of the Harvard Law School, is credited with introducing the case method in the early 1870s [4]. By the mid-1920s, the method was firmly entrenched in the Harvard Business School as well [5]. Currently, instructors in most academic disciplines use cases as an active learning technique that bridges the gap between theory and practice, offering a viable pedagogical method that encourages critical thinking and problem-solving skills [6]. In 1991, educator Kenneth Merseth [7] identified a number of benefits that derive from a case-based approach:

- Develop skills of critical analysis and problem solving.
- Encourage reflective practice and deliberate action.
- Bring reality into the arena of theory.
- Involve students in their own learning.
- Promote the creation of a community of learners.

In current parlance, using cases as a primary pedagogical technique is an element of "flipping" the classroom, empowering students to be active participants in their own learning [8]. With its emphasis on activity, as opposed to passive listening, the technique mirrors the National Training Institute's learning pyramid, which posits that retention increases as learner activity increases. Whereas learners remember only about 5% of the information presented in a typical lecture, retention increases to 50% by engaging in discussion groups, 75% for "practice by doing", and 90% for teaching others [9]. Although controversial [10], the learning pyramid reflects those features of the case method that make it such an effective approach: teamwork, reflection, critical thinking and analysis, and sharing results with others.

Cases also involve inductive reasoning and an attention to the particular, and, as Cruz and Frey explain, represent the natural direction of learning [11]. Rather than starting with abstract concepts, a case approach allows students to grapple with issues in a specific scenario and from that discover the larger principles or theories that are applicable to other similar circumstances.

The case method is not without its critics; however, most of the criticisms relate to fields other than engineering and technology. Ronald Yeaple of *Forbes* magazine, for example, suggests that lectures are a more efficient way to present the fundamentals in marketing classes [12], while Shugan [13] notes that cases are inadequate for teaching quantitative skills required for business fields, such as accounting. The Case Centre [14] suggests that a case-based pedagogy involves too much preparation for the instructor, involving a significant investment of time to "read and understand the case, devise a teaching strategy, decide on critical questions and plan time management and other classroom issues". One might note, however, that time devoted to most of these items is characteristic of teaching any course.

Overall, the bulk of the studies in the literature examining a case-based approach agree with the final assessment of (University of Virginia engineering professors) Richards and Gorman [15], who note that "Cases allow us to introduce problems and questions we could not otherwise consider, and they lead students to higher levels of cognitive functioning".

Cases

Cases come in all varieties: hypothetical or reality-based, high- or low-profile, global or local. Real cases are preferable to confected textbook scenarios, which usually have an obvious and relatively simplistic right answer. Real ethics is messy and involves an element of ambiguity, with multiple possibilities for a right answer. It is important, note trainers Hill et al. [16], that "the case be reasonably realistic and complex, and also stimulate intelligent discussion . . . in such a way that students will be better prepared for dealing with real world problems". In fact, the shift in ethics instruction in the 1990s from abstraction to practical cases resulted from the emergence of specific fields such as bioethics, research ethics, and engineering ethics.

According to Whitbeck [17], the context of an ethics problem became dominant, along with "the complex ethical presuppositions and commitments implicit in the practices of communities and social groups".

Choosing appropriate cases depends on a number of variables: time available for ethics activities and discussion, instructor knowledge and interest, class content, and course objectives. Instructors pressed for time may choose to incorporate small cases, those with a low media profile that have limited information. Local cases can be very useful. For example, several years ago, the Klamath Falls community was presented with a proposal, since withdrawn, to establish a hog farm—starting with 11,000 animals—on the outskirts of the city. Students in an environmental class examined the issues involved, including waste disposal and water rights; they investigated conditions in other states, especially Iowa, and concluded that the proposal was infeasible. For this particular class, this case was extremely beneficial in helping students understand the potential effects of an engineering-related decision, which was a major class objective.

Small cases may also be more reflective of students' career paths; they will probably face ethical challenges of the more mundane variety. Pritchard [18], an engineering ethicist, explains that emphasizing the role of engineers in big cases may actually be misleading: "While important and instructive, these cases focus on extraordinary rather than ordinary situations facing engineers. Exclusive concentration on such cases may give students a distorted picture of ethical concerns in engineering practice," as students may assume that engineering ethics simply consists of avoiding such situations. In reality, most students will face challenges of lesser significance than whether or not to blow the whistle on corporate wrongdoing. Big cases, on the other hand, can effectively support ABET Criterion 3h [1], which indicates that students display an understanding of "the impact of engineering solutions in a global, economic, environmental, and societal context" while underscoring course goals. In a structural engineering class, for example, examining building collapses is a dramatic way to explore corporate social responsibility, both domestic and global.

The 1981 Hyatt Regency Walkways Collapse in Kansas City offers a disturbing example of engineering negligence and emphasizes the need for professional engineers to accept responsibility for their decisions, or lack thereof. After the structural failure that killed 114 people and injured another 200, Jack Gillum (engineer of record) and Daniel Duncan (lead engineer) were adjudged by an ASCE panel to be "vicariously responsible" [19], stripped of their engineering licenses in the state of Missouri, and suspended from membership in the ASCE for three years [20]. They also became the subject of many engineering classroom discussions on responsibility.

In a global context, the 1995 collapse of Seoul's Sampoong Superstore provides a stunning instance of engineering negligence, coupled with faulty business decisions, that resulted in 500 killed and hundreds more injured, despite a closure recommendation from an investigative engineering team and clear signals, such as cracking and shivering, from the building itself [21]. The case effectively illustrates the negative interplay between business and engineering: initially conceived as a four-story office complex, owner Lee Joon changed his mind after the footings were poured, adding a fifth floor and converting the structure into an enormous shopping complex with eight traditional Korean restaurants occupying the new fifth floor.

The heavy heating slabs required for this style of dining, in addition to three 15-ton air conditioning units placed on the roof, increased the dead load by 35%, and a number of other modifications affected the building's stability [22], [23]. Although it somehow remained erect for nearly five years, on the evening of June 29, 1995, the building pancaked in 20 seconds, trapping nearly 1,500 shoppers and employees beneath hundreds of tons of concrete [22]. Post-disaster hearings found Lee and his son, who ran the construction company, guilty of gross negligence and bribery; both were incarcerated, along with 25 other public officials that the duo had bribed [24].

While high-profile cases consume more class time than smaller cases, they are effective in illustrating the larger impacts of engineering decisions: the Hyatt disaster affected nearly half of the residents of Kansas City [23], while the Sampoong collapse affected thousands [21]. For students who are just learning about ethics, these types of cases leave an indelible impression, one that they will hopefully carry into their professional lives.

Activities

Seamlessly integrating ethics discussion and activities is essential. While it may be convenient to make Friday the "ethics day," for example, this is tantamount to divorcing ethics from the course content. Not only does this approach defeat the purpose of integration, it also downplays the importance of ethics to engineering. As Davis [25] noted, ethics is not an add-on, but rather is integral to the profession: "Knowing engineering ethics is as much a part of knowing how to engineer as knowing how to calculate stress or design a circuit . . . insofar as engineering is a profession, knowing how to calculate stress or design a circuit is in part knowing what the profession allows, forbids, or requires" [25]. Offering a structure for analysis is very helpful, especially if students have limited backgrounds in ethical analysis. Figure 1, from the Illinois Institute of Technology, is a tried-and-true approach that includes elements of engineering problem solving.

1. **State problem** ("There's something about this decision that makes me uncomfortable"; "Do I have a conflict of interest?")
2. **Check facts** (many problems disappear upon closer examination of the situation, while others may change drastically)
3. **Identify relevant factors** (persons involved, laws, professional codes, other practical constraints)
4. **Develop list of options** (be imaginative; try to avoid "yes/no" dilemma; focus on who to go to, what to say)
5. **Test options** using the following:
   Harm: Does this option do less harm than any alternative?
   Publicity: Would I want my choice of this option published in the newspaper?
   Defensibility: Could I defend my choice of this option before a Congressional committee or committee of my peers?
   Reversibility: Would I still think the choice of this option good if I were one of those adversely affected by it?
   Colleague: What do my colleagues say when I describe my problem and suggest this option as my solution?
   Professional: What might my profession's governing body or ethics committee say about this option?
   Organization: What does the company's ethics officer or legal counsel say about this?
6. **Make a choice** based on steps 1-5.
7. **Review steps 1-6**: What could you do to make it less likely that you would have to make such a decision again?
   Precautions you can take as an individual (change job, etc.)?
   A way to have *more support* next time?
   A way to *change the organization* (suggest policy change at next departmental meeting?

Figure 1. IIT Ethical Decision-Making Guide [26]

Developing a variety of activities is important, both in maintaining student interest and illustrating a number of different aspects to case analysis. Discussion is a primary technique, especially small group discussions that involve a large group report-out. Discussions tend to be very dynamic and offer a participation outlet to students who are reluctant to speak in the larger class setting, as well as being a way to deal with a larger number of case-related issues. But even discussion can grow tedious when it is the only method employed. To add variety, instructors can consult websites that offer advice on teaching ethics; for example, Computingcases.org offers a number of suggestions for enlivening class discussions:

- Write a social impact statement based on the case and use that as a basis for discussion.
- Write a corrective action plan for a specific case, such as Therac-25 [Therac is an x-ray machine; in the 25 model, software coding errors resulted in massive overdoses, burning holes in a number of patients and killing three].

- Have students role-play [this technique as the added advantage of introducing the moral imagination, the ability to examine a situation from multiple perspectives].
- Have students write a script dramatizing the case problem.
- Rewrite computer science textbook exercises to add an ethical dimension [27].

In addition to discussions, guest speakers can offer dramatic examples of the role of ethics in the professions. The Oregon Institute of Technology (OIT) was fortunate to have Roger Boisjoly, one of the Challenger disaster's whistleblowers, as a speaker. Since he was familiar with the case approach used in that particular class, early in his presentation he declared, "I am a case." Students were stunned by his experiences, and in a debriefing during the next class period, many indicated dramatic perceptual changes because of Boisjoly's presentation: they were awestruck by the personal courage of whistleblowers, dismayed by the retaliatory actions of employers, and buoyed by the story of someone who truly made a difference. As Sean, a technical writing student, wrote, "I listened to a talk on ethics from a man I never heard of and will never forget."

Other possibilities for guest speakers include ethics/compliance officers from local businesses, alumni who have faced ethical challenges in the workplace, and faculty colleagues who have experienced ethical situations. Universities with the financial means can consult a number of speaker bureaus for possibilities.

Using videos is another possibility that is particularly effective for visual learners. The National Academy of Engineering and Texas Tech University offer short videos that focus on engineering scenarios (see the Resources section for details). Feature films, which students view outside of class, can also offer insight on ethics issues. In one class, for example, students watched *A Civil Action*, a popular film that details the ethical journey of attorney Jan Schlichtmann as he engages in a water-contamination case in Woburn, Massachusetts. Illegal dumping by Beatrice, UniFirst, and W.R. Grace resulted in 28 leukemia cases, a figure four times higher than average; six died, including several children [28]. It is a dramatic example of moral development, as Schlichtmann progresses from a rapacious personal injury lawyer, interested solely in money, to a caring individual who discovers the value of human suffering. Metaphorically, he morphs from moral bankruptcy and financial wealth to financial bankruptcy and moral wealth, as his initial greed is supplanted by compassion for others. The film can also be used as a vehicle for discussing engineering science issues and offers the possibility of introducing a mock trial similar to that developed by Bair [29]: "students exercise their analytical skills by learning sufficient geology, hydrology, and aqueous chemistry to write an expert opinion and defend it during deposition by opposing counsel". Such an exercise gives students a taste of the expert witnessing that they may experience professionally.

Writing exercises are another effective way to integrate ethics into technical classes. Possibilities include the following:

- Personal narratives: Asking students to write a narrative of some personal incident that involves ethics offers an opportunity for them to engage in self-reflection, a prerequisite for ethical analysis.
- Interview a professional: Have students interview a professional in their given field, avoiding potential conflicts of interest (e.g., relatives, friends, etc.). This will give them a sense of the role of ethics in the workplace.
- Professional codes: Develop exercises focusing on professional codes of ethics; Vesilind's [30] *Hold Paramount* has a number of very useful scenarios.

The items above are just a few examples of the many possibilities for classroom activities that can enhance student understanding of engineering ethics. Creative instructors can devise many different activities to emphasize the symbiotic relationship of engineering and ethics.

Resources

Instructors integrating ethics need to engage in self-development to acquaint themselves with the field, both methodology and content. While having a philosophy degree is not a prerequisite for teaching ethics, knowledge of the field certainly is. The Web-based resources listed below include cases as well as teaching materials, case commentaries, annotated bibliographies, publications, and digital materials. Note that these are limited examples; literally thousands of Internet sites offer advice and materials for teaching ethics in the context of technical classes.

The Case Study Collection at Illinois Institute of Technology (http://ethics.iit.edu/eelibrary/case-study-collection) offers cases in research and engineering ethics, in addition to an assortment of links to other case-based sites. The Center for the Study of Ethics in the Professions also maintains an extensive collection of codes of ethics, as well as informative publications on codes in general and application of codes to specific cases. If instructors require students to locate their code of ethics, the CSEP site has codes of conduct, engineering creeds, and statements of ethical principles from all of the major engineering organizations.

The Ethics Center at Texas A&M University (http://ethics.tamu.edu/) includes quantitative cases, developed as a result of a 1995 NSF grant, in chemical, civil, electrical, and mechanical engineering. In addition, the site also houses 33 different cases developed in 1992; cases are accompanied by commentaries by individuals who have published widely in the field of engineering ethics. Although a number of these are hypothetical, they correlate to real-life situations experienced by practicing engineers.

The Markkula Center at Santa Clara University (http://www.scu.edu/ethics/practicing/focusareas/cases.cfm) has enormous resources for teaching ethics in some 12 different fields; in engineering, its collection includes significant materials on Internet/technology and environmental ethics. In addition to printed materials, the site also includes video interviews with leaders in various areas (for example, Silicon Valley pioneers) and downloadable podcasts. The "ethical decision making" section has excellent information on various approaches—utilitarian, rights, fairness, common good, and virtue—as well as a very useful guide for making ethical decisions: "A Framework for Thinking Ethically." For instructors who are new to the field, this is a very helpful first source to consult.

Murdough Center for Engineering Professionalism/National Institute of Engineering Ethics (http://www.niee.org/murdoughCenter/index.php). Housed at Texas Tech University, these two centers collectively offer a wealth of materials on ethics across the curriculum, as well as study guides to the three NIEE-sponsored ethics videos: *Gilbane Gold*, *Incident at Morales*, and *Henry's Daughters*. In addition, the NIEE has produced a useful casebook, *Engineering Ethics—Concepts, Viewpoints, Cases, and Codes* (2008). The centers also offer various professional development courses and workshops in teaching ethics and ethics across the curriculum.

National Society of Professional Engineers, Board of Ethical Review (http://www.nspe.org/resources/ethics/ethics-resources/board-of-ethical-review-cases) includes real, but sanitized, cases that deal with issues engineers encounter in their professional lives, such as conflicts of interest, gift-giving/bribery, confidentiality, expert witnessing, and public health and safety, to name but a few. Cases incorporate all of the pertinent data, the BER's decisions and rationales, and citations of code violations. In addition, the Ethics Resources section of this site includes material useful for class, such as a true-false exam based on the NSPE Code of Ethics and various short videos focusing on issues in professional engineering. The NSPE also sponsors an annual essay contest for students and PEs throughout the country; the winner receives $1,000, a certificate, and recognition in *PE Magazine*.

Online Ethics Center for Engineering and Science (http://www.onlineethics.org/) is an immense repository of information managed by the National Academy of Engineering's Center for Engineering, Ethics, and Society. The site includes 495 cases, as well as case commentaries, scholarly articles, bibliographies, teaching resources, and ethics codes. Like the NSPE site, most cases are reality-based (those that are not are clearly labeled "hypothetical"), and many deal with larger societal concerns and responsibilities, such as the issues emanating from the aftermath of Hurricane Katrina, bioterrorism, and risk assessment. Especially useful are the historical cases, including the Tuskegee Syphilis Study, Love Canal, and the Tacoma Narrows Bridge Collapse, among others.

Discipline-specific cases are available on the websites of professional organizations or via local engineering examining board sites. In Oregon, for example, the newsletter of the Oregon State Board of Examiners for Engineering and Land Surveying includes a section on Investigation and Enforcement, which lists all infractions and sanctions for a specified period of time [31]. And, finally, the Association for Practical and Professional Ethics, an interdisciplinary group that focuses on applied ethics, has, for many years, sponsored an annual student competition, the Ethics Bowl. Modeled after the old *College Bowl* television program, teams of students representing schools from across the U.S. debate a variety of cases, ranging from water rights to sexual ambiguity to environmental issues to consumer safety. While many of the cases do not deal specifically with engineering, they are useful for introducing students to ethical thinking and modes of analysis. Cases for the past 14 years are archived at Illinois Institute of Technology (http://ethics.iit.edu/teaching/ethics-case-archive).

Conclusions

Ethics is a natural for integration into technical classes and, using a case-based method, is very effective for engaging students in a discussion of issues in the various engineering disciplines. As indicated by studies in the literature, cases are innately appealing, due to their narrative structure, and provide fertile ground for exploration. The emotional aspect of cases, especially those involving whistleblowing, augments student interest and facilitates knowledge acquisition [32]. Numerous resources for teaching ethics are readily available, and creative instructors can devise novel classroom activities that ensure the ethics material is relevant to course goals and objectives, while simultaneously linking it to professional life. Introducing ethics can result in classroom discussions that are vibrant, energetic, and meaningful.

Most importantly, integrating ethics into technical classes acquaints students with issues in professional engineering and reinforces Davis' [26] observation that ethics is part and parcel of the discipline, that thinking like an engineer is thinking ethically about decision making, responsibility, and the impact of those decisions. As Beder [33] states, "If engineers are to be more than technical functionaries in the next millennium, there is a need to provide young engineers with an understanding of the social context within which they will work, together with skills in critical analysis and ethical judgment and an ability to assess the long-term consequences of their work".

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Biography

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CRITICAL THINKING AND TECHNICAL DECISIONS

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Abstract

The world of organizational management including the Human Resource Management discipline holds the members of the legal profession in very high regard. The edicts issuing from the office of the general council in most organizations are taken as unassailable gospel. However the logical process which is the antecedent to this management approach fails, at times, to consider contemporary Critical Thinking doctrine. In this paper, the author proposes a more rational and level headed approach, capitalizing on the work of the paragons of the critical-thinking discipline; Richard Paul and Linda Elder. The author makes the case of rendering the decision-making process undertaken in every management endeavor as a juxtaposition to the Paul and Elder framework. A scenario from an organization in the construction industry is presented which illustrates the suggested revision to management's way of thinking.

Legal Issues Confronting the Critical-Thinking Manager: The Lay of the Land

In a large, heavy construction company presently engaged in the construction of a road project, the transportation superintendent (TS) reports to the Vice President (VP) of Operations that he is unable to move a piece of heavy equipment (an excavator) to a job sight as he was directed to do. He tells the VP that the equipment is oversize and that movement of this equipment on city roadways would require a permit from the city in which the move is to take place. The appropriate city office has been contacted and has declined to issue a permit because it places the heavy semi-trailer truck and large excavator on city streets during a period of high traffic. The transportation superintendent tells the VP that he is, thus, statutorily prohibited from moving the equipment.

The VP knows that work on the project will be idled until the excavator is delivered. The project is responsible for roughly \$8,000 in revenue for each day of operation. But the idling of the job has ramifications far beyond the mere loss of a day's revenue. For reasons relating to the project's critical path, it is a serious problem if the project is delayed. Against the protest from the transportation superintendent, the VP directs that the excavator be moved to the job sight as though a permit were in effect. The superintendent energetically cautions that a fine of as much as \$20,000 could be assessed if the move was detected by city police. "I don't want to break the law", declares the TS. Nevertheless, the VP insists that the move take place. He comforts the TS as he tells him, "You are not breaking the law, I am."

Critical-Thinking Application

The VP has to make a decision which must fall into one or the other of two fairly well defined categories. He could adhere to the city statute and risk turning the project into a loss. Or he could move the excavator, save the project but risk a very heavy fine.

Information as an Element of Decision Making

Managers manage risk. That is to say that as they move through their day, they are confronted by decisions in which they must select from a range of options. Each of the options, to some extent, presents the manager with a risk-versus-gain scenario. The manager is weighing potential loss with potential gain. He must properly understand the losses including the seriousness of the loss and the likelihood the loss will occur. He must also understand the potential gain and its associated likelihood. In order to make the right decision, more correctly, in order to avoid making the wrong decision, the manager needs information about the decision. In this paper, the author shows how this process fits precisely within the framework established by Paul and Elder [1].

Nearly all contemporarily accepted decision-making models have a commonality: the first step is problem identification. No decision can be properly made unless all of the alternatives are accurately understood. Betsch and Glockner [2] encourage managers to start the decision-making process by understanding all of the alternatives. The decision maker must embarks on an exhaustive search for information. Only when the alternatives have been fully comprehended, along with all of the ramifications, may the information search stop. This author recognizes that, in some cases, the length of the information search process is limited by the urgency of the situation. The present example was chosen both for its simplicity and for the fact that the decision must be made quickly.

The decision to be made by the VP appears relatively simple. That is to say that the information is limited in volume and seems to fully describe the situation. The VP's options are limited to moving the excavator or not moving the excavator. But he must decide quickly because the job is idled already. The facts are as follows:

a) An excavator is needed on a project in order for the project to continue
b) If the project is idled for any reason, the company could incur great loss
c) Movement of the excavator could expose the organization to a large fine

The door is now open to Paul and Elder's [1] conceptualization of critical thinking as they posit that information is one of the eight elements of thought. Lee and Dry [3] hypothesized that, as managers make decisions, they consider two things about the information that is presented to them. Primarily, decision makers consider how accurate (H1) they think the information is. Again, the reader is invited to consider Paul and Elder, who affirm that accuracy is one of the Universal Intellectual Standards. This is the basis for the first hypothesis presented in that study. In the second hypothesis, the aforementioned authors stated that the decision maker will also consider how frequently or how often the information is presented.

Through Lee and Dry [3], the decision-making process becomes more complex because information processing becomes more complex. Their H1 invokes the concept of accuracy. The VP must consider potential inaccuracies in facts a, b, and c. One need not be familiar with heavy construction in order to enumerate the potential inaccuracies. But for penetration consider for example, under fact c):

- How likely is it that the movement of the excavator will be detected?
- How likely is it that the full fine of $20,000 would be assessed?
- If the full fine is assessed, could an appeal reduce the fine?
- Is it possible that, in addition to writing a citation for the illegal move, that the police officer could impound the excavator and truck?

The first hypothesis (H1) is self-evident, but the second (H2) requires a bit of exploration to solidify understanding. In their study, Lee and Dry [3] demonstrated that the likelihood that a decision maker will permit a bit of information to influence their decision is directly proportional to the number of times they are presented with the information. In the construction company example, H2 is operationalized as the reader considers the possibility that the transportation superintendent comes into the VPs office with declined permit situations every day of the week. Thus, in the eyes of the VP, the superintendent has assumed the role of "Chicken Little". According to the conclusions emerging from Lee and Dry's study, the frequent messages, in this case the repeated reports of an inability to move a piece of heavy equipment, will influence the decision-maker's choice just as occurred with "Chicken Little's" incessant kibitzing.

In addition to accuracy of information and frequency of the message, decision makers will likely consider the degree to which the information comports with their view of the issue, as they use the information to reach their decision [4]. Stakeholder theory [5] presents a model in which the organization is understood as a politico-economic system. In this system, each interest group, or entity will view a given decision and the associated range of options against their own frame of reference. For simplicity, three groups in the construction industry example are defined: the policy maker (the VP), the information provider(s) (one of which is the transportation superintendent), and the stakeholders, which is a relatively non-descript group of individuals, who will be impacted by the VPs decision.

It can be said that the transportation superintendent is assuming a position akin to that which would be embraced by an attorney for the organization. This is true since the TS is advising action based solely upon a statutory position. He is telling the VP what the law says. This is very similar to a position that would be embraced by an attorney. On the other hand, the VP's responsibility to guard the interests of the greater range of stakeholders may impel him to an alternate course of action. The VP assumes the role of the "policy maker" in this scenario. As such he cares about long -term profit and the continued health of the organization which will not likely hinge on a fine of $20,000, especially given that the fine may or may not have to be paid. On the other hand the long-term interest of the organization would very likely be negatively impacted by an unprofitable project.

The Nature of Information Processing

It is incumbent upon the policy makers to carefully consider the information received as they make their decision. The organization has been described [5] as a "politico-economic system." In this example organization the group that Freeman [5] refers to as the stakeholders is joined by two additional groups, the policy makers and the information providers. Freeman portrays the organization as "an entity enmeshed within a set of interactions between parties inside the organization." The different groups emerge, attempting in their own interest to influence the functioning of the organization in a way they perceive as legitimate. In this case, the term legitimate is defined by both the policy makers and the stakeholders as meeting the stakeholder's needs and matching the stakeholder's viewpoints. This may or may not be the interpretation of the information providers. Freeman defines stakeholders as "the ensemble of parties who can have an effect on the organization or who can be affected by it.

Legality and the Decision-Maker's Choice

The author further notes that groups will attempt to influence the decision such that it is legitimate, as the members of the group perceive legitimacy. It frequently happens that one of the groups which has an interest in the outcome of the decision is a group which can be referred to as the "legal" interest. In large organizations, this group might include the general counsel for the organization. In small organizations which cannot rationalize a permanent group that contributes legal information, the group includes attorneys on retainer. This group will very likely equate legitimacy with the legality of a point in question. However, this equality may not be universally perceived by members of the various groups. Certainly, to the legal Group, legality is the primary consideration. Organizational lawyers may look at themselves as benevolent dictators, [6] attempting to mold their society in accordance with their own view of ethics.

It must be emphasized that, in the model suggested by Freeman [5], there is one and only one policy maker. That is to say that, of the three groups, the responsibility for making decisions rests solely within one group, that of the policy makers. That is their function. They cannot abdicate the responsibility nor can they evade accountability. The policy makers must demand that the other groups remain within their functional boundaries. Information Providers only provide information and stakeholders only reap the benefits or pay the consequences of the decisions.

When the information providers include persons from the legal community such as representatives of the general counsel for the organization, two potential problems may arise. Both of these situations stem from the fact that in the contemporary stridently legalistic culture, attorneys are placed on a pedestal. They are assumed to know everything there is to know about the law. This assumption is obviously wrong-minded. To debunk, it need only be considered that in every court case, half of the attorneys are interpreting the law incorrectly. Another misunderstanding rests in the assumption that when an attorney is providing advice, that advice must be carried out to the letter. This approach, in effect, transfers the decision-making function from the manager (the policy maker) to the attorney (the information provider). Since the attorney likely has only one point of information (the law) and the manager has many points of information (the law plus many other points) the decision-making responsibility must remain with the manager.

As regards the comparison of validity versus legality, it bears repeating that the relative importance of these two aspects of a situation is not universally accepted as being equal. Two things impact this perception. They are:

a) The question of who is doing the perceiving
b) The question of when the issue is being raised

The first instance proposes that different groups will perceive different things to be important to the decision at hand. To those in the legal group it will be absolutely unacceptable to select an option which is potentially actionable or illegal. However, if that viewpoint restricts the options available to the policy makers such that they are left with only those which are tremendously expensive to implement, the policy makers may be forced to bend the rules simply to permit the organization to survive. As a very real part of stakeholder theory, each member of Freeman's system will try to protect his or her interests by attempting to influence management decisions [4].

In effect, members of the three groups gain credibility when decisions go their way. So the legal group may present an opinion. If the policy maker decides the issue based solely upon the information provided by the legal group, the credibility of the legal group is reinforced. In some cases, the legal aspect of the decision is sufficiently compelling that the information originating with the legal group must be the sole consideration. But it is the policy maker who must make the decision and, hence, it is up to the policy maker which information guides the decision. In decisions that have a legal component, the policy makers determine the legal framework, while the legal experts merely provide information to the policy makers who will establish the framework.

Re-examination of the construction project example above is helpful. The legal group (in this case, that group includes only the transportation superintendent because he is speaking from a legal standpoint.) would tell the VP (the policy maker) that he must always follow all city ordinances. This opinion would be based upon the belief that it is never permissible to break the law. The policy maker has the right to accept or dismiss the superintendent's advice. But should the VP decline to take the advice, there is no reason for the superintended to be offended, or to become indignant. He must simply assume that the policy maker has information to which the superintendent as a single information provider is not privy.

The Universal Intellectual Standards Applied to the Information

In this paper, the author suggests a basic and proven technique in decision making. The decision-making process must adhere to the tenets of critical thinking. Under critical thinking, a decision cannot be made until a great portion of the information is received. As the connection between critical thinking and decision making is considered, reference again to the work of Paul and Elder [1], two major contributors to the field must be made. According to them, information is one of the "elements of thought" and, hence, is an essential component in the making of sound decisions. These authors gave us some Universal Intellectual Standards which should be applied primarily to the information component of every decision. The Universal Intellectual Standards may be helpful in informing the VP's response to the problem. The intellectual standards are summarized below, with an associated description of the way they should be understood by those who are parties to the VP's decision:

Clarity:	The extent to which the information is understandable
Accuracy:	The extent to which the information is properly descriptive
Precision:	The extent to which the information is expressed in terms of resolution
Relevance:	The extent to which the information should be part of the decision-making process
Depth:	The extent to which the information presents all possible effects in detail
Breadth:	The extent to which the information comprehensively covers all of the possible effects

An examination of these Universal Intellectual Standards compels the acknowledgement that the groups involved in the decision—the policy makers, information providers, and stakeholders—will view the information from differing viewpoints. To illustrate, the standard entitled accuracy is employed. To the superintendent, it is accurate to state that if he moves the equipment without a permit, the organization will be fined. He views that as the worst possible outcome and totally unacceptable. But from the viewpoint of the VP, it may not be completely accurate that a fine will be levied, since it assumes that the truck driver will be apprehended. Further, being fined for the offence may not be the worst possible outcome; it could potentially be very acceptable in comparison with other possibilities.

To arrive at the right decision, the policy maker must consider the legal input along with all other information which informs the decision. Failure to do so is falling into a trap which scholars encourage the policy maker to guard against. Adjibolosoo [7] refers to the pitfall as "the indiscriminate use of regulations and policies." That researcher is not advocating lawlessness. Clearly, if a decision is informed by the law to the extent that there is a potential for a law to be broken, the organization is compelled to proceed with a full understanding of the ramifications of that eventuality.

Other scholars encourage the legal group, when acting as the information provider, to operate within the legal advisor role in a way that is subservient to the VP's role as an advocate for the organization [8]. As he or she provides an input to the decision-making process, he or she must acknowledge both roles in their proper perspective. Policy makers are frequently pulled in different directions [9] as they try to adhere to an overly restrictive interpretation of the law, while simultaneously guarding the good of the organization.

The Synergy in the Groups

In the decision-making process, a manager has a responsibility to consider as much information as time permits. Legal information is one of the bits of information he must consider. However, that manager must acknowledge that the legal information is not the only bit of information and, in many cases, it may not be the most important bit of information. The manager is well-advised to apply critical-thinking guidelines as he views information as one of the elements of thought. He should further assess information using Universal Intellectual Standards.

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Biography

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PLUG AND PLAY MICROELECTROMECHANICAL SYSTEMS (MEMS) TECHNOLOGY INTO YOUR ENGINEERING AND TECHNOLOGY PROGRAMS

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Abstract

Advanced engineering and technology programs are under constant pressure to continually evolve and engage students. The MEMS (microelectromechanical systems) Industry has been growing at a rapid rate, 10-15% CAGR, fueling a demand for additional technicians and engineers. Developing new curricula to support these new technologies is time consuming and costly for education departments. The Southwest Center for Microsystems Education (SCME), a National Science Foundation (NSF) funded Advanced Technological Education Center (ATE) (DUE #1205138), provides support, training, mentoring, and materials targeting undergraduate technology programs: 2-year, 4-year, and secondary STEM programs.

In this paper, the author presents overview of SCME's wide range of modular educational resources that may be adapted, modified, and inserted into existing programs or used to create new course and program offerings. SCME has over 40 learning modules, multi-day cleanroom workshops at several sites, online streaming animations, lectures, archived webinars, and a dozen hands-on classroom kits available to enable evolving technology and STEM programs to maintain relevancy and allow students to upgrade their skills. These materials include topics ranging from cleanroom protocol and safety, MEMS history and applications, BioMEMS, and microsystems fabrication. Also provided here is an overview of SCME educational materials, hands-on kits, and web resources. SCME encourages collaborations and can support professional development.

What are MEMS?

Microelectromechanical Systems (MEMS) are small systems consisting of devices fabricated at the micron scale. MEMS typically fall into two categories, sensors and actuators. Actuators include devices such as inkjet print heads, digital mirror micro displays, and microfluidic pumps. MEMS sensors measure inertia, pressure, chemical, and magnetic parameters, for example. Inertial sensors are used in automotive crash-bag deployment, safety and navigation systems, heart pace-makers, and smartphones. They keep track of motion when global positioning system (GPS) signals fail (navigating in buildings or within cities with high-rise buildings). These also provide data used to adjust the heart rate in a pace-maker and inputs for gaming applications.

Micro-mirror-based display systems are dominated by the Texas Instruments digital micro-mirror device (DMD), part of the digital light processing (DLP) system. These chips consist of one to eight million individually controlled tilt mirrors, each measuring between 14 to 20 microns square. These system are found in mobile-phone projection systems and full-cinema digital display technologies covering a wide range of display resolutions. The most prevalent micro fluidic device is the inkjet print head. These MEMS systems consist of microfluidic pumps, channels, and nozzles, which deliver micro droplets at high rates over large areas to produce photographic-quality images on paper. Inkjet print heads were the #1 MEMS devices in the early 2000s and still make up a large portion of the MEMS market. HP is currently the #4 highest MEMS manufacturer with over $600 million in revenue in 2012.

Pressures sensors were arguably the first high-volume MEMS device. Kulite, one of the leaders in micro-pressure sensor technology, was founded in 1959 by Dr. Anthony Kurtz, and was the first commercially available source of silicon strain gauges [1]. Today, this $2 billion market segment provides micro-pressure sensors found in aviation, automotive, consumer, and medical applications. Bio-medical microelectromechanical systems, or Bio-MEMS, are one of the fastest growing segments in the MEMS industry. These include a variety of therapeutic applications from artificial retinas, cochlear implants, neural implants, glucose sensing, insulin dispensing, and pace-makers to diagnostic lab-on-a-chip applications including DNA micro-array and point-of-care (POC) systems. An increasing number of MEMS devices includes the micro-cantilever component. Cantilevers are part of inertial systems, chemical sensor arrays, memory arrays, atomic force microscopes, and radio frequency (RF) switches. There are hundreds of MEMS products and applications that can be utilized to engage undergraduate engineering or technician students. SCME has put together a series of learning modules, hands-on kits, videos, and animations to support STEM education utilizing MEMS as the delivery vehicle.

How MEMS are Made

MEMS differ from computer chips as they not only move electrons but also small mechanical components. MEMS sensors need to connect with the environment requiring fluidic, gas, light input/output channels, as well as electrical connections. MEMS fabrication includes the typical complementary metal oxide semiconductor (CMOS) materials and processes found in the computer chip industry, but also other processes such as LIGA (Lithographie Galvanoformung Abformung), micro plastic injection molding, electroplating, electrostatic discharge deposition, laser ablation, and micromachining. SCME has included materials which describe three of the most-utilized MEMS process categories: surface micromachining, bulk micromachining, and LIGA.

Surface micromachining is one of the most-utilized technologies for producing inertial sensors, mirror devices, and the like. This process is very close to that used in CMOS semiconductor fabrication and is based on building the MEMS devices on a crystalline silicon substrate. The devices are made by depositing alternating patterned layers of structural and sacrificial layers. The sacrificial layers are removed at the end of the process to release the moving parts. In semiconductors, the dielectric layers between the conductive layers are not removed. Bulk micromachining is used to remove relatively large amounts of starting material, for example, when making pressure sensors, where there is a need to create a reference chamber by removing crystalline silicon through anisotropic wet etching. It is also used to create free-standing cantilever arrays or RF micro switches. Channels for microfluidic applications and through-chip vias (holes) are also made using bulk micromachining methods.

LIGA was first developed in Germany to produce high-aspect-ratio micro parts and became commercialized in the 1990s. This consists of exposing a relatively thick material, such as PMMA (polymethyl methacrylate), with a highly collimated x-ray source (synchrotron radiation), subsequently developing out the un-exposed areas resulting in a high-aspect ratio mold. This mold is subsequently filled with metal through an electroplating process. The metal form is removed from the mold and can be used a stamp or as the actual part. Micro, high-aspect ratio stamps are used to repeatedly make microfluidic channels in plastic, for example.

MEMS: Industry Growth and Need

Microsystems, including MEMS, continue to grow at double-digit compounded annual growth rates (CAGR), as predicted by Yole Développement Group, the leading microsystems market research company. MEMS chips are found in biotechnology, transportation, homeland security, and consumer product applications. Common examples include crash-bag sensor systems, inkjet print heads, DLP televisions and projection systems, and microphones and motion sensors found in smartphones, remote controls, biometrics, and game controllers.

The most ubiquitous of modern gadgets is the smartphone, with the most advanced having over 15 MEMS devices including, but not limited to, accelerometers, gyroscope, electronic compass, pressure sensor, BAW filter, BAW duplexers, RF switches, TCXO oscillators, micro mirror display projection, CMOS image sensor, auto-focus actuator, front and rear cameras, ALS, proximity sensors, and micro displays with touch interaction. MEMS cell phone unit shipments comprised 45% of the total market in 2010 and the number is expected to grow to 50% by 2015. Conversely, the automotive market share has dropped from 75% of the MEMS devices shipped in 2005 down to 30% in 2010, and is expected to be only 20% of the market in 2015 [2]. The overall MEMS market continues to grow, even in the current economic downturn, as the younger generation considers smartphones a necessity, not a luxury; being socially connected is more important than owning a car or a home [3]. This also supports the concept of integrating engaging microsystems educational materials in order to enhance STEM core classes at the high school level.

In addition to enamoring students with the small devices within the smartphone, BioMetrics is another engaging topic for students. It is predicted that, in the near future, wireless MEMS-based devices "in your home will keep tabs on your medical status every day, as you go about your daily routine" [4]. Biometric sensors and ambient monitoring will become commonplace and could save up to $6.4 billion annually for the estimated 1.27 million U.S. patients at risk of heart failure through reduced hospital admissions:

> We are at an inflection point now, where wireless connectivity, personal cellular devices, pervasive sensing technologies, social networks, and data analytics are mature enough to make wireless medicine a reality. And there is a will as never before to find a way to reduce crippling health care costs. Already, new devices allow diseases like diabetes and chronic heart failure to be closely monitored outside the doctor's office; tools for tracking chronic kidney disease and a variety of lung disorders are sure to follow. Eventually, most health care will occur not during occasional visits to doctors' offices, clinics, or hospitals but continuously, during ordinary activities in people's home. (Wireless Health Care. January 18, 2015)

In 2011, the overall MEMS device market reached $10B followed by a 10% growth in 2012 to over $11 billion and is expected to continue this 10% growth rate in 2013 [6]. The 2012 MEMS growth is contrasted by the 2% contraction of the semiconductor industry in 2012. Inertial sensors overtook display and inkjet print technologies, while individual MEMS microphone companies saw a growth rate of 20-90% in supplying the smartphone industry. Inertial sensors have moved from the classic 3-axis stand-alone units to 6-axis integrated systems. Nine-axis accelerometer systems are on the horizon for wide-spread integration. The overall accelerator chip size has dropped from 3.5x5 mm to 1.6x1.6 mm, between 2009 and 2014. Even though the price per accelerometer has dropped below $1 in 2013, the overall accelerometer market share is $3.5 billion out of the $11 billion total 2012 market [7], [8].

Not only are MEMS found in consumer products, but also in biomedical applications. These systems make use of a variety of micro- and nano-scale manufacturing processes and materials outside of those found in the semiconductor industry. The BioMEMS market continues its rapid growth resulting in the microfluidic sector growing from $1.6 billion in 2013 to a projected $3.6 billion by 2018 [9]. The total MEMS device market for 2011 was projected at $10 billion and is expected to grow to $19.5 billion by 2016, at an average of 14% compounded annual growth rate (CAGR) [10]. Most recent projections indicate a 12-13% CAGR for the overall MEMS market with an expected $22.5 billion, 23-billion-part market by 2018 [11].

As these sources show, the MEMS manufacturing industry is growing at a rapid pace, which should translate into a higher demand for tech-educated graduates. SCME is focused on technician education and has tasked itself to survey industry and determine the overall demand for technicians. The survey was completed in 2012. Over 60 small-, medium-, and large-scale enterprises contributed to the survey, covering a range of industries including MEMS, semiconductor and capital equipment/support companies. The results of this survey indicated that all sectors planned to increase hiring into new positions by 10-100%. The larger, established semiconductor fabrication facilities planned to hire 10%, evenly split between new positions and replacement, while small, MEMS startups typically planned to double their tech staff in two years made up of mostly new positions [12]. This supports the evolution of tech and STEM programs to include microelectromechanical systems (MEMS) elements.

SCME has an industry advisory board made up of small-, medium-, and large-scale enterprises spanning semiconductor and microsystems industry. Meetings are held one to two times per year to seek industry input as well as review educational materials.

MEMS in STEM: SCME's Approach

SCME strives to increase educational capacity to produce technologists skilled in assisting microsystem research, design, and commercialization activities. SCME's regional center responds to the need in the rapidly emerging microsystems industry for the adaptation, development, and dissemination of educational materials and professional development for educators. To support these activities, SCME embraces a continuous improvement methodology, adjusting to the needs and requests of its stakeholders: students, educators, and industry – the key is to be constantly evolving. SCME has developed a series of educational resources to support the building of the technician's capacity for the microsystems industry. The skills and knowledge required by technicians have been identified by a series of industry meetings, surveys, and experience of the PI gained while in the semiconductor industry. It was decided early on to leverage the fabrication process of a simple micro pressure sensor as a guide to constructing a series of educational modules. The essential question "What does a technician need to know to fabricate and understand the workings of a micro pressure sensor?" was used as a guide. This process resulted in a series of topics:

<u>Cleanroom Fabrication Process</u>
- Photolithography
- Dry and Wet Etch
- Thin Film Deposition & Oxidation
- Materials

<u>Electronics</u>
- Wheatstone Bridge
- Transducer principals

<u>Safety</u>
- Hazardous Materials
- Chemical Lab Safety
- Material Safety Data Sheet
- Interpreting Labels
- Personal Protective Equipment
- MTTC Safety Course

As these core components were written, and courses developed, it was found that other modules needed to be developed to answer the following questions:

<u>What are MEMS and where are they used</u>?
- Application Overview

- BioMEMS Overview

How do they Work?
- Micro cantilever
- Micro pumps

What is the history of microsystems?
- History of MEMS

SCME realized early on that BioMEMS was a large, rapidly growing segment of the MEMS industry. Leveraging the Bio-LINK ATE National center, SCME collaborated with several bio-tech subject matter experts to create a series of Bio-MEMS-related topics covering a suite of BioMEMS topics:

- Overview
- Applications
- DNA Overview & Microarrays
- Bio-molecular Applications
- Clinical Laboratory Technics
- Diagnostics & Therapeutics
- Environmental and Bioterrorism
- Regulations

In addition to the above series of topical learning modules, SCME has created supplemental materials, including collaboration on two films by Carranza [13]:

1. *MEMS: Making Micro Machines*
2. *Nanotechnology: The World Beyond Micro*

SCME has created supporting educational modules which include background information activities that go along with the videos and also the script. Additional supplemental materials include videos and animations that can be found on the SCME website [14], and the Microsystems Education YouTube Channel [15]. SCME, in response to educator requests, has created a series of hands-on kits designed to enable teachers to bring microsystems topics to the classroom. These activities are part of the learning modules.

SCME Educational Materials Resources

NSF funding has fostered the creation and foundational development of SCME as a fully functioning ATE regional center of excellence with regional and national impacts, providing a sound basis for continued expansion of its local, regional, and national outreach and dissemination efforts. SCME has established competencies in the development and adaptation of modular, readily updated, and easily disseminated educational materials for the microsystems field. These materials are organized into units referred to as SCOs (Shareable Content Objects). The development process is loosely related to the Shareable Content Object Reference Model (SCORM), first conceived by the Department of Defense in 1999, as part of the Advanced Distributed Learning Initiative [16], [17]. It should be noted that the SCME modules are not fully "SCORM-compliant" but were developed to be used as stand-alone learning modules.

Each plug-and-play learning module consists of several SCOs: 1) PKs and primary knowledge; 2) FA and assessments; and, 3) AC activities (see Figure 1). The ACs include homework and lab units, as well as hands-on kit activities. Figures 2 and 3, taken from the Microcantilever Model kit, connects the experiment to microsystems applications. Learning maps assist the educator in developing lesson plans from which the instructor can utilize a series of modules to build an introduction to MEMS course, for example, or utilize one module or any of its components, to add emerging technologies content to an existing course. The Wheatstone Bridge Micro Pressure Sensor module is often integrated into electronics courses.

Figure 1. Example of a Learning Module Cover with a Listing of Included SCOs

The written educational materials can all be found on the SCME website. Educators are encouraged to peruse the SCME website and create an account. The website provides resources both for educators and students. Every one of the over 40 educational learning modules consists of both Instructor and Participant (student) guides. The instructor guides are available to registered users and include notes, answers to activities and assessments, as well as PowerPoint presentation files. Registered users can also access the original word documents so that they can modify these lessons to meet their needs and the needs of their students. There is no charge for access to these downloadable materials.

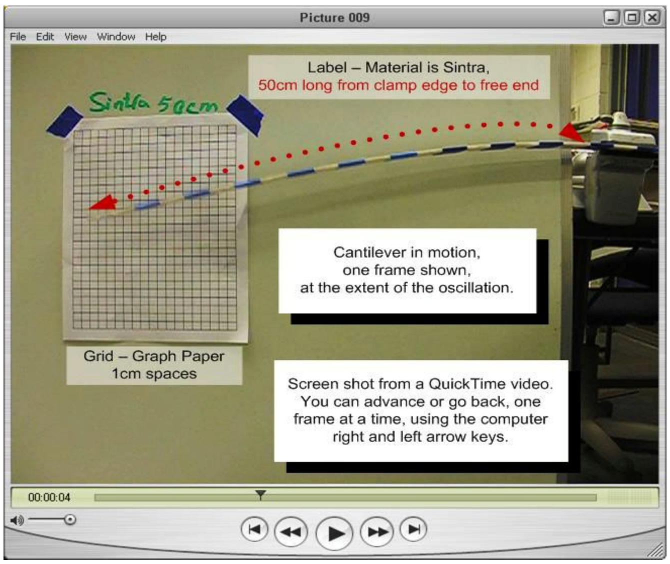

Figure 2. Image of How to Acquire Frequency versus Mass Added (microcantilever model kit)

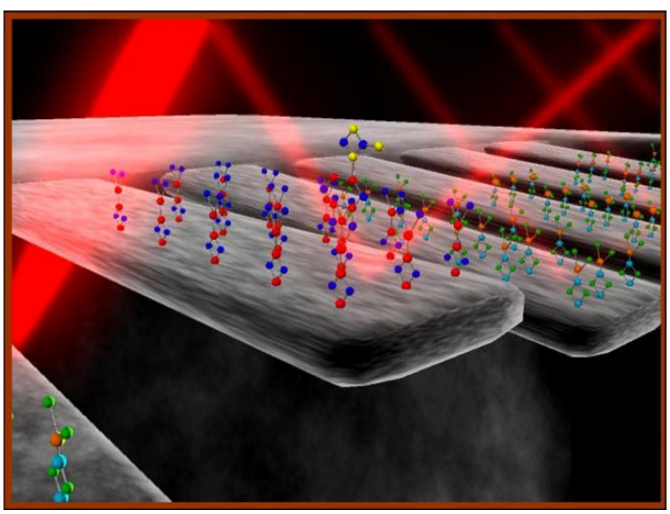

Figure 3. Screen Shot from one of the Supplemental Microcantilever Videos used to Describe the Operation of a Chemical Sensor Array

Key resource links

- Home Page - http://scme-nm.org
- Educational Materials [18]
- YouTube Microsystems Education Channel [15]
- Hands-on Kits [19] and Kit Store [20]

Listing of available hands-on kits

1. Modeling a Micro Pressure Sensor
2. Learning Microsystems through Problem Solving
3. LIGA Micromachining-Lithography & Electroplating
4. Surface Micromachining – Liftoff Process
5. Bulk Micromachining – An Etch Process
6. Micro Pressure Sensor Process
7. Science of Thin Films
8. Crystallography
9. Microcantilever Model
10. DNA Microarray Model
11. Nanotechnology: World Beyond Nano
12. MEMS: Making Micro Machines

Professional Development Resources

The Center also provides professional development resources and opportunities to educators. These include half- to full-day workshops at our site and partner sites, conferences, and webinars. In addition, a 3- to 5-day Pressure Sensor workshop is available, whereby participants go through an intensive training regimen which includes cleanroom experiences in Safety and Protocol, and Fabrication processes. In parallel, participants participate in classroom workshops to learn how to bring these concepts to their students in the classroom. Several of the SCME kits are utilized in these multi-day pressure sensor workshop classroom sessions. Figure 4 was taken from a workshop that included instructors and community college students; participants are shown displaying the wafers that they produced. Figure 5 is a magnified view of both the front and back surfaces of the final product. On the left is a view of the reference chamber from the backside of the wafer through the anisotropically etched crystalline silicon, where one can also see the silicon nitride membrane and Wheatstone bridge circuit. The right-most image is a front-side wafer view showing the sensing circuit being probed.

More recently, SCME is in the process of creating a series of online short courses modeled after its learning modules and kits. The online courses can be customized for individual organizations and/or educator needs. This will provide additional support to increase the utilization rate of SCME materials. Educators will be able to “flip the classroom” by assigning units to their students and leveraging SCME-created lectures, videos, animations, and online resources. The short courses are also used to prepare participants for workshops. These online course resources utilize an open-source platform “MOODLE” plugged into the “JOOMLA!” website content management system, making it very cost effective for all stakeholders.

Figure 4. Pressure Sensor Workshop at the University of New Mexico's Manufacturing Training and Technology Center

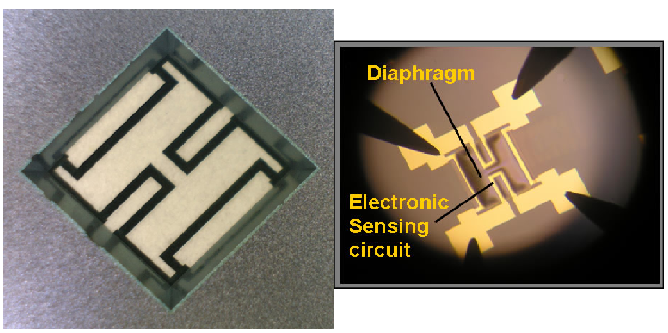

Figure 5. Close-up View of the Completed Micro Pressure Sensor

Summary

MEMS typically contain an integrated set of otherwise disparate technologies (e.g., mechanics, fluidics, materials, energy, photonics, biology, etc.) that span the entire spectrum of STEM components. Moreover, MEMS is one of the last bastions of hands-on learning, as colleges and universities move to replace physical labs with computer stations and simulators. The challenge is to engage and develop an agile, well-educated workforce to support this business growth and range of needed skills.

In order to continually evolve and innovate STEM and technology programs, conventional technical high schools, colleges, and universities have the responsibility to seek out and implement new, innovative, emerging, and technically engaging educational materials for their students. Given today’s economy, these educational organizations may not have the resources (financial as well as trained educators) to teach technically advanced topics. Over the last twenty years, the National Science Foundation (NSF), through its Advanced Technological Education (ATE) program, has funded many ATE centers across the country to advance the technician-level workforce in the U.S. One of these centers is the Southwest Center for Microsystems Education (SCME) located at the University of New Mexico.

The SCME website, http://scme-nm.org, has all of the written materials available for free download. Teachers are encouraged to register and gain access to additional instructor materials and resources. The kit store allows one to order kits online at a reasonable cost; all proceeds are used to replenish the kit stock. Webinars are also given and there is a series of over a dozen archived webinars available. Workshops are provided at the UNM site as well as partner institutions, which are generally free of charge. The annual Micro Nano Tech Conference is co-sponsored and hosted by SCME and the Nano ATE Centers (NACK, Nano-Link, SHINE, NEATEC) as well as MATEC. All of these centers also have a vast set of educational materials available to the innovated educator [21], [22].

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Biography

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USE OF A DELPHI STUDY TO IDENTIFY LEARNING OUTCOMES FOR AN ENGINEERING AND TECHNOLOGY PUBLIC POLICY CURRICULUM

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Abstract

The purpose of this study was to identify learning outcomes for an Engineering and Technology Public Policy (ENTPP) undergraduate curriculum. A pilot study and a three-round Delphi study were used to identify the ENTPP learning outcomes presented here. The Delphi study for this research consisted of a sequence of three surveys: one open-ended questionnaire to provide a list of possible ENTPP learning outcomes and two sequential rating questionnaires. The intent of the surveys was to gain a consensus around which ENTPP learning outcomes to include in an ENTPP curriculum. The first sequential ratings questionnaire was derived from the open-ended survey and a literature review. The second ratings survey items were presented to the participants in ranked order based on the results of the ratings of each item/outcome from the prior sequential rating survey. The results of the second sequential rating questionnaire determine participants' priorities of the outcomes for inclusion in a curriculum.

Participants included instructors or curriculum designers from colleges that had a graduate program in engineering and public policy; instructors or curriculum designers from colleges that had engineering and ethics courses; current or past local, state, or national politicians or lobbyists; engineering faculty members having a history of influencing public policy; faculty members teaching political science content; and, engineering or technology alumni involved in public policy creation and/or implementation. Qualitative methods were used to analyze the results from the open-ended questionnaire in the Delphi study. Descriptive statistics (mean, mode, and standard deviation) were used to analyze the results of the ratings surveys. The study yielded forty-five ENTPP learning outcomes that could be used in an undergraduate ENTPP curriculum.

Introduction

This study was undertaken because engineers and technologists are not normally cross-trained. In particular, those in the social sciences are not trained to think about technologies—particularly new, emerging, and converging technologies [1]. Engineers and technologists not typically trained in the need for public policy to limit the technologies' potential damage to the public. As innovators of technology, engineers and technologists need to become more involved in helping to shape public policy [1]. This study was intended as a practical application of the findings derived from that study.

Learning Objectives

Learning objectives are the topics, skills, and subject content foundations that provide the bases of what the instruction is attempting to achieve. Learning objectives are usually given to students in writing and may be referred to in connection with assignments and assessments. Documenting objectives provides the student and instructor with the expectations of the course/curriculum [2]. Learning objectives should be derived from the body of knowledge to be learned and the existing scaffolding of previous student learning. Learning objectives can be placed in one of three categories: cognitive, psychomotor, or affective domains.

- The cognitive domain "includes objectives concerning information or knowledge, and thinking- naming, solving, predicting, and other intellectual aspects of learning" [2]. This is based on Bloom's taxonomy, in which the cognitive domain comprises six levels: knowledge, comprehension, application, analysis, synthesis, and evaluation [2].
- The psychomotor domain concentrates on learning objectives that require physical skill and coordination. For this domain Kemp looks to Anita Harrow's 1972 work which identifies the six classes of physical behavior as reflex, basic fundamental movements, perceptual abilities, physical abilities, skilled movements, and non-discursive communications [3]. For example, a teaching objective in this domain could be learning to fly in a flight simulator.
- The affective domain addresses attitudes and emotions. Some attitudes and emotions are challenging to identify by observing behaviors, and even more challenging to measure [2]. An example is developing a positive attitude toward writing. Over time it may be difficult to determine if a student has simply improved technical expertise or has developed an appreciation for writing.

When writing learning objectives, the questions that should be asked about each objective are: “How well?” “How much?” “How accurate?” “How complete?” and “In what time period?” [2]. The outcomes of interest in this study are grounded in the affective and cognitive domains.

Desired Learning Outcomes for an Engineering Technology and Public Policy Curriculum for Undergraduates

A review of the literature provided no direct answer to the question, “What are learning outcomes for an engineering technology and public policy (ENTPP) curriculum?” With a lack of a body of knowledge to answer the question, a Delphi study was formed and conducted to provide answers. The Delphi is a reiterative research method used to refine the opinions of subject matter experts and stakeholders to arrive at a consensus concerning the items under study. The method’s application in curriculum development normally utilizes a series of surveys (typically three rounds) to distill experts’ opinions and to achieve consensus. The first round consists of open-ended questions, with rounds two and three consisting of ratings-type surveys [4]. The Delphi study’s first round open-ended questions are derived from the literature review, subject matter experts, and stakeholders [5]. An open-ended survey allows new thoughts and themes to develop that may not have emerged in the literature review and interviews.

Following the literature review, and to initiate this study, a pilot focus group of stakeholders and subject matter experts were polled and/or interviewed to identify constructs that could be included in an ENTPP undergraduate curriculum. These initial constructs were needed to develop the first round of open-ended questions for round one of the Delphi study. The subject matter experts targeted were:

- Instructors or curriculum designers for engineering and public policy.
- Current or past local, state, or national politicians or lobbyists.
- Engineering faculty members having a history of influencing public policy.
- Members of ABET, the accrediting body for engineering disciplines.
- Engineering or technology alumni involved in public policy.
- Faculty members teaching political science content.

The first round of the Delphi study was issued to a group of 555 subject-matter experts. These questions asked what students should know about each of the constructs and to identify any missing constructs that should be included in an ENTPP undergraduate curriculum. Round one yielded 167 comments from 26 respondents. This represents a response rate of 4.7%. These comments were collapsed into 55 possible ENTPP learning outcomes after a content analysis review. The 55 possible ENTPP learning outcomes were restated in common language (e.g., “Students should understand…”) and placed in the round-two Delphi ratings survey.

Using a four-point rating scale, the round-two Delphi survey asked the respondents to indicate for each item (learning outcome) whether they strongly disagreed, disagreed, agreed, or strongly agreed that the item should be included in an ENTPP curriculum. Round two had 25 respondents from the originally identified study group. This represented a 4.5% response rate. Analysis of the round-two survey resulted in the elimination of 10 items from further consideration. These items were eliminated due to a standard deviation score of 0.75 or higher, which, per the Delphi Method literature, indicated a lack of consensus concerning that item. No items had a mean score of 2 or less, which would have indicated agreement that the item should not be included [4]. The remaining 45 items were placed in the round three survey.

Using the shortened list, the round-three survey asked the same question as in round two: Should each item be included in an ENTPP curriculum? The round-three rating scale ranged from one to nine. This wider scale was used to allow for more variation and a clearer mean ranking of the items. Round three had 22 respondents, representing a response rate of 4%. Items with a mean score of five indicated neutral feelings about including the item as an ENTPP learning outcome. An item with a mean score below five indicated that the respondents’ overall consensus was that the item should not be included as an ENTPP learning outcome. None of the items received a mean score of five or below. This indicates that the consensus from the respondents was that all the items should be included in an ENTPP undergraduate curriculum. The mean scores for each of the learning outcomes in round three were also ranked. The ranked mean scores indicated the relative importance of each learning outcome considered by the participants, yielding the answer to the question, “What are the desired learning outcomes for an ENTPP curriculum for undergraduates?” [6].

Limitations

The results of this study are limited by the pool of respondents for the surveys, the research method used, the sampling method adopted, the response rate for each of the surveys, the content analysis method utilized, and others.

An illustration of the overall research process can be seen in Figure 1.

Findings

The Delphi study identified respondents' preferences for ENTPP learning outcomes. The respondents in the three rounds of this study reported belonging to at least one or more of the seven categories identified of interest to this study:

- Instructors or curriculum designers from a college that has a graduate program in engineering and public policy.
- Instructors or curriculum designers from a college that has an engineering and ethics course.
- Current or past local, state, or national politicians or lobbyists.
- Engineering faculty members having a history of influencing public policy.
- Faculty members teaching political science content.
- Members of ABET.
- Engineering or technology alumni involved in public policy.

The inclusion of instructors teaching engineering and ethics was an outcome of the results of the pilot study, which indicated that an ENTPP curriculum should also have an element of ethics embedded in the coursework. In all, 555 individual invitations to participate were sent for each of the three Delphi rounds. Table 1 shows the number of respondents in each of the three Delphi study rounds and the self-reported category that "best described" the basis for participation in the study. As shown in Table 1, each category had representation in all of the first three rounds, except for category number seven. Category seven is engineering or technology alumni involved in public policy. The final top 30 results of round three of the Delphi study, shown in Table 2, were sorted based on the mean score for each item. The scale for the round-three survey was a nine-point scale rang-

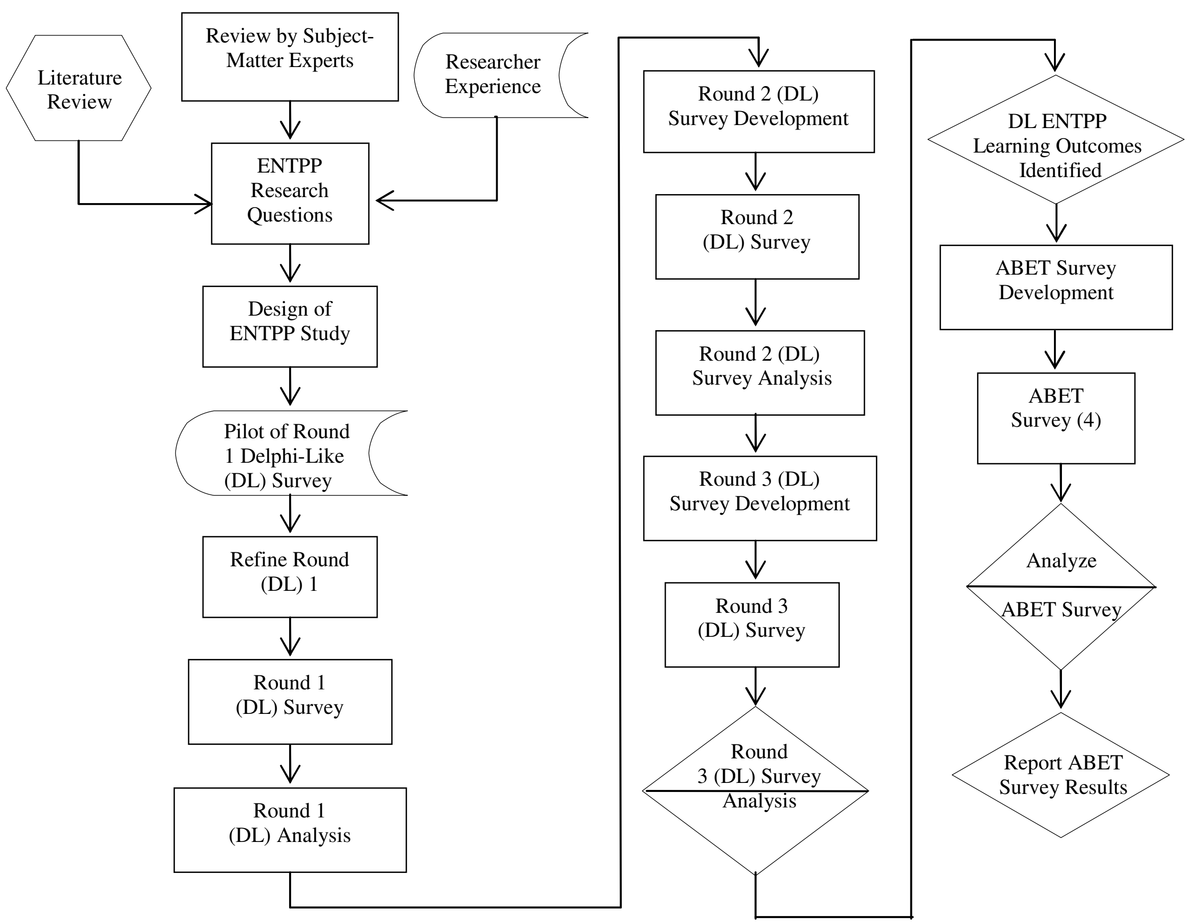

Figure 1. Flowchart of the ENTPP Study Process

ing from one (strongly disagree that the learning outcome should be included in an ENTPP curriculum) to nine (strongly agree that the learning outcome should be included in an ENTPP curriculum) and five (neutral) [6].

Table 1. Number of Respondents and Category Membership Rounds 1-3

Round	Categories							n
	1	2	3	4	5	6	7	
1	8	10	12	5	16	6	3	26
2	5	9	9	6	4	5	0	25
3	4	5	4	4	7	4	0	22
Invited	16	11	268	10	69	153	na*	

* not able to identify this group

Twelve of the top 15 items in round two remained in the top 15 items in round three; 20 out of 23 items from round two remained in the top 50% of round three. The outcomes listed in Table 2 have a mean score of 6.55 or higher, indicating that participants felt that the indicated outcome should be included an ENTPP curriculum. This Delphi process initially identified 167 possible outcomes to be included into an ETNPP curriculum and yielded 45 items with a mean score above five, with the top 30 presented in Table 2. A full list of the 167 possible outcomes can be seen in the online document by Myers [6].

Conclusion

This study provided a ranked list of ENTPP learning outcomes from an expert study group. These outcomes are now available to be used to create an ENTPP curriculum. Be-

Table 2. Round-Three Questions Sorted by Mean Rank of the Third Round

ENTPP Learning Outcome	Rank	Question No.	Mean	SD
Students should understand how engineering and technology can influence society both positively and negatively.	1	q20	7.95	1.214
Students should understand how engineering and technology policies can have positive and negative impacts on society.	2	q47	7.91	1.269
Students should learn who legislators rely upon for their guidance in technical policy issues.	3	q18	7.82	0.907
Students should understand how interest groups affect policy formation.	4	q22	7.73	1.386
Students need to understand the engineer and technologist' biases when examining public policy.	5	q9	7.68	1.171
Students should understand how cost-benefit analysis is used in regulatory agencies.	6	q10	7.68	1.211
Students should understand why those who possess special knowledge (technical) should participate in the policy-making process.	7	q16	7.64	1.329
Students should understand that most legislators are not technical experts.	8	q17	7.55	1.101
Students need to be able to frame problems/issues in engineering and technology based on observations of complex systems.	9	q50	7.50	1.472
Students need to understand how lobbyists influence public policy.	10	q31	7.45	1.143
Students need to understand how their discipline's professional associations attempts to influence public policy.	11	q32	7.45	1.299
Students should understand the function of the federal agencies that regulate discipline specific technology.	12	q7	7.41	1.221
Students need to understand that implementation results can vary due to interpretation of language in a law.	13	q43	7.32	1.249
Students should understand what factors a politician uses to decide whether to support an agenda/policy.	14	q28	7.32	1.393
Students should understand the difference between whether something is ethical or legal.	15	q49	7.32	1.673
Students need to understand how Congress oversees policy implementation.	16	q42	7.23	1.110
Students should understand how public policy emerges from the bottom up starting at the grassroots level.	17	q15	7.23	1.307
Students should understand how the separation of powers (legislative executive and judicial branches) in federal government as it affects engineering and technology public policy.	18	q6	7.18	1.402
Students should understand about the power struggle that exists amongst the players in any specific public policy.	19	q27	7.14	1.390
Students need to understand the role of the media in policy making.	20	q35	7.09	1.411
Students should understand the state regulatory agencies as they relate to their discipline.	21	q11	7.09	1.444
Students should understand how public policy emerges top down from government.	22	q14	6.95	1.214
Students should understand administrative law and how it can impact/challenge engineering and technology regulation.	23	q19	6.91	1.444
Students need to understand the international factors that influence policy-making.	24	q29	6.91	1.269
Students should understand the budgeting process for policy implementation.	25	q44	6.91	1.659
Students should learn definitions of "public policy".	26	q13	6.91	1.601
Students need to understand the role of money in elections.	27	q34	6.77	1.270
Students should understand duties and responsibilities of legislative staff.	28	q41	6.64	1.706
Students need to understand how to access their political representatives and gain their support.	29	q37	6.59	2.130
Students should know the primary contact points in government for the types of issues they may wish to address in their discipline.	30	q26	6.55	1.262

cause there were too many ENTPP outcomes identified to be included in a single course, they should be divided into multiple courses. The results of this study were used to create one Engineering Technology Public Policy course in the Russ College of Engineering and Technology. The top 21 learning outcomes with a mean score of seven or above, as identified in this study, were embedded in this course. This course was designed and approved as a junior-level writing course and satisfies the university's junior English writing requirements. The junior English course designation allows students to elect to take the ENTPP course without the need to add additional course requirements to their program of study.

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Biography

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INDUSTRY-DRIVEN POWER ENGINEERING CURRICULUM DEVELOPMENT IN AN ELECTRICAL AND COMPUTER ENGINEERING TECHNOLOGY PROGRAM

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Abstract

The power engineering industry has been experiencing a demonstrated shortage of skilled, well-trained, and educated power engineering technologists and technicians to fill positions in the electric power industry. The root cause of this problem is twofold. First, academic programs in power engineering have not been educating and graduating enough students in power engineering to address this shortage. Clearly, more needs to be done to encourage additional capacity within programs and inspire more diverse students to explore this career path. Second, nearly 75% of current power engineers and technologists are at or near the retirement age and will retire in the next 10 years. As a result, without coordinated and effective efforts, this demonstrated worker shortage will only get worse in the coming years. Industry and academia need to work together to address this problem.

The initiative described in this paper will re-shape, expand, and enhance the current power engineering focus of an existing electrical engineering technology program. New courses in power electronics, power transmission and distribution, and renewable energy will be developed, providing electrical engineering technology students the opportunity to learn technical concepts and acquire hands-on skills, which in turn will help to address the present and future needs of the power energy industry. One key factor of the proposed new program will be a revamping of the curriculum to meet the expectations of the power industry by supplying qualified technicians and technologists having extensive hands-on experience.

The cross-disciplinary electric power system training program presented in this paper is versatile. It is structured in a way to accommodate the needs of students enrolled at Michigan Tech, employees of industries looking to improve their knowledge in power areas, as well as students from other universities and colleges pursuing power education. The concept of a virtual laboratory is also included in the program to provide added flexibility in class offering strategies.

Due to the rapid changes in the technological world, faculty involved in teaching the proposed courses must be informed of advances in technology currently used in industry. On the other hand, industry wants to have qualified and well-educated employees who are ready to implement their knowledge on day one of their employment. As a result, the initiative of the power engineering curriculum development described in this paper is industry-driven.

Introduction

The power engineering industry has been experiencing a demonstrated shortage of skilled, well-trained, and educated power engineering technologists and technicians to fill positions in the electric power industry. The root cause of this problem is twofold. First, academic programs in power engineering have not been educating and graduating enough students in power engineering curricula to address this shortage. Clearly, more efforts are required to encourage additional capacity within educational programs and inspire more and more diverse students to explore this career path. Second, nearly 75% of current power engineers and technologists are at or near the retirement age and will retire in the next 10 years. As a result, without coordinated and effective efforts, this demonstrated worker shortage will only get worse in the coming years. Industry and academia need to work together to address this problem. Many electrical engineering technology programs have already started revamping their power engineering curricula to address the shortage of skilled technologists in the power energy industry by introducing courses in power electronics and renewable energy. For example, Texas A&M University is developing a new program in power engineering technology with a focus on the nuclear power industry [1].

A new nuclear power institute was formed in collaboration with community colleges to enhance both two-year and four-year technology programs relevant to the power industry. The new power engineering technology program is a multidisciplinary program with the aim of training the next power engineering technologist workforce. At the University of Cincinnati, the electrical and computer engineering technology department has developed a new two-year associate degree in power system engineering technology. The program started in the fall of 2006 with ten students; efforts are currently underway to extend the two-year degree into a four-year baccalaureate degree in power system engineering technology [2].

At the University of Houston, efforts are underway to reverse the traditional low enrollment of students in the electrical technology program. There, a new electrical power technology program was started in the fall of 2003 and, since the program began, enrollment has increased steadily from 60 students (in the previous electrical technology program) in the fall of 2002, to 91 students in the fall of 2003, and 109 students in the fall of 2004. The new electrical power technology program curriculum covers topics in power generation, power transmission and distribution, electrical machinery and machine control, electrical system design, and industry practice [3]. At the State University of New York, college in Buffalo, the power/machines option in the electrical engineering technology program has undergone major changes in order to enhance the program and meet power industry expectations. The new curriculum offers topics in power systems, electric machines, and power electronics [4].

The Electrical Engineering Technology (EET) program at Michigan Tech is ready to take the challenge and collaborate with local and regional industry to develop a power engineering curriculum to solve the current shortage and future expected growth in power engineering professionals within the State and beyond. The EET program will develop and expand its current power focus area to train a larger and more diverse future power engineering technologist workforce that will meet the changing needs of the industry.

University Overview

Michigan Tech is a public university committed to providing a quality education in engineering, science, business, technology, communication, and forestry. In the fall of 2014, there was a total enrollment of 7,100 students, including 1,442 (20.6%) graduate students [5]. Over 65% of Michigan Tech students are enrolled in engineering and technology programs [6]. The School of Technology offers programs covering the entire spectrum of technology. The School of Technology awards bachelor's degrees in Computer Network & System Administration, Construction Management, Electrical Engineering Technology, Mechanical Engineering Technology, and Surveying Engineering. The EET program at Michigan Tech offers a Bachelor of Science in Electrical Engineering Technology. The EET program is application-oriented and focuses on preparing students for entry into the workforce upon graduation. Graduates of the program are electrical engineering technologists with career options in micro-controller applications, robotics, industrial automation, instrumentation, and control.

The University Curriculum Content

Recognizing the need for the next generation of skilled technologists for the power engineering fields, the electrical engineering technology program at Michigan Tech will reshape, enhance, and expand its power engineering focus area. The development of the power engineering curriculum will incorporate the addition of three new courses that will be added to the current two courses, Electrical Machinery and Power Systems. The Electrical Engineering Technology program will re-shape the current power systems course to focus on power distribution and introduce three new courses (Power Transmission, Power Electronics, and Alternative Energy Sources). Figure 1 shows the current and proposed power engineering focus area curriculum; the descriptions of the three new courses are provided below.

The three new courses were added to the program curriculum without impacting the overall degree plan. The current EET program has a shortage of courses in power engineering; only one course (Power Systems) is currently offered. The EET program will still be structured as a 127-credit-hour program with 68 credits of technical courses in Electrical Engineering Technology, which is in line with ABET requirements [7].

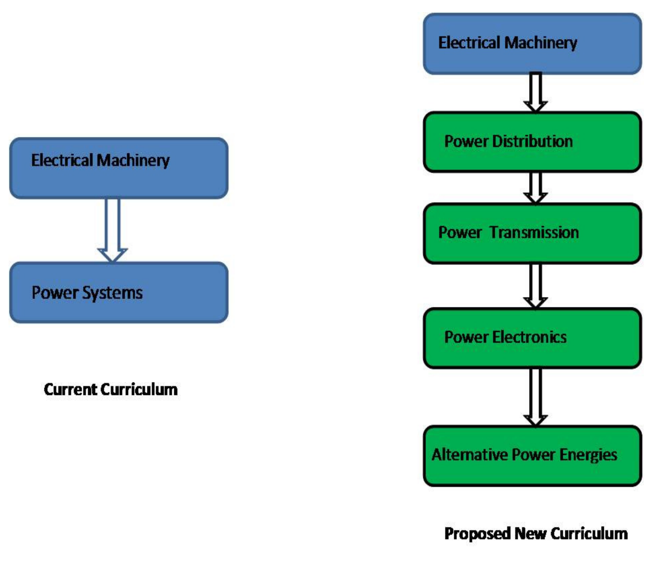

Figure 1. Current and Proposed Power Engineering Curriculum

Summary of Courses

EET3390 Power Distribution is a three-credit-hour course that provides an introduction to electrical power distribution. Fundamental concepts for modeling distribution lines, power system generators, power transformers, three-phase power, line faults, distribution system protection, and power system load are thoroughly covered. Simulation of power systems during normal/abnormal conditions is presented.

EET4390 Power Transmission is a three-credit-hour course that provides an overview of transmission systems. Topics such as transmission voltage levels, requirements for overall system stability, transmission line parameters, line faults and protection, and bulk power substations are discussed in depth. The fundamentals of line construction and planning are also covered in the course.

EET4391 Power Electronics is a four-credit-hour course in which is presented an introduction to electronic power conversion circuits. Also provided is an analysis of basic switching circuits and power converter topologies including DC/DC converters, AC/DC rectifiers, DC/AC inverters, and AC/AC frequency converters. The selection criteria for reactive elements and models of solid-state switching devices and the identification of common performance objectives such as efficiency and power factor are also presented.

EET4393 Alternative Energy Sources is a three-credit-hour course in which is presented an overview of the world's energy resources and energy consumption trends. Conventional and emerging energy sources and conversion methods are discussed in terms of their long-term viability, based on technical and political factors. Major types of renewable energy sources are discussed in the course in great detail. Relevant topics on energy transport and its technologies, and system perspectives on energy transports are also presented in the course**.**

Students' theoretical knowledge is enhanced through the use of PowerWorld software [8], which is commonly used in the power industry. This software also serves the purpose of providing extensive hands-on experience in the laboratories. "The PowerWorld Simulator is an interactive power systems simulation package designed to simulate high-voltage power system operation over timeframes ranging from several minutes to several days. The software contains a highly effective power flow analysis package capable of efficiently solving system operations" [8]. PowerWorld Simulator 14, the most up-to-date power system simulation software package, is licensed for educational use and available from PowerWorld Corporation to educational institutions at no cost.

Laboratories

Currently there is no laboratory component in the Power Systems course; however, the students receive hands-on training through field trips to local power plants and paper mills. A laboratory component will be an integral part of all three courses: EET3390 Power Distribution, EET4390 Power Transmission, EET4391 Power Electronics, and EET4393 Alternative Energy Sources. Michigan Tech will obtain necessary laboratory equipment by seeking external funds and donations from industry. A great selection of educational and training laboratory equipment that can be used to teach hands-on techniques in all the classes described above is available from U.S. Didactic, Inc. [9].

Laboratory exercises will be developed to provide students with extensive hands-on experience valuable to industry. Because most electrical power is produced by generators, hydroelectric, and wind generators, students will be provided with hands-on experience related to three-phase synchronous generator experiments. In addition to basic experiments dealing with three-phase synchronous generators, EUG modulus [9], [10] involving manual and automatic synchronizing circuits, the automatic power factor and power control will be developed. The "EUG" modules will be used to simulate power station operation in stand-alone (isolated) or interconnected operations. Adding EUL Power Transmission Line modules [9], [10], the three-phase line simulation of a high-voltage overhead power line for measuring various operational states (open-line, matched, short-circuit) will be demonstrated. In addition, EPP_SYS renewable and conventional power plants [9], [10] with transmission and distribution systems will be utilized to design and teach laboratories in EET3390, EET4390, and EET4393.

Power plants include synchronous generators, double-fed asynchronous generators with WindSim software, and photovoltaic stations. These educational training platforms will allow the involved faculty member to cover a wide variety of topics relevant to the subject and provide significant hands-on experience in topics related to manually operated synchronizing circuits, automatic synchronizing circuits, automatic power factor control, three-phase lines, generator protection, energy consumption, relays, bus-bars, and load monitor.

ET850 Steam Generator and ET851 Steam Turbine Modules [9], [10] will be utilized in EET2233, EET3390. The broad spectrum of topics such as the efficiency of a steam generator, the effect of the air feed of the exhaust gas, setting up energy balances, determining the temperature and pressure of saturated steam, determination of steam enthalpy, the heat transfer coefficient, specific steam consumption of the turbine, turbine power for different pressures of live and exhaust steam, and thermal and overall efficiencies will be calculated using this equipment. The EPE SERIES Power Electronics and Machine Drive equipment [9], [10] will support the laboratory component of EET4391 and introduce the fundamental concepts involving single-quadrant and 4-quadrant controllers, single- and three-phase power inverters, AC controllers/three-phase controllers, switched mode power supplies, pulse width modulation (PWM), power semiconductors, uncontrolled and controlled rectifiers, automatic control and speed adjustment.

Implementation of the virtual laboratories is a long-term goal of the program. Online material will be recorded and posted on the dedicated website with access permission provided to registered students. Virtual laboratories will be conducted over the Internet in real time. The lab assistant physically present in the laboratory and having access to the equipment will communicate with and assist the students in order to assemble various circuits and complete the laboratory assignment. The lab assistant will serve the purpose of the student's hands. The approach of virtual labs not only provides an effective way of conducting laboratory exercises for a broader range of students registered for the class on-campus or off-campus but also enables training of industry workers without them having to leave their place of employment.

Training Plan for Students and Industry Representatives

The cross-disciplinary electric power system training program at Michigan Tech is intended to be very versatile. It is structured in a way as to accommodate the needs of the Michigan Tech enrolled students, employees of industry looking to improve their knowledge in power areas, as well as students from other universities and colleges pursuing power education and electing to take online courses on power transmission, distribution, alternative energy, and power electronics. In addition, course materials developed through this project will be disseminated to increase the impact to engineering technology programs at other institutions. The overall training plan for students and industry representatives is outlined in Figure 2.

Michigan Tech students seeking a degree in power have two choices on how to complete the requirements associated with the courses of interest:

PATH 1: Students can register for semester-long, on-site courses and laboratories. Both the courses and the laboratories are taught in real time by faculty and lab assistants.

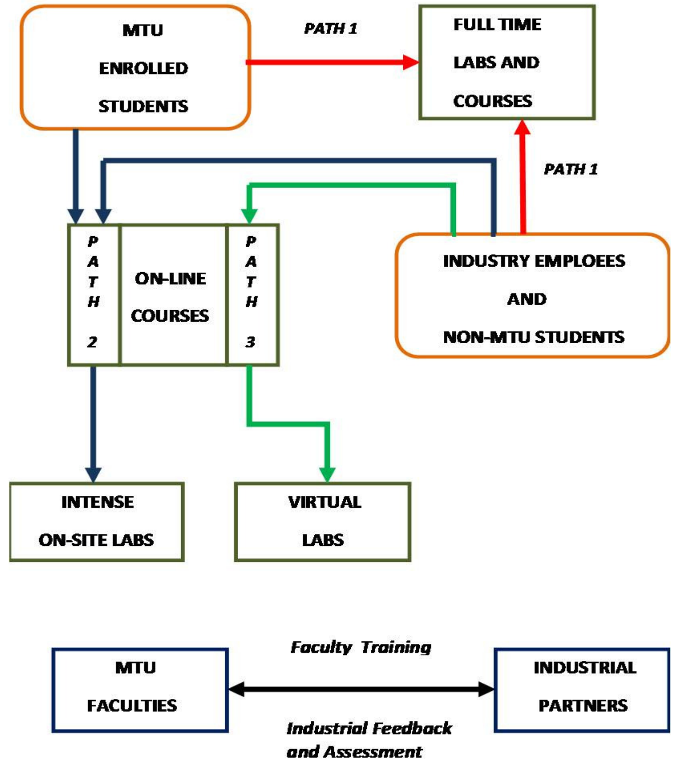

Figure 2. The Proposed Cross-disciplinary Electric Power Training program at Michigan Tech

PATH 2: Students can register for semester-long, on-line courses with intensive, one-week-long, on-site laboratories. Online material is recorded and posted on the specifically designed website with permission access for the registered students. One-week onsite laboratories are conducted by the faculty and lab assistants in real time.

Industry employees looking to improve their knowledge in the power area, as well as students from other universities and colleges pursuing power education, may elect one of the following three choices:

PATH 1: Students can register for the semester long on-site courses and laboratories. Both the course and the laboratories are taught in real time by faculty and lab assistants.

PATH 2: Students can register for semester-long, on-line courses with intensive, one-week-long, on-site laboratories. Online material is recorded and posted on the specifically designed website with permission access for registered students. One-week, on-site laboratories are conducted by the faculty and lab assistants in real time.

PATH 3: Students can register for semester-long, online courses with virtual laboratories. Online material is recorded and posted on the specifically designed website with permission access for registered students. Virtual laboratories are conducted over the Internet in real time. The lab assistant is physically present in the laboratory and has access to the equipment and communicates with and assists the students in assembling the circuit and completing the laboratory assignment.

Due to the rapid changes in the technological world, faculty involved in teaching must stay informed of advances in technology currently used in industry. On the other hand, industry wants to have qualified and well-educated employees, who are ready to implement their knowledge on day one of their employment. As a result, while academia needs to be fully aware of the current state-of-the-art knowledge requirements, industry must be driving the curriculum development. Also described here is an approach for curriculum development to help strengthen an existing link between Michigan Tech and industry. This partnership is a two-way street and advantageous for both parties in order to stay current.

Conclusion

Academic programs in the School of Technology at Michigan Tech are designed to prepare technical and/or management-oriented professionals for employment in industry, education, government, and business. This curriculum development will reshape, enhance, and expand the power engineering focus area in Electrical Engineering Technology programs, beginning at Michigan Tech. Curriculum revision will provide electrical engineering technology students the opportunity to learn concepts and hands-on skills and will address the present and future needs of the power energy industry. The curriculum revision will provide a model for other electrical engineering technology programs and resources developed will be made available to other programs. The primary outcome of this project will be a larger number of better-qualified engineering technology graduates with skills and knowledge that are current and relevant.

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Biographies

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MUSIC TOURING LOGISTICS MANAGERS' CRITICAL SKILL SET REQUIREMENTS

Kim LaFevor, Athens State University; Sam Khoury, Athens State University; Charles Roberts, Athens State University

Abstract

A challenge for any academic institution planning the development of a new degree program is determining the required skill set graduates should have by the time they enter the workforce. Institutions need accurate information that precisely identifies those skills most valued by experts in industry. To address this need, a state university in Alabama, planning the development of a touring logistics degree program, sought the help of experts in the music touring industry to determine the most valued skills necessary for music touring logistics graduates. Interviews and acquired documentation obtained from two music touring industry experts with over fifty years of combined experience produced a detailed list of critical skills necessary for the development and deployment of a new degree minor in music touring logistics management. In this paper, the authors present a detailed breakdown of these critical skills that are necessity for graduates of a music touring logistics management program of study.

Introduction

A challenge for any degree program is determining the required skill set graduates should have by the time they enter the workforce. The music touring logistics industry is no exception. This knowledge is usually gained from advisory groups and surveys of graduates that have entered the workforce. Unfortunately, the knowledge gained using these methods is limited, since advisory groups are a small representation of the employment market and provide advice in a limited capacity, while surveys of recent graduates only reveal the perception held by graduates and not necessarily those of the employer or industry experts.

In order to determine if degree programs are preparing students for rewarding careers, academic institutions need more precise data. They need data from organizations that will employ their graduates. Furthermore, these data should determine the exact skill set requirements these employers look for. Most of all, academics must keep in mind that career fields often change as a result of internal and external forces. This is especially true in the rapidly moving music touring industry. Therefore, programs have to be carefully planned and developed based on the most accurate and current information available.

While government employment agencies provide valuable job description data for common and well-recognized fields such as computer programming and marketing, data are limited on fields that are either emerging or do not operate in standardized industries. The music touring logistics management profession is an example of a field that has operated in an obscure and unstandardized fashion for decades. The obscurity can be attributed to the confidentiality and fierce competitiveness of the music touring industry, while the unstandardized nature of the industry is a byproduct of an ever-changing field that must assist artist with tours that often span continents. No two venues are identical, since there are different officials, environments, procedures, accommodations, and other characteristics at each location. Music touring logistics managers have to account for these variances and rapidly adapt to each situation. As a result, expertise and knowledge is gained through on-the-job experiences that can differ by individual circumstances and exposures to different environments.

Further adding to the problem is the fact that there is currently no music touring logistics management program of study in the U.S. Individuals operating in the music touring logistics industry were trained on the job and do not hold a degree in music touring logistics. They may have formal training or a degree in other music areas of study, but they acquired their hands-on touring logistics skills by supporting artists on tours. A fortunate few were able to gain these skills by working with others, while those less fortunate gained their skills through trial and error. Therefore, a need exists for formal academic programs that prepare students for these exciting and rapidly changing careers. The challenge for academic institutions will be determining what skills these students will need to acquire by the time they graduate. Furthermore, academics will need to find ways to connect the classroom environment to the actual work environment in which graduates will have to operate. Therefore, internships will be critical to the design and development of these programs of study.

To gather the critical skill set data needed to develop these programs, faculty at a state university in Alabama gathered documents and interviewed two touring logistics industry experts with over 50 years of combined experience in the music touring industry. In this paper, the authors present their findings by listing the skill set most often identified as a necessity of graduates of a music touring logistics program.

Background of Music Touring

A music touring company is typically created for the purposes of financially transacting business associated with a string of concerts referred to as "tours" performed by an artist or band. The tour company may be formed 6–12 months prior to the tour and may be dissolved as soon as all business for that tour has been transacted. A tour company will typically be comprised of two individuals, one representing the artist or band and one representing the business management firm hired by the artist or band. Individuals working for the interests of a tour company and traveling city-to-city are considered "on tour". These individuals primarily fall into one of two categories: individuals and vendor-supplied labor. Individuals are employed through temporary payroll companies and are hired "at will", with no written contracts in place. Vendor-supplied labor is hired through an agreement between the tour company and another corporation, usually a corporation that is providing equipment to the tour. Labor hired through an agreement with another corporation will answer to a foreman (crew chief) supplied by that corporation, but all labor on tour will answer to the stage manager, production manager or, if addressed, tour manager.

A typical on-tour roster includes a tour manager, a tour manager assistant, production manager, production manager assistant, stage manager, stage manager assistant, artist road manager, artist security director, tour accountant, and tour accountant assistant. Specially skilled labor directly hired by the tour company include riggers, lighting director, front-of-house audio engineer, backline technicians, lead carpenter, and carpenter crew members. Typical vendor-supplied crews include the lighting, audio, video, pyro, and catering crew chiefs and their associated crews. Additional vendor-supplied crews include the lead truck and bus drivers and their associated drivers. Also, positions that are associated with the tour company that will continue to interact with the tour include artist managers, publicity agents, business office personnel, booking agents, sponsors, and accountants.

The relationship of a tour to a concert is typically one where a promoter (buyer) agrees to provide an agreed-upon location (venue), qualified labor (stagehands), and infrastructure (power, dressing rooms, secure facilities, etc.) to the specifications laid out in a contract rider (written by the tour manager and production manager). The buyer agrees to pay a specific amount (guarantee) with the potential for the arrangement to become a percentage deal, if the buyer is able to attract a large number of patrons. Outside of deposits made on the contract, all financial obligations are resolved between intermission and the conclusion of the performance.

Literature Review

The popularity of music is as strong as ever. Touring, plus recorded music, and mobile ring-tone revenue continues to climb. One of the most notable television shows in this decade, American Idol, is based on music. This conveys in essence how central music remains in people's daily lives [1]. While the demand for music touring persists both in present day and in the predictable future, there is a critical need to assess personnel and their readiness for properly managing touring operations. While the focus of this study was primarily aimed at assessing the needed skill set for music touring logistics managers, the literature available focuses largely on market assessment, music touring venues, and other areas. A much smaller body of research addresses the topic of music touring management; however, there remains no existing literature that broaches the needed skill set of a music touring logistics manager. This literature review highlights some of these categories of literature that does exist in industry and frames the gap in this literature.

One area of the literature that appears saturated is the analysis of the music market. The research clearly points to how live music and the concert business is realizing great success. The positive trends in ticket sales are indicative of a loyal fan base to the live experience. In 2013, Billboard's Boxscore reported a record $4.8 billion in gross ticket sales worldwide, which reflects a 30% increase from the prior year, as well as being 9% higher than the largest recorded sales in 2009. This substantial growth was then followed by the music touring slump of 2010. According to Waddell [2], "Touring is, as ever, a cyclical business…this year's strong numbers came in a year short on such mega-tours, populated with acknowledged superstars and featured artists with conservative ticket prices."

On a global basis, live music is exploding. Artists are pricing better; there is great fan demand; and, it's one of the best places to spend two hours for the price. As one industry expert noted, "We're seeing a great supply of artists filling the venues, and when you add globalization to that, we think that the live business is booming and has a long growth period ahead of it" [2]. One business model used to promote touring bands focuses on the profitability of merchandising. Record labels provide financial support for the artist in return for a percentage of funds raised from all their income, including merchandise. Artists may use the funds for marketing, promotion, and touring. Furthermore, the role of the Internet has increased the sales opportunities for artists [3].

Researchers contended that the music touring industry, which has had to recover from a slump over the past decade, has rebounded. All industry indications reveal that this turnaround will last for years to come. One indication of the rebound is the increase in gross revenue, which is up nearly 16% from a year ago. At the same time, attendance at music touring is up 5.6% [4].

The touring business largely depends on a healthy Live Nation, the music touring industry's only public company, which posted record earnings in 2013. In their repertoire of hosted tours and concerts in 2013 were Justin Timberlake, Jay-Z, Beyonce, Rihanna, One Direction, Luke Bryan, Jason Aldean, Tim McGraw, Swedish House Mafia, Bruno Mars, Maroon 5, Roger Waters, Kid Rock, Mumford & Sons, Fleetwood Mac, the Eagles, and Imagine Dragons. The company also sought to increase its presence in the festival space realizing record attendance levels at Electric Daisy Carnival, HARD, Paridiso, and Digital Dreams. While these are positive trends of a currently healthy market, there are concerns whether it can remain that way. Live Nation Entertainment CEO Michael Rapino noted, "On a global basis, live music is exploding. Artists are pricing better, there is great fan demand…when you add globalization to that, we think that the live business is booming and has a long growth period ahead of it" [2]. Five of the most influential stakeholders—Managing Partner of Creative Artists Agency (CAA), Rob Light; William Morris Endeavor Head of Music, Marc Geiger; AEG Live CEO, Randy Phillips; C3 Presents Partner, Charlie Walker; and, Live Nation Global Touring Chairman, Arthur Fogel—in the live music industry agree in its current trajectory, although each adds some notes of caution.

While these industry experts agree that the health of the touring market is favorable, there are some challenges. Marketing has become more complex, due to the eclectic nature of fan preferences, which has expanded the venues in which they are reached. Social media has played a central role in marketing and sales. In addition, the festival market has seen significant increases, while classic radio media continue to resonate with some fans. Also, they all agree that international markets will continue to grow and expand opportunities to the music touring industry to increase sales and promote more venues worldwide [5].

Despite these positive projections, historical slumps have led the way for skepticism. As an industry, it is important to realize that when a show does not do well, there is good rationale which generally includes the wrong venue, wrong ticket price, wrong timing, and/or poor implementation strategy. In reality, even in the wake of a down year or period, the music industry will rebound, as live music can never be replicated in other mediums [6]. In 2009, Latin music fans responded to the decline in the economy and touring industry slump by becoming more selective as to the venues they choose to attend. Then and now, value has become a key concern. However, while there are fewer Latin acts to compete for the same ticket dollar, and with artists resorting to fewer acts to offset their decrease in revenues, it has become a price-sensitive market. In response, the Latin concert industry has responded with creative pricing, offering VIP packages which may include perks such as gift bags, tour laminates, lanyards, and souvenir tour tickets or a more upgraded floor-seat version that includes meet-and-greet and a separate VIP check-in and entrance. Ironically, this business model has resulted in sold-out tickets in presale for the more expensive VIP tickets and cheaper VIP tickets near sell-out levels [7].

While it is difficult at best to fully discern the health of the music touring industry, all indications are that from the seller side, it is especially healthy. In 2012, music touring reported gross ticket sales of $3.8 billion and more than 53 million in attendance. The primary areas of growth in the industry today are being realized in festivals and international business [8]. This was supported by Schwartz [9], who indicated that music touring is a solid and dependable source of revenue for international acts. In Japan, the world's second-largest music market, Lady Gaga sold 96,550 tickets over three nights at the Saitama Super Arena, grossing $18.3 million. Japan's largest ticket agency, Ticket PIA, which has operated since 1984, is approaching an average of 62 million in ticket sales each year and holds about 50% of the market share. About 20% of all ticket sales are for international acts.

While the topic of music touring tends to generate discussion and primary focus on the artists or on the market as discussed above, there is another layer to the industry, touring management, which is often overlooked or given little attention in the literature. Yet there are many music touring professionals behind the scenes that ensure that the event, artist, and venue planning are effectively executed. These touring managers can differ in their focus, yet the skill sets that define what they do are comparable. Some tour managers have set out to promote local artists [10], while some artists choose to largely manage themselves. Researchers, such as Knap [11] and Bertoni [12], point to success stories of artists, who were successful in managing themselves.

While these aforementioned management approaches are relevant to the industry, they fail to represent a definition of the skill set largely needed as a music touring logistics manager. This significant gap in the literature suggests specific research is needed that will outline the knowledge, skills, and abilities required to meet the relevant needs of touring management in this high-gross, high-demand, and high-profile industry.

Also, while there are some avenues for training available for a touring manager, it is limited in scope. Those avenues for training and education have centered on conferences, where industry participants can share experiences and ideas [13], [14]. Furthermore, a limited amount of researchers, such as Waddell [15], have helped educate touring managers on effective touring processes. In contrast to the limited training and education literate, there is significant literature centered on music venues. Music venues are central to the success of live music touring. Therefore, researchers such as Peters [16] and Waddell [17] are helping educate touring managers with their research that centered on the exploration of successful venues, while other researchers such as Somerford [18] and Morgan [19] helped educate touring mangers as well as artists on how to reduce tour expenses and to maximize revenues through technology and other resources.

Overall, the literature is rich with analysis of demand and trends by artist, genre, venue, and domestic and international geographies. By contrast, literature addressing competencies for touring professionals remains scarce. Based on the relevant need for well-trained touring professionals, especially music touring logistics managers, there is a critical need to define the knowledge, skills, and abilities needed for success in this high-demand and high-profile career.

Methodology

To identify music touring logistics managers' required skill set, an Internet search and interviews of two leading music touring logistics managers with over 50 years of combined experience was conducted. The data gathering attempted to determine the critical skill set requirements, job titles, career fields involved, current standing of academia in fulfilling the education and training requirements, how current touring logistics managers were educated, and if there was a viable need for a college-level curriculum to be developed. The search of academic institutions' websites was conducted in late fall, 2013, and early spring of 2014. The websites of institutions that had music-related programs were searched to identify any majors or minors in music touring logistics.

In order to ensure a detailed search was conducted, different music-related terms were used to conduct the Internet searches in www.google.com and www.yahoo.com. Terms used for the searches included "music program", "entertainment program", "music touring", "entertainment touring", "touring management", "touring manager", and "touring logistics". The intent of the search was to identify if any academic institutions offered programs in music touring logistics or had plans to offer such programs. Those institutions that were identified as having music-related programs with limited website information were contacted by phone to determine if they had any courses specifically related to music touring logistics.

A search of publisher websites was also conducted in order to identity possible textbooks that could be used in a music touring logistics program. A search of www.amazon.co was also conducted. The search terms used included "touring logistics", "music touring logistics", and "entertainment touring logistics". Books with music industry-related titles were assessed to determine if their content addressed music touring logistics. In addition to Internet searches for music touring logistics and phone calls to some academic institutions with music programs, two leading music touring logistics managers with over 50 years of music touring logistics experience were interviewed. One of the managers operates out of Nashville, TN, and the other out of Milton, Vermont. Each has supported well-known artists on domestic and international tours. The in-depth interviews attempted to determine what skill set is considered critical in the music touring industry. In addition to the interviews, the touring logistics managers were asked to provide detailed descriptions of positions within the music touring industry these managers would hold and the skills they would be expected to have.

Limitations

There are several limitations to this study that are worth noting. One of these limitations was the small number of industry experts that agreed to participate in the interview and data gathering. The inclusion of additional industry experts would have produced more accurate results. Another limitation of the study was the lack government employment data for touring logistics managers. While extensive government employment data exist for logistics managers and other similar fields, no data exist for touring logistics managers. Although some tasks performed by logistics managers in other environments may be performed by touring logistics managers, the music touring logistics profession is unique for the reasons noted above. Skills gained in typical logistics programs of study deal with the concepts and theories involved in the understanding of supply chains and the movement of goods from the raw-materials stage to the final delivery of the finished product.

In contrast, music touring logistics involves the planning, rapid positioning, and setup of equipment and personnel in various cities for a short period of time. This rapid deployment, packing, and redeployment to another city typically takes place in a 24-hour period. Supply chain management concepts and theories do not clearly fit this group of daily activities. Therefore, applying government employment data available on logistics managers to music touring logistics managers would not be appropriate because of their significant differences.

Another limitation of this study was the lack of previous studies of the music touring logistic profession. As a result, this study could not make a connection to any established music touring logistics theories and peer-reviewed literature documenting any required skill set that graduates should possess. Previous literature on music touring logistics managers' critical skill set would have served as a good starting point for this study and would have established a good point of reference in determining those skills that have been deemed critical. Also, the lack of music touring logistics degree programs in the U.S. further limited this study. Since there were no existing programs that centered on music touring logistics, textbook selection, lab exercises, and other academic materials could not be evaluated to help identify those skills that have resulted in student placement in music touring logistics. If these programs and their associated data existed, evidence of successful selection of critical skill sets taught in those institutions could have been identified and applied to this study's findings.

A final limitation of this study was the scope of the critical skill set being limited to only touring managers. Although this study gathered job descriptions of the various positions a touring logistics manager may hold, it attempted to summarize all of the positions, while determining the critical skill set of touring logistics managers. Limiting the scope of this study in this way, enabled the researchers to develop a general critical skill set considered necessary, regardless of the position held within the music touring logistics industry.

Findings

Despite an exhaustive search of websites and calls to academic institutions with music programs, no touring music logistics programs were identified. Music programs that do exist either concentrate on the development of artists or on the management of artists. In a few cases, a course was included in the programs that centered on music touring management. These courses did not address all of the aspects of the logistics operations involved in touring. Instead, they concentrated on management of tours in general. In all of these courses, logistics operations were slightly covered. Therefore, none of the courses identified all of the logistics critical skills required for effective employment within the music touring logistics industry. In-depth interviews of music touring logistics experts who participated in this study produced much better results than the search of existing music touring logistics programs and skill sets taught at those institutions. Furthermore, the job descriptions of music touring logistics professionals provided by these experts, significantly contributed to the music touring logistics skill set requirements outlined in Table 1.

The expert interviews and the accumulated data for this study revealed that logistics managers are required to perform a variety of highly specialized tasks, some of which are identified in Table 1. The summarized tasks in Table 1 take into consideration that graduates of music touring logistics programs can work in other positions besides touring manager positions, yet they all should possess the skills listed in Table 1. An analysis of the accumulated data revealed that most of the position descriptions provided by the industry experts listed these skills in one form or another. This study confirmed that the vast majority of music touring logistics managers acquired their skills by trial and error or, if fortunate enough, received on-the-job training where they learned from others already in the business. This study also confirmed the need for formal training programs that emphasize the development of the necessary skills listed in Table 1.

This study also determined that any proposed programs of study in music touring logistics should have substantial hands-on exposure to the tasks required of logistics specialists in the touring industry. Music touring touches many different fields of study such as accounting, marketing, and human resources that have well-established programs of study and countless bodies of knowledge. Unfortunately, this is not the case for music touring logistics. Therefore, hands-on training through formal programs of study is essential to ensuring the music touring logistics industry receives the same attention other business programs have received. Furthermore, an analysis of the literature determined that little to no research exists that addresses the needs and challenges music touring logistics faces. While substantial literature exists that addresses other areas of the music industry, such as artist management and promotion, no body of knowledge exists that can help bridge the gap between what is known by others who have been in the industry for years and those considering a career in this field.

Conclusions

This study confirmed the need for formal music touring logistics programs of study to address skills that are inherent in other business-related programs. Skills such as teamwork, leadership, problem solving, and cultural awareness are essential to all business programs of study. The lack of formal business programs specifically addressing the unique requirements of the music touring industry has left touring

Table 1. Music Touring Logistics Managers' Required Critical Skill Set

1. **Good communication skills**: This is required in order to serve as a liaison between the artist and management, booking agent, publicity, and the promoter. The tour manager also maintains close communication with all upper-echelon in case of emergencies or catastrophes.
2. **Attention to detail**: This skill is required in order to arrange flights, hotel, and other travel arrangements for the artist, band crew, and drivers.
3. **Organizational skills**: The tour manager will have to gather information on frequent-flyer accounts, seat preferences, next-of-kin, emergency contacts, passport details, medical history, criminal history, food allergies and preferences, financial history, salary, show pay, per diem, list of doctors nationwide on the tour route, and who can make a call to the venue if required. Furthermore, the tour manager organizes police escorts in and out of venues.
4. **Ability to manage budgets**: This skill is required in order to budget the complete tour. This includes inception, pickup, rehearsal, all equipment rentals, truck rentals, bus rentals, fuel, road cash, return of all equipment, and final-cost closeout.
5. **Basic understanding of account auditing principles**: During the tour, along with the tour accountant, the tour manager makes sure costs are in check, verifying reasons for excess and in turn reporting these issues to management for review and approval with suggestions on how to remedy. Also, the tour manager maintains all accounting, accurate road reports, cash disbursements to road personnel, and submits to the tour accountant for review with explanation when necessary.
6. **Basic understanding of marketing and promotions**: The tour manager makes sure promotion is adhered to for maximum sales, day-of-show ticketing, guests, meet & greet, and VIPs. The tour manager also interfaces, schedules, and executes time with the press, radio, and TV in local areas.
7. **Detailed understanding of transportation**: The tour manager must be able to view routes and create a complete detailed itinerary, nationwide and worldwide, well in advance that can be issued to all personnel and families in a timely manner. Also, the tour manager organizes private jets, limos, transportation for artist/band, management, and crew.
8. **A cultural awareness**: Since international tours are common in various cultures, the tour manager must acquire a basic knowledge of the customs of other countries.
9. **Knowledge of current events**: Tour managers must acquire knowledge of a host country's political stability and unrest so they can plan accordingly.
10. **Effective people skills**: In order to manage people during rapidly moving tours, touring managers must be able to maintain a positive attitude and possess good people skills. Teamwork skills are also necessary for this profession.
11. **Effective problem solving**: Since problems are likely to arise during tours, managers must be able to develop solutions that lead to satisfaction among many different types of stakeholders.
12. **A detailed understanding of safety practices and principles**: Touring managers will need to adhere to all safety and security aspects affecting or potentially affecting tour personnel, the venue, and spectators. They must be aware of safety regulations and mandates established by local safety officials.
13. **Understanding of leadership principles and proven effective leadership practices**: Since logistics managers will be expected to manage a variety of resources and personnel in a rapidly changing environment, they will need to develop their leadership skills.

companies with no choice but to hire untrained labor and train them on the job. This approach carries many potential risks, some of which can be catastrophic, where the artist, crew, and spectators lives could be placed in jeopardy if the wrong decisions are made. As noted above, considerable research is needed in many different areas of the music touring logistics field. Further studies should look at the relationships between music touring logistics managers' skills and their on-the-job effectiveness. Other studies could attempt to determine if the skills noted in Table 1 are the most appropriate. Studies of music touring logistics pedagogy, lean logistics, and safety are also need.

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USING STRATEGIC PARTNERSHIPS TO DELIVER REALITY-BASED EDUCATION

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Abstract

Meeting our nation's needs for trained individuals is the responsibility of our educational institutions. Engineering education continues to face criticism by industry for not producing students with relevant problem-solving experiences. Instructors are faced with providing such experience for their students, while the political trend today is to reduce funds for higher education. Motivating students using abstract, hands-off assignments that students perceive as having little practical application in the real world is a challenge. This challenge can be resolved through a self-funded, reality-based, hands-on experience that can motivate students and provide focus for the instructor.

Faced with these challenges, the instructors of the sustainability class in The College of Technology, Architecture and Applied Engineering at Bowling Green State University (BGSU) in Bowling Green, Ohio, searched for a class activity that would also meet these challenges. In their search, the instructors concluded that the objectives of the evGrand Prix program had the potential to fill the need. The evGrand Prix competition requires students to field an electric racer and participate in a series of events that include wheel-to-wheel racing, efficiency runs, technical reports, and public outreach activities. The program requires students to organize as teams, fund, design, build, and race electric-powered racers. In the class, the students are given individual subprojects to design and build the racer according to specifications and to conduct the outreach campaign.

In this paper, the authors report the experience of three separate classes of students, both in building the industrial partnerships and the results from the evGrand Prix projects conducted over a three-year period. The authors also share their mixed success in achieving the class goals. This has application for continuing the program and for other instructors, who may be considering using similar extracurricular experiences in their classes.

Introduction

The College of Technology, Architecture and Applied Engineering (COTAAE) at Bowling Green State University in Bowling Green, Ohio, offers a baccalaureate degree in engineering technology and graduate degrees in technology management [1]. The faculty of the college recognizes a national need to reduce energy dependence, maintain clean air, and create jobs for Americans. To meet this need, the faculty developed curricula in sustainable technology. It is also clear that there is a demand for electric-powered vehicles that requires trained personnel to design, build, and maintain them [2], [3]. The COTAAE has a tradition of providing up-to-date, hands-on education for students. This is becoming increasingly difficult considering the trend toward reducing public funds to higher education, keeping tuition costs from rising and reduced funding from private donations and industry grants in the current economy [4]. To counteract this trend, hands-on experiences in technology education nationwide are being replaced with computer simulations and online programs to reduce costs [5], [6].

Nationally, industry has been calling for educational reform because manufacturers find that today's graduates lack experience and creativity. Articles as far back as 2009 attest to the fact that many new workers lack collaborative workgroup experiences that prepare them for idea sharing. Industrialists are calling for learning environments where people of different ages and skill sets work together to solve complex problems [5-7]. James Plummer, Dean of Engineering and Professor at Stanford, provides a list of attributes that engineering students need, including such things as undergraduate research, teamwork, participation in competitions, etc. [7].

Determined to overcome financial difficulties and meet the challenges of industry and the mission and goals of the COTAAE engineering technology program, the authors searched for an activity for their sustainability class. The activity had to involve problem solving, have team and individual focus, provide real deadlines, and be a reality-based enterprise that could motivate and focus participant effort, include public outreach and demonstration, and address national needs and goals.

It also had to be funded by strategic industrial partnership, provide up-to-date equipment to the educational process, and provide experience with the latest electric vehicle technology. After considering a number of alternative activities, the authors decided that the reality-based, collegiate evGrand Prix program would best fulfil their needs.

The evGrand Prix Program

The evGrand Prix program, started in 2010, uses intercollegiate motorsports competition as motivation to develop and showcase electric vehicle technology and performance, increase public awareness and acceptance, and provide relevant technical training for personnel. The evGrand Prix events are open to organized student teams from any post-secondary institution. The evGrand Prix program provides the basic specifications for the racer and event rules. These cover safety, fairness, cost and venue, and event management [8], [9]. The program requires students to organize themselves in teams in order to fund, design, build, and race electric-powered racers. The evGrand Prix Intercollegiate competition judges the participating teams in four categories of wheel-to-wheel racing, educational outreach, technical report, and energy efficiency.

The educational outreach category focuses on educating the public at large about electric vehicle technology. It consists of producing marketing/advertising materials, and offering exhibitions, demonstrations, and seminars. Vehicle design and development work was documented in a technical report that is submitted for evaluation. The event was held at the Indianapolis Motor Speedway. The student-built machines were put to the test in wheel-to-wheel, 30-mile races travelling at speeds nearing 50 miles per hour. The efficiency of the racer was evaluated during the race using data from required on-board recorders. Winners are awarded in each of the four categories. The champion is declared as a result of the finish in all categories. Though bragging rights came with a first-place finish, the authors consider that the real winners are the students, who choose to compete and bring their racers to the starting line.

The Course and the evGrand Prix Project

ENGT 3250 Sustainable Technologies is a 3-credit-hour class and forms part of the Engineering Technology curriculum. The class consists of two components: classroom-based instruction and a hands-on, project-based laboratory. In the classroom, students learn about such technologies as recycling, green design, and green building, among others. The class is taught using lectures, field trips, guest speakers, and small, self-discovery assignments. The class, though open to all university students, is primarily taken by engineering technology students with a mechanical technology design emphasis. The goal of the project portion of the class is for students designing, building, fielding, and promoting electric vehicle technology, and developing industrial partnerships for funding. Secondary learning objectives included gaining experience in project management, teamwork, verbal and written communication, designing and manufacturing engineering products, and conducting undergraduate research.

The project was divided into subtasks that could be conducted on a group of two to three students, which reflected the vehicle and team equipment specifications [9] provided by the evGrand Prix and tasks deemed necessary and would make the difference in vehicle performance and help the team field the racer. The students were given the choice of selecting a topic of their interest. After reviewing their choices, some changes were made in order to ensure that all of the essential tasks could be completed. No guidelines or specifications were provided for the 2011 outreach competition, so the instructional team formulated a list of objectives and requirements for the students to follow. These guidelines were adopted in subsequent years by the evGrand Prix program. As in the design completion, students were given a choice. In 2012, topics for the outreach group included: flyers and marketing material development, developing displays and coordinating outreach events, STEM activity development, developing an eV demonstration program, website master development, and media relations. There were 17 students in the 2011 class, 17 in the 2012 class, and 20 in the 2013 class.

In addition to the class, student members of the BGSU Motors Sports Club were responsible for fund raising and working closely with the students for purchasing of parts, and marketing partner relations. Following project-management procedures, the instructional staff made a list of milestones that showed the dates by which some of the work had to be finished. These were based on some of the shows and exhibitions occurring in the area and also the evGrand Prix events. These were posted both electronically on Blackboard and as paper calendars in the main meeting room. The project was conducted in the Electric Vehicle Institute (EVI), housed in the college.

Students worked independently on their individual sub-projects under the supervision of the instructional team. Students were also encouraged to consult with vendors and industry experts. They were instructed on how to find materials and learn about technical areas with which they were not familiar. Students working on the technical element designed and specified the needed components and fabricated many of these using the shop equipment available in EVI. Fabrication of some components was outsourced to local workshops primarily where safety, complexity, or meeting of deadlines necessitated it. Similarly, students working on the outreach element designed their materials and had some of these made by involving students from the Visual Communications Technology program in the CO-TAAE.

EVI personnel and some of the motorsports club student members had been working to raise funds or seek in-kind donations from industry partners. Consequently, the class students had the opportunity to work with the latest technologies such as lithium-ion batteries and AC motor drives. The Enerdal Battery Company provided the batteries and grants from the BGSU Green Fund, and the City of Bowling Green utility fund are three examples of such partnerships. Figure 1 shows the names of the 12 major partners supporting the team efforts. Smaller contributions from alumni and private individuals rounded out the funding. No tuition or institution budgets were used.

Figure 1. Some of the Sponsors and other Organizations Involved

Each lab session started with a short meeting, where students reported any problems they were encountering and reviewing the upcoming milestones. This allowed others to help with suggestions or even resources and kept everyone informed about the overall progress. This provided teachable moments, where all students learned from one another. Figures 2-4 illustrate some of the results of the hands-on activities conducted. As the semester progressed, each student kept weekly logs and updated a Gantt chart, which were used by them to write the final reports and served as a project-management tool.

A volunteer team of students was ultimately selected to travel to the final event and represent the institution. Several were involved with the logistics of the trip to Indianapolis. Drivers and crews were trained. This required much planning and securely stowing the racer and other equipment in the truck used to transport the equipment. The travel team also made several test runs and practiced pit stops, tire changing, and battery charging. The same team was responsible for setting up and presenting the outreach and design exhibits at the speedway and worked as the pit crew.

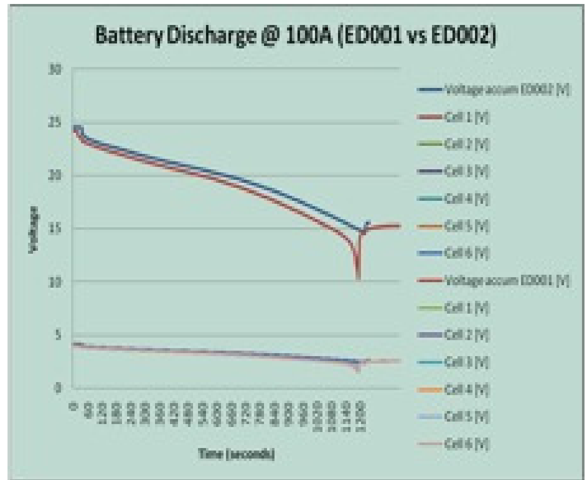

Figure 2. Results of the Battery Charging/Discharging Experiment

Figure 3. Student-designed and -built Battery Exchange System

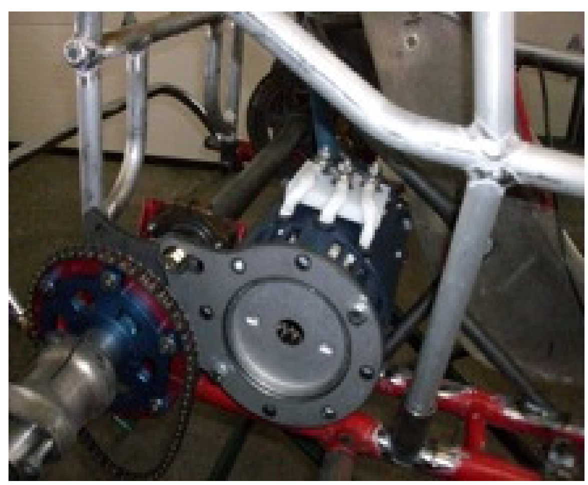

Figure 4. Student-designed and -built Motor Mounting and Drive System

Results

Through the research and development process, the students built a racer with specifications shown in Table 1. The cost of building the first racer amounted to $13,000. Additional funds were used to complete outreach, design, and travel commitments. A large portion covered the cost of advanced batteries. This investment can be used and prorated over several years of competition, which lowers the cost to field the racer next season. A key point is that the students did the majority of the fundraising by partnering with various organizations. Cash and in-kind donations for 2011 totalled $21,000. Similar funding was secured for prior and later seasons by the efforts of students and faculty advisors.

Table 1. The Racer Specifications

Electric Motor	38 Hp peak rated, 14.5kw (allowed) 3 phase induction
Motor Controller	Rated 0-80 Volt Out, 48-80 Volt In, 0-300 Hertz, 400 amps, operated at 48 volt nominal.
Chassis – kart based	Wheel Base – 40.5” :Front Tread Width- 36” Rear Tread Width-49” :Direct Chain Drive Eco Friendly MG Race Tires
Energy Storage	3 battery packs, 8640 watt hours/race Lithium Ion. Energy .213 gge/race (gas gal equiv)

Featured Outreach Efforts

Over the semester, the 2011 outreach effort reached a documented 10,000 people through partnering with other local colleges, vocational schools, and racing clubs. The most notable of the sustainability class student efforts were the presentations made to post-secondary school groups. Other efforts included vehicle shows, visits to the BGSU Electric Vehicle Institute, STEM workshops, and working with the local adult vocational school automotive class on building an electric vehicle. In the latter, the BGSU students guided the vocational students as they began to build a second electric racer, copying the design of the first one being built by the BGSU students. Figures 5 and 6 illustrate some of these activities.

The Race

A total of 50 student teams entered the 2011 evGrand Prix competition at the Indianapolis Motor Speedway (INDY). Of the 50, only 30 teams (60%), representing 10 post-secondary institutions including two teams from the UK, managed to bring their racers, technical report, and outreach documentation to the international competition. Figure 7 shows the BGSU racer setting up a pass during the race. Table 2 shows the results of the races in 2011, 2012, and 2013.

Figure 5. Radio Show at a Racing Show in the City of Bowling Green as Part of Outreach

Figure 6. Display at Woodville Mall Show as Part of Outreach

Figure 7. BGSU Racer (#9) Setting up a Pass during a Race

Table 2. Results of the Races in 2011, 2012, and 2013

Year	Results
2011	• 2nd fastest in posted qualifying speed • Ran in first three places during most of the race. • Completed 7-second pit stop, fastest in competition. • Finished 8th in race as a result of a late in race mishap with slower racer. • First Place in Educational Outreach Competition
2012	• 2nd and 8th place finish in race • 1st place in Outreach Report competition • 3rd in Design report

Discussion

The project met all of the original objectives stated above. The students solved real problems and used their previously learned skills and education to design and build their electric racer. Students gained experience working alone and in teams, learning the value of communicating with others. They experienced how a project is managed, including what must be done to meet deadlines and what happens when deadlines are not met. This could only have been realized in a reality situation with an ultimate deadline. Since the project involved many facets, the students saw how projects benefit from multidisciplinary interaction. In this case, it involved mechanical, electrical, marketing, and fundraising dimensions. The problem of reduced funding, and consequently the inability of educational institutions to expose their students to the latest technology, was also solved. For example, the students gained the opportunity to work with the latest types of batteries that were donated; the other costs were born by the funds raised.

In addition, longer-term relations with industrial partners were established. This later became a resource for continued funding and internship opportunities. Students often had to interact with vendors of parts and work to meet the specifications provided by the evGrand Prix. They had to design (invent) parts for the racer. The outreach students had to plan with external exhibitors and schools and had to work on logistics of organizing the events. All of these activities are examples of activities carried out by engineers in industry. Hence, clearly this project was a reality-based project.

The experience also proved the advantage of working as a team to achieve a goal. The competitive events and, ultimately, the performance success and awards achieved by the BGSU student teams over the three years of participation shows that they measure up to their peers from other institutions. Most importantly, the students experienced individual success and failure as a direct result of their individual abilities and commitment. This is a hallmark of reality-based education. Finally, it can be concluded that the evGrand Prix experience provided the challenge and opportunity that it was designed and expected to do. Regardless of team success in competition, educators seeking a training tool or method must evaluate how the experience affects and helps the development of individual students.

Observations

As in any learning situation, some students were highly motivated. The committed students from the class and volunteer (not for credit) students from the Motor Sports Club, regardless of personal situation, stuck with it and gained the most from the experience. These typically were the students that became the members of the travel team that raced and presented at Indy. Some students were not interested in electric vehicles or racing but most performed adequately in both lecture and project activities, though some did not. Some students could not see the relevancy of building an electric racer to solve technical problems, while others could not see the correlation between the lecture topics on sustainability and the project side of the class, even though the instruction was carefully orchestrated to include examples.

In a few cases, there were students who were failing the lecture component of the class and yet were top performers on the project side. The average students found the project component to be challenging. Some simply were not prepared to give the time commitment required. Being a reality-based project, some project topics demanded reliance on other students completing their tasks on time. Students were susceptible to the vagaries of external agents such as the vendors and parts suppliers. This often necessitated that the students work outside of normal class time, which many found difficult. This difficulty was exacerbated by the fact that many of these students worked part-time in other jobs to earn money. Other students scheduled an overload of classes in an attempt to graduate early and save money in the long run. Some students simply could not handle the rigor and discipline required to complete a project. Some were simply overwhelmed. It was also surprising to the instructors that some junior and senior students had simply not written a technical report or failed at using the Internet to look for technical materials.

From the faculty instructional delivery side, there were also some difficulties. Though teachable moments presented themselves continuously in the program, the students needed to have access to a smorgasbord of expertise when they were ready. This expertise was typically not found in one individual, which required more than one faculty member or community volunteer to mentor and guide the students. In this case, some faculty members who had the expertise could not or would not participate in helping the students. In these situations, volunteers from the community provided much-appreciated help to the instructors. This level of volunteer commitment was difficult to sustain and rely upon by the instructors. It was simply not in the educational budget for the college administration to staff this activity over a long period of time using paid faculty or college staff, or to persuade reluctant faculty members to incorporate such an experience into their classes. So the problem soon became the need to increase the level of external funds to help cover support personnel.

As in any partnership, both parties gain. Some of the ways the industrial partners gained were credit for philanthropy, access to technical students not only within the project but also through internships, confidential product testing with feedback, access to new markets through name recognition via media, shows, and other venues.

Conclusions and Recommendations

It was obvious that the reality-based program magnified some of the students' inadequacies that were being seen by industry. The best news was that these problems could be seen, while the students were still enrolled at school. The news is only good if a way can be found to treat the inadequacy prior to a student starting an internship or receiving a degree. Though reality-based programs similar to the evGrand Prix provide all that has been advertised, the 3-year experience of the authors showed that these capstone experiences are most valuable as an extracurricular supplement to the normal educational program. Some effort needs to be placed on encouraging students to participate in these programs by the faculty. Another possibility is to require a for-credit capstone experience as a substitute or requirement prior to an internship and graduation. Because of high-visibility events and the needs of industry, these programs may be self-funding, giving some consideration for modest student scholarships to be awarded. Faculty may continue to find value in carefully incorporating specific problem topics from such programs in structured classes.

In the final analysis, these become issues for discussion at-large between lawmakers, industry, and the educational institutions, as to how to sustain these activities and meet the needs of developing the type of engineering technology graduates that the industry has been calling for. It is likely that more study will be needed before the problem is solved, and some form of reality-based or capstone experience can help.

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Identifying Employer-Demanded Skill Sets for Undergraduate Engineering and Technology Employees

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Abstract

The manufacturing sector is a driving force of the U.S. economy. The National Association of Manufacturers (NAM) has warned that the country will face a severe shortage of skilled workers—up to 10 million by 2020—if current employment and job training trends continue. NAM is the U.S.' largest industrial trade association, representing more than 14,000 large and small manufacturers. Unfortunately, very little information exists about the specific skill sets that are most in demand, especially among graduates of four-year colleges with degrees in engineering and technology fields. In this paper, the authors present findings of a pilot study which was conducted to investigate the skill sets that manufacturing employers seek when hiring new four-year college engineering and technology graduates.

Introduction

Manufacturing added $2.08 trillion to the U.S. economy in 2013 and "for every dollar spent in manufacturing another $1.32 is added to the economy" [1]. Manufacturing is critical to the economic future of the U.S. Robust job creation in this sector and recent on-shoring trends have made development of this sector increasingly important. In his 2014 State of the Union Address, President Barack Obama announced the formation of a commission to be led by Vice President Joseph Biden that was tasked with training Americans with employer-preferred skill sets, in areas such as but not limited to advanced manufacturing and information technology [2]. A July 2014 report submitted to the White House by the commission noted three key issues with American job training:

1. Employers can't find enough skilled workers to hire for in-demand jobs that they must fill to grow their businesses.
2. Education and training programs need better information on what skills those in-demand jobs require.
3. Whether they are studying, looking for work, or seeking better career paths, Americans often aren't sure what training to pursue and whether jobs will be waiting when they finish [2].

One of the keys to creating manufacturing jobs is finding employees with the right skill sets. In a 2011 congressional hearing on ways to develop America's manufacturing workforce, Illinois Rep. Daniel Lipinski stated that he constantly hears from manufacturers in sectors ranging from steel to nanotechnology about their increased difficulty in finding qualified workers [3]. And if there are no qualified workers, there is no job creation. Even during tougher economic times, manufacturers complain about not being able to find people with the right skill sets. In a March 2005 press release, the National Association of Manufacturers (NAM) warned that the country will face a severe shortage of skilled workers if current employment and job training trends continue [4]. NAM is the nation's largest industrial trade association, representing 14,000 small and large manufacturers in every industrial sector and in all 50 states [5]. NAM's prediction held true even during the great recession of 2007, when employers were still finding it difficult to hire skilled people [6]. By 2020, according to NAM, the gap could equal more than 10 million workers [4]. However, a recent study by the University of Massachusetts, Dartmouth suggests that the manufacturers may not be looking at the right educational programs [7]. If so, the problem could be a disconnect between employers and educational programs.

Background

Even though reports from various manufacturing-related organizations indicate a shortage of skilled labor, very little information has been published about the specific skill sets required, especially among graduates of four-year colleges with degrees in engineering and technology-related fields. The need for this study evolved from that lack of information. In this paper, the authors focus on a pilot study that investigated the skill sets that employers seek when hiring four-year college graduates to fill manufacturing-related positions.

Methodology

During this research project, the authors conducted a pilot study to identify the specific skill sets demanded by the employers for positions ranging from entry-level to upper management. To acquire the most recent data possible, the researchers analyzed 165 manufacturer job postings for engineering and technology-related positions—ranging from entry-level to upper management—on the most popular employment resource websites. The search area selected for this study was the U.S. and its territories. Two types of searches, both using the keyword engineering, were performed. The first, hereafter described as “unfiltered”, included jobs at all experience levels. The second was restricted solely to entry-level positions in order to determine which specific skills employers sought from graduates just out of college. The search discovered jobs available across the nation with titles such as process engineer, manufacturing engineer, design engineer, and product engineer, among others.

Analysis of the raw data revealed roughly 125 specific skills listed in the job postings. The researchers used their educational backgrounds in engineering and technology and management, as well as experience in industrial manufacturing, to analyze the data and combine similar terms to yield 43 specific skill sets. These 43 specific skill sets fell into four major categories: engineering skills, soft skills, managerial skills, and business skills.

Findings

The 43 specific skill sets were consolidated under four major categories, as shown in Table 1. Each of these skill groups comprised a specific skill set. An example of this would be the skill group CAD, which included 2D, drafting, GD&T, and other similar skills. Figure 1 depicts a Pareto chart for skill sets that the employers demanded when hiring for entry-level positions. The numbers corresponding to each of the legends shows the percentage of the total occurrences and number of times those have occurred. For example, 40% of the skills demanded were engineering skills, which were 416 out of the total 1,047 skill-demand occurrences. Soft skills were the second highest category sought with 33%, followed by management skills at 21% and business skills at 6%.

Further analysis of the Pareto curve showed that the first nine items accounted for 57% of the total demand; this included engineering skills, soft skills, managerial skills, and business skills. Data from the unfiltered search was also analyzed; a Pareto histogram of the results is shown in Figure 2. It should be noted that the first 10 items accounted for 53% of the skill-demand occurrences.

Table 2 depicts the top 10 skill groups sought by employers in descending order of their occurrences.

Table 1. Skills by Category and Group

Skill Category	Skill Group
Engineering Skills	CAD
	3D Modeling
	Basic Math
	Advanced Math
	Statistical Data Analysis
	CAM/Machining
	Quality
	Robotics and Controls
	Design Tooling
	Design
	Applied Skills
	Plastics
	Machine Optimization
	Determine Best Process
	Technical Writing
	System Monitoring and Analysis
Soft Skills	High-Performance Teams
	Attention to Detail
	Time Management
	Self-Driven
	Legal, Supervisory, and Management
	Current and Relevant
	Emotional Intelligence
	Interpersonal
	Coordinate Activities Across Company
	Problem Solving/Decision Making
Managerial Skills	Purchasing
	New Equipment Implementation
	Document Control
	Process Documentation
	Lean
	Risk Management
	Operations Management
	Project Management
Business Skills	Marketing
	Technical Sales
	Cost
	Basic Business Knowledge
	Multifunctional Sales Team
	Identifying Competitors
	Identifying Changes In Industry
	Sales
	Function With Business Department

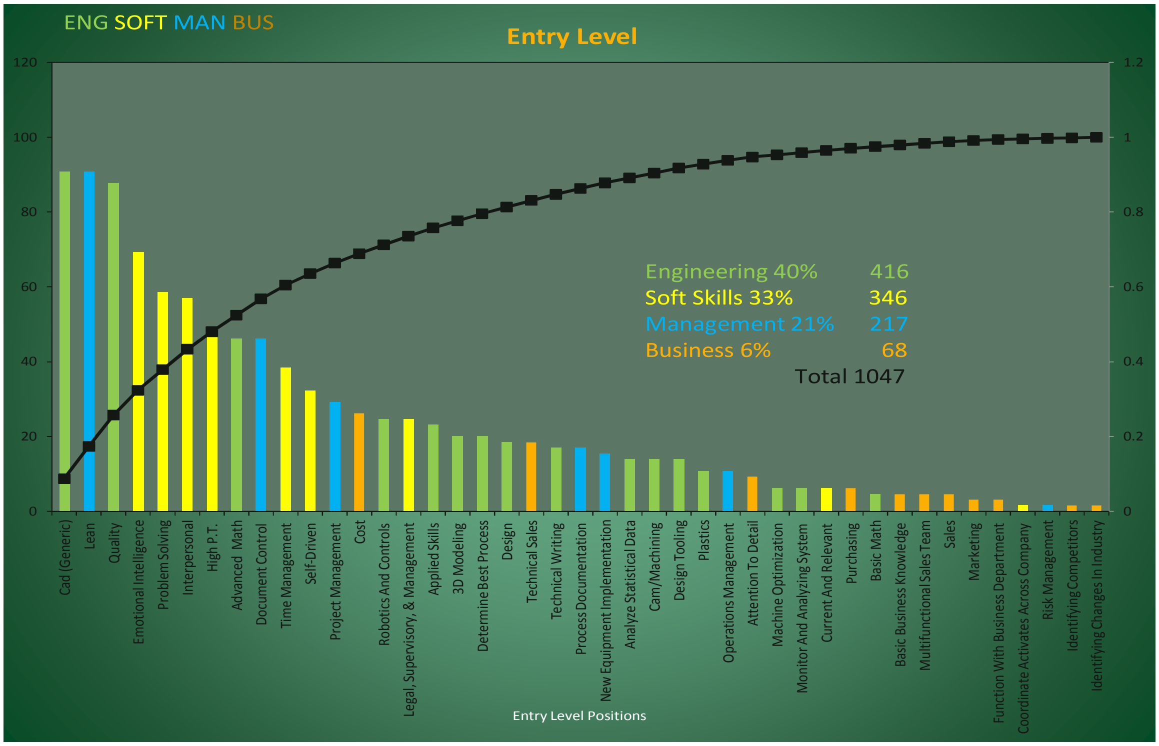

Figure 1. Manufacturers' Desired Skill Sets for Entry-level Employees

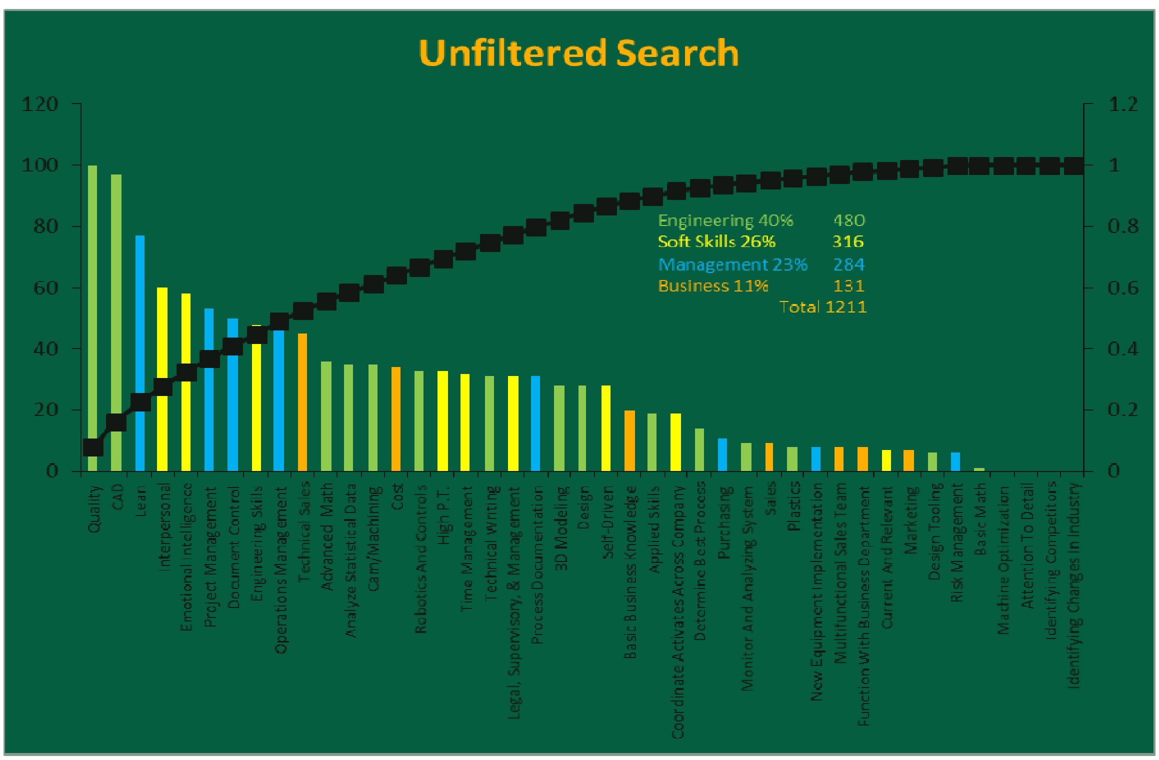

Figure 2. Manufacturers' Desired Skill Sets for Employees of All Experience Levels

Table 2. Top 10 Skill Groups in Descending Order

No.	Entry-Level	Unfiltered
1	CAD	Quality
2	Lean	CAD
3	Quality	Lean
4	Emotional Intelligence	Interpersonal Skills
5	Problem Solving	Emotional Intelligence
6	Interpersonal Skills	Project Management
7	High Performance Teams	Document Control
8	Advanced Math	Problem Solving
9	Document Control	Technical Sales
10	Time Management	Advanced Math

Conclusion

The findings showed that seven of the top 10 most-demanded skill groups were common between entry-level and unfiltered searches. The skill groups included CAD, lean, quality, emotional intelligence, problem solving, interpersonal skills, document control, and advanced math. The scope of this paper, then, is to provide a list of the most needed/preferred skill sets that engineering and technology employers seek in today's marketplace (see Table 3).

Most of these skills are general transferable skills, not specializations such as plastics or welding. Two groupings on this list (emotional intelligence and interpersonal skills) are even less technical in nature and more managerial in nature. This study raises a question: Are today's engineering and technology programs offering curricula that satisfy the needs of today's employers?

Next Steps

For the next phase of this study, the authors plan to develop a survey to send to potential employers in the manufacturing sector to validate the 125 specific skill sets and groups identified in the pilot phase. This survey may include face-to-face interviews with engineering and technology hiring managers and/or employment agencies. Subsequently, the authors plan to compare the in-demand skills identified in this current study with the skills being offered in today's engineering and technology curricula.

Table 3. Manufacturers' Preferred Skill Sets for Engineering and Technology-related Positions

Skill Group	Specific Skill
CAD	CAD
	2D
	Floor Plans
	Drafting
	Write/Read/Modify
	Basic Understanding
	Read Blueprints/Floor Plans
	GD&T
Quality	Quality
	Failure Modes and Analysis
	Quality
	6 Sigma
	System Effectiveness
	ISO-9000
	Industry Standards
	Develop Testing/Ins Procedure
	Define Quality Standards
	Design Methods
	Properly Dimensioned Parts
Lean	Lean
	Time Studies
	Maintenance
	Analyze Down Time
	Continuous Improvement
	Kanban
	JIT
	TPM
	Standardization within Company
	Layout Design
	Workflow
	Motion Studies
Emotional Intelligence	Professionalism
	Leadership
	Leader Personality
	Leading Teams
Problem Solving/ Decision Making	Effective Decision Making
	Problem Solving
	Analysis Skills
	Troubleshooting
Interpersonal	Communication
	Basic Writing
Document Control	Nonconformance Report
	Engineering Change Request
	Maintaining Documents
	Controlling Documents
	Producing Documentation
	Creating Work Instructions/Manuals
	Bill of Materials
	Routing Sheets
Advanced Math	Complex Commutations
	Finite Element Analysis
	Materials (Strength, Load, etc.)
	Complex Parts (Jet Turbine Design, etc.)

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A REVIEW OF COMMERCIAL TRAINERS AND EXPERIMENT KITS FOR TEACHING RENEWABLE ENERGY MANUFACTURING

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Abstract

In this paper, the authors summarize product information from major suppliers of commercial trainers and experiment kits that are used to teach renewable energy manufacturing. It is hoped that this will serve as an informational resource for universities, colleges, and schools interested in obtaining their lab equipment from these suppliers.

Introduction

Economies of the U.S. as well as the rest of the world have long depended on nonrenewable fossil energy sources (coal, oil, and natural gas). Supplies of fossil energy are expected to decline in the future and become more expensive. Meanwhile, their use contributes to the accumulation of greenhouse gases in the atmosphere. Therefore, there is an urgent need for renewable energy sources [1]. Renewable energy manufacturing is considered a new worldwide industry. Renewable energy manufacturing is referred to as the process of converting one form of energy from a renewable source, such as sunlight, wind, or biomass, into another form of energy that consumers can use directly (for example, electricity or transportation fuel). Countries that make and sell more renewable energy will have a competitive advantage. Many countries are competing for leadership in renewable energy manufacturing. To enhance the global competitiveness of the U.S. in renewable energy manufacturing, there is a dramatic need for a skilled workforce that has been trained in the field [1].

To meet workforce needs, more and more academic programs offering renewable energy are being formed [2]. In these programs, renewable energy lab exercises have become an essential component. Several educators [3-8] have highlighted the importance of lab activities in teaching renewable energy manufacturing. According to their observations, the students can better comprehend complex concepts and theories through a series of lab experiments and projects. The authors of this current study researched which trainers and experiment kits are being used by different universities to teach renewable energy manufacturing. It was found that the majority of the schools built their own equipment for labs and projects [4], [7-13]. Only a few schools used commercial lab equipment and experiment kits for their teaching [6], [14], [15].

The authors posted a question in March, 2013, on the Engineering Technology listserv (etd-l@listproc.tamu.ed) to seek more information on the trainers and experiment kits: "We are looking for experimental kits that introduce renewable energy (such as wave, tide, geothermal, biomass energy) to the students. Could anyone share information with us on where we can find these kits? So far, we have found some experiment kits for wind and solar energy." The authors received dozens of responses from 18 higher education institutions, four equipment suppliers, and five related individuals. A lot of repliers expressed the same interest as the authors. These communications clearly indicated that the public domain needs a comprehensive informational reference to the commercial educational trainers and experiment kits in the renewable energy manufacturing areas. To satisfy the needs of the public domain, the authors collected product information from all major suppliers of commercial trainers and experiment kits that are being used to teach renewable energy manufacturing. The authors hope that these trainers and experiment kits can be used by educational institutions to help their students more effectively obtain professional skills in problem identification, engineering design, hands-on experience, team management, communication and documentation, and social and environmental impact assessment.

Solar Energy Trainers

The major providers of the solar energy experiment equipment include:

- EDIBON (http://www.edibon.com)
- Lab-Volt (http://www.labvolt.com)
- De Lorenzo (http://www.delorenzoenergy.com/products_energia.html)
- Hampden (http://www.hampden.com)

EDIBON Equipment

- Computer-controlled photovoltaic solar energy unit: This is a computer-controlled unit to study the transformation of solar energy into electric energy. This unit uses the photo conversion solar system for the direct conversion of solar radiation into electricity. (http://www.edibon.com/products/?area=energy&subarea=alternativeenergies)
- Photovoltaic solar energy modular trainers: This is designed for the theoretical and practical study of the electrical installations with photovoltaic solar energy. (http://www.edibon.com/products/catalogues/en/units/energy/alternativeenergies/MINI-EESF.pdf)
- Computer-controlled thermal solar energy unit: This unit transforms solar energy into calorific energy. (http://www.edibon.com/products/catalogues/en/units/energy/alternativeenergies/EESTC.pdf)

Lab-Volt Trainers

- Solar thermal energy training system: This is a solar hot water heating system. (http://www.labvolt.com/products/alternative-and-renewable-energy/solar-energy/solar-thermal-energy-training-system)
- Solar power technology training system: This is designed to study the production of electrical energy from solar power. (http://www.labvolt.com/products/alternative-and-renewable-energy/solar-energy/solar-power-technology-training-system-8805)

De Lorenzo Trainers

- Photovoltaic solar energy trainer: This equipment is for the theoretical and practical study of photovoltaic solar energy facilities. (http://www.delorenzoenergy.com/sheets_en/DL%20SOLAR-A%20ENG.pdf)
- Solar energy modular trainer: This modular trainer is for the theoretical and practical study of electrical installations with photovoltaic solar energy. (http://www.delorenzoenergy.com/sheets_en/DL%20SOLAR-B%20ENG.pdf)
- Photovoltaic solar energy trainer: This trainer is for the theoretical and practical study of the applications of the photovoltaic solar energy in houses. (http://www.delorenzoenergy.com/sheets_en/DL%20SOLAR-C%20ENG.pdf)
- Photovoltaic solar energy trainer for connection to mains: This unit studies the generation of electrical energy and its connection to the mains network. (http://www.delorenzoenergy.com/products_solare_en.htm)
- Photovoltaic and thermal panel simulator: This unit performs the experiments and troubleshooting on photovoltaic cells in series and in parallel and thermal panels with liquid circulation. (http://www.delorenzoenergy.com/sheets_en/DL%20TM11%20ENG.pdf)
- System for the study of photovoltaic solar energy: The system is composed of a set of electronic sub-boards for basic experiences on solar photovoltaic cells. (http://www.delorenzoenergy.com/sheets_en/DL%203155BRS%20ENG%20photovoltaic.pdf)
- Solar thermal energy trainer: This trainer is for the study of thermal solar energy with heat exchanger and water storage tank. The solar energy is simulated by means of a panel provided with electric resistance. (http://www.delorenzoenergy.com/sheets_en/DL%20THERMO-A1%20ENG.pdf)

Hampden Trainers

- Solar photovoltaic trainer: This trainer demonstrates the electrical characteristics of the solar array, storage battery, AC/DC distribution, and AC/DC loading. (http://www.hampden.com/tortoisecms/uploads/files/Alternative%20Energy.pdf)
- Solar system trainer: This trainer is a solar hot-water heating system. (http://www.hampden.com/tortoisecms/uploads/files/Alternative%20Energy.pdf)

Wind Energy Trainers

Suppliers include:

- Quanser (http://www.quanser.com)
- EDIBON (http://www.edibon.com)
- Lab-Volt (http://www.labvolt.com)
- De Lorenzo (http://www.delorenzoenergy.com/products_energia.html)
- Hampden (http://www.hampden.com)

Quanser Wind Turbine

This wind turbine consists of a wind blower inside a wind tunnel.

EDIBON Wind Energy Trainers

- Computer-controlled wind energy unit: This is a laboratory-scale unit designed to study the wind energy and the influence of some factors on this generation. (http://www.edibon.com/products/catalogues/en/units/energy/alternativeenergies/EEEC.pdf)
- Computer-controlled wind energy basic unit: This unit is a small-scale unit and is designed to study the wind energy and the influence of some factors on this generation. (http://www.edibon.com/products/catalogues/en/units/energy/alternativeenergies/MINI-EEEC.pdf)

Lab-Volt Trainers

- Wind-farm simulation software: This unit simulates the behavior of every aspect of the wind turbines in a wind farm. (http://www.labvolt.com/products/alternative-and-renewable-energy/wind/wind-farm-simulation-software-46128)
- Wind power systems: This is an interactive program for technicians in the systems of wind-power generation. (http://www.labvolt.com/products/alternative-and-renewable-energy/wind/wind-power-systems-46127#)
- Wind power training system: This unit studies the complete process of wind-power generation right in the classroom. (http://www.labvolt.com/products/alternative-and-renewable-energy/alternative-and-renewable-energy/wind-power-training-system-8010-3)
- Wind-power technology equipment: This is designed to introduce students to the small-scale production of electrical energy from wind power. (http://www.labvolt.com/products/alternative-and-renewable-energy/wind/wind-power-technology-8216-86618-86630)
- Nacelle training system: This system offers hands-on training for real-world operation and maintenance situations. (http://www.labvolt.com/products/alternative-and-renewable-energy/wind/wind-turbine-nacelle-training-system-46122)

De Lorenzo Trainers

- Wind tunnel: This trainer is for the theoretical and practical study of the generation of electricity by means of wind power. (http://www.delorenzoenergy.com/sheets_en/DL%20WIND-B%20ENG.pdf)
- Wind-energy modular trainer for indoor use: This trainer includes a set of control and application modules, such as inverter, battery, loads, etc., and a DC motor to use the system without wind. (http://www.delorenzoenergy.com/sheets_en/DL%20WIND-A1%20ENG.pdf)

Hampden Trainers

- Wind-power generator: This trainer has been designed to provide students with the basic understanding of wind generator function as an alternate source of energy. (http://www.hampden.com/tortoisecms/uploads/files/Alternative%20Energy.pdf)
- Wind turbine. (http://www.hampden.com/tortoisecms/uploads/files/Alternative%20Energy.pdf)

Fuel Cell Trainers

Suppliers include:

- Lab-Volt (http://www.labvolt.com)
- Heliocentris (http://www.heliocentris.com)
- EDIBON (http://www.edibon.com)
- Shatz Energy Research Center (http://www.schatzlab.org)
- De Lorenzo (http://www.delorenzoenergy.com/products_energia_en.html)
- Hampden (http://www.hampden.com)

Lab-Volt Trainers

- Hydrogen fuel cell training system: This trainer is designed in a modular format to integrate with the existing systems. (http://www.labvolt.com/products/alternative-and-renewable-energy/energy-efficiency/hydrogen-fuel-cell-training-system-8010-80)

Heliocentris Trainers

- 50-W fuel cell training system: This trainer introduces the operating principle of a fuel cell system, thermodynamics, characteristic curves and efficiency ratings, system and power electronics. (http://www.heliocentris.com/en/academia-offering/products/training-systems/fuel-cell-trainer/overview.html)

- 1.2-kW fuel cell training system for system dimensioning and hybridization: Students can design and simulate fuel cell energy systems towards specific load profiles on the basis of the system's industrial components. (http://www.heliocentris.com/academia-angebot/produkte/trainingssysteme/nexa-training-system/uebersicht.html)

EDIBON Trainers

- Computer-controlled PEM fuel cell advanced unit: This unit was designed to allow students to understand fuel cell technology especially that of a proton exchange membrane fuel cell (PEM). (http://www.edibon.com/products/catalogues/en/units/energy/alternativeenergies/EC6C.pdf)

Shatz Energy Research Center Trainer

- Fuel cell test station: This test station allows students to gain hands-on experience in testing proton exchange membrane (PEM) fuel cell stacks. (http://www.schatzlab.org/projects/hydrogen/masdar.html)

De Lorenzo Trainers

- Trainer for experiences on hydrogen fuel cells: This trainer includes a PEM fuel cell stack, electrolyser, monitoring software, hydrogen storage tank, lamp, fan, and solar module. (http://www.delorenzoenergy.com/sheets_en/DL%20HYDROGEN-A%20english.pdf)
- Fuel cells systems trainer: This system is designed for the study of fuel cell systems. It teaches engineering principles and allows students to perform a set of experiments. (http://www.delorenzoenergy.com/sheets_en/DL%20HYDROGEN-B%20ENG.pdf)

Hampden Trainers

- Fuel cell technology trainer: This trainer allows students to create a grid-independent power supply that uses only hydrogen as the fuel. (http://www.hampden.com/tortoisecms/uploads/files/Alternative%20Energy.pdf)

Solar/Wind/Fuel Cell Hybrid Trainers

Some companies provide hybrid trainers in which solar, wind, and fuel cell energies are incorporated together. These companies include:

- Heliocentris (http://www.heliocentris.com)
- Lab-Volt (http://www.labvolt.com)
- De Lorenzo (http://www.delorenzoenergy.com/products_energia_en.html)
- Horizon (http://www.horizonfuelcell.com/contact_us.html)
- Hampden (http://www.hampden.com)

Heliocentris Trainers

- Training system for solar hydrogen production: This system enables complete balancing of solar/hydrogen generation. (http://www.heliocentris.com/academia-angebot/produkte/trainingssysteme/solar-hydrogen-extension/uebersicht.html)
- Hybrid energy training lab for experiments related to energy management: This off-grid hybrid system allows the study of each technology individually or in combined set-ups. (http://www.heliocentris.com/academia-angebot/produkte/labore-fuer-erneuerbare-energien/new-energy-lab.html)
- Training and demonstration unit for solar and hydrogen technology: This unit resembles a complete solar/hydrogen cycle. (http://www.heliocentris.com/academia-angebot/produkte/schulprodukte/professional/uebersicht.html)

Lab-Volt Hybrid Trainers

- Wind-solar energy training system: This unit consists of a wind turbine generator powered by a DC motor drive without turbine blades, for classroom safety. (http://www.labvolt.com/products/alternative-and-renewable-energy/solarwind-energy/solarwind-energy-training-system)

De Lorenzo Hybrid Trainers

- Wind-solar fuel cell energy trainer: This is for the study of renewable energy, solar energy, wind energy, and hydrogen fuel cells.

(http://www.delorenzoenergy.com/sheets_en/DL%20GREENKIT%20ENG.pdf)

- Wind-solar energy modular trainer: This unit includes a set of modules for practical exercises for the theoretical and practical study of a hybrid system with solar energy and wind energy.
(http://www.delorenzoenergy.com/sheets_en/DL%20SUN-WIND%20ENG.pdf)
- System with master-slave inverters: This trainer is for the study of a wind-solar energy system, where one of the two inverters, operating as a master, synchronizes the frequency of the second inverter.
(http://www.delorenzoenergy.com/sheets_en/DL%20SUN-WIND2%20ENG.pdf)

Horizon Hybrid Trainers

- Zero carbon panel: This H_2/air and H_2/O_2 fuel cell system includes modular panels.
(http://www.horizonfuelcell.com/educationcatalog2013/educationcatalog2013.html)

Low Enthalpy Geothermal Energy Trainers

The major suppliers for low-enthalpy (low-temperature and low-pressure) energy trainers include:

- Lab-Volt
(http://www.labvolt.com)
- EDIBON
(http://www.edibon.com)

Lab-Volt Trainers

- Geothermal training system: This system is designed to teach the fundamentals of heat transfer, refrigeration, and air conditioning applied to geothermal energy HVAC projects.
(http://www.labvolt.com/products/alternative-and-renewable-energy)

EDIBON Trainers

- Computer-controlled geothermal (low-enthalpy) energy unit: This unit introduces how to use geothermal energy to control the climate of buildings.
(http://www.edibon.com/products/catalogues/en/units/energy/alternativeenergies/SCE.pdf)

Bio-Fuel Trainers

The major suppliers of bio-fuel trainers include:

- EDIBON
(http://www.edibon.com)
- De Lorenzo
(http://www.delorenzoenergy.com/products_energia_en.html)

EDIBON Bio-Fuel Trainers

- Computer-controlled biogas process unit: This unit is designed for the study of the different processes given during biogas generation through anaerobic breakdown, as well as the study of the different parameters that affect the anaerobic digestion and the value of the obtained biogas.
(http://www.edibon.com/products/catalogues/en/units/energy/alternativeenergies/EBGC.pdf)
- Computer-controlled biodiesel process unit: This is a unit which allows the study of the different biodiesel production cycle stages.
(http://www.edibon.com/products/catalogues/en/units/energy/alternativeenergies/EBDC.pdf)
- Computer-controlled bioethanol process unit: This unit is designed for the study and control of the process of bioethanol.
(http://www.edibon.com/products/catalogues/en/units/energy/alternativeenergies/EBEC.pdf)
- Computer-controlled biomass process unit: The main objective of this unit is for the study of the biomass process for heating applications, using different types of biomass fuels such as pellets and wood chips.
(http://www.edibon.com/products/catalogues/en/units/energy/alternativeenergies/EBMC.pdf)

De Lorenzo Bio-Fuel Trainers

- Biodiesel plant: This unit undertakes a chemical process of transesterification with methanol and produces biodiesel, which is a vegetable-oil or animal-fat-based diesel fuel.
(http://www.delorenzoenergy.com/sheets_en/delor_biodiesel_low.pdf)
- Bio-ethanol plant: This trainer is for the production of bio-ethanol from sugar cane or, optionally, from tubers (sweet sorghum, manioc, potatoes, rice, or corn).
(http://www.delorenzoenergy.com/sheets_en/DL%20ETAL-15%20Bio-Ethanol%20Pilot%20Plant%20-ENG.pdf)

Wave, Tide, and Hydro Trainers

Major suppliers include:

- EDIBON
  (http://www.edibon.com)

EDIBON Trainers

- Computer-controlled energy waves unit: The unit is mainly formed by a rectangular transparent tank, to be filled with water, where the different energy generation modules will be placed.
  (http://www.edibon.com/products/catalogues/en/units/energy/alternativeenergies/EOMC.pdf)
- Generating stations control and regulation simulator: This unit is designed to simulate the regulation behavior of a hydroelectric generating station, as a didactic application with different aspects of regulation, control, and simulation.
  (http://www.edibon.com/products/catalogues/en/units/energy/alternativeenergies/SCE.pdf)

Smart Grid Training Systems

Major suppliers include:

- Lab-Volt
  (http://www.labvolt.com)

Lab-Volt Training Systems

- Smart-grid technologies training system: This unit combines Lab-Volt's modular design approach with computer-based data acquisition and control to provide unrivaled training in smart grid technologies.
  (http://www.labvolt.com/downloads/datasheet/dsa8010_C.pdf)
- Grid-Tied training system: This unit provides hands-on training in developing the skills required for installing a grid-tied system.
  (http://www.labvolt.com/products/alternative-and-renewable-energy/solarwind-energy/grid-tie-training-system-46125)

Experiment Kits

There are quite a few suppliers for the experiment kits. These companies provide inexpensive kits that use solar, wind, hydro, bio-fuel, and fuel cell energies. The companies listed here are the ones either appearing in the literature, the authors reviewed, or were sent to the authors via the ETD listserv. The products provided by these suppliers are very diverse.

- Heliocentris
  (http://www.heliocentris.com)
  - Students science kit for solar hydrogen technology
    (http://www.heliocentris.com/academia-angebot/produkte/schulprodukte/science-kit/uebersicht.html)
  - Model car with reversible fuel cell
    (http://www.heliocentris.com/academia-angebot/produkte/schulprodukte/model-car/uebersicht.html)
  - Experiment set for energy generation, storage, and supply.
    (http://www.heliocentris.com/academia-angebot/produkte/trainingssysteme/clean-energy-trainer/uebersicht.html)

- Lab-Volt
  (www.labvolt.com)
  - GREENtech Energy Efficiency & Renewable Energy Training Lab
    (http://www.labvolt.com/products/alternative-and-renewable-energy/solar-energy/graymark-greentech)

- Kid Wind
  (http://learn.kidwind.org)
  - Wind kits
    (http://store.kidwind.org/solar-kits/solar-electric-kits/solar-car)
  - Solar Boat Science Kit
    (http://store.kidwind.org/solar-kit)
  - Advanced wind experiment kit
    (http://store.kidwind.org/wind-energy-kits/complete-kits/advanced-wind-experiment-kit)
  - Kid Wind Science fair wind project
    (http://store.kidwind.org/wind-energy-kits/complete-kits/science-fair-wind-project)
  - MudWatt microbial fuel cell kit
    (http://store.kidwind.org/more-kits/miscellaneous/mudwatt-microbial-fuel-cell-kit)
  - Hydro power wheel

- PITSCO Education
  (www.pitsco.com)
  - Solar car, wind turbine, solar panel/hydrogen fuel cell

- PASCO
  (http://www.pasco.com/home.cfm)
  - Hydro accessory
    (http://www.pasco.com/prodCatalog/ET/ET-8772_energy-transfer-hydro-accessory/)
- Horizon
  (http://www.horizonfuelcell.com/#)

- Ethanol fuel cell
    (http://www.horizonfuelcell.com/educationcatalog2013/educationcatalog2013.html)
  - Fuel cell storage, super capacitor
    (http://www.horizonfuelcell.com/education_catalog2013/educationcatalog2013.html)
- Fuel cell store
  (http://www.fuelcellstore.com/en/pc/home.asp)
  - Tutorial HyRunner
    (http://www.fuelcellstore.com/en/pc/viewPrd.asp?idproduct=1253)
- Shop4ScienceKits.com
  (http://www.shop4sciencekits.com)
  - Wind, solar, hydro, fuel cell energies
    (http://www.shop4sciencekits.com/alternative-energy-and-environmental-science.htm#TK623913)
- Eastern Kentucky University, Center for Renewable and Alternative Fuel Technologies
  (http://www.craft.eku.edu/BEAM)
  - Bio-Energy Activity Module
- Kelvin Educational
  (http://www.kelvin.com)
  - Wind tunnel, solar, fuel cell
    (http://www.kelvin.com/catpdfs.html)

Conclusions and Future Research

In this paper, the authors identified the major suppliers of commercially available trainers and experiment kits for teaching renewable energy manufacturing. The major product lines of these suppliers were presented. It can be seen that most of the trainers and experiment kits focus on the study of solar, wind, low-enthalpy geothermal, bio-fuel, hydrogen fuel cell energies, and smart-grid technologies. The option for wave and tide energy trainers is quite limited. The trainers for high-enthalpy geothermal energy were not found (even though EDIBON claimed that they had the design available). Among these commercial trainers and experiment kits, many products have the following distinct features:

- They have more sophisticated control systems for better reading and analysis.
- They have pre-designed lab assignments, thus saving the instructors a lot of time in lab preparation.
- They are made according to industrial standards, thus they are safer and more reliable to use.

In future research, the authors plan to focus on comparison of the equipment included here. Analysis will be made on costs, technical specifications, operation performances, product warranty, advantages, disadvantages, and training options.

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