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Leadership Styles and Careers in Engineering

Philip Weinsier, TIIJ Editor-in-Chief

I feel comfortable saying that virtually all of us have worked for someone at some point in our lives. Pick any memorable experience with your employer or supervisor and ask yourself if it was a positive or negative experience; and then ask yourself why. If we strip away factors such as money, type of job, physical appearance (either or both of you), or even physical attraction, what we eventually will be left with is leadership style. Did the person from your memorable experience treat you as an equal; act in a demeaning and verbally abusive manner towards you; make you feel as if you were part of the decision-making elite at the company; treat you as a worthless, replaceable peon; consider you as a member of the team and always be there to help and guide you; exploit you and your talents—perhaps even taking credit for your work; treat you as a valuable asset to the company that should be respected and trusted; patronize you, while obviously not respecting you? Or did your "boss" offer a combination of these or other fronts on different occasions, which ultimately led to your experience being positive or negative?

If we stop and analyze such interactions, we will likely come to the conclusion that no one front or style will always yield similar results; not just with us but with the other employees, who come after you and work under the same person. I also feel that you will agree that a person's leadership style—or skills—are not necessarily inherent; they could be learned. And, if you are honest with yourself, I think you will also find that no one style will be perfect every time, every day, and in every situation. In an Indeed survey, "55% of employers cited asking about leadership skills in an interview as the most accurate evaluation of a candidate's ability to succeed in a role." Leadership is crucial for effective functioning of any organization. And, I dare say, the most successful leaders recognize all of this and are able to tweak or even modify their styles based on the person they are dealing with at any given moment and based on the job being performed by that person. So the authors of this featured article posed the following questions:

- What is the dominant industrial leadership style?
- What is the dominant leadership style in the broader engineering sector
- What is the dominant leadership style entry-level engineers should know in order to be successful?

In this study, the authors explored prevalent leadership styles found in industry from an engineering student's internship experiences. Over the course of four years of internships, observations and interview responses were recorded to address these three questions. Leadership is far more than simply occupying a leadership role, it extends to every aspect of life and will benefit each facet in which it is utilized. As the results of this study indicate, multiple leadership skills are required for entry-level engineers to be successful and for industry to prosper. As the information from observing and interviewing technical leaders suggests, knowing how to effectively use a multitude of leadership techniques will positively change the trajectory of one's technical career and quite possibly enhance their lives as well. Further, this study builds upon prior research on the correlations between leadership skills taught in college and the resulting success beyond the classroom.

According to the U.S. Bureau of Labor Statistics, "STEM occupations (during the years noted) made up 6.2 percent of overall national employment, but between one- and two-thirds of employment in some industries." And, "Employment in STEM occupations grew by 10.5 percent…compared with 5.2 percent net growth in non-STEM occupations." With such growth, and the reliance of our nation's backbone on science and engineering, it behooves us as educators and industry employers to find the right stuff, when it comes to making employees feel appreciated and part of the team; this improves devotion and job longevity on the part of the employees, and satisfaction and quali--of-products for employers.

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Hardware in the Loop for Embedded Code Development in an Introductory Undergraduate Course

Dale Litwhiler, Penn State, Berks

Abstract

Hardware In the Loop (HIL) is a powerful method in the development and testing of embedded processor software. HIL provides a means of simulating a system to be monitored and/or controlled with an embedded device such as a microcontroller. This method allows the embedded device's code to be developed in parallel with the hardware development of the system, thereby shortening overall development time. HIL is also useful when the actual system to be controlled is too complex and/or costly to operate just to verify software during the early stages of development. The ideas of HIL are also very useful in the delivery of undergraduate courses in embedded systems. Using simple computer-controlled hardware, an interface to a simulated system can be created that is much more interesting and insightful than simply blinking an LED or displaying Hello World. The students can also develop the simulator-side HIL hardware and software to gain further understanding of how the overall system operates. In this paper, the author presents some of the HIL work developed for and by students in a four-year mechanical engineering program. PIC microcontrollers were used as the target devices for the embedded course. *LabVIEW* software with associated controllable hardware was used to create the HIL system. Design considerations and practical implementation details are presented and discussed.

Introduction and Motivation

Hardware-in-the-loop (HIL) simulation is a technique by which real signals from a controller are connected to a test system that simulates reality, tricking the controller into thinking it is in the actual physical system (National Instruments, 2020; Mathworks, n.d.). This technique allows the embedded controller hardware and software to be developed and tested without the need for the actual hardware to be present. This is especially useful in applications where the system to be controlled is complex or costly to operate. Implementing an HIL system also allows for controller development in parallel with that of the system to be controlled (Ellis, 2012). The concepts of HIL can also be applied to academic instruction in an embedded systems course. Here, the desired system to be controlled may not actually exist at the institution, yet the embedded control algorithms can still be developed and explored. Students can also learn to develop the HIL models to simulate the system to be controlled. This can further enhance their knowledge of how the system works and how it should perform.

Students in the four-year mechanical engineering program at Penn State, Berks, may enroll in an elective course that explores the role of hardware and software for measurement and control of electromechanical systems. A large part of this course employs embedded processors (microcontrollers) such that students become familiar with the concepts of making measurements from various sensors. The measurements are then used together with a simple control algorithm to decide what action should be taken. Some sort of control output is then produced to close the loop. In some cases, the HIL hardware and software is used in an open loop manner, where it functions more as a simulator that produces a response to the controller output that mimics that of an actual system.

Figure 1 illustrates the basic idea behind hardware-in-the-loop simulation. Students are first introduced to the concepts of HIL by presenting examples of common machinery that contain embedded processors to control their motion. Examples include automobiles and farm/construction equipment. The complexities of the machinery's motion are then discussed to help the students appreciate the role of embedded control.

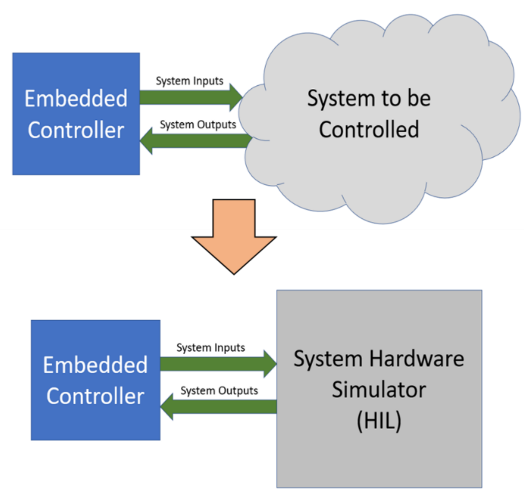


Figure 1. The concept of Hardware in the Loop simulation.

Many students are not aware of how ubiquitous embedded processors have become. The motivation for developing the HIL models is to provide the students with an experience that demonstrates the types of systems that could be controlled with the embedded processor. Although it is initially somewhat satisfying to blink an LED with embedded code, being able to demonstrate that the same process can be used to control more useful hardware helps to keep students interested and engaged.

Examples

Throughout a semester, as the students become more familiar with the embedded processes and the concepts of HIL, the features of the HIL simulators become more sophisticated. For most examples, a National Instruments USB-6003 USB Data Acquisition (DAQ) device is used as the hardware interface. The USB-6003 has several analog inputs, analog outputs, digital input/outputs, and counter inputs (National Instruments, n.d.). Custom *LabVIEW* code is used to control the DAQ.

<u>Example 1: Residential Thermostat</u>
The first example is that of a thermostat for controlling a residential heating system. The controller uses a simple hysteretic (bang-bang) control scheme as would be found in a commercially available thermostat.

Interestingly, designing the actual code to realize hysteretic control is challenging to many undergraduate students. The "house" is modeled to have a first-order temperature response. The first-order differential equation is discretized with a 50 ms Δt time step. The maximum and minimum temperature asymptotes can be adjusted to set "furnace on forever" and "furnace off forever" (outside temperature) temperatures. The house time constant can also be modified to help speed up the simulation. The default time constant is 30 seconds, just to keep things moving along but still allowing the user to easily observe the response. Figure 2 shows the user interface (*LabVIEW* Front Panel) for the HIL house simulator. Figure 3 shows a flowchart for the *LabVIEW* code. (For those familiar with *LabVIEW* code, the block diagram is provided in Appendix A.) One digital input of the DAQ unit is used to determine if the furnace is on or off. One analog output is used to simulate the output from a temperature sensor with a sensitivity of 50 mV/°F. Figure 4 shows a connection diagram for the HIL system.

<u>Example 2: Water Flow/Level Control Trainer</u>
The concepts and usefulness of HIL simulation become very evident to the students in this example. The system to be controlled is a water flow/level trainer, *Basic Process Rig model 38-100*, manufactured by Feedback (Feedback, n.d.).

Figure 5 shows a photograph and functional block diagram of the system (Litwhiler, 2012). The interface unit was constructed to house the solenoid driver and a connector adapter for the water-level sensor. The laboratory contains four of the Feedback Basic Process Rig units for students to use. However, due to scheduling constraints in the shared laboratory space and the time required to setup and breakdown the system connections, students needed another means for testing and debugging their microcontroller code. This also provided a perfect situation to emphasize the HIL concept. Therefore, an HIL simulator was developed.

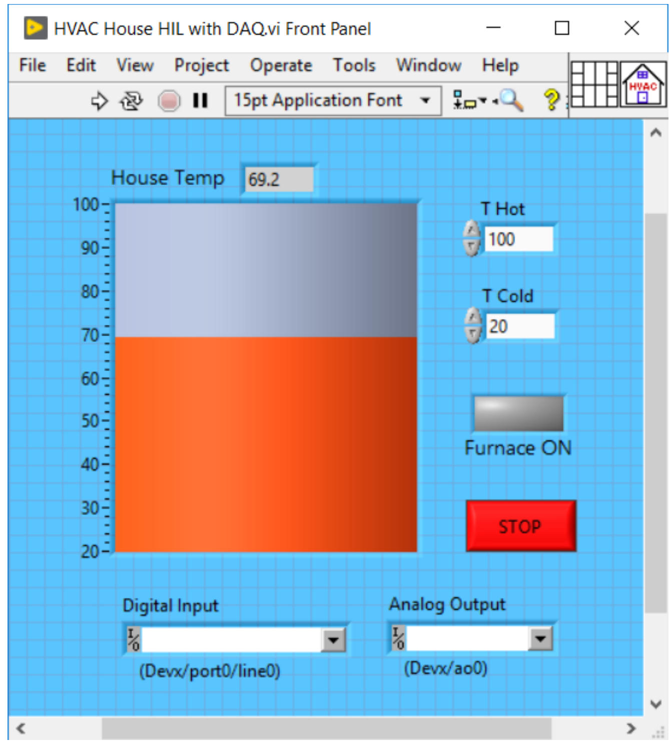


Figure 2. HIL example of a user interface for a residential heating system.

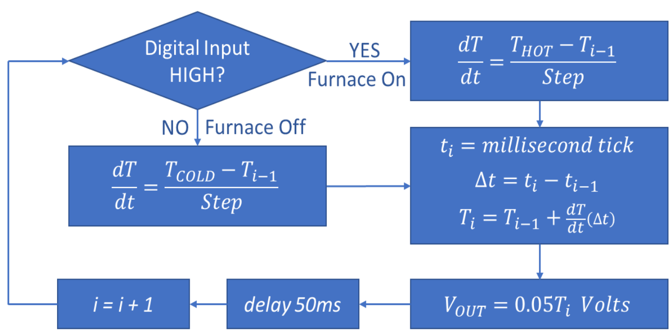


Figure 3. *LabVIEW* code flowchart for residential heating system HIL example.

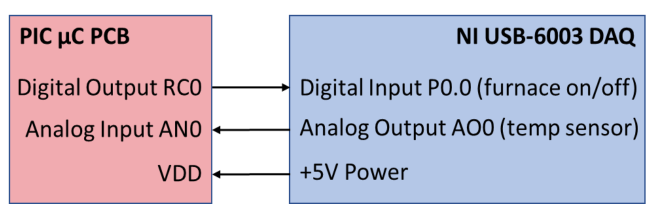
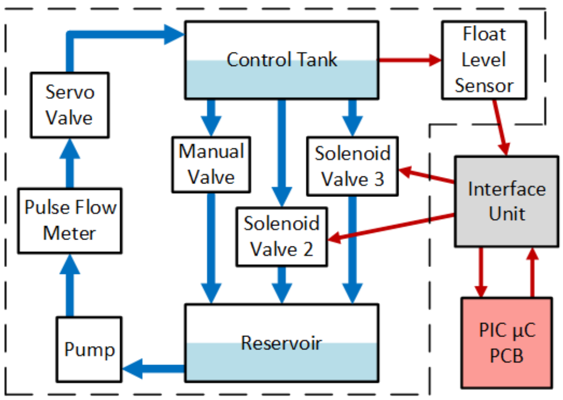


Figure 4. Connection diagram for residential heating system HIL example.

Students were tasked with making measurements of water flow and transducer outputs and control input responses to be used in the HIL model. Again, a USB DAQ device and *LabVIEW* were used to develop the HIL system. Figure 6 shows a connection diagram for the HIL hardware.

(a) Photograph of the water-flow trainer.



(b) Block diagram of the water-flow trainer.

Figure 5. Water-flow/level-control trainer photograph and functional block diagram.

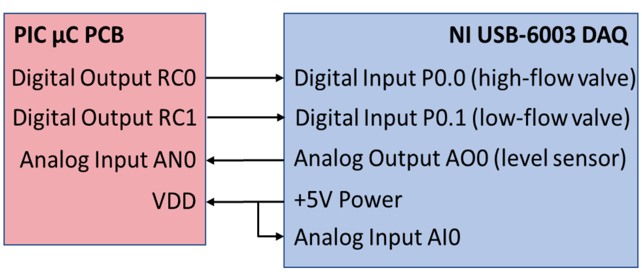


Figure 6. Connection diagram for the water-level control HIL example.

The objective of this example was to control the water level in the control tank as set by the user. Water is pumped from the reservoir to the control tank at a constant rate. The pump flow can be adjusted with a manual valve. The water level in the tank is measured by a float connected to a potentiometer. The control tank can be drained via two solenoid valves of different diameters (high-flow valve, SV2, and low-flow valve, SV3) and a manual valve. Again, a "simple" hysteretic control algorithm was to be used. The user would set the desired water level as an integer percentage of full (via the serial port). The controller used a ±2 dead band around the desired value. In normal operation, only one solenoid valve was controlled (SV2); however, if the water level exceeded +2 of the desired value, the other solenoid valve would also be opened to arrest the rising water level. Figure 7 shows the *LabVIEW* user interface for the water-level control example.

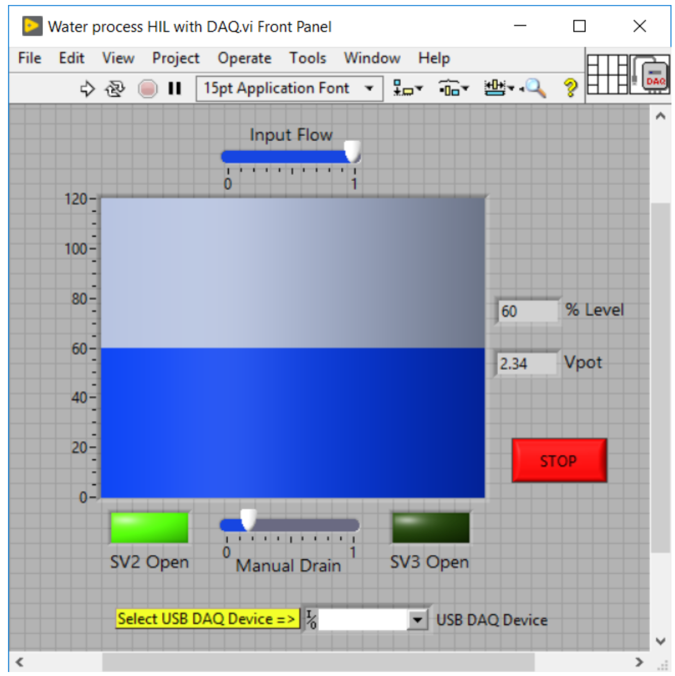


Figure 7. HIL example of the user interface for the water-level control system.

Table 1 shows the results of measurements on the control tank input and output flows. For each test, only one valve was open, and the water level change was timed. The water level was measured using a percentage of full scale, as indicated by markings on the tank. Despite the change in head pressure, the drain rates were essentially constant. These rates were then used in the HIL model given by Equation 1:

Table 1. Measured control-tank fill/empty rates.

Test Condition	Water Level Rate of Change
Only Input Valve Open	2.466 %/s
Only SV2 Open	-1.324 %/s
Only SV3 Open	-0.517 %/s
Only Manual Drain Valve Open	-3.488 %/s

$$\frac{dH}{dt} = 2.466(F_{in}) - [1.324(SV2) + 0.517(SV3) + 3.488(MV)] \quad \%/\sec = f(F_{in}, SV2, SV3, MV) \tag{1}$$

where,
Fin = Analog position of manual input flow valve (0.00 through 1.00)
SV2 = Boolean state of solenoid valve 2 (0 if closed, 1 if open)
SV3 = Boolean state of solenoid valve 3 (0 if closed, 1 if open)
MV = Analog position of manual drain flow valve (0.00 through 1.00)

As a further exercise in the ways of HIL, the subtle difference between the water-level sensing potentiometer output and the DAQ analog output was also accounted for. The potentiometer output voltage from the wiper to either end of the element is ratiometric with the power supply voltage. The DAQ analog output voltage, however, is derived from an internal fixed voltage reference and is therefore not ratiometric. (The microcontroller A2D converter uses the power supply voltage as its reference, so it is ratiometric.) To correct for this difference, the USB-derived +5V power supply is measured with a DAQ analog input channel and the analog output is scaled to mimic ratiometric behavior. The scaling and offset values were again determined by measurements on the actual control tank-level measuring potentiometer. For a typical control tank, the analog output voltage, as a function of the water level, H, and the power supply voltage, Vcc, are given by Equation 2:

$$V_{out} = V_{CC}\left[7.03\times10^{-3}(H) + 0.0781\right] \quad Volts = g(V_{CC}, H) \tag{2}$$

where,
Vcc = Measured power supply voltage (nominally 5V)
H = Control tank water level in percent of high mark (0 – 120)

Figure 8 shows the flowchart for the *LabVIEW* code used for the water-level control system HIL simulator. For those familiar with *LabVIEW*, the block diagram is provided in Appendix B.

Conclusions

The examples presented here represent an introduction to the concepts of hardware-in-the-loop simulation. By keeping the simulated systems simple and recognizable, the students could easily understand and relate to the expected performance. This helped with their ability to also develop the models for the simulation. After the students became comfortable with developing code to blink an LED and read the status of an external pushbutton switch, they were quickly ready for something more substantive. Integrating the concepts of HIL, which were already part of the course, provided a means for keeping the coding tasks more interesting. The residential heating HIL simulation exercise was the students' first exposure to the concepts required for both the simulation and the embedded processor code. Although both seem simple at first glance, the students were sufficiently challenged and seemed intrigued by the concepts.

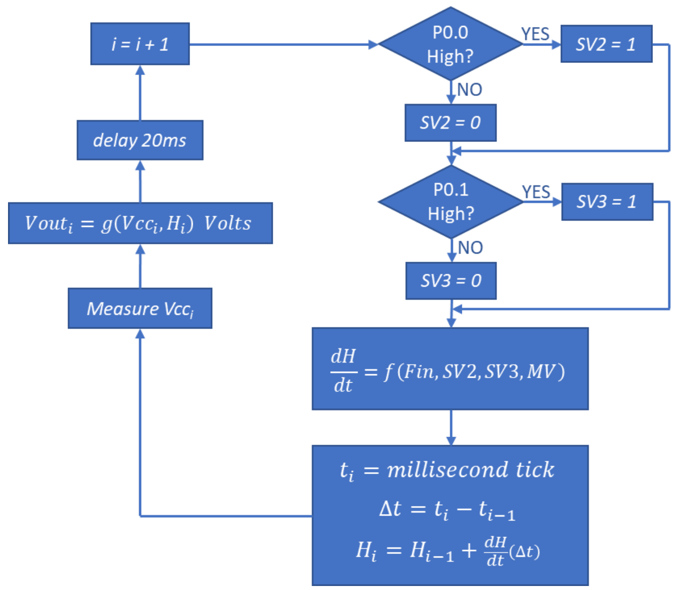


Figure 8. LabVIEW code flowchart for the water-level control system HIL example.

The water flow-control trainer hardware allowed the students to have a hands-on experience with the actual system that they modeled to help "close the loop" on the ideas. The associated scheduling and setup issues also gave them a small taste of the motivation behind HIL simulation. The hardware, software, and concepts presented here have also been used to develop other HIL systems to be controlled with an embedded processor in the course. Household appliances, such as clothes washers and dishwashers, lend themselves to HIL simulation to be controlled by an embedded processor running as a state machine. Stepper motors and DC motors are also good candidates for HIL simulations.

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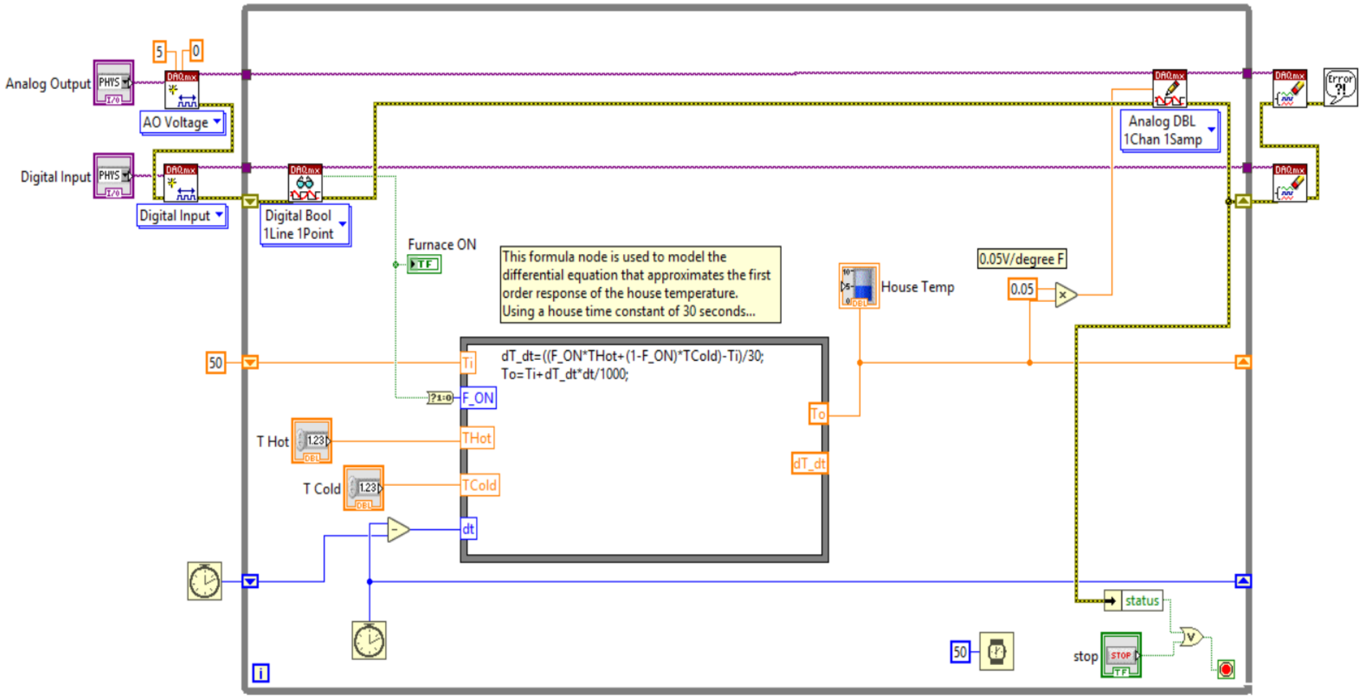
Biography

DALE H. LITWHILER is an associate professor of electrical engineering at Penn State, Berks Campus. He received his BS from Penn State University, MS from Syracuse University, and PhD from Lehigh University, all in electrical engineering. Prior to beginning his academic career, he worked with IBM Federal Systems and Lockheed Martin Commercial Space Systems as a hardware and software design engineer. Dr. Litwhiler may be reached at dale.litwhiler@psu.edu

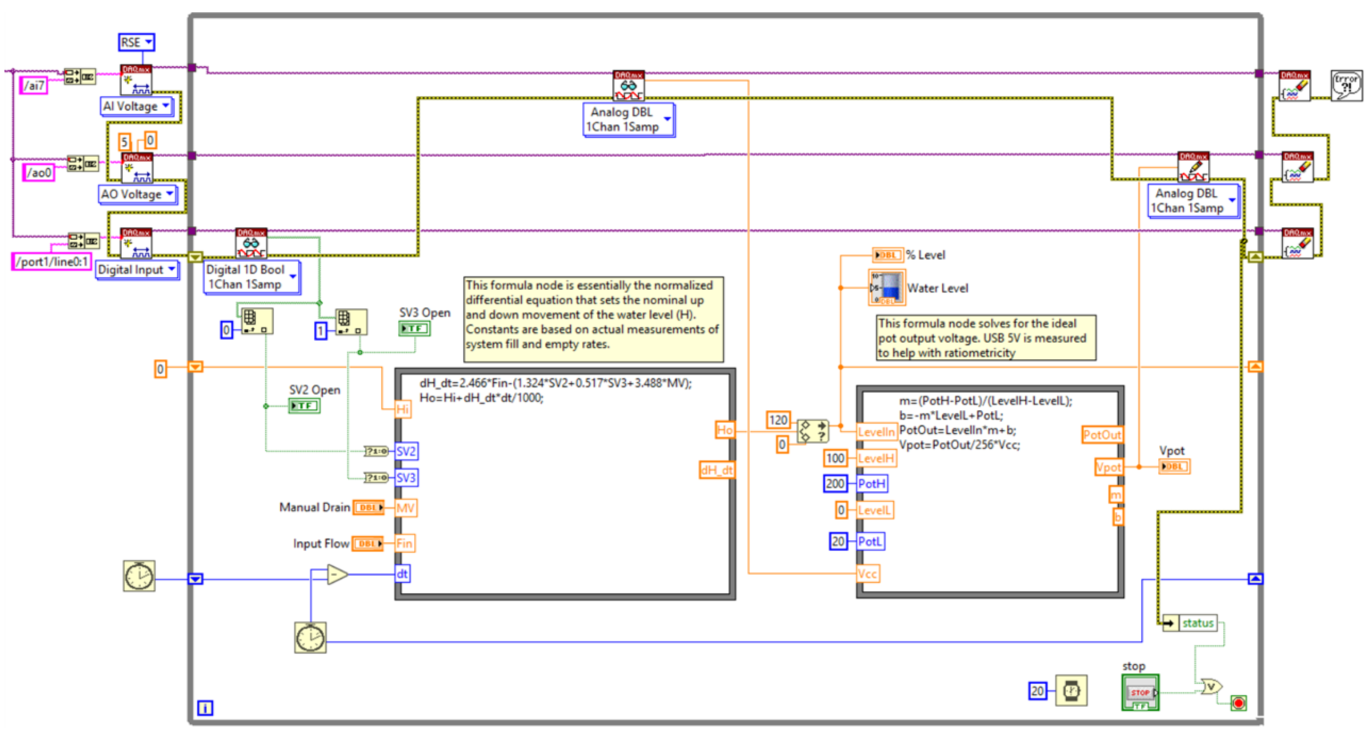
Appendix A

LabVIEW block diagram for residential heating system HIL example.



Appendix B

LabVIEW block diagram for water-level control HIL example.



Interdisciplinary Educational Modules: Using Smart Colored Windows in Responsive Façade Systems

Negar Heidari Matin, University of Oklahoma; Forough Zareanshahraki, Eastern Michigan University;
Ali Eydgahi, Eastern Michigan University

Abstract

Collaborations between different disciplines provides unique opportunities for integrating ideas and methods, infusing skills, sharing tools, utilizing teamwork, improving cognitive abilities, and thinking critically to develop and form new knowledge and products. The process of designing, prototyping, and evaluating the performance of a contemporary building with smart-colored windows can assist students in architecture programs to be more involved in interdisciplinary projects that are inspired by use of knowledge from other fields. In this paper, the authors present interdisciplinary activities that can be used in senior design projects, independent studies, and graduate theses by both undergraduate and graduate students in architecture and interior design programs. The proposed hands-on activities include design and implementation of smart color coating for glass windows, determination of optical properties, and characteristics of the colored windows by using an ultraviolet-visible spectroscopy method and performance evaluation of the designed colored windows by using Rhino software along with its Grasshopper and DIVA plug-in modules. In the proposed activities, students gain practical interdisciplinary experience by utilizing the data obtained from design and implementation in the laboratory environment for testing and evaluating the design in a simulation environment. These activities also improve students' professionalism and team-work skills that are crucial attributes in contemporary working environments.

Introduction

Innovation arises from the intersections of different disciplines, as declared by the U.S. National Innovation Initiative (Innovate America—Council on Competitiveness, 2005). The training of students as innovative thinkers in dealing with today's complexity of global challenges requires interdisciplinary education, which integrates information, data, techniques, tools, perspectives, concepts and theories from two or more disciplines and answers questions beyond the scope of a single discipline (Edwards & Association for Integrative Studies, 1996; Hargittai, 1997; Heidari Matin, Eydgahi, & Shyu, 2017; Jutraz & Zupancic, 2014; Klein, 1996; National Academy of Sciences, 2005; Ochsner, 2000; Wortham, 2007; Yocom, Proksch, Born, & Tyman, 2012). Materials that can significantly alter one or more of their inherent properties with application of external stimuli such as stress, temperature, moisture, pH, electrical fields, and magnetic fields, in a controlled fashion, are known as smart materials. Materials science, promoting smart materials that can improve energy efficiency, user comfort and well-being, and decreasing CO_2 emissions in built environments, can be considered as one of the frontiers in sustainability (Bechthold & Weaver, 2017; Heidari Matin et al., 2017).

Working closely with material scientists can provide an opportunity for architectures to generate, synthesize, and implement innovative sustainable ideas in design practices (Arens, 2008; Wilkes & Miodownik, 2018). A building's responsive façade is one of the main contributors of providing user comfort and well-being in sustainable indoor environments (Dewidar, Mahmoud, Magdy, & Ahmed, 2010; Grobman, Capeluto, & Austern, 2017; Karanouh & Kerber, 2015; Heidari Matin & Eydgahi, 2019). The implementation of advanced material-based technologies has provided a capability for responsive façade systems to continuously change their own functions, features, or behavior over time in response to environmental stimuli and occupant preferences in order to improve the thermal and visual performance of the façade (Heidari Matin & Eydgahi, 2019).

Different types of smart materials, such as electrochromic (Geoff, Angus, Matthew, & Michael, 2016; Granqvist, 2014; Gugliermetti & Bisegna, 2005), thermochromic (Seyfouri & Binions, 2017), gasochromic (Feng, Zou, Gao, Wu, Shen, & Li, 2016), liquid crystal (Hosseinzadeh Khaligh, Liew, Han, Abukhdeir, & Goldthorpe, 2015), and photochromic (Meng, Wang, Jiang, Wang, & Xie, 2013), have been utilized to develop smart windows for responsive façade systems. The coating of photochromic materials can be applied on the surface of window glass as a thin film to provide a capability for the glass to dynamically adjust its own color, transparency, and, consequently, its reflective properties upon exposure to various intensities of sunlight (Meng et al., 2013). The range of colors created with photochromic materials not only decreases the transmittance of visible light, but also reduces the transmittance of ultraviolet (UV) and infrared (IR) wavelengths, which are considered harmful to human skin, furniture materials, and paints up to 60%, as compared to standard float glasses (Khoo, Burry, & Burry, 2011; Meng et al., 2013; Wu, Zhao, Huang, & Lim, 2017).

In an effort to provide students in the interior design program at Eastern Michigan University an opportunity to get involved in an interdisciplinary project that promotes sustainable concepts in building design, a set of hands-on modules for the processes of designing, prototyping, and evaluating the performance of responsive façade systems utilizing smart-colored windows were developed.

The objectives of the proposed modules are to provide both undergraduate and graduate students in architecture and interior design programs with a set of multidisciplinary activities that could be utilized as independent studies, senior design projects, or graduate theses so that students learn and gain knowledge of topics that are out of the scope of their programs, yet still related to their fields of study. In addition, students gain experience in applying the learned knowledge in a hands-on manner in a laboratory environment that is not part of their curricula, but is related to their programs of study. The proposed activities provide students with the knowledge and hands-on experience of a façade system with smart-colored windows that include identification of smart coating materials, understanding the smart coating formulation process, characterizing the optical properties of coated glass, utilizing the ultraviolet-visible (UV-VIS) spectroscopy method, evaluating the performance of smart-colored windows through their optical properties, and analyzing the data obtained from the performance evaluation of a façade system with smart-colored windows. Also, as students are working in multidisciplinary groups, their collaboration as well as written and oral presentation skills will be improved.

Interdisciplinary Activities

The proposed activities consist of four modules that provide students with hands-on experience of working on the design, implementation, and performance evaluation of a responsive façade system using colored windows as an interdisciplinary project. Figure 1 demonstrates the relationship between the modules and the activities. The first two modules concentrate on the design and development of smart windows with a photochromic coating formulation and the optical properties and characteristics of the coated glass substrates of the windows in a laboratory environment. The last two modules use the laboratory data obtained in the first two modules to design and simulate a responsive façade system with the designed smart-colored windows and then evaluate performance of the façade system by utilizing various software packages.

Module #1: Development of Coatings

The purpose of this module is to familiarize students with primary principles of coating and how these principles are applied in the development of colored glass. In this activity, students are introduced to the theoretical concepts related to coatings, photochromic dyes, and development of photochromic-coated glass prior to practical experimentation. Coatings are thin films applied on the surfaces of objects for two primary functions: enhancement of aesthetics aspects and surface protection. Coatings can be found everywhere from interior applications such as walls, furniture, kitchen appliances, and electronic devices to exterior uses such as façades, automobiles, power cables, air crafts, roads, etc. (Jones, Nichols, & Pappas, 2017; Mirabedini, Zareanshahraki, & Mannari , 2019; Zareanshahraki, Asemani, Skuza, & Mannari, 2020; Zareanshahraki, Lu, Yu, Kiamanesh, Shabani, & Mannari, 2020). Coating formulations are usually comprised of four main ingredients (Jones et al., 2017). First, a binder, which acts as a film former and holds all the ingredients together. Second, pigments and/or dyes, which provide color and opacity. Third, additives, which are used in very small quantities to enhance special properties. Finally, solvents, which are usually used to adjust the flow of the coatings.

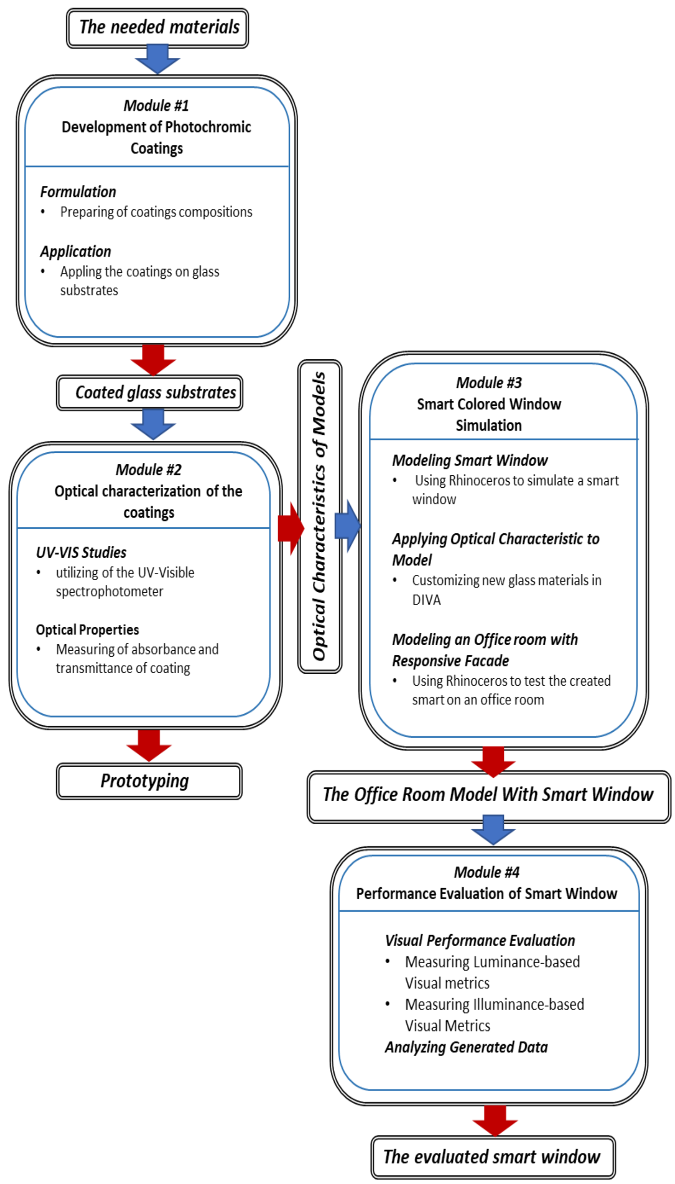


Figure 1. The relationship between proposed hands-on modules.

Photochromic coatings are a specific class of smart coatings that typically contain a photochromic dye in their formulation. Photochromic dyes are in crystalline powder form that could reversibly change color when dissolved in proper solvents and exposed to ultraviolet light. Table 1 shows that all of the activities are designed to be completed within a laboratory period of about 2.5 hours. It should be mentioned that these experiments could be easily performed in modern university laboratories to provide a brief overview of the smart-coatings landscape. Furthermore, nearly all of the experiments can be conducted on the benchtop without the need for specialized equipment.

Table 1. Overview of the main experimental activities in the first module.

Activity #1: Description		Time (min)
1	Introducing coatings, photochromic dyes, color perception, and smart windows through a brief lecture	30
2	Explaining the lab safety rules and experimental procedure, dividing students into groups and distributing tasks among the group members	15
3	Labeling the vials and preparing the dye solutions with various colors	30
4	Formulating the coatings by blending the dye solutions with resins and additives	15
5	Cleaning the glass substrates and applying the coatings using square film applicators	30
6	Organizing and cleaning the glassware, equipment, and supplies	30
Total time for all activities		150

Module #2: Optical Characterization of the Coatings

Visible light is composed of a range of wavelengths of light. The color of an object is determined by what wavelengths of light the object absorbs and reflects. According to additive Red-Green-Blue (RGB) (Schwarz, Cowan, & Beatty, 1987; Westland & Cheung, 2016) and subtractive Cyan-Magenta-Yellow (CMY) color models (Verikas, Malmqvist, Malmqvist, & Bergman, 1999), the color we perceive is complementary to the light colors absorbed by an object. Ultraviolet-visible (UV-VIS) spectroscopy is a popular analytical method used to quantify the optical characteristics of materials. The instrument used in UV-VIS spectroscopy is called a UV-VIS spectrophotometer. It measures the intensity of light after passing through a material (I) and compares it to the intensity of light before it passes through the sample, I0. The ratio, I/I0, is called transmittance (T) and is usually expressed as a percentage (%T), which is equal to 100T. Transmittance is mathematically related to absorbance (A), as demonstrated by Equation 1 (Forster, 2004):

$$A = -\log\left(\%T/100\right) = 2 - \log\%T \tag{1}$$

Transmissivity can then be calculated using Equation 2:

$$\text{Transmissivity} = \left(sqrt\left(0.8402528435\ +\ 0.0072522239 \bullet T^2\right) - 0.9166530661\right) / \left(0.0036261119 / T\right) \tag{2}$$

This module deals with how to run the UV-VIS spectrophotometer in order to study the optical characteristics of the photochromic coatings. This activity starts with charging Toluene, as the baseline, into a quartz cuvette, which is a small tube-like container used in UV-VIS spectrophotometers. A baseline measurement is similar to a "zero" measurement in which a "baseline" measures a zero correction for each wavelength in a scan. After scanning the baseline, the cuvette is charged with the photochromic solution and scanned. Scanning the colorless photochromic solution is referred to as the bleach state.

Next, the solution is irradiated with a UV lamp for 30 seconds then immediately scanned. Scanning the colored photochromic solution is referred to as the colored state. This process is performed for each color used. Next, the data are imported into *Excel* spreadsheets and the transmittance and transmissivity variables, using Equations 1 and 2, are calculated. Then, the calculated data are imported into the simulation in the next module. Table 2 shows that this module is also designed to be completed within a laboratory period of about 2.5 hours.

Table 2. Overview of the main experimental activities in the second module.

Activity #2: Description		Time (min)
1	Introducing students to the fundamentals of color perception and UV-VIS spectroscopy	30
2	Reviewing the lab safety rules and experimental procedure	15
3	Instructing each group to run UV-VIS spectroscopy on the photochromic solutions	60
4	Importing the UV-VIS data into an excel spreadsheet and plotting it	15
5	Calculating the variables needed for simulation	30
Total time for all activities		150

Module #3: Simulation Process

The purpose of this module is to use Rhinoceros software to simulate two-pane windows made of low-e glass for exterior, photochromic-coated glass for interior sides. In this module, the data obtained from UV-visible spectroscopy is utilized for the simulation of three shades of photochromic glasses. Prior to use of this activity, students were required to study high-performance façade systems by focusing on responsive façades with material-based control technologies. This would educate them on how one integrates sensors, actuators, and control systems of a responsive façade system into the body of a photochromic glass. Students also need to learn about how to customize material in DIVA-for-Rhinoceros, how to characterize two-pane windows using the transmittance and transmissivity, and how to evaluate the performance of coated glass. Table 3 shows that this module was also designed to be completed in about 2.5 hours.

Table 3. Overview of the main simulation activities in the third module.

Activity#3: Description		Time (min)
1	Simulating two-pane windows that are constructed from exterior low-e glass and interior photochromic glasses using Rhinoceros.	90
2	Utilizing DIVA-for- Rhinoceros for characterizing two-pane windows using the transmittance and transmissivity	60
Total time for all activities		150

This activity provides an opportunity for students to evaluate performance of the designed two-pane windows in a responsive façade system. It starts by simulating a simple office located in a desired location by using Rhinoceros software. Then, a visual performance evaluation is performed by utilizing DIVA-for-Rhinoceros to measure indoor illuminance, useful daylight illuminance (UDI) and daylight glare probability (DGP). The visual performance of a variety of colored photochromic windows are evaluated and compared in order to identify the best photochromic shades for controlling daylight. Building performance is evaluated by considering Energy Plus Weather files (EPW), sky condition, sunlight patterns, and time parameters. In addition, glare discomfort effects are evaluated by utilizing the measured hourly DGP at the specific point of the simulated office. Table 4 shows that this module was designed to be completed in about six hours.

Test of the Proposed Modules

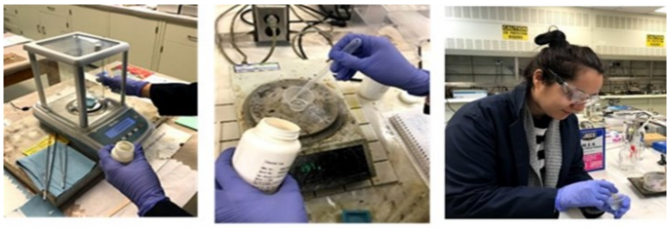
An interdisciplinary team of students from the Interior Design program and Polymers and Coating program at Eastern Michigan University used the proposed modules to develop and create seven different shades of smart photochromic-coated glass windows for use in a façade system. For module #1, after a lecture on the principles of coatings, the students started the experiment by preparing the photochromic dye solutions to make different color shades. This was done by dissolving the required amounts of dyes in Toluene solvent and storing the resulting solutions in the labeled vials. Figure 2(a) shows how students then prepared the coating formulations by mixing the different coating ingredients according to Table 5. Figure 2(b) shows how students were subsequently instructed on how to apply a film of photochromic coating on the glasses using a square film applicator. After the application, the coated glasses were kept at room temperature in a closed cabinet to prevent dirt pick-up during the drying period. Figure 2(c) shows one attractive and exciting feature of the photochromic phenomenon during the preparation of the coated glass was observation of the color change upon exposure to UV-light, which was conducted using a 40-watt UV lamp. Figure 3 shows that, in this experiment, seven different coated-glass substrates were created.

Table 4. Overview of the main simulation activities in the fourth module.

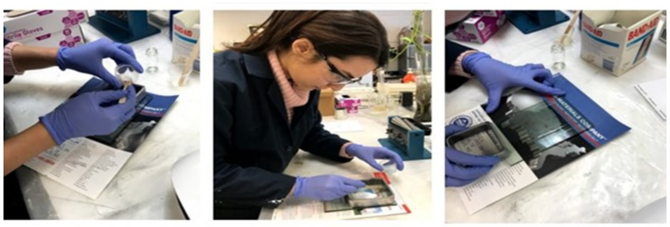
Activity#4: Description		Time (min)
1	Utilizing Rhinoceros to simulate a simple office room and apply three designed two-pane windows to its façade in order to evaluate its visual performance.	60
2	Providing EPW climate files, sky condition, sunlight patterns, time parameters and façade orientations using DIVA.	30
3	Creating performance evaluation by using DIVA to measure selected metrics, indoor illuminance, UDI and DGP.	90
4	Using Microsoft Excel for importing, interpreting, analyzing, visualizing and recording the generated data.	120
5	Analyzing the data and recommending improvements for the designed responsive façade.	60
Total time for all activities		360

Table 5. Formulation of the photochromic coatings.

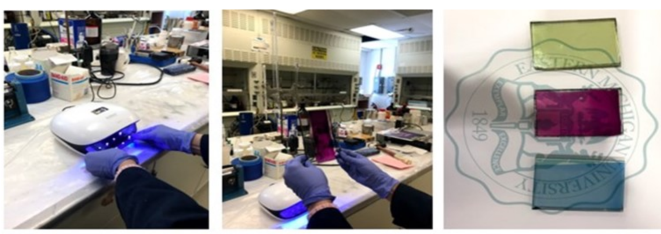
Ingredients	Weight (gr)
Binder	92.5
Photochromic dye solution	4
UV absorber	2
Light stabilizer	1
Leveling agent	0.5
Total weight	100



(a) Preparation of the photochromic coating formulations.



(b) Application of the coatings on glass.



(c) Photochromic activity of coatings by light exposure.

Figure 2. Illustration of the color coatings procedure

Figure 3. The developed photochromic coatings upon exposure to UV for a specific time.

For module #2, after review of the safety rules, experimental procedures, fundamentals, and use of UV-VIS spectroscopy for obtaining the optical characteristics of the photochromic coatings, the experiment started with charging Toluene, as the baseline, into a quartz cuvette. After scanning the baseline, the cuvette was charged with the photochromic solution and scanned. Then, the solution was irradiated with the UV-lamp for 30 seconds and then immediately scanned. This process was performed for three of the developed photochromic coatings—namely red, blue, and yellow colors. Figure 4 demonstrates the absorbance as a function of wavelength for the red photochromic solution. As discussed previously, since this solution absorbs light in the green region (495-570 nm), its color is perceived as red.

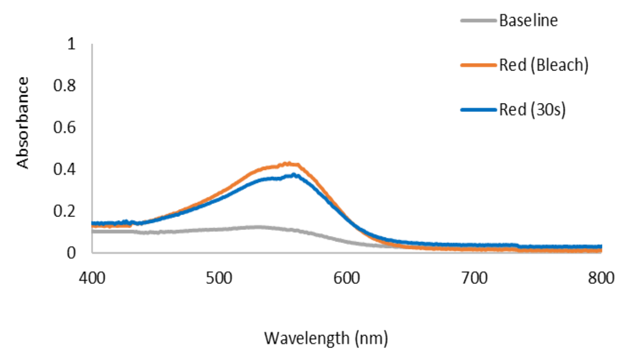


Figure 4. UV-VIS spectrum of the red photochromic solution.

Table 6 presents the data relating to the optical characteristics of the coatings that were imported into *Excel* by the students, who then calculated transmittance and transmissivity using Equations 1 and 2:

Table 6. Transmittance and transmissivity values of three photochromic solutions.

Color	%Transmittance	Transmissivity
Red	56	61.04
Blue	48	52.32
Yellow	70	76.3

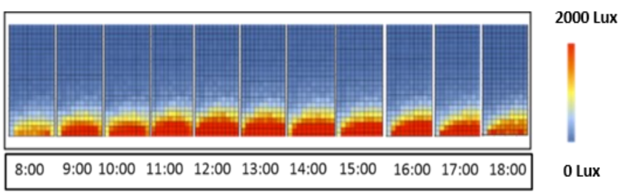
For module #3, after students learned about responsive façade systems with material-based control technologies, Rhinoceros software along with the data from Table 6 were utilized to simulate three different two-pane windows for the designed photochromic glass. Students defined red-colored photochromic glass with 56% of transmittance in DIVA-for-Rhinoceros. Then, rtn, gtn, and btn factors, which are representatives of transmissivity at red, green, and blue wavelengths, respectively, were derived from the transmittance of the glass. Figure 5 provides the definitions of photochromic glass used in DIVA.

At the final stage of this activity, students worked on an experimental workflow for evaluating the visual performance of two-pane windows and visualizing it with diagrams. For module #4, students started by simulating a simple office located in Ann Arbor, Michigan, by utilizing Rhinoceros 6.0. The dimensions of the designed office were 4.0m wide, 9.0m deep, and 3.0m high (floor-to-floor). It was assumed that the simulated room had a south-facing opening with 2.6m width and 3.6m length for a window.

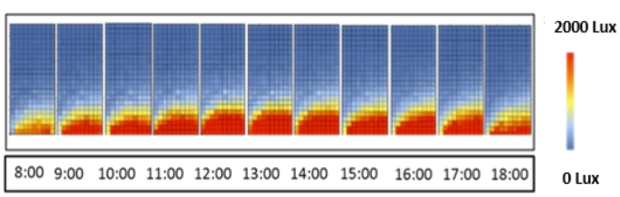
```
mod glass id
0
0
3 rtn gtn btn


mod glass RedPhotochromic_glass_Transmission_56
0
0
3 0.6105 0.6105 0.6105

mod glass BluePhotochromic_glass_Transmission_48
0
0
3 0.5232 0.5232 0.5232

mod glass YellowPhotochromic_glass_Transmission_70
0
0
3 0.763 0.763 0.763
```

Figure 5. The definition of photochromic glasses in DIVA.

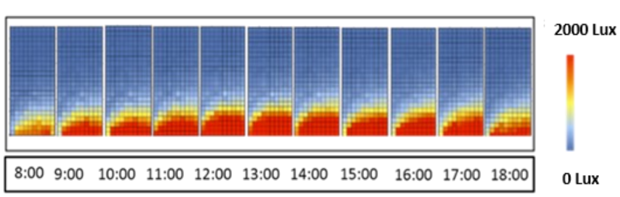
Then, three different windows were designed for testing. The exterior pane of all three windows was made from low-e, clear glass with a visible light transmittance of 50%. The interior pane of the windows was made from photochromic glass for three colors: red, blue, and yellow. All three windows were individually tested as a part of the responsive façade system of the office. Next, students used DIVA-for-Rhinoceros to measure indoor illuminance metrics of UDI and DGP. Figure 6 shows the results of the generation of hourly indoor illuminance for June 21st, compared with the performance of all three two-pane windows.



(a) Red photochromic glass.



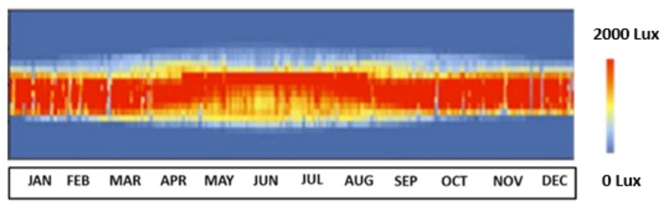
(b) Blue photochromic glass.



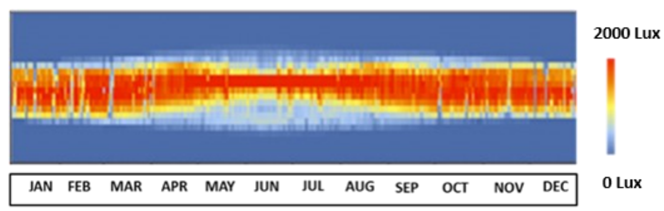
(c) Yellow photochromic glass.

Figure 6. Hourly indoor illuminance for photochromic glass on June 21st.

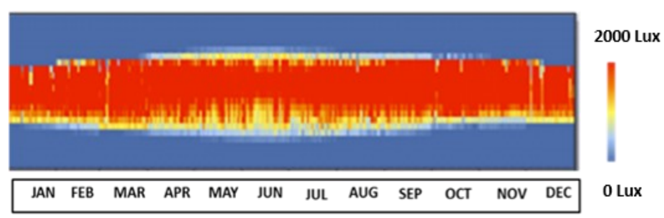
Indoor illuminances in the range of 300 to 2000 Lux are perceived as desirable for office spaces (Giovannini, Goia, Verso, & Serra, 2018; Mardaljevic, Andersen, Roy, & Christoffersen, 2012). Students used UDI metrics to identify the percentage of time, over the course of an entire year, for the comfort zone range of 300-2000 Lux for various areas of the office. The results of the UDI metrics showed that red and blue coating colors had higher amounts of useful daylight illuminance in comparison with the yellow coating. This indicates that red-coated glass provides a higher percentage of comfort time. Next, students ran an annual glare test, which was calculated by measuring hourly DGP at a specific point in the room. The heat maps of Figure 7 show the results of annual glare in four ranges of DGP, which indicate that the blue photochromic coating had the desirable performance in controlling glare during summer time from April to September. It should be noted that daylight glare probability was classified in four ranges: 30-35 (imperceptible), 35-40 (perceptible), 40-45 (disturbing), and 45-100 (intolerable) (Khoo & Salim, 2013).



(a) Red photochromic glass.



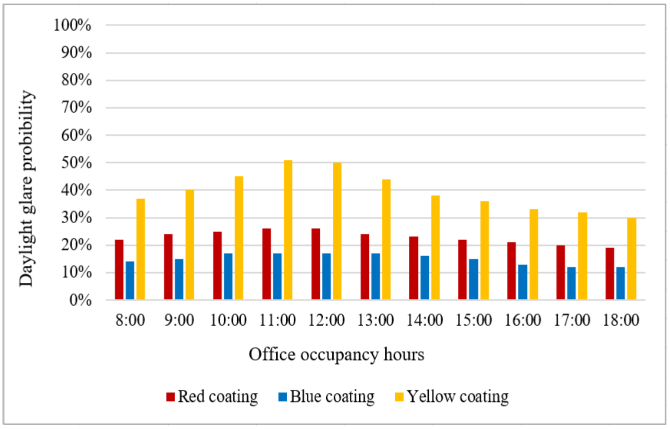
(b) Blue photochromic glass.



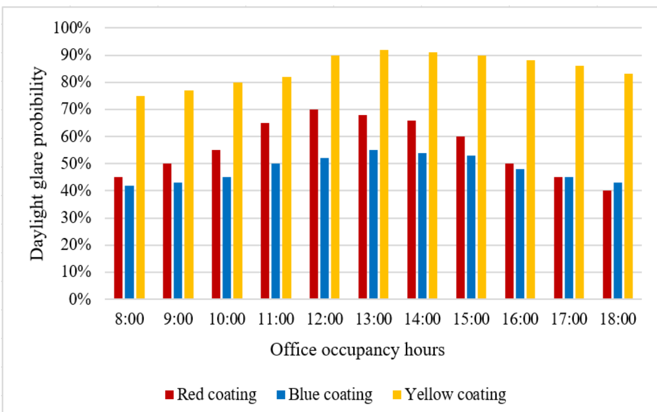
(c) Yellow photochromic glass.

Figure 7. Annual glare analysis of photochromic glass.

Figure 8 shows the results of repeatedly tested point-in-time glare during occupancy hours of 8:00 AM to 6:00 PM on the 21st of June and the 21st of December. The values of DGP related to the red and blue photochromic glasses were reported in the range of imperceptible on June 21st and perceptible on December 21st, while the DGP of yellow photochromic glass was reported as intolerable at solar noon on the 21st of June and the 21st of December.



(a) On June 21st.



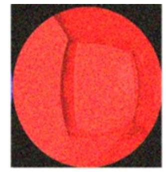
(b) On December 21st.

Figure 8. Hourly daylight glare probability.

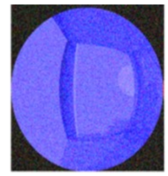
Figure 9 show the fish-eye images that the students generated for glare analysis in DIVA, which provides DGP values of specific points in the room at specific times of the year. The blue and red colors approximately met the imperceptible rate for glare that is less than 35% of the DGP value. The blue color coating indicated a high ability to decrease glare in comparison to the red-colored glass. The yellow-colored glass was almost placed in the intolerable range with a DGP value above 45%.

Conclusions

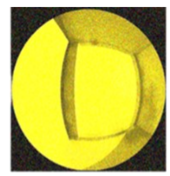
In this paper, the authors presented a number of educational activities suitable for both undergraduate and graduate students in architecture, interior design, chemistry, and polymer/coating programs, who want to gain hands-on learning experience in the design process of an interdisciplinary project on using photochromic glass for responsive material-based façade systems. These activities can be utilized in senior design projects, independent studies, and graduate theses.



(a) Red photochromic glass with imperceptible glare (26% DGP).



(b) Blue photochromic glass with imperceptible glare (17% DGP).



(c) Yellow photochromic glass with intolerable glare (50% DGP).

Figure 9. Fish-eye images of photochromic glass on June 21st at 12:00pm.

Working in multidisciplinary research provided an opportunity for students to understand the value of integrating two different disciplines (material science and interior design) in addressing the challenging subject of sustainability in buildings. The multidisciplinary character of the team helped students to start and continue the project with an overall positive attitude, thinking that their diverse perspectives and multiple problem-solving approaches would result in better solutions. The students' comments about their experiences in using the modules were very positive and indicated a desire for more learning opportunities with multidisciplinary types of activities. The comments also indicated that learning about photochromic materials, their application in buildings, and using advanced tools such as the UV-VIS spectrophotometer broadened their knowledge of advanced building material development.

Moreover, students stated that the use of real data that was obtained from hands-on activities in the lab was a new experience for them and enhanced their skills in using Rhinoceros and DIVA software. In addition, students indicated that collaboration within a team with members having different backgrounds provided an opportunity to enhance their oral and written communication skills. Furthermore, it was conveyed that their knowledge base was expanded beyond their programs of study, which would help them to explore design concepts beyond their fields of study in future design activities.

The multidisciplinary environment helped students to develop self-confidence, occupational identity, and teamwork skills that will be very useful for their future careers. Moreover, the process of continuously giving and receiving feedback in the meeting sessions allowed students to work more efficiently by reducing the distance between their current and desired performance.

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ALI EYDGAHI started his career in higher education as a faculty member at the Rensselaer Polytechnic Institute in 1985. Subsequently, he has worked at the State University of New York, the University of Maryland Eastern Shore, and Eastern Michigan University. Between 2006 and 2010, he was Chair of the Department of Engineering and Aviation Sciences at the University of Maryland Eastern Shore. In 2010, he joined Eastern Michigan University as Associate Dean for the College of Technology, and is currently a professor in the School of Engineering. Dr. Eydgahi has served as a member of advisory and editorial boards for many international journals in engineering and technology, as a member of the review panel for NASA and the Department of Education, as a regional and chapter chairman of IEEE, SME, ASEE, and as a member of scientific and international committees for many international conferences. Dr. Eydgahi may be reached at aeydgahi@emich.edu

Design and Development of an Optically Linked Raspberry Pi Beowulf

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Abstract

Beowulf clusters are a common solution when large-scale calculations need to be performed. The recent introduction of the relatively inexpensive Raspberry Pi has led to its use as computation nodes in Beowulf clusters. The Raspberry Pi is also easy to use with many different devices, including sensors and lasers. With a great amount of progress already made in laser communications by other researchers, the authors of this current study combined these technologies in order to create a Beowulf cluster of Raspberry Pi's that was connected using lasers for data transmission. This was an observational study for experimental learning; and while it did not provide the desired improvements in cost and/or performance of the Beowulf cluster, the student performing this study gained valuable insight as well as practical experience.

Introduction

Beowulf clusters have been a reliable solution for performing large-scale calculations since the 1990s. These clusters are generally popular because they are much more reasonably priced than a supercomputer, and yet are still able to perform larger computations than a standard PC. Raspberry Pi's are small computers that are not as powerful as a PC, but are cheap enough that they can be bought and used in bulk. They have proven to be effective as cheap nodes in a Beowulf cluster, while still performing large computations. Any Beowulf cluster must use software to determine the roles for each node and to perform parallel calculations. The widespread use of optical links provides an interesting improvement to the wired solutions regularly used for passing data between computers. In this project, the authors explored the use of beams of light as optical links in order to pass data between the nodes in the cluster. In this paper, the authors describe the design and development processes of a Beowulf cluster with Raspberry Pi nodes that were optically linked in order to evaluate the viability and speed of an optically linked Beowulf cluster and discuss the issues encountered during these processes.

Related Work

Beowulf clusters are a concept that was first implemented in the 1990s, and which has continually improved as technology has advanced (Becker, Sterling, Savarese, Dorband, Ranawake, & Packer, 1995). The clusters are built using commercial off-the-shelf (COTS) hardware. These clusters use each computing node to perform calculations in parallel and send results back to the master node. Due to its utilization of consumer-grade hardware, Beowulf clusters are a cheap alternative to the more expensive supercomputers on the market (Sterling, 2002). Apart from using cheaper hardware to minimize costs, a Beowulf cluster also uses inexpensive or open-source software to run its core functions. Some of the software used includes Linux, GNU, and MPICH. By using this software, Beowulf clusters remain flexible and have ample support when users need help (Gottlieb, 2011). Larger Beowulf clusters, ones containing hundreds or thousands of nodes, require more specialized management software to perform effectively and remain easy to maintain (Uthayopas, Maneesilp, & Ingongnam, 2000). Beowulf clusters have been found to be more cost efficient per calculation performed than a supercomputer, but may not reach as high a level of performance (Gottlieb, 2011). Not only are Beowulf clusters monetarily cheaper, they also take less time to set up and operate. This is accomplished in part by using common hardware that is used for other purposes as well, which means there is wide availability of parts and support when needed (Sterling, 2002). All of these factors contribute to making Beowulf clusters an effective tool for researchers in calculation-heavy fields, who do not have the time or money for a supercomputer.

An emerging instructive technology in the world of computing has been the Raspberry Pi, a small computer that has interfaces to allow it to connect to other hardware (Richardson & Wallace, 2012). Since its creation in 2012, the Raspberry Pi was designed to be a teaching instrument. However, it has also played a large role in research, as it is an extremely affordable way to process data and is customizable through its interface ports. Since it provides more processing capabilities and utilities beyond a normal microcontroller, such as an Arduino, the Raspberry Pi allows for more features to be added to its programs, while still interfacing with sensors (Richardson & Wallace, 2012). Raspberry Pi's also have the processing capabilities to act as a normal computer for certain tasks, including playing games and surfing the internet (Anwaar & Munam, 2015). The Raspberry Pi's abilities to use Wi-Fi and Bluetooth connections makes it a viable choice for wirelessly connecting to sensors and other devices and managing their data (Richardson & Wallace, 2012; Ferdoush & Xinrong, 2014). Raspberry Pi's are also easy to manage and maintain, due to their use of operating systems based on Linux. Linux allows for many people to get started using the Raspberry Pi, as many people have some experience using Linux already, and it provides a great amount of support and tutorials for those not already familiar with it. The current operating system for the Raspberry Pi is Raspbian. Raspbian is a Debian GNU/Linux-based operating system that was specifically designed for Raspberry Pi hardware. It offers an easy-to-use GUI for users not familiar with Linux commands. Other flavors of Linux also exist for use on Raspberry Pi's, though most of these are lighter and omit unnecessary features that take up memory. The Raspberry Pi's low cost, power efficiency, and computing power allow it to be the centerpiece of many research projects. An infrared blaster (IR Blaster) is a device that uses infrared sensors to function as, or simulate, a remote control. If connected to a PC, it can be used to control all other IR devices in its vicinity. An IR Blaster works similar to a remote control, with the exception that it has a digital-to-IR light converter (Circuits Today, 2011). IR Blasters are available for the Raspberry Pi and connect via the USB port.

Raspberry Pi's in Beowulf Clusters

In this project, the interest was specifically in exploring the use of Raspberry Pi's in Beowulf clusters. As Raspberry Pi's have grown in popularity, so have their uses as nodes in cluster computing. Raspberry Pi's are often used in clusters to perform many tasks, including working as data centers and energy-efficient cloud computing (Ferdoush & Xinrong, 2014; Abrahamsson et al., 2013). Many clusters have already been built for research and teaching purposes, including the Iridus-pi cluster, Glasglow Raspberry Pi cluster, Bolzanno Raspberry Pi cluster, and Raspberry Pi's in a server rack (Schot, 2015; Adams, Caswell, Matthews, & Peck, 2015). In research involving these clusters, temperature and processing power have been the main concerns; therefore, the Raspberry Pi was the optimal choice to be used as nodes (Schot, 2015; Kiepert, 2013).

As mentioned previously, Raspberry Pi clusters are easier to keep cool and require less power to keep up and running. Raspberry Pi clusters may provide a better way to do large-scale computing, due to their lower power consumption and their ability to be passively cooled in some cases. In most research on Raspberry Pi clusters, the clusters are linked with Ethernet cables, while some recent projects have used the Wi-Fi capabilities included in the newer models of the Raspberry Pi to allow for communication between nodes (Cloutier, Paradis, & Weaver, 2016; Kiepert, 2013). This current project focused on how a change in medium for passing the signals would affect speed and other measurable features of the cluster. Apart from their hardware components, Raspberry Pi clusters operate with much of the same software as a normal Beowulf cluster, including the use of MPICH and Linux. In a recent project, the authors investigated the viability of using Apache Hadoop to perform the parallel computations across the nodes (Schot, 2015). Overall, the Raspberry Pi's usage in Beowulf clusters has shown promise, and research is still being conducted to see if they are a power-efficient and effective alternative to the clusters that were used in the past.

The last technology relevant to this research was the development of wireless optical communications between devices. This technology can take many forms, including the more common forms of infrared and visible-light transmissions. Research in this area has been underway since 1979, and it continues to be a prominent field, since the use of wireless optical communications would revolutionize how networks are maintained and deployed. (Hranilovic, 2005). While data has been passed with optical signals through fiber optics, wireless optical communication has not been widely used, due to environmental issues. Weather and other environmental factors have limited the use of wireless optical communication, as they can cause attenuation and scintillation, which can damage the signal (Kim, 1998). While these factors have limited long-distance usage of wireless optical communications, short-distance communication is possible and reliable. Another wireless technology of note that emerged in 2000, but has been growing due to new hardware capabilities, is Visible Light Communication, or VLC (Pathak, Feng, Hu, & Mohapatra, 2015). VLC has become viable as the use of LEDs has become more prevalent and the ability to quickly change between light frequencies developed. These systems require the use of LEDs to send signals and a photodetector or imaging sensor to detect the changes in frequency. By using this system, multiple devices can receive data from an LED at considerable distances.

This approach becomes cheaper as LEDs become more efficient and their lifespan increases (Pathak, Feng, Hu, & Mohapatra, 2015). However, laser communication (lasercom) has shown the most promise, due to its speed and feasibility. Lasercom currently operates at 622 Mbits/s and aims to expand to 2.5 Gbits/s in the future (Kim, 1998). Aside from its speed, lasercom is also secure, as jamming or intercepting is difficult to perform consistently. The last advantage lasercom has is its ease of deployment and portability (Kim, 1998). All of these factors point to lasercom being a key area of research and a promising technology to leverage when connecting systems over short distance. Both lasercom and VLC show great promise but, for this current project, the authors decided to leverage lasercom to connect the Raspberry Pi's in the cluster in order to maintain high speeds and because it can be expanded to longer distances than LEDs, if necessary.

Methodology of Experiment

By building on the progress made in each of these areas of research, this current project had two key goals. The first goal was to prove that a powerful cluster of Raspberry Pi's could be created without the use of conventional hardware, including Ethernet cables and switches or hubs. This would help make clusters cheaper and more flexible when setting them up. A portable cluster would open many new possibilities, especially when combined with Internet of Things (IoT) devices. A portable, optical cluster would allow one to have Raspberry Pi's across an area and receive data from sensors, while, at the same time, also performing computations in parallel. This could drastically change the way data are gathered and calculated. The second goal of the research project was to test the viability of laser data transmission as a method of communication between Raspberry Pi's. Previous research has shown that lasercom is a fast method for transmitting data, but little research has been done on its use with Raspberry Pi's and whether or not it is fast enough for use in a cluster. Several Raspberry Pi clusters built by others were examined for this project. Many technologies are available to build a Beowulf cluster using Raspberry Pi's as nodes. A wired cluster was chosen to serve as a baseline for computational speed, latency, and bandwidth of a traditional cluster of Raspberry Pi's. Figure 1 shows that the cluster consisted of nine nodes, with one master node and eight worker nodes connected by a hub.

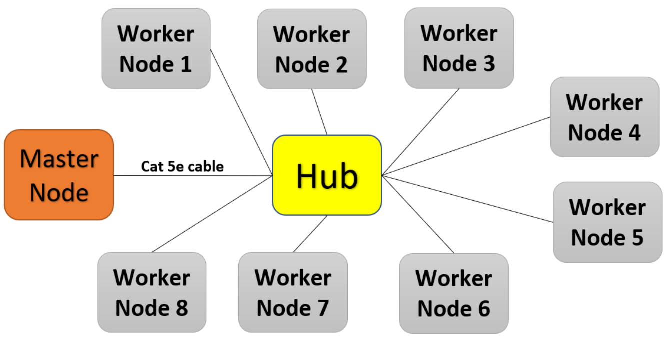

Figure 1. Connection diagram of the Raspberry Pi cluster.

The nodes were Raspberry Pi 2 Model B Pi's. The nodes used Raspbian as their operating system, which was based on Linux. For wired transmission, a local network was created with the master node having access to each node and the permission to perform actions on those worker nodes. This was accomplished by using Nmap, a network scanning interface used to map nodes, to find each node on the network, and then establish a secure shell (SSH) connection ("Nmap network scanning"). Once the SSH connection was made, RSA keys were created for each node. Copies of worker's keys were shared with the master node and the worker nodes were given a copy of the master's key. This allowed the master node to be able to access each node and run programs on those nodes. Open Message Passing Interface (Open MPI)—an interface used for passing messages in parallel computing—and the specific installation built for python, mpi4py, were used in order to pass data between nodes (Dalcin, n.d.). The use of mpi4py made it possible to run the latency and bandwidth baseline programs that have been used as baselines for many clusters. These tests were run five times each.

After creating the wired cluster, the optical cluster followed a similar structure, with one exception. The proposed cluster had nine nodes with one master node and eight worker nodes, the same as for the wired cluster. The transceivers were 650 nm, 5mW lasers and connected to the Tx pin in the Raspberry Pi's GPIO pins. The receivers were photodiodes that were connected to the Rx pin in the GPIO pins. Together, these formed serial connections between the Raspberry Pi's and allow for the data transmission needed for parallel computing, instead of using the Ethernet port as the wired cluster had previously. The Ethernet port was not used initially, as it was not the simplest solution for the problem. The GPIO pins are easier to access and integrate peripheral devices easily. The use of these pins instead of the Ethernet seemed to be the obvious course of action.

Results

The tests on the wired cluster provided a baseline for the bandwidth and latency that would be needed in order to measure the effectiveness of the optical cluster. The important points to mention regarding these tests was that a maximum average bandwidth of approximately 342 MB/s was achieved, while maintaining relatively low latency. Figure 2 shows that bandwidth was sufficient for sending large amounts of data between the nodes quickly, which is one of the criteria for a successful cluster computer.

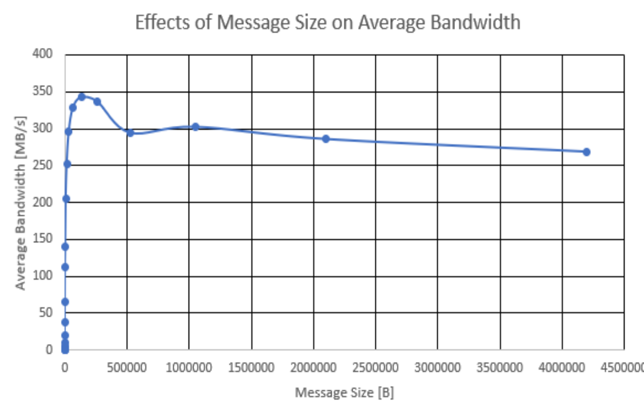

Figure 2. Effects of message size on average bandwidth.

Figure 3 shows that the latency had a steady increase, but a few outliers skewed the data. Overall, these results give a clear picture of what criteria the optical cluster must match or exceed in order to be a viable alternative.

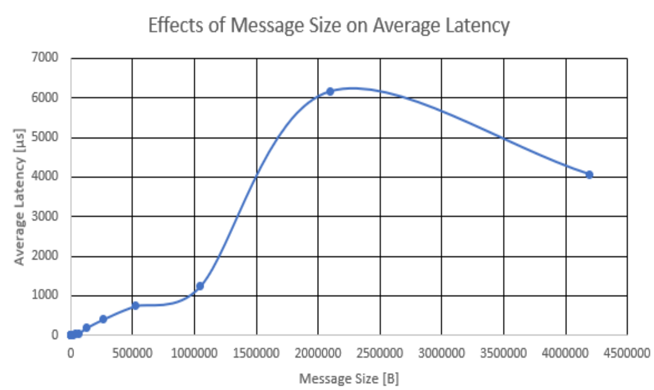

Figure 3. Effects of message size on average latency.

While attempting to build the optical cluster, three problems appeared that need to be addressed. The first problem focused on passing the master's laser to the multiple worker nodes' receivers. Figure 1 helps visualize this issue, because this project focused on removing the hub and wires from the network, which effectively removes the central connection for all of the nodes. This was crucial, as the master had to be able to communicate with each worker, and a single transmitter was preferable to multiple lasers being used on the master node. A laser on its own can only hit one receiver, thus adjustments had to be made. The proposed solution involved wrapping a thin, semi-transparent material around the laser in order to cause a region of it to glow when the laser turned on. This created an illuminated area large enough such that all of the photodiodes could pick up the signal and process the data the master was sending. Figures 4 and 5 show a photo and a circuit diagram, respectively, of what the proposed solution would look like when implemented.

Figure 4. Photo of laser wrapped in semi-transparent material.

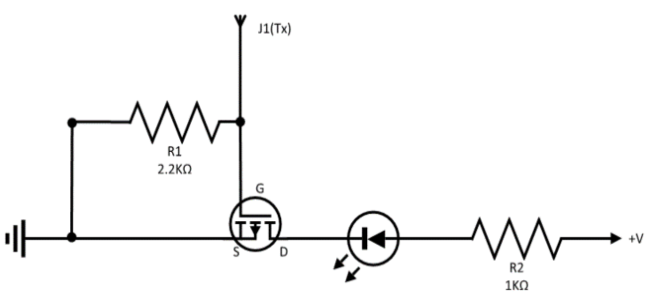

Figure 5. Circuit diagram of transmitter.

The second problem revolved around the master's receiver photodiode. With only one photodiode, it is hard to focus all of the workers' lasers onto that small target. In order to allow the cluster to work across the room, as planned, the master needed to have an array of photodiodes in order to allow for a larger area that the workers could reach with their lasers. The array was created out of multiple photodiodes with their non-ground pins wired together onto the single Rx pin on the master node. The photodiodes were fanned out and sticking out of the bottom of a Styrofoam cup in order to create a large area for the lasers to hit. Figures 6 and 7 show a photo and a circuit diagram, respectively, of what the proposed solution would look like when implemented.

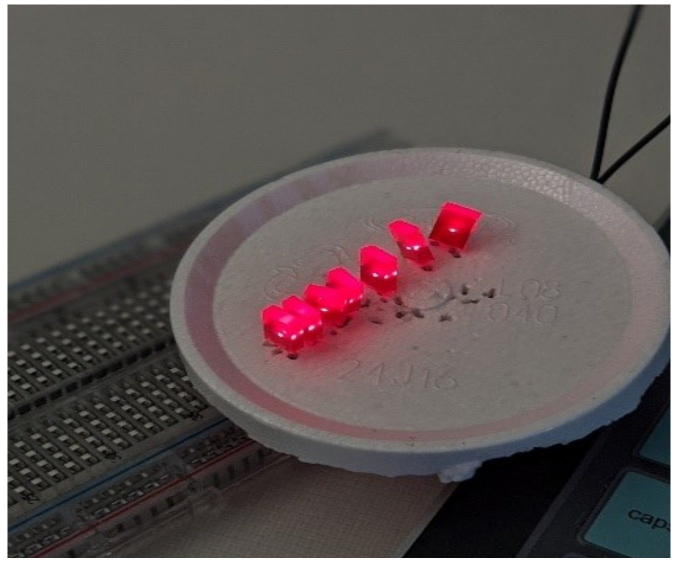

Figure 6. Photo of photodiodes on the bottom of a Styrofoam cup.

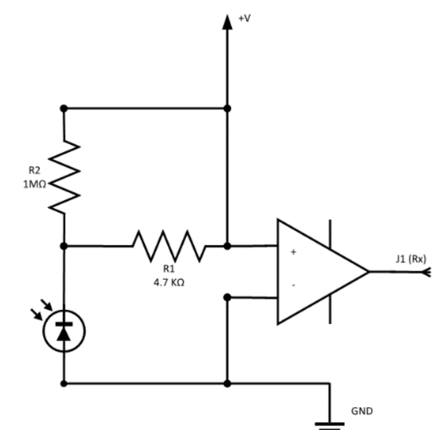

Figure 7. Circuit diagram of receiver.

The third problem encountered dealt with the software portion of the cluster. Due to the sensors used to pass the data, a serial connection had to be implemented over the GPIO pins. The use of a serial connection limited the number of protocols available for data transmission. The following summary of the three protocols supported by the Raspberry Pi will help in understanding this issue. The first protocol available for use is I²C. This protocol uses only two wires to create an efficient, effective, and lightweight connection between all devices without data loss (Pandey, Kumar, Kumar, & Goel, 2014). This protocol allows for masters to initiate data transfer with workers, the devices receiving the data. This protocol also allows for a multi-master bus that can have many senders and receivers, by using addressing to keep track of the devices. This protocol can reach bandwidths of up to 5Mbit/s in ultra-fast mode for unidirectional data transfers, or it can reach 3.4 Mbit/s for bidirectional data transfers (NXP Semiconductors, 2014). While this protocol allows for many nodes and easy addressing, it is far too slow to accommodate the amount of data transfers that will occur while performing parallel processing.

The second protocol available on the Raspberry Pi for serial connection is SPI. This is a protocol that requires 3+N wires, where *N* represents the number of nodes attached to a single master (Myers, 2007). This protocol can only allow a few nodes to be connected, due to the large amount of space it takes up on the GPIO pins of the Raspberry Pi. This protocol allows for full-duplex communication between a single master and many workers. Unlike I²C, SPI does not require addressing and uses pins to identify workers connected to the master. While it is one of the fastest protocols around, it generally can only reach several Mbit/s (Myers, 2007). Because of the low overall transmission speed and the restriction on how many nodes can be connected to one master, this protocol was not a viable option either.

The third protocol option is UART. This universal asynchronous receiver transmitter (UART) is a low-cost, short-distance protocol using a receiver, a baud rate generator, and a transmitter (Ashwini, Yadav, Kumar Reddy, & Krishna, 2015). It utilizes the Tx pin, Rx pin, and ground pin on the Raspberry Pi's GPIO pins. This was the best protocol to use for data transmission, as a laser could be connected to the Tx pin and a photodiode could be put on the Rx pin to communicate. Although it is easy to modify for the use of optical communication, UART is an older serial protocol, and is slower than I²C and SPI. This protocol is limited by the baud rate it uses and can only support up to 115,200 bits/s with half-duplex communication. This is not nearly fast enough for parallel processing and would cause the cluster to be incredibly slow. Using USB instead of UART would be a possible solution.

Implications/Conclusions

After examining all three protocols, it became clear that a new approach to data transmission between the nodes had to be found. All of the serial protocols examined did not have the specifications needed for an optical cluster. Serial connections are designed for quick data transfers with a small amount of data being sent from sensors. Because of this, they are built to have a low bandwidth, which will severely hamper a parallel-computing cluster. Also, many of the protocols utilize a bus to send data, and this cannot be easily converted into an optically linked network. For an optical cluster to work, the master must access each worker, and each worker should be able to contact the master. A protocol that uses a bus requires all of the nodes to be connected to each other and required multiple pins in order to send different data, which will not work with only one laser and one receiver at each node. The results from this study showed that serial connections are easy to use for sending and receiving small amounts of data, but they have a very low bandwidth, which makes them poor choices for passing data between nodes in a cluster. The Raspberry Pi can handle large amounts of data being passed by wired connection, up to 342 MB/s, but there needs to be more research into other methods that do not use serial protocols for incorporating optical links between nodes in order to still have the speed necessary for parallel processing and have the added flexibility of less hardware.

The student performing this research gained valuable insight into the design of Beowulf clusters and how optical devices communicate with each other. Budget permitting, future research should be conducted by either individual students or teams of students under faculty supervision to explore these options.

Future Research and Limitations of the Study

For future work, further study should be done on other protocols and optical data-transmission options. Of all the options available, two stand out as being relatively easy to implement on Raspberry Pi's. The first promising option for creating the optical cluster is to use infrared signals to communicate between nodes. This mode of communication still requires a line of sight between the nodes, but also uses the USB port to send and receive data. Raspberry Pi has devices available for use in the USB port to send infrared signals. These USB dongles are called IR Blasters and are easy to plug in and use. There are a few libraries available to communicate over infrared with Raspberry Pi's, so custom commands and message structure can be used if needed. Also, studies have proven that Linux machines can use infrared signals for FTP and transferring large amounts of data. The ability of the Raspberry Pi to use infrared and the ability for other Linux machines to use infrared for larger data transfers opens up the use of infrared for optical clusters as a possible option to be explored.

The second option that may yield good results is optical Ethernet transmitters and receivers that can plug into the Ethernet ports on a Raspberry Pi. Normally, these are used to provide lightning-fast connections to PCs via laser, but they could be repurposed for use by Raspberry Pi's. While the Raspberry Pi will not be able to take advantage of the extreme speeds, due to its slower processor, it will be able to transmit data at a sufficiently fast rate using a laser in order to allow for fast parallel processing. This could achieve the speeds previously found with the Ethernet ports on the wired cluster, or even faster. If using the devices available on the market, this option is much more expensive than infrared communication, so more research needs be done to ensure compatibility with the Raspberry Pi before moving forward. This option can be explored more cheaply if the wireless transceiver/receiver pairs can be built in-house instead of being purchased. There are research projects in which researchers have built these devices for Ethernet ports of Raspberry Pi's themselves, but more research is needed to determine if they will be a viable solution.

This current study was conducted by a student as part of his senior honor's thesis and was, therefore, limited by time constraints. Also, Murray State University is a teaching and not a research institution and, for that reason, has a very limited research budget. It is, therefore, very difficult to purchase some of the parts and materials needed to perform further experiments.

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Robotics Vision System Integration for Sorting and Pick-and-Place Applications

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Abstract

Continuous process improvement is a quality concept that has helped achieve company success by saving money, while at the same time increasing productivity. Companies are constantly looking for ways to increase their productivity while staying competitive. In order to stay competitive, they have to constantly look for innovation and ways to make their operation process more effective. In recent years, robots have been used in industry as an innovative approach. Applications that are repetitive and low-skilled are being found for the most common robotics applications. However, these applications are limited to stationary parts and isolated environments. Performing tasks with blind robots requires expensive fixtures, such as synchronized conveyors and precise palletizing. Additionally, if during the process an object is not in the fixed position for the robot to work, it can cause delays, waste money, and stop the entire production. In this paper, the authors shows the steps and projects that could be used to setup a vision system in a lab environment in order to help students understand the integration of a robotic vision system. Three projects were developed in this study to help students enhance their skills in robotics system integration in order to make them more marketable in the future. Furthermore, the authors discuss the details of how students established robot vision integration skills needed in the current job market.

Introduction

Most robotics applications in industry involve highly constrained setups that rely on knowing the orientation and exact location of all the equipment that will be used for the robot to perform its task. Besides having that knowledge, extra equipment is generally required to ensure that workpieces are firmly located in a specific place, such as expensive fixtures and elaborate jigs (Chatterjee, 2014). Alternatively, a vision system will save time, as it will not cause delays or stop processes when there has been a misplacement of certain items. The focus of this paper, then, is to show and guide students on how to establish robotic integration within a vision system. The authors also demonstrate how vision systems can be applicable in more complex and diverse industrial applications. The applications used for this purpose consist of sorting and pick-and-place. Results of this study should provide insight into how vision systems can help to improve efficiency, quality, speed, and accuracy by establishing different scenarios. In this study, the authors developed three projects based on vision system applications that would provide insight into the efficiency of using integrated vision to perform complex and more diverse industrial applications. The authors specifically developed three projects that could be applicable to industry. The sorting application used cards, where the program would take one card from the deck and sort it by suit. The pick-and-place application demonstrated the use of round wooden tools that were inserted into free slots in a box. The pick-and-place application, combined with a sorting application, was demonstrated by using numbered cubes, which the robot would pick and place by its matching number.

Review of Literature

Vision systems have guided robots to perform functions beyond the capability of a blind robot. This feature can help robots locate parts, determine the condition of tools, or inspect the quality of a product. It can guide the robot to perform operations while avoiding obstacles as well as pick up objects that have been dropped during the process (Development of an Educational Robot Vision System, 2017). That study supported a variety of applications that vision systems could be applied to. The study focused on the development of an educational robot vision system for identifying and sorting objects of different sizes. The system used iRVision. The authors of that study concluded that the system of object tracking could be applied in applications such as automated plant operations, security systems, and entertainment robots (Development of an Educational Robot Vision System, 2017).

In another study on the prospects of automated sorting systems, the authors explained the applications of sorting in the food industry, which included the sorting of crops, detecting defects, sorting baked good having the same characteristics before packing, and the sorting of ripe and unripe fruits or vegetables (Nandi, Tudu, & Koley, 2014). Another study applied an inspection and sorting application that could be applied in the food industry (Narendra & Hareesh, 2010). The project focused on automatic grading in which a computer vision system was developed to collect the video image of mangoes and to process images from different features. The features focused on the quality and the maturity level of the mangoes. Depending on the maturity level, the mangoes were sorted into four grades. Results of this project showed a fast, low-cost, intelligent system with a performance very similar to a manual inspection. Yet another study focused on the developments of a computer vision system in the food industry (Xiaokuan, Yong, & Zhilei, 2019). Here, the author concluded that computer vision systems proved to be more consistent, hygienic, rapid, could assess economic objectives, and had a performance level very similar to manual inspection.

An article on the Robotics Industries Association mentions the most common applications of pick-and-place and the benefits to industry. The main methods of pick-and-place application consist of assembly, packaging, inspection, and bin picking. In the case of bin picking, a vision system can help pick a part out of bin, even if mixed together with other parts, and place it on a conveyor. For inspection, the vision system can remove the defective products from the conveyor. This article also mentions the benefits that include speed and consistency. Regarding consistency, the robots can help to improve quality and reduce downtime. In terms of speed, it was mentioned that a pick-and-place robot can reach 200 products per minute; however, vision systems can identify 100 products per second. Speed helps to improve productivity and, therefore, increase profits, yielding a high return on investment (Robotics Online Marketing Team, 2018).

Materials and Setup of Equipment

Materials used for in this current project consisted of a Sony camera, camera cable, Fanuc R-30iB controller, laptop, Ethernet cable, UIF vision software download from the Fanuc website, and tools required to sort, pick up, and place parts. This process involved connecting the camera to the controller and the controller to the PC. The communication protocol used between the robot and the PC was TCP/IP, so an Ethernet cable was connected to both sides. IP addresses needed to be configured in the robot controller and the PC. In the PC, the setting of internet and windows firewalls had to be modified in order to prevent communications to be blocked between the controller and the PLC.

Procedures

The first step was to create a grid-pattern calibration. This calibration was required prior to starting work on the project. The vision system had to recognize the same coordinate system as the robot. This is the most common calibration used for vision systems. In order to do this calibration, a tool frame had to be set up first for the pointer that was going to be used for the user frame calibration, then a proper calibration grid would be chosen, which needed to be within the field of view. The calibration had to be trained in the robot homepage. The next step was to create a sorting application. To demonstrate a sorting application using a vision system, a set of cards was sorted by their four suits. The program was able to detect any suit from the deck of cards and place the associated card with the rest of the corresponding suit. This involved creating a 2D, single-view vision process. This program was used to teach the different suits from the deck of cards and assign their corresponding model IDs. The calibrated camera was selected and the multiple locator was set to find the best match so that it could detect the card with the highest score, which was expected to be from the deck of cards. In addition, the sort key was set to score and in descending order so that it could detect the best card first. The program was set to find one object at a time; thus, a calibrated user frame was selected and the snap window was focused on the area where the deck of cards was located. The exposure time used for this particular application was 2.5 ms. The 2D, single-view vision process consisted of four GPM locators that were set up with different model IDs and the score threshold was set to 90% so that it could be more precise when finding the deck of cards. Figure 1 shows the setup of the 2D single-view vision process used for the deck of cards recognition.

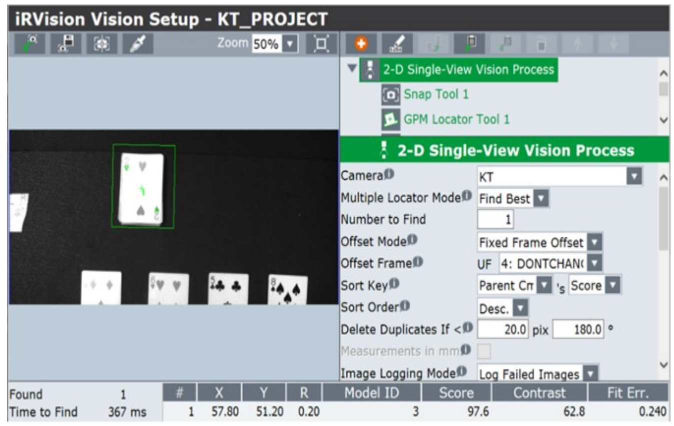


Figure 1. A 2D single-view vision process program used for sorting applications.

A separate 2D Single-view vision process was created for the matching cards so that the snap window would be more focused on the area where the matching cards were located. Also, it was created to prevent a situation where the card below had the same suit, thereby causing the robot to move to an incorrect position. The settings would be the same as the previous view process, except for the snap window area. Figure 2 shows the 2D single-view process for the matching card only.

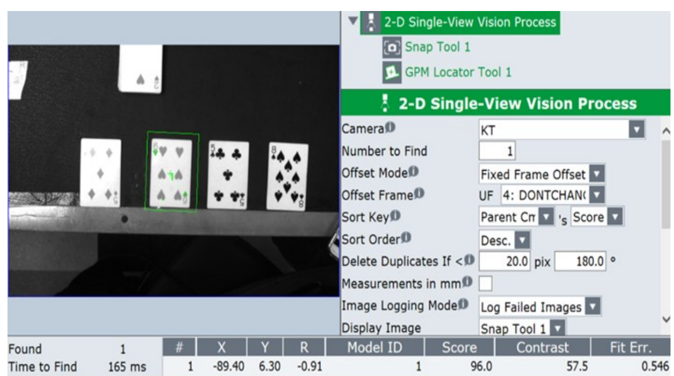


Figure 2. Separate program for sorting applications.

Next, it was necessary to configure a teach-pendant program. The program consisted of identifying the suit from the card at the top of the deck of cards and then placing the card where the matching card was located. These steps included:

Specify frames
1. UFRAME_NUM=4
2. UTOOL_NUM=6
   These were frames used to calibrate the user frame and tool frame.

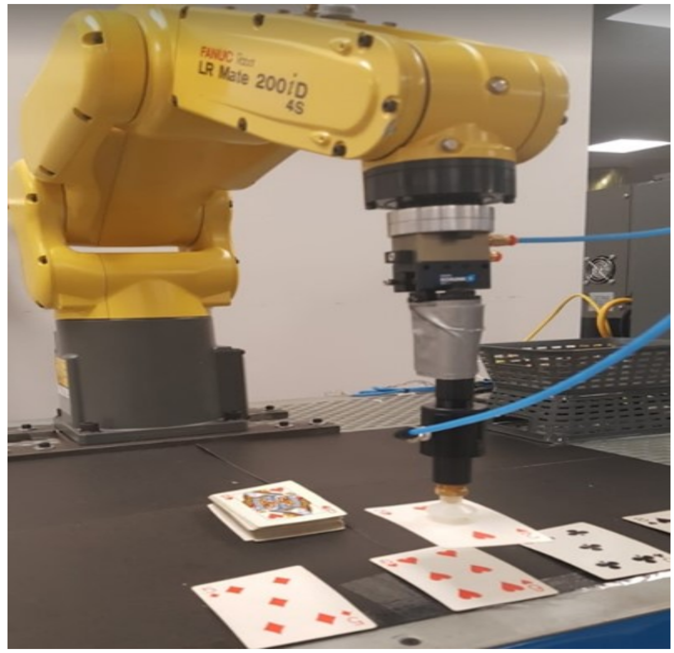
Execute deck of cards program
3. R [1] = 0
4. VISION RUN_FIND ‘SORTING_DECK’
5. VISION GET_OFFSET ‘SORTING_DECK’ VR [] JMP LBL []
   Execute the program to detect the suit and initialize the vision register.

Set IF conditions
6. R [1] = VR [1]. MODELID
   It copies MODEL ID from vision register into the register.
7. IF R [1] =1, JMP LBL [1]
8. IF R [1] =2, JMP LBL [2]
9. IF R [1] =3, JMP LBL [3]
10. IF R [1] =4, JMP LBL [4]
    If suit of card is spades, it will go to label 1; if clubs, it will go to label 2; if hearts, it will go to label 3; if diamonds, it will go to label 4.

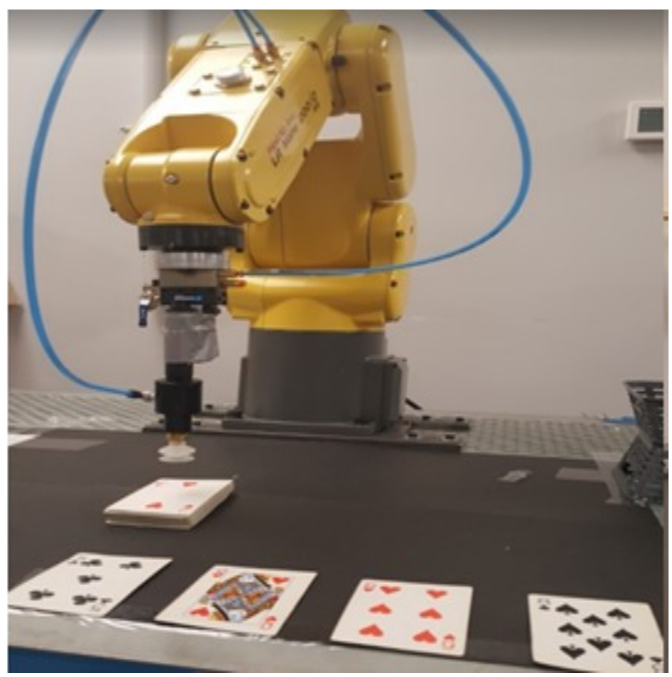
Pick up card
11. LBL [1]
    Specify VOFFSET, VR [1] points to pick up the card.

Execute program for the suit
12. VISION RUN_FIND
13. VISION GET_OFFSET ‘’ VR [2] JMP LBL []
    Execute the program for the suit spades and it will match the card with the same suit.
14. R [2] = 0
15. R [2] = VR [2].MODELID
    Copy the MODEL ID from the vision register into the register.
16. IF R[2] = 1, JMP LBL [10]
17. LBL 10
    Specify VOFFSET, VR [2] points to place the cards. Repeat the same steps from 11 to 17 for LBL 2, 3, and 4.

Figure 3 shows the robot operating the sorting application. A sub-application was developed for picking and placing. To demonstrate this application, round wooden pieces were picked up and placed into holes in a box. The program was able to identify the empty holes and place the remaining wooden tools into the available spots. The next step was to create a 2D single-view vision process. This vision process was created to identify the wooden tool and pick it up. In the 2D single-view vision process, the camera was calibrated with the corresponding frame and the exposure time was set to 3 ms. In the sort key, the score was selected to be from highest to lowest. This option was selected so that the program would not find any other rounded surfaces coming from the box. The score was set at 70% and the contrast was set at 40% in order to get better results. Figure 4 shows that this program had only one GPM locator tool, since all of the other tools had the same shape.



(a) Recognize the card’s suit.



(b) Drop off the card with its matching suit.

Figure 3. Robot operating the sorting application.

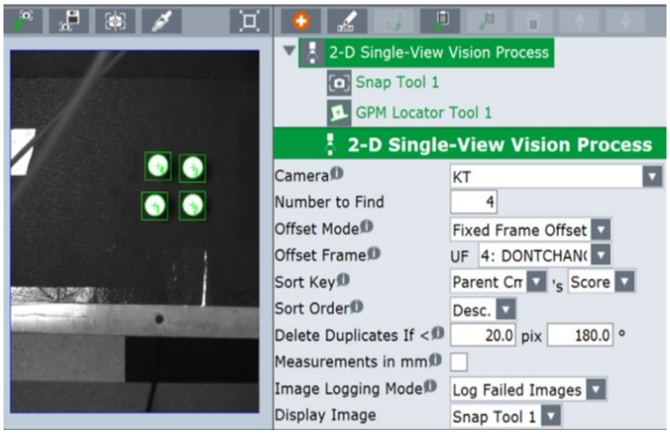


Figure 4. 2D single-view vision process system for the picking and placing application.

Another 2D single-view vision process was created for the holes in the box for the purpose of limiting the search area and accurately finding the desired target. The settings were the same as for the previous 2D single-view vision process, except that score threshold was set to 96 with the goal of detecting only the free slots and not the ones that already had an object inside it. Figure 5 shows the setup of the 2D single-view vision process for the target destination.

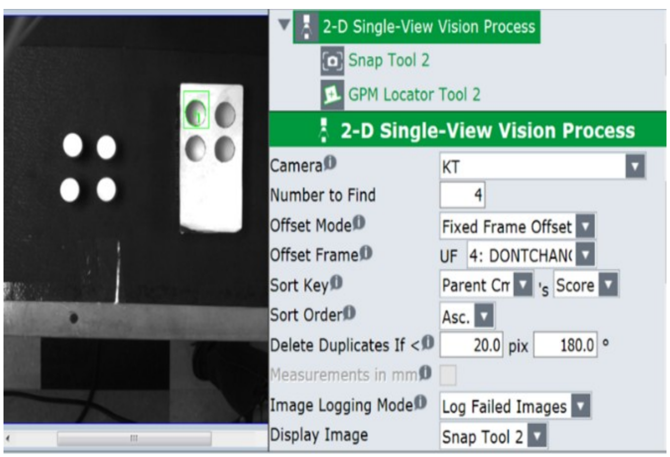


Figure 5. 2D single-view vision process program for the target destination.

For creating the teach pendent program, the program consisted of finding the wooden object, picking it up, and placed it inside the holes located in the box.

Specify frames
1. UFRAME_NUM=4
2. UTOOL_NUM=6
3. LBL 200
   These were frames used to calibrate the user frame and tool frame. The label was used for the program to jump to pick up the wooden tool after the piece had been inserted into the slot.

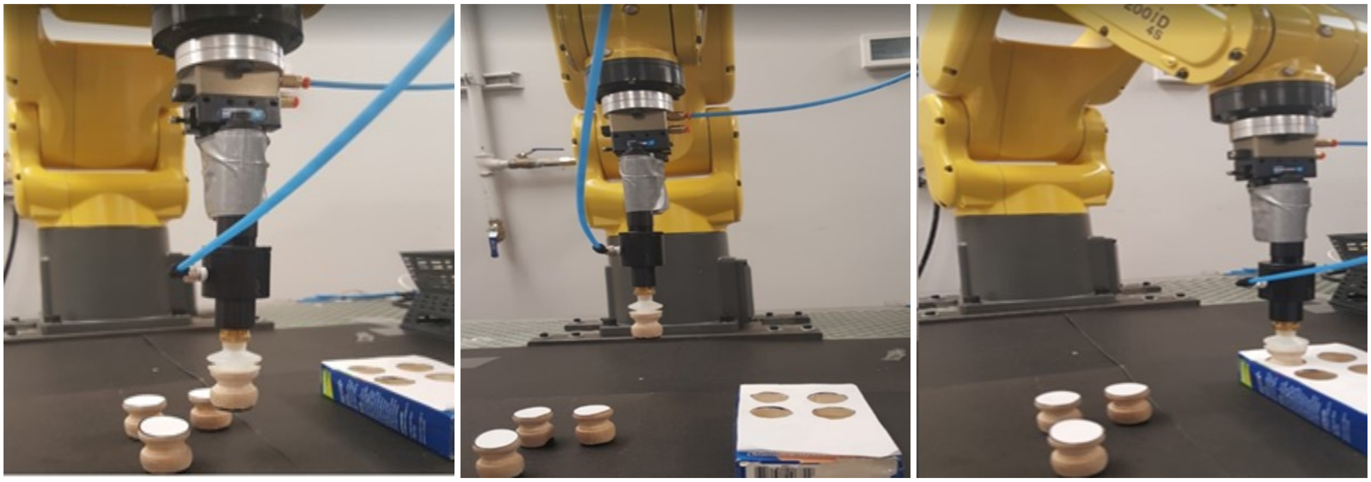
Pick up wooden tool
4. VISION RUN_FIND ‘PICK_UP_TOOL’
5. VISION GET_OFFSET ‘PICK_UP_TOOL’ VR [1] JMP LBL [200]
   Execute the program and retrieve the offset to the vision process.

Find available slots in which to place the tool
6. VISION RUN_FIND ‘TARGET_POINT’
7. VISION GET_OFFSET ‘TARGET_POINT’ VR [2] JMP LBL [300]
   Execute the program to find the best slot for the object to be placed in.
8. JMP LBL [200]
   Once a spot has been found, the program will come back to pick up another object.
9. LBL 300
10. VISION RUN_FIND ‘TARGET_POINT2’
11. VISION GET_OFFSET ‘TARGET_POINT2’ VR [2] JMP LBL [400]
12. JMP LBL [200]

The program would still jump from target point 1 to 2 to 3 and to 4 until it finds an object; and, since the score was set to 96, it would only find the most suitable point. This process was repeated from 5 to 7 for the rest of the target points. Figure 6 shows the robot performing the pick-and-place application. The next step was the sorting and pick-and-place application. This application was demonstrated by using two Lego cubes. The robot was able to identify the number on the cubes, pick them up, and place them into their respective locations. For this to work, a 2D single-view vision process was developed. This program was created for the sides of the cube. The calibrated camera and user frame were selected, the mode was set to find the best part, and the sort key was dependent upon a descending order of the score. Figure 7 shows that the program had 10 GPM locators for each number on a side of the cube, as there may have been 10 different model IDs and the parameters used were the default ones. The next step of the process was to develop the teach pendant program. The program consisted of identifying the number from the cube, pick it up, and place it in the spot corresponding to that number.

Specify frames
1. UFRAME_NUM=4
2. UTOOL_NUM=6
   These were frames used to calibrate the user frame and tool frame.

Execute the pick-up-cube program
3. R [1] = 0
4. VISION RUN_FIND ‘PICK_UP_CUBE’
5. VISION GET_OFFSET ‘PICK_UP_CUBE’ VR [] JMP LBL []
   Execute the program to detect the number and initialize the vision register.



(a) Pick up the wooden object. (b) Identify empty slots. (c) Place the part into the slot.

Figure 6. Robot performing the pick-and-place application.

Set IF conditions

6. R [1] = VR [1]. MODELID

Copy the MODEL ID from the vision register into the register.

1. IF R [1] =1, JMP LBL [1]
2. IF R [1] =2, JMP LBL [2]

These steps are repeated from 7 to get the rest of the numbers 3 through 10. If a number on the cube is one, it will go to label one, two will go to label two, etc.

Pick up the cube

3. LBL [1]
   Specify VOFFSET, VR [1] points to pick up the cube.
   Execute the program to find the respective location
4. VISION RUN_FIND
5. VISION GET_OFFSET ‘’ VR [2] JMP LBL []
   Execute the program for target points
6. R [2] =0
7. R [2] = VR [2]. MODELID
   Copy the MODEL ID from the vision register into the register.
8. IF R [2] =1, JMP LBL [10]
9. LBL 10
   Specify VOFFSET, VR [2] points to place the cube.

A different program was created for the target numbers. The parameters used were the same as for the first program. Figure 8 shows that this program also had 10 different model IDs for the 10 GPM locator tools. Steps 9 through 15 are repeated for the rest of the target points. Figure 9 shows the robot performing the sorting and pick-and-place applications.

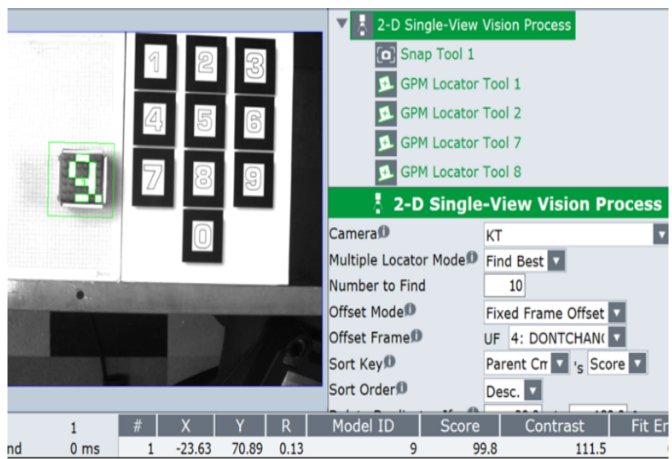


Figure 7. 2D single-view vision process for identifying the number on the cube.

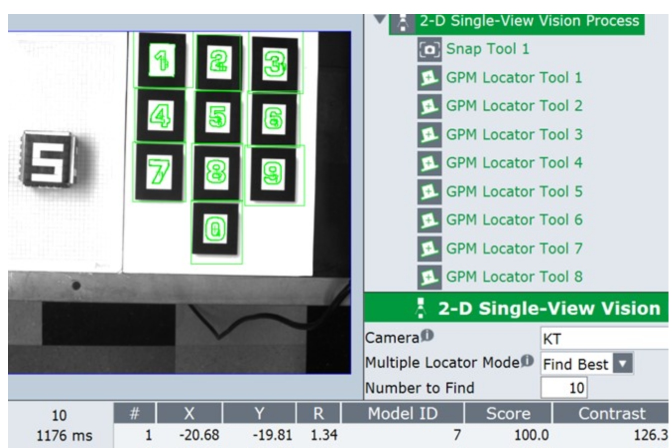
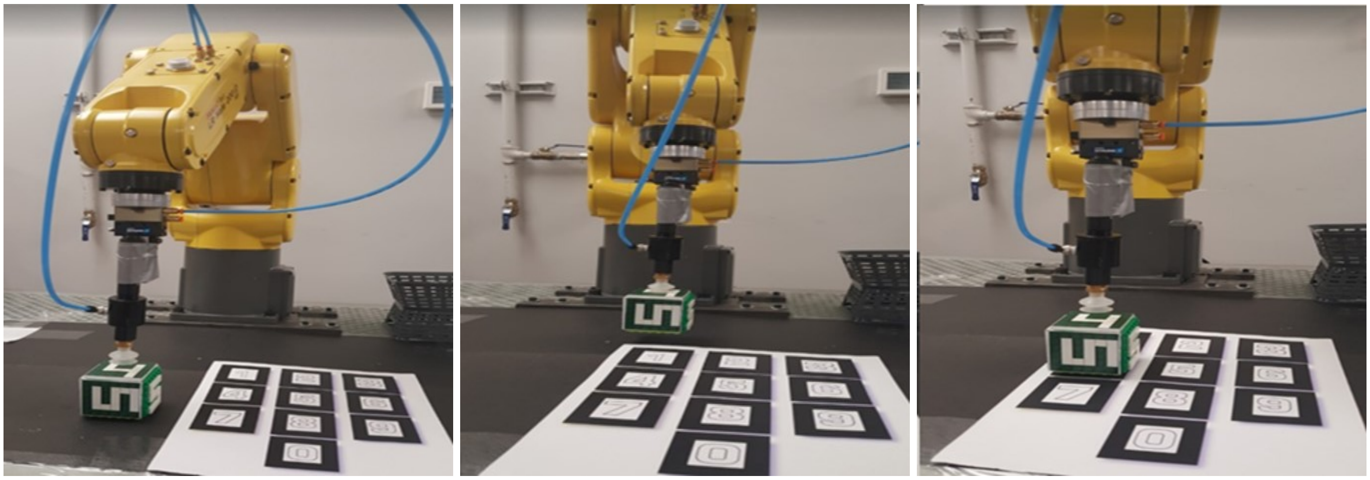


Figure 8. 2D single-view vision process to drop off cube.



(a) Pick up cube. (b) Destination identification. (c) Drop off.

Figure 9. Robot performing the sorting and pick-and-place applications.

Implementation Challenges

To implement the integration of a robotic system, there are many challenges that students will encounter. Some of these challenges may well occur during the set up and implementation phases. Setting static IP address for the computer and robot were not easy steps, and getting the configuration parameters correct in the teach pendant required knowledge of robotic programming and configurations. For the better results, the robot vision system needs very accurate user frames and tool-frame setups, otherwise the accuracy for detecting an object's position will be quite low. The user-frame is required for teaching the robot its position using the 4-points technique. The calibration grid used in the process needs to be clean and completely captured by the robot's camera. The four large dots in the calibration grid are required for the minimum amount of camera calibration. For better results, the maximum amount of error in the calibration grid should not be more than 1. The camera software GUI has many variables to set up, such as training the object and masking out unnecessary features, which can be challenging and time consuming. Also, using appropriate light and background is very important in this stage. Finding the object's score is rather challenging in many of the situations presented as well. Finally, adjusting the camera field view and search area is critical for vision processing and robot speed.

Parameters

The analysis for the sorting application was performed using default values. However, when the snap-and-find feature was selected, it would find a lot of random cards that did not belong with a desired suit. After changing the score threshold to 90%, it found only the object that corresponded to the suit that it was taught. In addition, and to ensure that it could detect a specific suit, the search area was limited so that the card could only be found from the deck of cards or only from the matched object. The picking and placing project also required a lot of accuracy to pick up the small wooden object and insert it into the box. At first, the pick-up position was not very accurate, and for the target it would detect target points that had a tool inside of the box. In order to increase accuracy, the contrast was changed to 40% and the orientation box was unchecked, as it caused some inaccuracy. For better accuracy, the four target points were taught. The score threshold was very limited so that the program would only detect the specific point that corresponded to the free slot. The picking and placing program combined with the sorting application did not require the setting of the extra parameters, since all of the objects' details that were trained were different from each other; thus, the robot found the object with high accuracy. In the teach pendant program, two conditions were used: one for picking up the object and the other for placing it in the correct spot.

In the first project, the score threshold was set to 90%, contrast to 50%, and orientation check from -180 to 180. Different aspects influenced the time that it took to find the different suits. A test was performed to analyze the time it took to find a suit. Results from suits of cards showed that the diamonds suit took 22.5 ms above the average, which was influenced by an R reference value of 177.71, which was different compared to the average value for the other suits, which had an R value of 1.47. The diamond suit was the only suit having the same shape when rotating, so the orientation was hard to identify, which could have forced the camera to take more time to find the suit. For the second part, corresponding to the matching card, the score was set to 70%. The cards located in the deck had more contrast than the ones located below; because of this, the score threshold was set to 70%. The score threshold also influenced the time it took to find the object (165 ms), which was very low compared to the values obtained from the suit of cards.

In the second project analysis, the score threshold was set to 70% and the orientation was disabled. The results of the test showed that the time it took to find the round wooden objects was 68 ms. Comparing the results with the first project, the contrast was a lot higher, with an average value of 168.1 ms. The reference *R* also differed from the first project with a value of 1.34 for all of the objects. The situation for the round wooden objects was similar to the diamond card; the only difference being that rotation was disabled in this test. Disabling the orientation also helped to get a higher score (99.1 ms) in the second project, thereby increasing the accuracy of the application. In the second part of project two, in order to detect the target point, the score threshold was set to 96% and the orientation was disabled. The test show that it took 111 ms to find the target. These results showed a lower contrast (98.8 ms) and the score threshold was more limited. In the second project, the contrast and the score threshold were parameters that made a difference with the time needed to detect the object.

In the third project, the score threshold was set to 70% and the orientation was disabled. Results of the test showed an average time of 129.8 ms for the contrast and score of 100 percent. The time it took to find all of the numbers was 1176 ms, which was low compared to the time of the first project, which looked at just one object, and considering that 10 numbers had to be found. The cube had a score threshold of 70% and the orientation was enabled, since the number had to be placed in the correct orientation. The time that was needed to find the cube number was 0 ms. The cube results showed a good contrast of 111 ms and a score of 99.8 ms. In the third project, the contrast and score threshold contributed to a faster detection of the object. The robot used for this application could reach up to 250 mm/s, which was configured when touching up the points used to move the robot to the desired object. The frame speed of the camera used for this project was 50 fps. A good contrast, a low score threshold, and disabling the rotation were some of the parameters that could be configured in order to minimize the time it takes for the camera to find the object. The time the camera takes to recognize the object is relatively low compared to the speed of the robot, which would take longer to reach the object.

Conclusions

Integrating a robotic vision system can bring many benefits into an industrial setting. It improves the accuracy of performing a task, it saves time, it reduces ergonomic problems, it can be used for heavy load applications, it can be used in dangerous environments, it improves the speed and consistency of a designated task, etc. Three projects were completed in order to demonstrate how vision systems can be used in an industrial environment. The sorting and pick-and-place applications used in this project used the Lego cube. This project can be applied in an industrial setting when a product needs to be inspected, picked, and sorted. All of these applications can be performed at the same time, using condition statements and the vision system. The tools from the GPM locator device were very useful for getting the best out of the image acquisition system by defining a score, changing the contrast, and changing the area of search. These tools helped to make the vision system more accurate and allowed it to be changed, depending on the application needs. Programming the teach pendant using conditions can be very useful when different tools need to be sorted. It provides a quick and effective way to sort the items. These project designs demonstrate that vision systems can help to improve the accuracy, efficiency, and quality when performing different kinds of industrial applications. All of these benefits in an industrial setting will help to increase profits and yield a high return on investment.

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Biographies

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Preparation of MET Students for the NCEES FE Exam: Lessons Learned

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Abstract

The National Council of Examiners for Engineering and Surveying (NCEES) provides professional licensure for engineers and surveyors. The fundamentals of engineering (FE) exam is the first step in the process to becoming a professional licensed engineer (PE), which is required for professional engineering positions governed by the GS-0800 policy for individual occupational requirements. Private companies may also require having a certified PE on staff for liability protection. There are some obstacles in place in the U.S. for engineering technology graduates, even if they successfully pass the FE exam. Engineers are licensed at the state level by professional licensing boards, each having different regulations, even though the examinations to become a PE are the same in all states. The purpose of this study is to investigate the process used to prepare students for the FE Mechanical exam in an ETAC/ABET-accredited manufacturing and mechanical engineering technology (MMET) department.

Data gathered from 2014-2019 have influenced program improvement efforts and professional practice teaching course methodology. FE exam results increased over time, but some factors influencing the increase remain unknown. Methods used to teach the professional practice course include creating question banks developed from sample course exam questions in the university's learning management system (LMS), utilizing PPI resources such as FE review manuals (Lindeburg, 2011, 2014) and access to the practice problems and exams for students online. FE results can assist in program improvement efforts, and these credentials provide advantages for many students in the job market. Support for baccalaureate graduates from ETAC/ABET-accredited engineering technology programs to become licensed professional engineers without additional requirements is evidenced by the 2020 ASEE Position Statement on Professional Licensure of Baccalaureate ETAC/ABET Graduates.

Introduction

In the Department of Manufacturing and Mechanical Engineering Technology (MMET) at Michigan Technological University (Michigan Tech), there is a BS in Mechanical Engineering Technology (MET) degree. Figure 1 shows that, for this degree, enrollment has fluctuated between 75 and 169 students in the years that span this study. The exit exam for program assessment accreditation purposes from 2013-2020 is the National Council of Examiners for Engineering and Surveying (NCEES) Fundamentals of Engineering (FE) Mechanical exam, also referred to as the Engineer-in-Training (EIT) exam. The exam is given to students during the fall or spring prior to their graduation. Students enroll in a required Professional Practice Seminar course used to prepare and provide practice sample problems similar to those on the exams. This course has a pass/fail grading system with the following grading criteria: 25% for attendance, 25% for in-class quizzes, and the remaining 50% for exams. Students must achieve at least 70% to pass the course. Students have the option to either retake the exam or redo quizzes in order to raise their scores above the passing level. The quizzes are FE practice questions completed online in a computer lab with the use of the electronic FE Reference Handbook (National Council of Examiners for Engineering and Surveying, 2013) as the only reference material. This is done to provide students practice using the FE Reference Handbook, which is their only reference material during the FE exam.

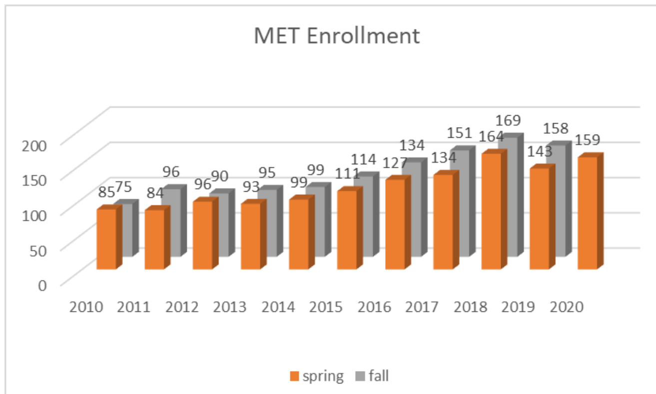

Figure 1. MET enrollment (2012-2020).

In this current study, the authors investigated the data from exit exams in order to determine what factors influence student performance. Presented here are explanation for how the methods of delivery of the Professional Practice Seminar course are related to student success on the FE exam.

Background

Exit exam data are widely used as a direct measure for program assessment purposes. Both ABET (Criterion 4. Continuous Improvement) and ATMAE (7.19 Outcome Measures Used to Improve Program) require that programs have a continuous improvement plan that is documented and for which data support decision making. Also, the first step for graduates from an undergraduate engineering or engineering technology degree from an EAC- or ETAC/ABET-accredited program in the process of becoming a professional licensed engineer (P.E.) is the FE exam. The decision to use the FE exam was made in 2013 in order to provide increased emphasis on engineering fundamentals in response to the ASME Vision 2030 Recommendations for Mechanical Engineering Education (Kirkpatrick, Danielson, & Perry, 2012), and was also expressed as a need by MET program employers and alumni. Michigan is among the 18 most restrictive states prohibiting ETAC/ABET-accredited MET graduates to receive professional licensure, although 33 states are less restrictive with 12 of those requiring no additional requirements for MET graduates.

The purpose for this current study was to relate how a person perceives the value of obtaining professional certifications. The PE designation is required for engineers pursuing a career as independent consultants, owning an engineering firm, and being employed as a government engineer in either federal, state, or municipal agencies. Also, in academia, many states require that engineering faculty be licensed—or at least this is a preferred qualification. Another factor to consider in the preparation of engineering and engineering technology students for professional certification is that, on average, PEs tend to have higher salaries than their non-licensed counterparts; according to an American Society of Mechanical Engineers (ASME) 2017 salary survey, Pes earn nearly $16,000 more than those without a PE license (Kosowatz, 2018). The number of PEs in the U.S. has been declining over the years, which could put the safety, health, and welfare of Americans at risk. Therefore, in providing methods for the preparation of students to take the FE exam, it is important to include such a professional practice seminar course in any engineering program.

Koehn (1989) found that a high pass rate on the FE is a result of motivated students, who complete a comprehensive review course. Although, according to Watson (1998), the overall value of the NCEES reporting of results is compromised by variable student motivation and the confidentiality of the questions used in the exam. The results do not provide the questions that were correct or incorrect for each student taking the exam. Only the students that do not pass the exam receive a report showing the percentage of missed questions in each category.

Methodology

The subjects in this study were Michigan Tech MET graduates having taken the FE exam in the semesters between the fall of 2013 through the fall of 2019. This represents a total of 136 seniors that took this exam in their final semester of the ETAC/ABET-accredited program. The FE exam results are arranged by topical categories. The data from each category are correlated to individual courses using a matrix. Not every course in the curriculum is directly related to the FE exam, but many of the MET student outcomes are included.

The NCEES supplies a report that can be used for assessment purposes to compare the level of attainment of each category in the test to the other ETAC students, who completed the exam that year. As explained by Nirmalakhandan, Daniel, and White (2004), student scores are converted to a scaled score, which adjusts for any minor differences in difficulty across the different exam forms. This scaled score represents a student's ability level and is compared to the minimum ability level for that exam, which has been determined by subject-matter experts through psychometric statistical methods. NCEES does not publish the passing score. The exam is electronically scored and results for 15 categories are transmitted in a report from NCEES.

1. Mathematics
2. Probability and Statistics
3. Computational Tools
4. Ethics and Professional Practice
5. Engineering Economics
6. Electricity and Magnetism
7. Statics
8. Dynamics, Kinematics, and Vibrations
9. Mechanics of Materials
10. Material Properties and Processing
11. Fluid Mechanics
12. Thermodynamics
13. Heat Transfer
14. Measurements, Instrumentation, and Controls
15. Mechanical Design and Analysis

Results

The target set by the MET faculty was that at least 70% of students pass the exam. This goal has not yet been met in any of the semesters, but the percent passed has been above the national average in most semesters. Also, in almost all semesters, the average ratio score was above the target of 1.00. It should be noted that the NCEES reports for recent years differ from the student reports provided by NCEES at the completion of the semester. The reason for these differences may be that when the students register for the FE they may incorrectly code that they are EAC ME program students rather than ETAC MET program students. Table 1 shows the FE exam results from 2013-2019.

Individual topics for the FE exam are recorded to provide a longitudinal look at student performance over time (see Figures 2 and 3). It should be noted that NCEES results do not provide a percentage of questions that were correct for each topic. The values represented in the graphs are the average ratio scores for each topic area. This is a ratio of the group of students from this institution taking the exam compared to all students from similar institutions, which in this case were ABET ETAC-accredited institution students taking the Mechanical FE.

Table 1. MET NCEES FE exam results (2013-2019).

Semester/instructor	Number students passed	Total students	Percentage of students passed	Average ratio score/target	Percent passed/ABET comparator (NCEES does not publish the passing score)
Fall 2013 (pilot)	2	3	67	NA	67/NA
Spring 2014 (pilot)	1	2	50	NA	50/NA
Fall 2014	3	11	27	1.03/1.00	27/32
Fall 2015	4	8	50	1.01/1.00	50/47
Spring 2016	6	15	40	1.04/1.00	40/40
Fall 2016	6	11	55	1.09/1.00	55/38
Spring 2017	4	15	27	.98/1.00	27/36
Fall 2017	4	11	36	1.05/1.00	36/27
Spring 2018	7	23	30	1.00/1.00	30/41
Fall 2018	13 (*14)	20 (*21)	65 (*67)	1.08/1.00	65 (*67)/38
Spring 2019	4 (*5)	13 (*14)	31 (*36)	1.01/1.00	31 (*36)/33
Fall 2019	7	14 (*16)	50 (*44)	1.01/1.00	50 (*44)/41
Totals: 2013-2019	61	136	45	NA	NA

* Indicates the number reported by NCEES to the students by the instructor of the course at the completion of the semester.

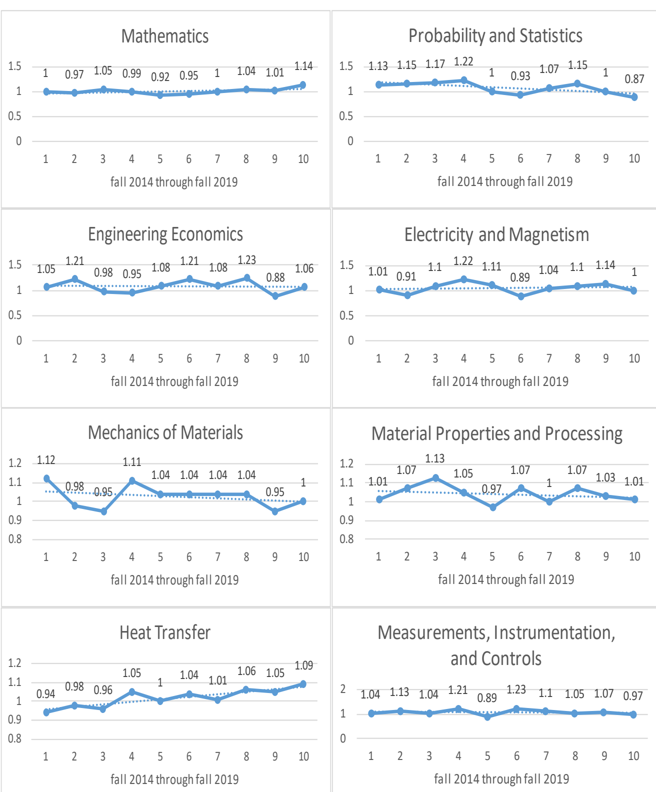

Figure 2. MET NCEES FE topics 1-8 (2014-2019).

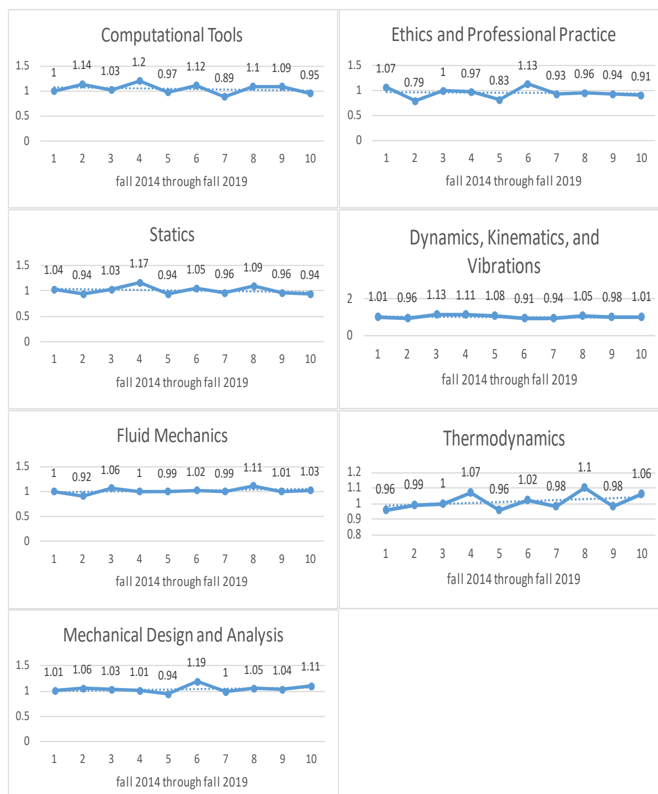

Figure 3. MET NCEES FE topics 9-15 (2014-2019).

Figure 4 shows the results of how well students are scoring on each subject of the NCEES FE exam. For the semesters from the fall of 2018 to the spring of 2020, the scores on the core engineering courses of Statics and Mechanics of Materials were lower than the other engineering courses taught in the department. As a result, it was decided to break up the single-semester combined Statics and Strength of Materials course into two separate semester-long courses. This change started in the fall 2020 semester.

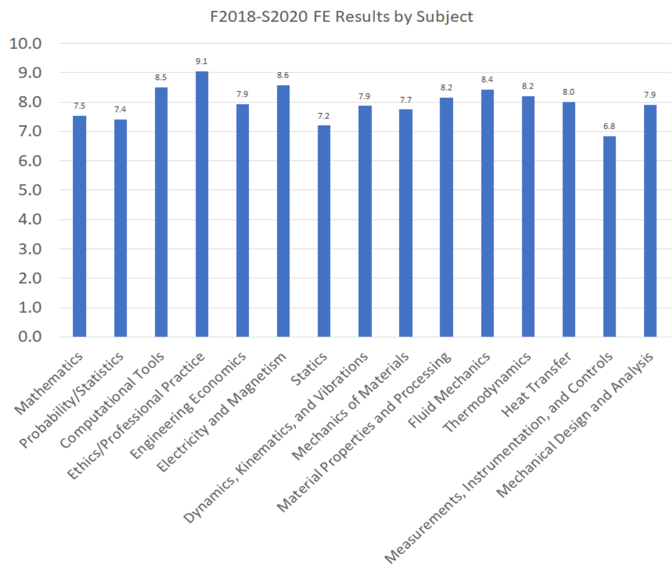

Figure 4. FE exam results by subject (F2018 through S2020).

Discussion

Various MET faculty taught the Professional Practice Seminar course until the fall of 2018, when an instructor with a PE license took over the course. Until the fall of 2018, a different instructor taught a different topic each week. Each instructor used a different teaching style for homework-vs-quizzes-vs-doing-example problems. Students were assigned practice problems from the FE Mechanical Review Manual that were reviewed on a given Friday in one 120-minute lab session. The following week, in a 50-minute class session, the material would be reviewed quickly, after which the students would take an online quiz, having to complete 10 questions in 30 minutes. Faculty members teaching the topics created the questions for the online quizzes that were saved in the course LMS system.

In the fall of 2018, since one instructor taught the entire course, the teaching method was the same throughout the entire semester. The 15 categories mentioned previously were reviewed during the course. Each week consisted of a 50-minute class early in the week, where the instructor and students did FE practice problems together. The students were given three minutes to solve each problem and then the instructor would solve the problem on the board. The problems were taken from the FE Mechanical Review Manual that the students were required to purchase along with the optional FE Review Manual. The students used an electronic copy of the FE Reference Handbook for reference material. Each Friday there was a 120-minute computer-based quiz administered using the University LMS containing FE-style problems worth 25% of the final grade. Again, the students were only allowed to use an electronic copy of the FE Reference Handbook for reference material. Each quiz included approximately 80 questions, which were intentionally more than the students could work in the time allowed. The scores for each quiz were then scaled to a total of 40 questions. This was done to encourage the students to first solve all of the questions they knew how to solve and that could be solved quickly. Then they were instructed to solve the other questions that they knew and that were going to take more time. Students were instructed to save enough time at the end of the class to go back and take educated guesses at the remaining problems. Table 1 shows that this method resulted in an improvement in numbers of students passing the FE. The pass rate jumped up to 67%, the highest pass percentage seen to date.

During the spring semester of 2019, the class was delivered completely online through PPI2Pass. The PPI2Pass website contains practice books, including the book students were required to purchase in previous semesters along with practice quizzes and practice exams. Students did online practice quizzes during the 50-minute class early in the week. In Friday classes, students did online quizzes, where the instructor was able to monitor the results online. The instructor was able to see the number of attempts taken for each quiz and the results of each attempt. These Friday quizzes accounted for 25% of the overall grade. Going online allowed the students to take practice quizzes that included solutions any day and time during the semester. The students overwhelmingly agreed that this was an advantage over purchasing the book(s). The negative was that the practice quizzes taken during the first class each week had randomly selected problems; thus, the students and instructor were not able to work problems together. The instructor would help students individually with questions they had. Table 1 shows that the pass rate dropped to 36%. It was thought that this drop could possibly be partly due to not doing practice problems together and/or not having graded quizzes that could only be done in class under instructor supervision.

Therefore, in the fall of 2019, the only change made to the class was to return to in-class graded quizzes using the University LMS during the Friday classes. This allowed the instructor to ensure that the students were doing the quizzes individually and with only the FE Reference Handbook. These quizzes also returned to the format where there were too many to solve in the time allotted. Table 1 also shows that the pass rate did increase to 44%. In the spring of 2019, the course started out with the same format that was used in the fall of 2019, until about half way through the semester, when the COVID-19 pandemic caused the class to go completely online. Students scheduled times for taking the FE exam were also moved out to June and July; a significant time lag after the end of the class. None of the results from this semester have been returned, but preliminary results suggest a pass rate under 30%.

Conclusions

The subjects in this study scored equal to or above the NCEES-reported ABET Comparator value for the majority (60%) of the ten semesters reported in this study. The methods used to teach the Professional Practice Seminar course during the semesters that the students scored highest on the FE were a significant contribution. There were additional factors to consider, such as student demographics, differences in course structure, and the circumstances around the timing of when the student took the exam. Some students took the exam prior to the end of the semester, due to exam-site availability and the students' schedules. With the limited data available, teaching this course with one instructor compared to being shared by several instructors resulted in some improvements. The recommendation was to hold weekly in-class quizzes using the University LMS, and a return to working out problems together in class. PPI2Pass will grant the instructor of a course the same access to the website as the students at no charge, as long as there is a sufficient number of students purchasing access to the website. Therefore, this could allow the class to go back to working problems together with the use of the instructor's computer and the projector.

The ability to do practice problems 24/7 on the PPI2Pass website makes this an easy choice for future semesters. Miller (2006) suggested another method, which is to use the FE Reference Handbook throughout the Professional Practice Seminar course as the only formula sheet. Koehn (1989) and Watson (1998) concluded that motivation of the student is a key factor in success rate on the FE exam. It should be noted that it is mandatory for MET students at Michigan Tech to take the exam rather than it being voluntary. The course requirement may motivate some students to perform well, but others may be intimidated by the pressure of a pass/fail course and not perform as well under that pressure. A final recommendation to consider is that 100% of the grade for a professional practice course should not be dependent on the FE exam score. Also, as ET graduates continue to pass the FE exam in high numbers, all states should allow ET graduates to be licensed as professional engineers.

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Assessment of the Highway Safety Manual's Empirical Bayes Method

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Abstract

The Highway Safety Manual (HSM), published by the American Association of State Highway and Transportation Officials (AASHTO), provides a comprehensive set of directions for managing and measuring safety (AASHTO, 2010). The expected average crash frequency, crash type, or crash severity for a freeway network can be predicted by using the HSM. The predictive method of the HSM enables us to determine the adjustment in accident recurrence or seriousness on a roadway, due to changes in traffic volume or roadway geometry. In this paper, the authors presents an overview of the predictive methodology of HSM, along with a discussion of its application to Interstate 84 from milepost (MP) 41 through MP 49 in Boise, Idaho. Because of crash reporting thresholds, weather, terrain, and animals, which may have a significant impact on crashes in various ways, the authors calibrated the result locally to account for local influences from these factors.

The use of Crash Modification Factors (CMF) to account for deviations from base conditions is also illustrated. Data from 2011 to 2018 were used to calculate the predicted average crash frequency and estimate the expected crash frequency for 2018, using the period 2016-2017 as the crash period and comparing it with the actual, observed crashes for 2018. The expected average crash frequency for fatal accidents in 2018 was 54.1 crashes/year, and the expected average crash frequency for property damage was 35.6 crashes/year. The actual, observed crash frequency was only 16 crashes/year in each category. This discrepancy is significant and it is recommended that the HSM recommendation of allowing a minimum of two years as the crash period be amended. The authors also highlight here the potential difficulties that highway agencies may face when using the HSM, with the hope that all agencies in the U.S. may benefit from this current study as they develop safety management systems for their jurisdictions.

Introduction

In July of 2010, The American Association of State Highway Transportation Officials (AASHTO) published its first edition of the highway safety manual (HSM) as a result of extensive road safety research conducted over the past few decades (AASHTO, 2010). The National Cooperative Highway Research Program of the United States of America sponsored seven independent research projects to develop different parts and chapters of this manual. All of the research projects were conducted between 1999 and 2007. The Transportation Research Board Joint Task Force for the Development of the Highway Safety Manual (ANB25T) guided the projects. In 2014, the supplement to the first edition of the HSM was published. The supplement provides safety performance functions (SPFs) for freeway and ramp facilities (AASHTO, 2014). This supplementary edition includes two new chapters that describe predictive methods for estimating the expected average crash frequency, crash type, or crash severity for freeways and ramps. The third chapter of this edition, Appendix B, describes two special procedures, Calibration of Predictive Models and the Empirical Bayes (EB) method, to be used with the predictive methods of the first two chapters. The EB method helps to combine observed crash frequencies with the estimates provided by the predictive methods.

The aim of the HSM is to be a definitive, science-based guidebook that provides quantitative methods for performing safety evaluations. It provides an opportunity to consider safety quantitatively along with other transportation measures. There are four major parts in the HSM.

<u>Part A: Introduction, Human Factors, and Fundamentals</u>
In this part, a description of the purpose and scope of the HSM is presented, which explains the relationship of the HSM to planning, design, operations, and maintenance activities. This part also includes the fundamentals of the processes and tools described in the HSM.

<u>Part B: Roadway System Management Process</u>
Presented here are suggestions for steps to monitor and reduce crash frequency and severity on existing roadway networks. It has six chapters that can be used to reduce crash frequency and severity for an existing network. It also includes methods that are useful and effective for overall safety improvement.

<u>Part C: Predictive Method</u>
A predictive method for estimating the expected average crash frequency on a network, facility, or individual site, based on different factors, is given here in Part C. It also introduces the concept of safety performance functions (SPFs).

<u>Part D: Crash Modification Factors</u>
Here, treatments and, where applicable, the associated crash modification factors (CMF) for roadway segments, intersections, interchanges, individual facilities, and road networks are described. CMFs help to find the change in expected average crash frequency as a result of geometric or operational modifications to a site that differs from base conditions.

After estimating the expected crash frequency, based on the methodology described in Part C of the manual, the CMFs, described in Part D, will need to be developed. A prior study found that the variation in the safety effects of the treatment over time cannot be represented by a single CMF (Sacchi & Sayed, 2014). Crash modification factors are available for various factors such as horizontal curves, lane-change maneuvers, non-standard median width, and shoulder rumble strips. They all can have a significant impact on the prediction. For example, Elvik, Hoye, Vaa, and Sorensen (2009) found that the safety effectiveness of horizontal curves varies with the lengths of their radii.

In another study, Turner, Affum, Tzoitis, and Jurewicz (2009) found that shoulder rumble strips reduce injury crashes by roughly 23%. Gross and Jovanis (2007) estimated the safety effects of shoulder width, using case-control and cohort methods. Both methods showed that crashes decrease as shoulder width increases. Moreover, according to Pitale, Shankwitz, Preston, and Barry (2009), the safety effects of paving shoulders, widening paved shoulders (from two to four feet), and installing shoulder rumble strips on rural, two-lane roadways accounted for 16%, 7%, and 15% reductions in crash rates, respectively. Kononov, Bailey, and Allery (2008) found that there was a lack of prior studies about the safety effects of the number of lanes on urban freeways.

Four-lane divided roadways were safer than two-lane roadways, as evidenced by a 40-60 percent reduction in total crashes in California, Michigan, North Carolina, and Washington State (Council & Stewart, 1999). Fitzpatrick, Schneider, and Park Sug (2005) also found that four-lane divided roadways in Texas showed better safety performance when the average daily traffic (ADT) was higher than 10,000. On the other hand, Abdel-Aty and Radwan (2000) found that the crash rate increased as the number of lanes on urban roadways increased.

This review of the literature revealed that many factors need to be considered for safety analysis, and that a proper calculation of the calibration factors is needed. To improve the estimation of expected crash frequency, the development of calibration functions was explored in recent studies to improve local calibration (Claros, Sun, & Edara, 2018; Farid, Abdel-Aty, & Lee, 2018; Hauer, 2015; Srinivasan, Colety, & Bahar, 2016). The latest comprehensive study on HSM freeway and ramp calibration, using Maryland crash data, was done between 2008 and 2010 (Shin, Lee, & Dadvar, 2016). The results of that study indicated that the HSM methodology over predicted both fatal and injury crashes as well as property damage-only (PDO) crashes for all freeway and ramp facilities. Avoiding the site selection bias is also important. To avoid this issue, the site should be selected randomly, after which the crashes should be determined. The study time period is also important; in order to limit the influence of the time period, the analysis should extend over several years (e.g., 5-7 years).

From this current study, the authors provide an overview of the predictive methodology of HSM with a discussion of its application to a segment of Interstate 84 in Boise, Idaho. The predicted crash frequency was estimated and compared with the observed crash frequency. The results were calibrated locally to get the most appropriate results. The expected crash frequency was also calculated by using the project-level Empirical Bayes (EB) method. The data were analyzed based on different factors, such as severity type, lighting conditions, and weather conditions. A brief description of lessons learned is also provided for the benefit of the staff at highway agencies that plan to use the HSM methods in their jurisdictions.

Site Selection

The goal of this current study was to work with a suitable site located in the state of Idaho. To avoid site selection bias, the site was selected randomly and then the crash data were collected. A segment of Interstate 84 on the western edge of the city of Boise was found to be a good fit for the study. The section of the freeway used was from MP 41 to MP 49. This segment is used to enter Boise city in the morning by people coming from the western part of Boise Valley. In the afternoon, the peak flow direction is reversed. This segment has a relatively high traffic volume; thus, a high crash rate was expected on this segment. Figure 1 shows the freeway segment with the locations of crashes.

Data Collection

In order to minimize the influence of the study period on the crash data analyses, and to minimize the impact of short-term fluctuations that are possible over a short study period, the authors extended the study to eight years. The annual average daily traffic (AADT) data for the 2011-2018 period were downloaded from an Idaho Transportation Department (ITD) website. Data for the freeway segment as well as the ramps were available. The percentage of the AADT volume during high-volume hours throughout the study period for different segments was calculated. The AADT data were available from 1999 to the time of this study.

Crash data within this study area from 2011 to 2018 were collected from another ITD application named "Webcars" (*Crash Analysis Reporting System - WEBCARS*). The segment code, desired milepost range, year range, counties, and severity type were entered on Webcars to get the reports. The reports were saved in *Excel* files for the analysis. These reports had most of the necessary information, such as crash date, severity, location by mileposts, date, and time. Data related to road infrastructure, such as the number of lanes, lane width, median width, presence of rumble strips, and clear zone width, were also needed. Most of these data were collected using Google Maps, with the remaining data coming from ITD.

Figure 1. Study area—Segment of I-84 in Boise, Idaho.

Analysis

The focus of all analyses was on freeway segments. Freeways have full access control and grade separation at all intersecting roadways. The study area can be classified as an urban area. As indicated by the Federal Highway Administration (FHWA), areas with populations greater than 5000 persons and inside municipal boundaries are classified as urban areas. The study segment was divided into four sections. Such divisions can be done based on different factors, such as the number of lanes, lane width, outside shoulder width, inside shoulder width, median width, ramp presence, clear zone width, and so on. The presence of ramps was used as the basis for the division. Mileposts corresponding to the four segments, Segment 1, Segment 2, Segment 3, and Segment 4 were 41-41.63, 41.63-44.76, 43.67-45.43, and 45.43-49, respectively.

The expected average crash frequency for the freeway facility was estimated by applying the predictive method of the HSM. The crash frequency can be defined by total number of crashes, crash type, or by severity. The predictive method was completed in stages. The analyses started by characterizing the data as much as possible. These included characterizing the data according to the crash severity and location. The area of investigation was determined as explained earlier. The period of interest had to be determined next. All AADT values for the freeway segments and ramps (in both directions—increasing and decreasing mileposts) were collected. The observed crash data, essential for the Empirical Bayes (EB) method, were also collected.

The next step was to determine the geometric design of the road. This included the number of lanes, lane width, presence of streetlights, and shoulder width features. Appropriate safety performance functions (SPFs) from the HSM were then used to estimate the predicted average crash frequency for the site. The percentage of AADT occurring during high-volume hours for different sections in the different study periods had to be estimated. The freeway segments had eight lanes. By using the segment length, segment AADT volume, and appropriate values for the SPF coefficients as specified in the HSM, SPFs for multiple vehicles and single vehicles were calculated. Fatal and injury crashes, and property damage-only crashes were found for both multiple vehicles and single vehicles. The estimated SPFs were:

1. Multiple vehicles with fatal and injury crashes
2. Multiple vehicles with property damage-only crashes
3. Single vehicles with fatal and injury crashes
4. Single vehicles with property damage-only crashes

The next step was to work with crash-modification factors (CMFs). The CMFs applicable to the SPFs estimated previously were calculated. Several CMFs included a variable defining the proportion of the segment's length along with some features such as horizontal curve, rumble strip, and median barrier. All applicable CMFs were applied to estimate multiple-vehicle and single-vehicle crashes for fatalities, injuries, and property damage only. The next step was to estimate the calibration factor based on local conditions. A calibration factor represents the ratio of the total number of observed crashes for selected sites to the total number of predicted crashes for the same sites within the study period using the applicable predictive model. If there were fewer observed crashes than predicted by the predictive model, then the computed calibration factor would be less than 1.00. The local calibration factor for the study area was calculated after which the project-level EB method was applied. Application of the EB method produced a more statistically reliable estimate of the project's expected average crash frequency. The EB method is described in detail in the Appendix of the 2014 Supplement of the HSM (AASHTO, 2014).

There are two options of the EB method available: site-specific or project-level. The project-level EB method was used in this current study. There are six steps required for estimating the expected average crash frequency for a future time period. The authors selected 2018 as the future time period for which an estimate of the expected average crash frequency was desired. To do this, the selection of a crash period was needed. The crash period needed to be at least two years for which observed crash data were available. In this study, the period 2016-2017 was selected as the crash period. The study period consisted of the consecutive years for which an estimate of the expected average crash frequency was desired. As noted, 2018 was selected as the study period for which an estimate of the expected average crash frequency was desired. The details of the six steps are not included here. The sixth step is where the expected average crash frequency for the study period is calculated using Equation 1:

$$N_{\text{expected,2018}} = N_{\text{expected,2016}} \times \frac{N_{\text{predicted,2018}}}{N_{\text{predicted,2016}}} \quad (1)$$

Equation 1 was used to estimate the expected crash frequency for both fatal-and-injury and property-damage-only crashes. The estimates were then compared with the observed crash frequency for that year. The findings from this analysis are presented in the Results section later in the paper. Other variable values found were the number of crashes each year, the percentage of crashes by severity type, and miscellaneous factors such as lighting conditions, road surface conditions, and weather conditions. The crashes by month and time of the day were also analyzed.

Results

The predicted average crash frequency for fatal-injury crashes and property-damage crashes for the different segments within the study area were calculated. Using the available data on the number of observed crashes for the same time period, the calibration factors for the two crash types were:

- Calibration factor for fatal-and-injury crashes: 0.96
- Calibration factor for property damage crashes: 0.27

In both cases, the calibration factor was less than 1.0. Thus, the predictive analysis used in this study over-predicted crashes, especially property-damage crashes. These calibration factors were used to compute the final predicted average crash frequencies for fatal-and-injury and property-damage crashes. Table 1 shows the total number of fatal-and-injury and property-damage crashes predicted in this study area for the study period noted.

Table 1. Calculated and observed crashes for the study period.

Year	Predicted Crashes		Observed Crashes	
	Fatal-and-Injury	Property Damage	Fatal-and-Injury	Property Damage
2011	37	25	20	53
2012	41	27	32	50
2013	42	29	40	56
2014	42	29	71	19
2015	42	28	67	18
2016	48	34	66	25
2017	51	37	46	14
2018	54	39	16	16

The expected average crash frequencies for 2018, using the project level EB method described earlier, were:

- Fatal-and-injury crashes = 54.1 crashes/year
- Property-damage crashes = 35.6 crashes/year

It can be seen that the expected crashes for fatal-and-injury and property-damage for 2018 were similar to the predicted crashes for 2018. However, the observed crashes were much lower than the predicted crashes. Even though the calibration factor for fatal crashes was 0.96, which is close to 1, for any given year, the predicted or the expected crashes can differ significantly from the observed. Another interesting observation was that the predicted and expected crash frequencies for property-damage crashes for 2018 were closer to the observed frequencies in 2018, when compared to fatal-and-injury crashes, despite the fact that the calibration factor for this severity type was 0.27, which was significantly lower than the factor of 0.96 obtained for fatal-and-injury crashes.

Another observation was that, from 2014, the observed crashes were consistently lower than the predicted crashes for property-damage accidents. But for fatal-and-injury accidents, such a consistent pattern was not observed; the observed crashes were lower than the predicted crashes in 2011, 2012, 2017, and 2018 only. There might be many reasons behind this difference, such as the improvement of awareness of drivers. Also, some local factors such as weather, terrains, and many others might be responsible for this discrepancy. Figure 2 shows a plot of the number of total observed crashes by year. In 2013, there were 96 crashes in this corridor, which was the highest within this study period. The number of crashes decreased after that for two more years before increasing again in 2016 to 91 crashes. Then there was a drastic decrease until 2018, the last year of the analysis period. Overall, there was a decreasing trend in the total number of crashes per year on this corridor.

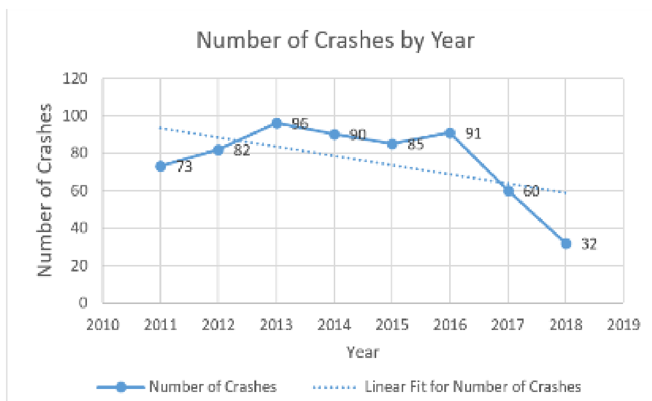


Figure 2. Number of observed crashes by year.

Fatal crashes are defined as crashes in which there is at least one fatality. A-injury crashes are crashes in which the highest level of injury is an incapacitating injury. If the highest level of injury in non-incapacitating, though still visible, then the crash should be labeled a B-injury crash. Any crash reported or claimed in which the highest injury does not fall under the categories of momentary unconsciousness, limping, complaint of pain, nausea, hysteria, and/or claim of injuries are labeled as C-injury crash. Figure

3 presents the percentage of crashes by severity type over the study period. Only 1% of the crashes within this period were fatal. The highest rate of the crashes (46%) was property damage-only crashes.

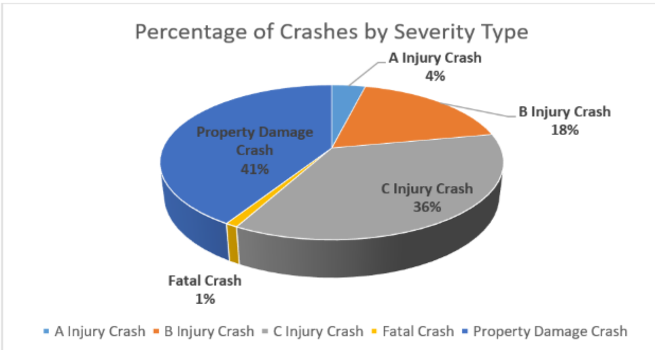


Figure 3. Percentage of crashes by severity type.

Figures 4 and 5 show fatal crashes and A-injury crashes for different years that occurred in the study area. The symbols "A" and "D" in the legend of these figures denote "Ascending" and "Descending" mileposts, respectively. Figure 6 represents the distribution of crashes by weather conditions, road surface conditions, lighting conditions, month, and time of day when the crashes occurred. This study revealed that it is important to calibrate the predicted crash frequency based on the observed crashes. It was found that the calibration factor for property-damage crashes was much more significant than the calibration factor for fatal-and-injury accidents. The expected number of fatal-and-injury crashes was 54.1 crashes/year and 35.6 crashes/year for property-damage crashes for 2018 using the EB method. These numbers are close to the predicted crashes of 2018, which were 53.5 and 39.2 crashes/year for fatal-and-injury and property-damage crashes, respectively. The actual, observed crashes in the two categories were, however, much lower at 16 crashes/year in each category.

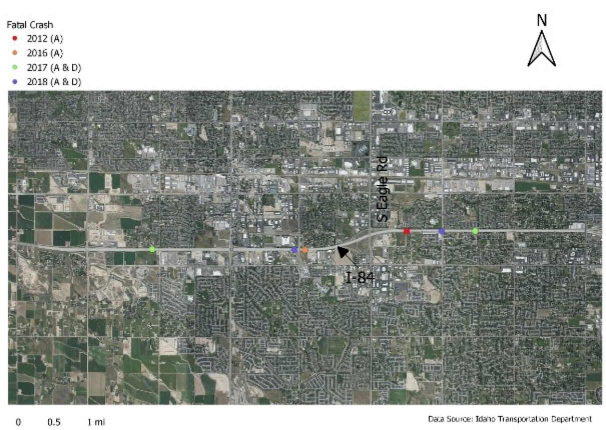


Figure 4. Fatal crashes in the study area.

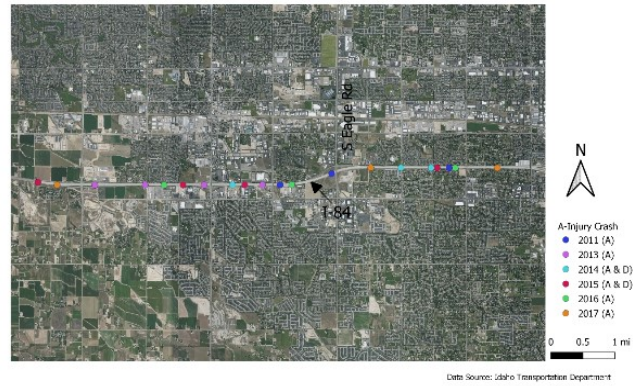
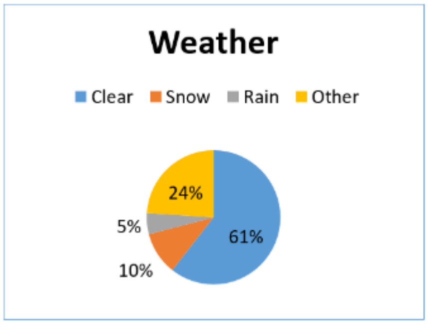


Figure 5. A-injury crashes in the study area.

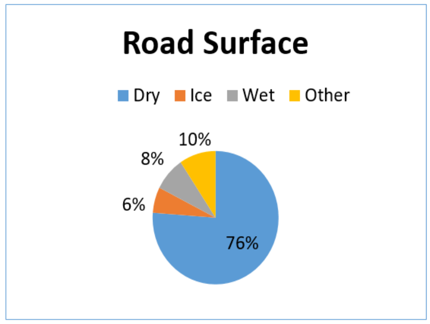
Based on the discrepancy between expected and observed crash frequencies described above, it can be concluded that the HSM method is not a reliable tool for forecasting expected crashes. No obvious reasons for the discrepancy were found, except perhaps the short crash period of two years that was used in the analysis. According to the 2014 HSM supplement (AASHTO, 2014), a period of two years can be used as the crash period. It appears that this recommendation needs to be changed. Looking at the fluctuation in crash frequencies for the period 2011 to 2018 (see again Table 1), using only two years does not appear to be a satisfactory length of time. Had a longer crash period been used, say from 2011 to 2017, an expected crash frequency estimate for 2018 that was closer to the observed value would have perhaps been obtained. This is a topic that needs further research.

The road characteristic data developed for calibration can be preserved, and calibration factors can be updated for future years, such as future observed crashes and future AADT values. The additional effort needed to do this will be lower if the base work, as explained in this paper, is completed beforehand. The distribution of crashes revealed that most of the crashes occurred on dry road surface conditions, clear weather conditions, and during daylight hours. Also, crash frequency was higher in the morning rush hours in this study area. Figure 4 shows the locations of the six fatal crashes that occurred in the study period. Four of the six crashes were found to have occurred in the ascending MP direction. Most of the crashes occurred on Thursday, Friday, or Saturday. Figure 5 shows the A-injury crash locations. There were a total of 23 A-injury crashes in the study period. Only two of these occurred in the descending MP direction. Most of the severe crashes occurred in the ascending MP direction.

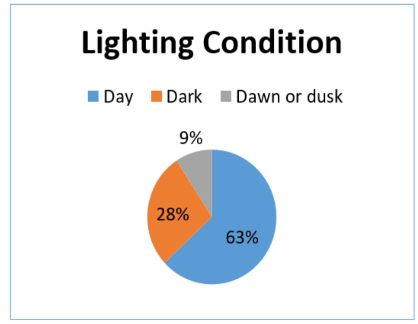
Figure 6(d) shows that a higher number of crashes occurred in August (72), December (68), and January (63). More crashes are expected in winter months, and the data



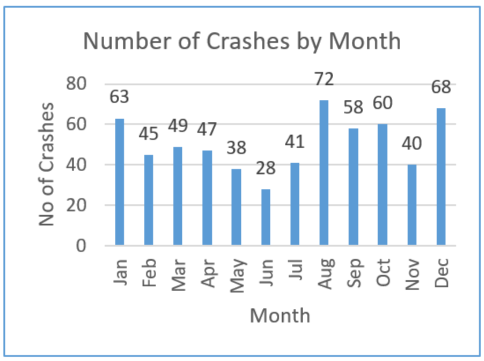
(a) Percentage of crashes by weather.



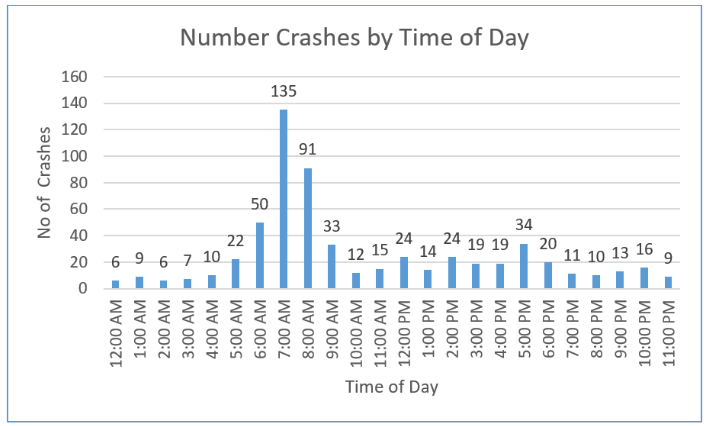
(b) Percentage of crashes by road surface.



(c) Percentage of crashes by lighting.



(d) Number of crashes by month.



(e) Number of crashes by time of day.

Figure 6. Crash distribution by various factors.

that were collected for this study displayed a similar trend. It is not clear why there were so many crashes in August. This is a topic that needs further research. Fewer crashes occurred between May and July. So, there were fewer crashes in the summer time. Also, Figure 6(e) shows that most of the crashes (37.1%) occurred between 7:00 and 9:00am, which is the peak travel time. Seventy-six percent of the crashes occurred when the road surface was dry. Sixty-one percent of the crashes occurred under clear weather conditions. Sixty-three percent of the crashes occurred during daylight hours.

Conclusions

The primary benefit from the analysis presented in this paper is a better understanding of the expected crash frequency on this segment of I-84. This study also helped to identify the priority locations with high crashes. As motor vehicle crashes are one of the primary reasons for deaths in the U.S., safety improvements for roadways are vital for improving current conditions. Studies like the one presented in this paper will help transportation agency personnel to implement low-cost safety improvements and foresee possible future impacts of improved roadway design. Although the adaptation of the HSM calibration method is a straightforward procedure, the analyst has to be careful when selecting appropriate calibration factors, as some data were not available. Also, the results of the estimated crash-modification functions indicated that the CMFs vary across the segments with different roadway characteristics. For the years of 2018 and 2017, the total predicted crashes were found to be much higher than the observed crashes. But before that, total predicted crashes were lower than the observed crashes. There was no information about any special measures that may have been taken after 2016. This possibility should be investigated further, as any special measure can reduce the number of crashes.

A major conclusion from this work is that the HSM recommendation of allowing a minimum of two years for a selected crash period should be amended. The research presented in this paper shows that using only two years for the crash period resulted in an estimate of the expected crash frequency for a future year that was not close to the observed crash frequency. Further research is needed to determine the minimum number of years required for the crash period.

Limitations

The predictive method described here does not account for the influence of urban freeways with 11 or more lanes, rural freeways with nine or more lanes, high-occupancy-vehicle (HOV) lanes, ramp metering, toll plazas, and reversible lanes. Nor does this strategy check contrast between barrier types, such as cable barriers, guardrails, or bridge rails. In this analysis, these limitations were not present. Proper data for horizontal curves were not available for the study area. Hence, the CMFs for the horizontal curve could not be computed. Calibration factors for local accidents were found; and driving behavior was one of the factors behind using this factor. However, there was no information about the number of accidents that could be attributed to people living outside the state. Such information will be needed to find differences in crash rates between local and outside drivers. The percentage of AADT data that occur during peak hours was calculated manually; this may have caused minor errors. Also, The CMFs provided in Part D of the HSM were primarily based on empirical studies conducted in the U.S.; these analyses would be more appropriate for U.S. driver behavior and roadways. To apply these methods outside the U.S., further exploration is needed. Also, collision types of different crashes were missing in the raw datasets. If these data were available, then more research could have been done based on the crash types.

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Prevalent Technical Leadership Styles and Impact on Early Engineering Careers

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Abstract

In this study, the authors explored prevalent leadership styles found in industry from an engineering student's internship experiences. Over the course of four years of internships, observations and interview responses were recorded to address three questions: What is the dominant industrial leadership style? What is the dominant leadership style in the broader engineering sector? What is the dominant leadership style entry-level engineers should know in order to be successful? Reflections on personal experiences within the engineering industry suggest an ideal leadership style that can be utilized by an entry-level engineer or a similar technical individual. Previous research on leadership and success formed a basis for claims as to which techniques of leadership can lead to success for an entry-level engineer. Further, this study builds upon prior research on the correlations between leadership skills taught in college and the resulting success beyond the classroom. Leadership styles are ranked in order of their utilization in industry with a corresponding value for entry-level engineers. They are: pacesetting, authoritative, democratic, coaching, and delegating. From the study, the authors concluded by suggesting that there is a correlation between knowledge in leadership for both subjective and objective success of entry-level engineers. Ideally, every engineer should be taught a multitude of techniques, and recommendations are that engineers should strive to learn many leadership styles, whether they intend to hold a position of leadership or not.

Introduction

Leadership is a skill that may be intuitive, learned experientially through the trials and tribulations of life, or learned through academic training (Allen, Jenkins, & Schwartz, 2017). Many novice engineers aspire to be leaders such as Elon Musk and Bill Gates, who are constantly at the center of attention. This trend is particularly obvious within engineering, as successful leaders are continuously innovating and pushing the limits of what they and their teams can accomplish (Gordon, 2011). Researchers search for the commonalities that might explain how the success of these innovators created such great results (Eby, Butts, & Lockwood, 2003). In this study, the authors used a simple strategy to learn about leadership directly from technical leaders, who were observed and analyzed for their leadership styles and routines. Learning from the leaders of today is needed now more than ever during this current critical shortage of technical leaders (Gordon, 2012; Gordon & Silevitch, 2009; Holdren & Lander, 2012; Malcolm & Webster, 2014).

Further research into the current state of engineering leadership within industry could produce many examples that would aid in exploring the lack of leadership training engineers undergo during their undergraduate studies (Gordon, 2012). For it is in this area of leadership and soft skills development that "the industry believes our educational system is lacking" (Knight, 2012). Companies create job descriptions when looking for entry-level hires that require different leadership traits (Hartmann, Stephens, & Jahren, 2017) and, as many studies point out, these "companies still struggle to find applicants with these clearly defined traits" (Hartmann & Jahren, 2015). Additionally, Hartmann and Jahren (2015) call for further research to resolve this dilemma and suggest that more partnerships and interventions are needed.

Research Design

In this current study, the authors used a qualitative research design to gather and analyze data about leadership styles at three companies. More specifically, they sought to understand the dominant leadership styles that entry-level engineers might expect to encounter at the start of their careers. As a recent graduate of mechanical engineering, the principal author had a unique vantage point during internships over four years to observe, ask questions, and interpret information gathered in order to address the research question regarding leadership styles in engineering. The opportunity to learn about leadership on the job from coworkers and from those who understand and practice leadership is a crucial opportunity. Newly employed engineers strive to combine and reconcile such experiences with the training received as engineering students. Novice engineers look to answer this same question about leadership and endeavor to progress through the professional challenges in their careers.

Two qualitative data collection strategies were utilized in this study. First, the authors observed three leaders at each of the three companies, while serving as a temporary employee or an intern. These observations were recorded in a notebook and later analyzed to determine the leadership style. The observational data were coded for leadership characteristics and divided into common themes and categorized by dominant leadership style. The data were also peer (parallel) analyzed using an independent constant comparative analysis strategy (Fram, 2013; Glaser & Strauss, 1967; Lincoln & Guba, 1985; Maykut & Morehouse, 1994), and the results were integrated to determine the leadership style exhibited.

Secondly, all nine leaders were questioned separately about their leadership backgrounds, experiences, and perspectives using a semi-structured interview protocol with open-ended questions and discussion (Creswell, 2007; Kvale & Brinkmann, 2008). Their responses were recorded and transcribed for coding and thematic analysis. As was done for the observation data, a comparative analysis approach was used to compare and verify the results and to determine the dominant leadership style (Kolb, 2012; Maykut & Morehouse, 1994). The outcomes provided insight into common leadership styles and characteristics that these leaders frequently employed to lead extremely successful organizations. Next, a case-by-case discussion of leadership styles and project results is presented. Individuals and company names have been replaced with pseudonyms and fictitious labels to ensure confidentiality.

Leadership Styles Defined

This study used the six styles of leadership developed by the Collegiate Leadership Competition (CLC) (Allen et al., 2017), which are listed below (in no order of importance):

1. Authoritative style is defined as leading with a clear description for the path ahead or all the knowledge needed to succeed.
2. Coaching style, also known as teach and coach, describes the process leaders use to pass knowledge and information on to their teams. Although time consuming, this builds the team for the long run and can produce future leaders.
3. Coercive style, also known as the yell, tell, and hard sell style, takes place when a leader pushes their group hard to do the task their way, ensuring the group complies.
4. Democratic style involves the leader seeking wisdom and knowledge from the group and using this input to build ownership moving forward.
5. Pacesetting style, commonly known as energize and push, is highly defined by time constraints or defined results. The leader may need to "raise the heat" as they push their teams to work to the next level.
6. Delegating style, implies giving each member of the team a set of tasks. This is great for allowing team members to do tasks in their own manner and accomplish more in less time.

Results from Observations and Interviews

Through shadowing and interviewing leaders in industry, the authors followed a systematic process of qualitative data collection and analysis as described earlier. Both observational and interview data were documented and categorized into one of the respective leadership styles referenced above. These results are summarized below to provide accounts from the leaders with whom the authors interacted at each company.

Company 1

Located in the southeastern U.S., this company is one of the largest manufacturing facilities in the world. Company 1 produces beverages for almost half of the U.S. Throughout a six-month internship, the authors learned what it takes to run the facility and what their leaders do to enable the company to remain successful.

Person A: The Assistant Facility Manager at Company 1 was an extreme leader, who utilized the coercive style or "yell, tell, and the hard sell" style (Allen et al., 2017). His employees were constantly in fear in his presence and some were frustrated. This form of extreme leadership worked well within the union environment. However, it was quite overwhelming for many of the other non-union managers under Person A. All employees wanted a sense of accomplishment, but this was almost impossible when they always felt as though they were in a losing battle.

Person B: The General Manager (GM) at Company 1 had a pacesetting style (Allen et al., 2017) and was often the one to bring all the energy into the room. Most GMs choose to share their visions; he, instead, went beyond this by providing new information and timelines to constantly keep pushing the team. The company, currently one of the top beverage manufacturers in the world, had one goal, which was to stay on top. As such, it was everyone's responsibility to keep that up. This led to a very fast-paced and exciting day-to-day work environment.

Person C: The lead chemist and director of the internship program always relied on coaching and pacesetting. He was aware that Company 1 needed to reduce the number of managers and understood that hours of teaching and training were required to help employees become more self-sufficient. He developed a coaching strategy to accomplish this task. However, he was also strong on the pacesetting style. For example, when the team was having a long week, he would simply reward employees with things like luncheons or leaving early on a Friday, if possible. When employees only needed more energy, he would quickly shoot out a message congratulating them on how close they were to completing a task or what a great job they had done.

Company 2

This corporation is a mechanical contractor located in the Midwestern U.S. This company is a mid-sized firm that other larger companies hired in order to expand and improve their existing technical capabilities. The leadership styles utilized at Company 2 included the following.

Person D: The Vice President for the firm relied on two styles of leadership: coaching and pacesetting. He was highly involved with training. The coaching part of leadership stood out when he took trainees around the workplace, showing them how things ran day-to-day. Perhaps most importantly, Person D took time to explain the why behind the way tasks were to be completed. As the team learned more, he listened to their questions and quickly used this engagement to move them into the activities that allowed them to further their learning. Person D was fond of engagement and was always waiting to reward excellent work. Consequently, when work was subpar or behind, he sometimes postponed this reward. If motivation was needed, he rewarded the team before the completion of their tasks. This early reward often gave the extra push needed to finish the job on time. Pacesetting was ever-present, as all contracts had deadlines and budgetary requirements associated with meeting key dates.

Person E: The Senior Project Manager utilized the delegating and pacesetting styles. (Allen et al., 2017). He performed the role of interacting with the team the entire day and seeing that the day-to-day tasks were completed. It was his job ensure that the crew had all the tools required to do the job. He made sure the best team members were assigned to each job to enhance overall efficiency. He was responsible for delegating tasks and, consequently, he was very good at conveying why these tasks were important or why such deadlines were necessary. Rather than simply dictate to employees what to do, he communicated how it needed to be done and what the end reward was, thus he used the pacesetting style (Allen et al., 2017) to get each team member back on pace and working toward a common goal.

Person F: The Safety Manager on site at Company 2 performed her job by employing the coaching style. Through mandatory safety talks, walks, demonstrations, and luncheons, she was able to demonstrate the coaching style well. Her job became easier and easier the more she taught each employee. As people became more educated on keeping themselves safe, they required less formal teaching. She then relied on simple refreshers to maintain safety standards, and the result was increased awareness and safety. The coaching leadership style used by Person F was both in and out of the classroom. She demonstrated efficiency by training people to do tasks correctly in the classroom first rather than having to always learn by experience in the workplace. This effective strategy should be promoted more in today's engineering classrooms and within industry, as young engineers enter the workforce.

Company 3

This up-and-coming architectural firm in the Midwestern U.S. was created through a partnership of friends in a field that uses many kinds of engineering. At the beginning of this research study, the firm had just opened and was beginning to experience the growing pains of a new company, when they decided to bring on their first intern. This resulted in a firsthand experience of how a small business struggles to get off the ground and what style of leadership it takes to do so successfully. The accounts of three leaders at this company are documented as follows.

Person G: The owner of the firm made the entire staff feel like family through the use of the democratic and pacesetting leadership styles. This family atmosphere and use of the democratic style was an extremely effective way to run the firm. He also knew how to have fun and energize this family environment. The pacesetting style (Allen et al., 2017) was also one of Person G's fortes. If things started to feel stagnant, he simply dressed up the workplace or took employees on a site visit. These small changes allowed the team to push themselves to be much more effective.

Person H: Person G's assistant, and one of the firm's best architects, saw the value each employee could add to the team and took the time each day to utilize the coaching style in combination with the delegating style (Allen et al., 2017). Without her style of leadership, many employees never would have known what they were doing in the architectural world. Person H was great at delegating and she would send employees on site visits to bring back information about the project site. Many employees learned the most while on their own, which illustrated the importance of delegating. This strategy empowered coworkers to work independently and forced them to figure out how to complete the given task. The delegating style was very effective for both the employees and the firm.

Person I: An architect hired by the firm often used the democratic and authoritative styles (Allen et al., 2017) to assist in working with the client. This is how the firm avoided conflicts by having him listen to the clients' issues and assisting in finding solutions. As the old saying goes, "the customer is always right," and this was Person I's viewpoint with his clients. After listening to the clients' wants and needs, he would go even further using problem-solving. If their ideas did not coincide with the proposed project design, he would convincingly communicate the reasoning behind the design, and that was when he employed the authoritative leadership technique. He never shut them down completely, but instead communicated effectively where these somewhat simple edits would result in significant and beneficial changes to the project in the end.

Quantified Results

The authors of this current study examined leadership styles from the point of view of a leader within a company as well as that of the company as a whole. In the graphs and tables to follow, all of the qualitative data discussed above was filtered for leadership characteristics and arranged into common themes and divided by dominant leadership styles. Figure 1 summarizes the study results and reveals which leadership styles were observed. The data from the nine leaders indicated that 33% of these leaders utilized the pacesetting style, 27% used the coaching style, 13% used a democratic or delegating style, and only 7% made use of authoritative or coercive leadership styles. It is perhaps no surprise that pacesetting (33%) was the most-utilized style of leadership, followed closely by coaching leadership at 27%. Due to the fast-paced and straightforward nature of the engineering environment, these are effective leadership styles for the novice engineer to effectively detail and implement a plan of action in a timely manner.

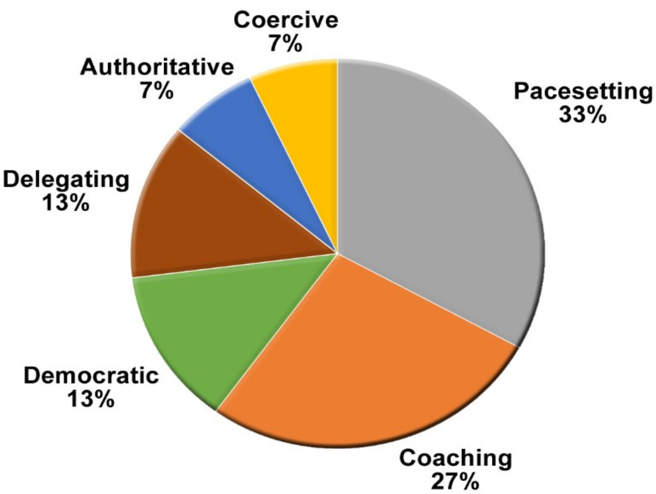

Figure 1. Leadership styles observed in nine leaders from three companies.

Table 1 summarizes the leadership styles evident in the results of this study. Considering the above definition of career success, the leadership styles are ranked as to how useful they are in the engineering industry. From Table 1, each leader seems to prefer a different style; and, within most well-run companies, a variety of leadership styles seem more effective and appealing to increasingly diverse teams and employees. These leaders successfully applied different leadership styles for different tasks and situations (i.e., situational leadership), or according to their own preference. Table 1 documents this along with the overall company leadership style observed to be used most frequently.

Table 1. Leadership styles usage.

Company	Leader	Style Utilized
1	A	Coercive
	B	Pacesetting
	C	Coaching & Pacesetting
2	D	Coaching & Pacesetting
	E	Delegating & Pacesetting
	F	Coaching
3	G	Democratic & Pacesetting
	H	Coaching & Delegating
	I	Democratic & Authoritative

Data used in Table 1 was reconfigured in Figure 2 in order to show how many styles were observed per company for each of the nine leaders. Each set of three leaders was pooled to display how many leadership styles were exhibited cumulatively for each company. Results displayed in Table 1 and Figure 2 show that even among a sample of only three leaders per company, there were many different styles used. On average, there was one or two leadership styles per leader, which benefits the company and its employees alike. Additionally, leadership across companies varied. Figure 2 also shows that Company 2 and Company 3 had a diverse number of styles among their three leaders. However, the leaders in Company 3 exhibited the most leadership diversity with five different styles used and six leadership styles cumulatively across the three employees.

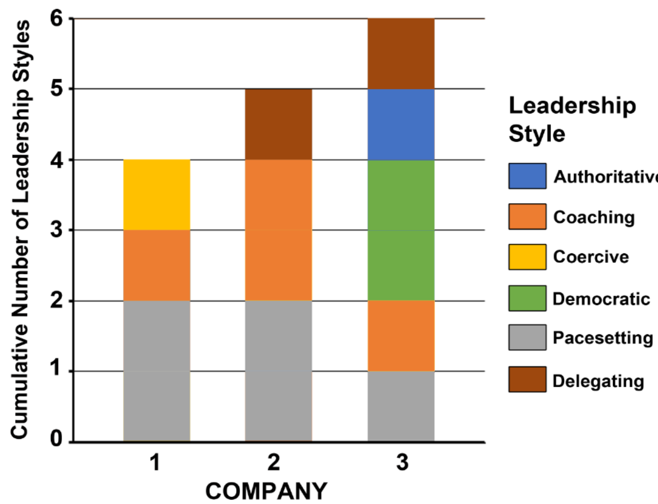

Figure 2. Leadership styles observed in three companies.

Discussion

Engineering and leadership are far more integral than people may realize, and the examples presented above show how engineers and leaders can be one and the same. While CEOs of many companies were business majors, as was the case with Company 1, many organizations were created or led by an engineer. Even at a conglomerate like Company 1, which had a CEO, COO, and other top executives who were non-engineers, many engineers remained in leadership positions at their global level. This emphasizes the importance of current and future engineers learning to utilize leadership skills (Gordon, 2011; Gordon, 2012). However, which leadership skills are most useful in industry?

Looking at this question from a singular perspective, the definition of "success" must be presented and considered. Career success defined by Paul and Falls (2015), professors at the University of Calgary Schulich School of Engineering, includes not only the consideration of constructs of "objective success" (salary, upward mobility, and managerial level), but also includes agents of "subjective success" (self-defined aspirations, values, needs, standards, and career stages). Examining success through this holistic lens is essential and can impact which leadership styles one should utilize in order to achieve overall success. In their article, *Comparison of Career Success Competencies and Engineering Leadership Capabilities,* Paul and Falls (2015) delve into how the results of "an engineer's career successes are directly impacted by leadership education." All of these leadership traits correlated to success competencies. Paul and Falls stated that, "This indicates that teaching engineering students' skills in leadership would have a positive impact on their career. These results are valuable to all engineering students, not just those who plan to pursue a career in leadership." Students must strive to learn and develop leadership in its entirety, and be able to apply leadership under myriad circumstances throughout their careers.

Leadership Observed and Lessons Learned

First, and predictably, the pacesetting style was used most often in this rapidly changing world in which innovative teams cannot afford to become stagnant. The ability of leaders to push their teams without burning them out is imperative in this style of workplace. This is the one style used most often, and leaders must know how to utilize this technique at a moment's notice.

Second was the coaching style. For entry-level engineers, "being able to learn and develop the characteristics of a lifelong learner is a must" (National Academy of Engineering, 2004). Fundamentally, anyone has the potential to coach others, especially with general tasks or at the most basic levels of an organization. All that is needed is the experience and knowledge of how to complete a task and the desire to help someone learn. In the workplace, this can be as simple as coaching an employee who was unknowingly performing an unsafe act. It is common for people to forget simple things, and a coaching session can remind everyone and refresh their previous knowledge.

Third was the democratic leadership. In a technological world, one might assume that people would not question decisions, but humans are not robots. A leader may "share a vision" (Allen et al., 2017) and state why employees are doing each job, but the employees will likely still have questions about when, where, or how they are to get the job done (Eby et al., 2003). They might not verbalize their questions if the leadership style is ineffective or prohibitive. This is where the democratic style can be effective. When people want to share their input to better the product, the leader should always provide the opportunity and listen to their thoughts. Every organization is better when everyone can communicate their ideas openly, as was observed many times in each workplace documented above. Even the newest or least experienced employee can have a bright moment when empowered, and it is the leader's responsibility to take these ideas and utilize them for the collective good.

Fourth was delegating, perhaps the easiest leadership style to use but the hardest to perfect. Initially, it seems easy to give orders and make each team complete the job. However, in order for delegation to be truly successful, the leader must make sure each team understands the "why" behind each task and stay on pace to complete the task.

Fifth was the authoritative style. It is impossible to get a team working efficiently without strong direct leadership. It is paramount that the leader clearly communicates, such that each team member understands the reason for performing each task. Employees, managers, co-workers, and leaders all need to feel useful and participate in the communication. Understanding why they are performing each job provides insight towards the end goal and gives them a purpose for showing up and putting forth extra effort every day.

Lastly, the coercive style is one that can often be used incorrectly and come off negatively or seem aggressive. For engineers who are largely self-driven, being told exactly what to do is not the most positive experience. They would rather be able to come up with their own unique solutions. As was observed in this study, there were instances when this style was effective, but leader need to be cautious in order not to degrade team morale.

Conclusions

It is important to remind engineering students and educators that leadership is in many ways a learned routine that transcends the career space. Diverse and effective leadership will benefit the professional engineer on the job and in many ways beyond the workplace. Leadership is far more than simply occupying a leadership role, it extends to every aspect of life and will benefit each facet in which it is utilized. As the results of this study indicate, multiple leadership skills are required for entry-level engineers to be successful and for industry to prosper.

As suggested in multiple examples, leadership skills have a clear correlation to both "objective and subjective success" within engineering (Paul & Falls, 2015). Novice engineers seeking success in entry-level positions should acquire proficiency in at least one leadership style, and long-term growth within such positions will be greatly enhanced if the engineer has a toolbox of leadership styles mastered. As the information from observing and interviewing technical leaders suggests, knowing how to effectively use a multitude of leadership techniques will positively change the trajectory of one's technical career and quite possibly enhance their lives as well.

Acknowledgments

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Strategies for Increasing the 4-Year Graduation Rate of Engineering Students at San José State University

Patricia Ryaby Backer, San José State University; Cynthia Kato, San José State University

Abstract

San José State University (SJSU) has implemented several strategies for increasing its graduation and retention rates. One of these strategies was block scheduling. Incoming freshmen students in the College of Engineering were put into at least two classes with the same students so that they formed a learning community. This effort began in the fall of 2015 with the first of the four-year graduates receiving their degrees in 2019. The College of Engineering volunteered to participate in the first cohort of block scheduling because of the historic low rates of retention and graduation in the college. Block scheduling had a positive impact on the retention of students at SJSU. Except for the retention rates for fall 2017 freshmen, each of the one-year, two-year, three-year, and four-year retention rates were higher after the implementation of block scheduling than for the two preceding freshmen cohorts—fall 2013 and fall 2014. Overall, the percent of engineering students graduating in four years increased from 7.3% for fall 2013 freshmen to 17.4% for fall 2015 freshmen, the first freshmen cohort in this project.

Introduction

There has been extensive research on the factors influencing retention in engineering. Johnson and Sheppard (2004), in their study of undergraduate engineering majors, identified points at which the numbers of engineering majors drop significantly. Marra, Rodgers, Shen, and Bogue (2012) looked at factors that led to students leaving engineering. They found that both academic factors, such as the difficulty of the curriculum and poor teaching, and non-academic factors, such as a feeling that a student does not belong, contribute to a student's decision to leave engineering for another field of study. In a recent work, Thiry (2019) focused on factors that increase the persistence of students in STEM majors. Her work was based on in-depth interviews and focus groups of 346 students across six institutions, including students who left STEM majors and those who persisted. She found that persistence in a STEM major is usually an interaction of several factors, including "self-efficacy or determination; behavioral adjustments, such as refining their study habits; practical behaviors, such as navigating the college system and STEM courses in a way that will best ensure their success; and social and institutional factors, such as peer support or university services" (Thiry, 2019).

In a research study across 17 universities, Besterfield-Sacre, Moreno, Shuman, and Atman (2001) found that women had lower self-confidence about their studies than men. Women and underrepresented minority (URM) students often feel excluded from engineering, due to negative social cues from faculty and students (Marra, Rodgers, Shen, D., & Bogue, 2009; Zeldin & Pajares, 2000; Seymour & Hewitt, 1997; Kugler, Tinsley, & Ukhaneva, 2017). For STEM undergraduates, the first two years of most STEM fields focus on students "passing" gateway courses in calculus, physics, and chemistry. This process of completing prerequisite courses, while sitting in large lecture halls, "weeds out" many students, with most dropouts from STEM majors occurring in the first two years (Griffith, 2010; Scheidt, et al., 2019; Weston, Seymour, Koch, & Drake, 2019), and women and URM students leaving STEM majors at disproportionately higher rates (Bauer-Wolf, 2019; McDade, 1988; Chen & Thomas, 2009; Tyson, Lee, Borman, & Hanson, 2007). Student retention in engineering is well known and ranges from 40-60% (Desai & Stefanek, 2017).

As in many other universities, SJSU loses engineering undergraduates to other non-STEM disciplines. Of the freshmen who graduated with undergraduate degrees in 2017, 2018, or 2019, 71% (980 out of 1366 students) began as students with an engineering major upon entry to SJSU. The others who graduated from SJSU switched to business (148 students), science (79 students), social sciences (74 students), humanities and the arts (57 students), and health and human sciences (28 students) (CSU Student Success Dashboard, 2020). However, there is an equity gap in the graduation rates of students at SJSU. For first-time freshmen who entered in the fall of 2013, the six-year graduation rate for non-URM students was 61.8%, compared to only 44.5% for URM students. A gender gap in SJSU engineering still persists. The percent of women undergraduates in engineering has increased to 19.1% for the fall 2019 freshmen cohort, compared to 13.7% for the fall 2010 cohort. However, the number of women undergraduates in engineering is still less than national averages (National Science Foundation, National Center for Science and Engineering Statistics, 2018).

Compared to research on retention in engineering, there is less research on the factors that influence time to graduation. Nationally, the four-year graduation rate for all 2011 freshmen was 41.6%, according to the National Center for Education Statistics (2018). Yue and Fu (2017) studied the time to graduation for all first-time freshmen between 2002 and 2014 at one large public university. Of the 12,069 students in their sample, 58% graduated with an average time to graduation of 10 terms (5 years).

The American Society of Engineering Education (ASEE) conducts a survey every two years. Included in this survey are the persistence and time-to-graduation rates of undergraduate engineering students (ASEE, 2016). The number of engineering schools participating in this survey has varied each cycle from around 150 schools (2005-2011) to 111 (2013-2015). Although there are differences in the numbers of students, the four-year graduation rates show improvement in engineering (ASEE, 2016). The nationwide numbers show that the overall four-year graduation rates for all universities that participated in the survey increased from 29 percent in 2006 to 33 percent in 2011.

> Asian-American graduation rates were highest of all groups, around 10 percent above the national rate. White students graduated at around the same rate as the national average. Black or African-American students and Hispanic or Latin American students' graduation rates were lower. Both were 15 percent in 2006 and increased to 20 percent and 22 percent in 2015, respectively. (p. 5)

Although four-year graduation rates are unusual for undergraduate engineering students, some institutions have managed to maintain high four-year graduation rates in engineering. Eighty-three percent of freshmen engineering students at the University of Virginia, School of Engineering graduated in four years, according to the ASEE Retention and Time to Graduation survey (Mather, 2016). However, this graduation rate does not include students who transferred to a non-engineering program at UVA. When considering all freshmen who started UVA in 2011 and earned any bachelor's degree, the four-year graduation rate was 89%. UVA implemented a system of "total advising" to help students persist in engineering. This approach integrates academic, career, and personal counseling.

Ohland, Camacho, Layton, Long, Lord, and Wasburn (2009) used the MIDFIELD (the Multiple Institution Database for Investigating Engineering Longitudinal Development), which included 75,686 engineering freshmen at nine public universities in the southeastern U.S. The researchers found that eight-semester persistence is a good indicator for six-year graduation in engineering disciplines. This finding has been verified by other research on retention in engineering (Astin & Astin, 1992; Lord, Camacho, Layton, Long, Ohland, & Wasburn, 2009). Krause, Middleton, and Judson (2015) analyzed the persistence rates of students at Arizona State University, which is one of the top ten producers of bachelor's degrees in engineering (Roy, 2019). They found that about 50% of students left engineering before graduation; however, the vast majority of those leaving (85%) left in the first two years.

Valle and Leonard (2014) looked at factors that influence time to graduation; specifically, they looked at issues that cause students to graduate in more than four years. The researchers focused on one institution, Georgia Tech. They found that AP credits and transfer credits help students graduate faster. In addition, foreign students graduated faster—usually by 11 semesters of attendance. In addition, receiving at least one failing grade (D, F, or W) or being a student athlete delayed the time to graduation; however, this factor affected men more than women engineering students.

SJSU's block scheduling initiative is based on the literature indicating how learning communities contribute to increased retention and graduation rates (Mangan, 2019). SJSU hoped to provide incoming students with a sense of community by purposely putting them in a small group, thus SJSU created small learning communities for the incoming freshmen that were adapted from other universities (Siegel & Cutright, 2005). Research has shown that students who have a strong community of peers are more likely to succeed than students who attempt to navigate college on their own (Stassen, 2003; Ferrare & Miller, 2020). Unfortunately, many freshmen struggle to make a connection to SJSU. One of the main reasons for this is that students often take classes with largely separate groups of people. Since there are over 3000 freshmen each year at SJSU, students rarely are placed in the same classes together.

Research shows that student learning communities can increase the level of student belongingness to a university; and, if students feel more connected to a university, they are more likely to be retained and graduate (Astin, 1993; Kuh, Kinzie, Schuh, & Whitt, 2005). SJSU has students from a myriad of backgrounds and a high level of first-generation college students. Research has shown that URM students can benefit from being in student learning communities (Anderson, 2004; Engstron & Tinto, 2008; Liptow, Chen, Parent, Duerr, & Henson, 2016; Xu, Solanki, McPartlan, & Sato, 2018; Zhao & Kuh, 2004).

In 2015, Georgia State University (GSU) implemented its block scheduling program for incoming freshmen. Incoming freshmen were asked to choose a meta-major—science, technology, engineering, and math (STEM), business, arts and humanities, policy, health, education, or social sciences. The freshmen were then put into a learning community of 25 students, based on their choice of meta-major. GSU found that students who were in block-scheduled learning communities had higher retention and graduation rates than the students who opted out of block scheduling their freshmen year. (Renick, 2018; Georgia State University, n.d.). By giving freshmen a student learning community, the students' engagement increased. Engstrom and Tinto (2008) analyzed the impact of student learning communities through a study of 19 two- and four-year colleges. They found that students in learning communities had higher one-year retention rates. By implementing block scheduling, SJSU rethought the freshmen year and focused on the students' connections to each other and the university. According to Cuseo (2005), "intentionally designed interventions are needed to improve the effectiveness of first-year students' academic decision-making and career planning."

Institutional Characteristics

SJSU is one of the oldest postsecondary institutions in California and is part of the California State University (CSU) system. SJSU enrolls over 33,000 students each year in its undergraduate, graduate, and credential programs. It is accredited by the Western Association of Schools and Colleges. Most programs in the College of Engineering are accredited by the Accreditation Board for Engineering and Technology (ABET). SJSU is located in San José, California. The demographics of SJSU mirror the diversity of the region. SJSU has high percentages of three ethnic groups among its undergraduates: Asian, Hispanic, and white. In the fall of 2019, 41% of undergraduate students were Asian, 31% were Hispanic, and 14.6% were white. With respect to gender, SJSU has reached parity—49.8% of its undergraduate students were women in the fall of 2019. The enrollments for the College of Engineering at SJSU differ from the other colleges within the university. For undergraduate students in engineering, in in the fall 2019, 2282 (49%) were Asian, 1066 (23%) were Hispanic, and 740 (16%) were white. For College of Engineering undergraduates enrolled for the fall 2019 semester, 19.1% were women and 80.9% were men.

Retention Efforts at SJSU

SJSU has been working over the past ten years to improve its retention and graduation rates. SJSU received a U.S. Department of Education Strengthening Institutions grant in 2014. There are five major initiatives under the grant: block scheduling of freshmen, creating a new First-Year Experience course, creation of new student learning communities in housing, expansion of the peer mentor program, and development of a new faculty-staff mentor program. The grant's main focus is to improve 5-year graduation and retention rates and close the achievement gap for underrepresented minorities (URMs) at SJSU. Block scheduling relates to the major goal of the grant—to increase the retention and graduation rates of freshmen at SJSU. The first initiative that was started under this grant in the fall of 2015 was block scheduling. The structure and implementation of block scheduling in the College of Engineering at SJSU have been discussed in prior articles (Backer, Green, Matlen, & Kato, 2018; Backer & Kato, 2017). The first cohort for block scheduling came from volunteers in the university. Two colleges (the College of Business and the College of Engineering) and one department (Child and Adolescent Development) volunteered to participate in the fall of 2015. Students in each major were pre-assigned at least two classes with students from the same major. Students selected additional classes at the mandatory orientation sessions.

The College of Engineering volunteered to participate in block scheduling, given the historic low retention and graduation numbers in the college. Table 1 shows that, at the time of the grant's writing in 2013, the 4-year graduation rates in the College of Engineering was 7.3%. Although the 6-year graduation rates were much higher (57% for fall 2013 freshmen), the college had a desire to improve them. From institutional data, SJSU determined that the first two years were critical to students chances of graduating. If students were retained into their third (junior) year, they were increasingly likely to graduate.

Table 1. Four-year graduation rates for SJSU College of Engineering freshmen (fall 2010 to fall 2013).

	Fall 2010	Fall 2011	Fall 2012	Fall 2013
Asian	5.1%	6.3%	8.2%	8.7%
Hispanic	0.0%	0.0%	1.0%	3.7%
White	6.5%	7.1%	7.2%	6.2%
Foreign	0.0%	15.4%	12.5%	8.5%
Other	3.7%	0.0%	7.9%	16.0%
Black	14.3%	5.3%	13.3%	5.6%
Total	3.9%	4.7%	6.8%	7.3%

Results

The first cohort of block scheduling included all of the fall 2015 freshmen in the College of Engineering. Table 2 shows the one-year, two-year, three-year, and four-year retention rates of College of Engineering freshmen at SJSU. The percentages in bold indicate the cohorts that were block scheduled. Except for the retention rates for the fall 2017 freshmen, each of the one-year, two-year, three-year, and four-year retention rates were higher after block scheduling than for the two freshmen cohorts (fall 2013 and fall 2014) preceding this project. It is interesting to note that all of the fall 2017, one-year retention rates were low across the entire university. This could be attributed to the unusually large incoming freshmen class in the fall of 2017. In that semester, SJSU admitted 4351 first-time freshmen, compared to 3654 in fall 2018 and 3740 in fall 2019. Since SJSU is an impacted campus, the increased number of first-time freshmen in fall 2017 indicated that SJSU took more students who fell at the bottom of the eligibility scale for the school.

There are differences in the retention rates of engineering students at SJSU when analyzed by ethnicity. As stated previously, the three largest ethnic groups in engineering at SJSU are Asian, Hispanic, and white. Tables 3 and 4 indicate that block scheduling appears to have had the greatest impact on Hispanic students. Even though the retention levels of Hispanic students was lower than for Asian and white engineering students, the number of Hispanic freshmen retained each year after block scheduling was implemented was much higher than prior to block scheduling. For example, the number of Hispanic freshmen retained after two years was 73.6% for fall 2015 freshmen, 72.7% for fall 2016 freshmen, and 70.5% for fall 2017 freshmen. In comparison, only 66.3% of fall 2013 and 60.1% of fall 2014 Hispanic freshmen were retained after two years.

Table 2. One-, two-, three-, and four-year retention rates of SJSU College of Engineering freshmen.

	FA13	FA14	FA15	FA16	FA17	FA18
1 year RR	86.8%	88.0%	**90.2%**	**91.9%**	**87.8%**	**88.7%**
2 year RR	75.6%	78.3%	**80.4%**	**82.8%**	**80.8%**	
3 year RR	71.1%	73.8%	**75.9%**	**81.2%**		
4 year RR	67.8%	71.3%	**75.2%**			

Table 3. Retention data for College of Engineering freshmen, before block scheduling, by ethnicity (fall 2013 and fall 2014).

Before Block Scheduling						
	Fall 2013 freshmen			Fall 2014 freshmen		
	Asian	Hisp	White	Asian	Hisp	White
1 year RR	92.2%	79.5%	82.2%	92.5%	78.4%	90.1%
2 year RR	83.5%	66.3%	70.5%	87.5%	60.1%	77.2%
3 year RR	80.1%	58.4%	67.1%	85.3%	53.6%	72.3%
4 year RR	75.1%	58.4%	62.3%	83.0%	52.9%	69.3%

Table 4. Retention data for College of Engineering freshmen, after block scheduling, by ethnicity (fall 2015-2018).

After Block Scheduling						
	Fall 2015 freshmen			Fall 2016 freshmen		
	Asian	Hisp	White	Asian	Hisp	White
1 year RR	**94.3%**	**85.0%**	**86.6%**	**96.9%**	**85.9%**	**89.2%**
2 year RR	**87.3%**	**73.6%**	**73.2%**	**90.3%**	**72.7%**	**81.9%**
3 year RR	**83.3%**	**69.2%**	**68.8%**	**90.3%**	**69.5%**	**78.3%**
4 year RR	**82.0%**	**68.3%**	**71.4%**			
	Fall 2017 freshmen			Fall 2018 freshmen		
1 year RR	**90.4%**	**82.2%**	**86.2%**	**92.6%**	**81.7%**	**84.3%**
2 year RR	**85.5%**	**70.5%**	**78.9%**			

The four-year graduation rate for fall 2015 freshmen increased dramatically, as compared to the freshmen cohorts from previous years. Overall, the four-year graduation rate for fall 2015 freshmen was 17.7%, which was much higher than the four-year graduation rate for fall 2013 freshmen (7.3%). Figures 1-3 show the four-year graduation rates of the three largest ethnic groups of SJSU engineering freshmen. When compared to a best-fitting regression line from the previous four cohorts of students, the fall 2015 graduation rates were higher than what would be expected for students from all three ethnicities.

Figure 1. Four-year graduation rates for Asian engineering freshmen (fall 2010 to fall 2015 cohorts).

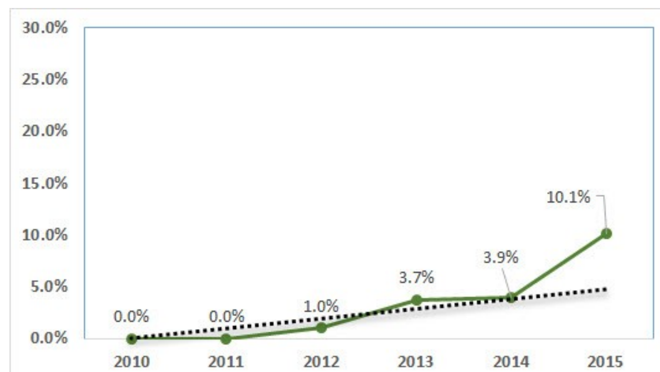

Figure 2. Four-year graduation rates for Hispanic engineering freshmen (fall 2010 to fall 2015 cohorts).

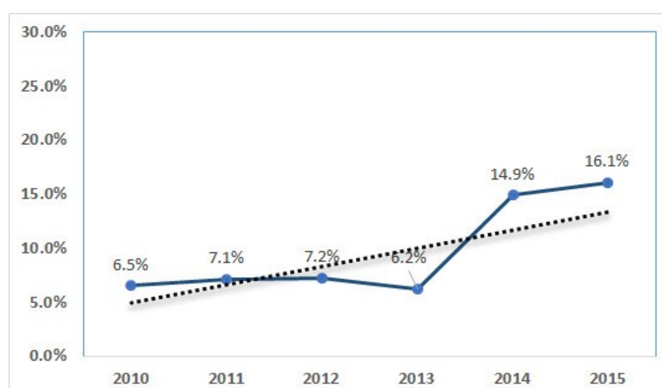

Figure 3. Four-year graduation rates for white engineering freshmen (fall 2010 to fall 2015 cohorts).

Conclusions

SJSU implemented block scheduling of freshmen beginning with the fall 2015 cohort. Both yearly retention and four-year graduation rates increased, compared to previous freshmen cohorts. The four-year graduation rate for fall 2015 freshmen increased dramatically, as compared to the freshmen cohorts from previous years. Overall, the four-year graduation rate for fall 2015 engineering freshmen was 17.7%, which was much higher than the four-year graduation rate for fall 2013 engineering freshmen, which was 7.3%. The graduation rates for all three subgroups in the College of Engineering increased since block scheduling was implemented. The four-year graduation rates for the fall 2015 freshmen were 10.1% for Hispanic students, 16.1% for white students, and 25.3% for Asian students. It is not possible to disaggregate the effects of block scheduling on time to graduation. These results, however, led SJSU to decide to implement block scheduling for all incoming freshmen beginning with the fall 2019 semester. In addition, the success at SJSU led other CSU campuses to implement block scheduling of all incoming freshmen, starting in the fall of 2019.

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Biographies

PATRICIA BACKER is a full professor at San José State University in the Department of Aviation and Technology. She received her BS degree in chemical engineering from Rutgers University, MA (Teaching Mathematics, 1982) and MS (School Administration, 1982) from Tennessee Temple University, MS (Neurocognition, 1986) and PhD (Neurocognition, 1987) from The Ohio State University. She served as chair of the Department of Aviation and Technology from 2001 to 2007 and as Director for General Engineering from 2007 to 2013. Dr. Backer has helped bring in many grants that have enriched SJSU, most notably the U.S. Department of Education AANAPISI, the Strengthening Institutions grant (Project Succeed), and the First-in-the-World grant. She received the *20-21 CSU Faculty Innovation and Leadership Award,* the *2011 SJSU Distinguished Service Award*, and the *College of Engineering's McCoy Family Faculty Award for Excellence in Service* in 2015. Dr. Backer may be reached at patricia.backer@sjsu.edu

CYNTHIA KATO (retired) is the former Director of Academic Advising and Retention Services at San José State University. She holds a BA in French and German from the University of Southern Mississippi and an MA in Comparative Literature from Purdue University. She has also completed doctoral-level coursework in Educational Psychology: Learning and Cognition at the University of Minnesota. At the University of Minnesota, Ms. Kato worked in the unit for academic advising for student athletes for 15 years. As Assistant Director for Learning, she designed and implemented an intensive retention program for academically at-risk student athletes and a comprehensive learning support program for 750 student athletes. The program had a 90% first-year retention rate for the most academically fragile student athletes and a 6-year graduation rate of 50% for students whose entering profiles predicted an 8% graduation rate. Ms. Kato began working at SJSU in 2005, when she was hired as Director of Student-Athlete Success Services. In 2006, she was named Director of AARS. In this role, she led general advising but also implemented multiple institutional initiatives related to tracking of student progress to degree, including block scheduling for Project Succeed.

A Novel Framework for Network Traffic Prediction using Machine Learning

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Patrick Appiah-Kubi, University of Maryland University College

Abstract

In this paper, the authors present major technology management challenges faced during the implementation of machine learning techniques when predicting network traffic in an automated networked system. Using the principles of technology management for digital communication, ideas, and applications of various ML techniques, the authors investigated approaches for network traffic forecasting. In this study, the authors investigated the traditional network traffic prediction techniques and their limitations in catering to non-linear data, and propose a novel framework by implementing an additional layer of intelligence in the software defined networking model to predict real network traffic in an intelligent manner. Network traffic forecasting is important in the implementation of network planning and routing configurations to improve the quality of service for users, to reduce congestion, and increase resource control by altering the network parameters to fit traffic characteristics.

Introduction

Network traffic prediction is critical for realizing intelligent routing and optimizing network performance. During the process of network planning and design, network traffic forecasting aids in estimating the expected traffic load that the network must support. Machine learning (ML) techniques are applied in a range of sectors such as customer experience, business processes, assisted self-driving cars, and recommendation systems. For applications that require automation, ML has seen an unparalleled increase (Boutaba, Salahuddin, Limam, Ayoubi, Shahriar, Estrada-Solano, & Caicedo, 2018). The increase in information accessibility, major advances in ML approaches, and developments in computational resources are among the main drivers in incorporating ML for traffic prediction.

Although researchers have focused on predicting network traffic during a certain period of time with the application of ML techniques, practical models for implementing ML for traffic forecasting in real networks is very limited. Machine learning can be segmented into two types of techniques: supervised learning and unsupervised learning. Supervised learning trains a model on known input and output data, while unsupervised learning is used to find hidden patterns in input data. Supervised learning uses classification and regression techniques to train a model to predict the output. Classification techniques predict categorical responses, while regression techniques predict continuous responses. Unsupervised learning uses a clustering technique of data analysis to find hidden patterns in input data. Figure 1 shows the difference between supervised and unsupervised learning.

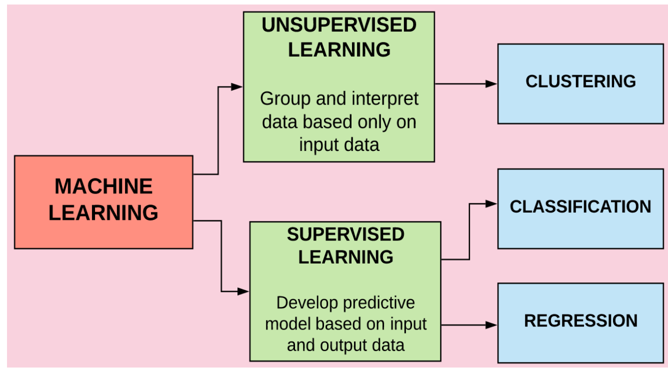

Figure 1. Supervised learning versus unsupervised learning.

Both artificial intelligence (AI) and ML are quite advanced innovations in every industry, providing opportunities for new ideas that are accelerating digital transformation (Stoughton, 2018). However, these traditional approaches are showing serious limitations, especially in view of the increased complexity of communication networks (ComSoc, 2019). Looking back through the literature, the authors found numerous ML techniques for network traffic prediction that have been employed, four of which the authors will discuss here.

Linear time series model:
This is a conventional technique used in network traffic forecasting. In the time series, linear techniques have a covariance structure making up an auto-regressive, moving-average model.

Non-linear time series model:
This technique displays features such as time-change variance, higher-moment structures, breaks, and threshold. Neural network and fuzzy logic techniques are used to forecast network traffic.

Hybrid model:
The hybrid model is accurate in forecasting network traffic, as it is a combination of linear and non-linear models; as such, it can accommodate both linear and non-linear data. The hybrid model provides effective results in network traffic forecasting.

Decomposed model:
There are three components of the decomposed model.

- Trend component—shows the structural variations in the time series.
- Cyclical component—shows medium fluctuation and the rise and fall in the absence of a specific period.
- Seasonal component—variations come through the seasonal factors that do not occur frequently, but rather in months or years. It also has stable time series data.

These four models represent the existing machine learning techniques, which are useful for linear traffic. However, for atypical conditions, these techniques have limitations. The networking field has evolved a lot, but the software-defined network (SDN) is in need of time. To obtain real-time network traffic information precisely, there is a dire need for implementation of technology management to achieve an ML-enabled SDN platform.

Digital Communication

Digital communication includes electronic information and knowledge management systems, providing tools for handling the development, storing, sorting, sharing, and exchanging of information. Its advantage is that digital information tends to be far more resistant to transmission and interpretation errors, as compared to the information represented in an analog medium, which mostly accounts for the clarity of digitally encoded systems. Digital communication technology involves the design, construction, and maintenance of communications systems and technology to exchange digital information. Its advantages include easy access to information with improved communication. It provides innovation and creativity to existing digital communication systems and increases efficiency and productivity.

Technology Management

The U.S. national research council based in Washington DC has defined technology management as a link "to design, develop and implement technological capabilities that shape and achieve the strategic and operational objectives of the organization in engineering, science, and management." Although innovation management solutions themselves are critical for business success, they help in achieving the strategic objectives of the organization (Alexander, 2005). The classic definition of technology management is referred to as the integrated planning, designing, optimizing, operating, and control of products, processes, and services related to technology; or the management of the use of technology to benefit mankind. The field of technology management has emerged as an essential force for addressing the specific ways that companies approach technology in their business strategies and operations. Technology is hard to manage, because it is constantly evolving, often not predictable. It increases the capacity of production and productivity, integrates all the departments under one umbrella, provides better blueprints and real-time support operations through effective assessment, planning, forecasting, development, and selection of suitable technological strategies corresponding to the competitive position of the organization.

Management of technology is a series of management disciplines that include effective technology assessment and planning that allow companies to manage their basic technologies to create a competitive advantage. It helps in utilizing technological assets to achieve customer satisfaction by providing scalability across enterprise. In an enterprise, management of technology is important for the development of effective strategies to help gain a competitive advantage in the market. Continuous technological advancement is necessary to maintain consumer trust and, as per need, a company's technical department is liable to engage in the technological advancement process. This coordinated scheduling, development, implementation, execution, and management of software goods, systems, and facilities involved in the process of technology management and innovation management help in the strategic use of technology for human benefit (Definitions, 2020)

In the international economy, technology management with respect to digital communication has a significant and rising role in businesses. Businesses and policymakers greatly benefit through constant developments in the digital communication arena, including wider applications of the internet in the international economy. Technology management has encouraged market creativity, production, and production efficiency, while at the same time promoting supply and operating cost control (Paletta & Vieira Jr., 2008). This provided a mechanism for organizational reforms, increased coordination of labor, increasing the costs of daily business transactions, and streamlined supply chains for businesses. Information and computer technology are therefore responsible for recording, obtaining, editing, distributing, and receiving digital data.

Network Traffic Prediction: Concept of network traffic

Network traffic prediction refers to the management of a network to determine the estimated load or traffic on a computer or telecommunication network (Geurts, Khayat, & Leduc, 2004). Network traffic can be investigated through modeling, analysis, optimization, and prediction/forecasting techniques. Research for traffic prediction started about 50 years ago; today, traffic can be predicted for a very short span. Normally, network traffic predictor applications try to forecast what is going to happen 10-15 minutes later and what may be the state of traffic in the upcoming days or weeks.

For instance, in previous studies (Joshi & Hadi, 2015; Fishkin, 2015; Connor & Martin, 1994; Burney & Raza, 2017; Syed, S. M., & Sami, 2009; Piedra, Chicaiza, López, & García, n.d.; Peng & Tang, 2015; Xian, Rui, Wei, &

Keping, 2013; Xiang, Qu, & Qu, 2015), the authors found that traffic could be predicted using congestion in the network or the activity based on several protocols, such as TCP and UDP, using the logs collected over a long period of time. This historical traffic data can then be analyzed and fed into machine learning models to forecast short- or long-term traffic.

Importance of Network Prediction

Network traffic forecast analytics is useful in ensuring safe, accurate, and qualitative interaction between the network components. The purpose of network traffic forecasting is to provide a steady variation in the traffic with respect to the pattern of changed historical data. Network prediction issues gain much attention from the computer network community, as it avoids that state of being congested, it speeds up the networks, and it monitors the networks and their security (Hassan, Chou, Li, Kubi, & Tamer, 2019). To achieve efficient and effective results, several interesting combinations are put into practice for network analytics and prediction techniques (Manish, Ganvir, & Salankar, 2015) Networking technology is growing considerably and rapidly with new protocols and standards; and the scale of networks has also gained escalation in a very short time, further amplified by Cloud-, Edge-, and IoT-based services and augmenting the complexity and amount of data traffic.

Networking traffic plays an important role in measuring the load and status of network operation (IAMNetworks, 2017). The features that identify network traffic include non-linear, multi-fractal, chaotic, long- and short-range dependence, and nonlinear characteristics (Iqbal, Zahid, Habib, & John, 2019). The network-sharing resource is part of network management, maintenance work, and operation. The network managers perform the distribution of resources to save traffic from blocking. Besides, anomaly networks can help in sourcing network traffic variations without any difficulty or effort. Methods such as network traffic forecasting are likely to succeed or be effective in the network security field (Chen, Shang, & Chen, 2019). Values of forecasting are not too far off and have connections with time series values.

Neural networks long-/short-term memories (LSTMs) usually are the tools that provide good results, as noted in previous studies. To produce even more precise traffic prediction, researchers have utilized atypical conditions, which represent a deviation from a conventional behavior/condition. For instance, atypical behavior in network traffic (Abbasi, Guleria, & Devi, 2016) is higher than the normal usage of video or voice traffic during a holiday season, or voice traffic during natural catastrophes, or during any other irregular circumstances. In all such cases, the traffic flow will be different from the normal routine. In these cases, it will be difficult to forecast the traffic, due to anomalies in traffic behavior. Hence, regular practices in analyzing data will not be enough to provide accurate results.

In scenarios where there is non-linearity in the traffic flow, tools such as Mininet can be used with traffic generators such as IPERF or D-ITG for traffic simulation, which pre-describes the entire network and can introduce various parameters to simulate such atypical network traffic. This type of prediction is called a “what-if” prediction, because the output is predicted considering the change in the estimated output brought by changing any of the traffic parameters. If the traffic cannot be predicted, even after a change in parameters (e.g., delay, throughput, or bandwidth settings) then the next step is to use network optimization.

The issue with network traffic predictions is that the characteristics of potential network traffic are required to be anticipated according to recent traffic measurements. Several applications of network traffic prediction include network control, management of resources, and threat detection. A traffic prediction of the abstract-network is achieved by analyzing past traffic data. This strategy can be realistic while at the same time handling and organizing linear traffic networks. Recurrent neural network (RNN) methods are used for the simulation of time series data, which aim to predict future time series based on past data. RNN includes various network architectures, including a basic RNN, LSTM gated recurring unit (GRU), an identity recurring neural node (IRNN) that knows the time trends of large arbitrary length channels, and long-range dependencies (Vinayakumar, Soman, & Poornachandran, 2017).

Network Prediction Process

Figure 2 presents the network prediction process in which input data are trained by using ML algorithms to develop a prediction model that can predict an output.

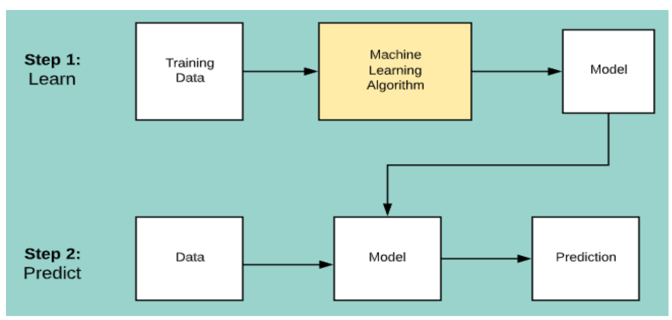

Figure 2. Network prediction process.

The function of the reliable network traffic predictor is to centralize most of the activities of network management, such as resource allocation, short-term traffic planning and rerouting, long-term capacity planning, network design, and network anomaly identification. Therefore, network traffic forecasting is important for network providers to deliver and manage effective wireless and fixed network services (Troia, Alvizu, Zhou, Maier, & Pattavina, 2018). Reliable real-time traffic forecasts (YÜksel, Akay, & ÇÝftÇÝ, 2018) are required in many networking applications, including dynamic asset allocation and technology management. In the past decade, internet traffic has increased considerably, due to the development of new technologies, industries, and applications (Narejo & Pasero, 2018). Because of wireless networks, there are also more mobile users, and usage growth gradually grows by the number of total data per device. Between 2018 and 2020, mobile internet traffic grew by 70%. In the future, mobile traffic will be even higher, as the variety of devices connected to the internet, such as IoT and in-cloud and data-center applications increases. Networks have to meet increasing traffic demands and provide better service to customers. The successful use of networking tools has been encouraged. This function can be easily achieved by accurately forecasting network traffic (Cisco, 2013). Exact traffic forecasts are relevant in various networking fields, such as saving energy, control of network resources, and mobile sensor networks.

Technology Management Applications in Network Prediction

The six important facets of technology management include technology evaluation, product and process integration, planning, implementation, training, and change. These six facets are interrelated and share a common goal if implementing change; and effective implementation of change requires sufficient knowledge of all these facets. Figure 3 presents six facets of technology management that help in implementing technology-based change effectively (Kearns, Taylor, & Hull, 2005).

Figure 3. Six facets of technology management.

All of these facets of technology management sufficiently help in forecasting network traffic in an automated network by providing a novel framework to estimate network traffic, to avoid network congestion (Tajiki, Akbari, Shojafar, & Mokari, 2017), and to improve the user interface. Table 1 summarized the functionalities of each facet.

Technology Evaluation

Current technology, used for network prediction, includes the application of various ML techniques to provide accurate results when applied to linear data. However, when there are anomalies in data, network prediction results are far from accurate. Network prediction is very important for non-linear data in order to determine real-time traffic.

Table 1. Technology Management application in network prediction.

Technology Management facets	Functionalities in a network prediction model
Technology evaluation	Evaluated the existing technology deployed and its limitations for network prediction
Product and process integration	Integrated ML Neural Network Algorithm to improve the Network Prediction process to cater to traffic in Atypical conditions
Design and planning	Designed a new framework for better network Prediction using SDN by addition of an intelligence plane in the management plane
Implementation	Implementation of Network Prediction using ML in Open Daylight (ODL) SDN Controller
Training	Training is provided to the Network and System Engineers
Change	Change can be implemented over the period of time after monitoring the traffic trend and by anticipating the parameters causing change.

Using the principles of technology management, the authors of this current study proposed the deployment of an SDN controller (Yu, Yang, & Yoo, 2018; Lessing, 2021) that uses real network devices—such as routers, switches, firewalls, and load balancers—to manage and control these devices. The network data generated by the devices would be utilized in a closed loop for predictive network analytics (Hassan, 2019) to improve service and be more reactive.

Implementation

Based on the this design, the authors implemented machine learning (ML) in an OpenDayLight (ODL), software-defined network (SDN) controller (Hassan & Omar, 2018; SilverPeak, 2018; Parsaei, Sobouti, khayami, & Javidan, 2017; Latah & Toker, 2019; Cooney, 2019) without OpenStack on physical machines to control real network devices, including router, switches, load balancers, and firewalls. For this study, a Mininet network simulator was integrated with ODL and tested with customized standard network topologies to monitor the traffic. The end goal was to predict network traffic and take appropriate action in order to mitigate latency issues.

Organizational innovation is an important element in successful implementation of technology and, therefore, it can bring significant change in the selected technology over the years; for example, consider the trend in network traffic based on the activity in a particular network. To better adjust to the changes, network traffic is constantly anticipated and monitored in order to manage and control the network prediction model. To introduce change, a clear strategy must be framed with the vision to change the way network traffic operations are performed in the conditions of heavy network loads. The need for a specific change in the machine learning model must be thoroughly investigated considering the goals, progress, and reasons to bring change. Based on the inferences drawn, older ML technology can be deactivated and will be replaced by implementation of the new technology, which itself is a huge change.

It is well understood that without proper training, an effectively planned implementation model will be ineffective. Therefore, training must be provided to network and system engineers so that they are able to perform better. Training should include user guides, help menus, ML traffic models, etc. Training should include planning and implementation of processes to help engineers learn the system. Also helpful would be to address specific applications and procedures as well as enable them to introduce innovation into the system.

Intelligence Plane Framework

In this paper, the authors also introduce a new element in the SDN framework called an intelligence plane, which resides as the top layer on the control and user plane. The intelligence plane, as the name suggests, gives brainpower to the network to make automated decisions using ML models.

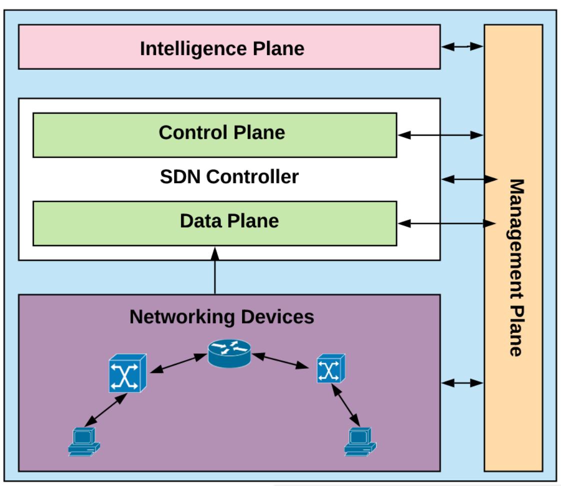

Figure 4. Intelligence plane framework.

This intelligence plane provides an added layer of functionality to the SDN controllers to predict future traffic based on past traffic patterns. Figure 4 presents an interrelation of networking devices with the management plane and the addition of an intelligence plane in the management plane. A similar concept was discussed in previous studies by Mestres, et al. (2017) and Clark, Partridge, and Ramming (2003). This current study differentiates itself by demonstrating the close association of the intelligence plane with other SDN layers, considering atypical conditions, and being used an open source SDN controller to suggest the design elements.

When the intelligence plane framework is used for network traffic prediction, it includes intelligence, management data, and control planes. The intelligence plane has ML models and data was continuously being fed to make predictions that are acted upon by the SDN controller to regulate network elements. Traffic prediction was done previously by using universal prediction methods (Narejo & Pasero, 2018), including straightforward methods such as regression analysis (SRA), decomposition, and an exponential smoothing method (ES). These methods were implemented in some predictions, but they continue to have drawbacks. These methods can easily predict linear data, but the output is not as robust when applied to non-linear data.

The proposed SDN model in this current study is better-suited for predicting network patterns and is more effective for network traffic forecasting. SDN (Karakus & Durresi, 2017) integrates traffic engineering to optimize network configurations according to traffic. The idea proposed by the current authors builds upon the capability of the networks to be dynamically reconfigured by traffic evaluation. However, in certain scenarios, reconfigurations do not occur due to route stability, forwarding rule instantiation, individual flow dynamics, traffic monitoring overhead, etc. So, some manual intervention methods may be required. Figure 5 shows the cases of intelligence plane framework that can be used for network prediction, automatic bandwidth allocation, network planning, network security, predictive congestion control, and identification of optimum routing paths (Odom, Healy, & Donohue, 2010).

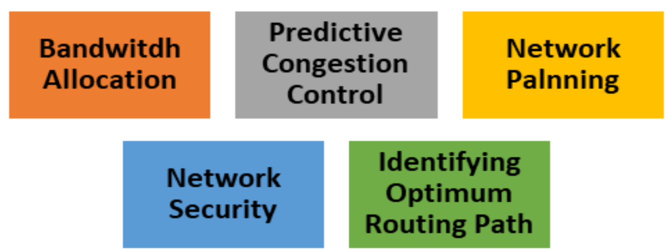

Figure 5. Use cases of intelligence plane framework.

Network Traffic Prediction with a Machine Learning-Enabled SDN Platform

Network traffic prediction can be realized with the use of an SDN controller that will control real network devices such as routers, switches, firewalls, and load balancers to manage and monitor these devices. The network data generated by the devices is then fed into a closed loop for predictive network analytics to improve the service and be more reactive. The authors suggest using an ODL SDN controller (Riverbed, 2019; SD-WAN Experts, 2016) without OpenStack on physical machines to control real network devices including router, switches, load balancers, and firewalls. For simulation purposes, Mininet can be integrated with ODL as a controller in order to predict network traffic. With the use of network analytics, the intelligence plane of the SDN can provide an active platform to mitigate cybersecurity attacks on the network.

Experimentation and Results

In this study, the authors used a Knime analytics engine (Knime, 2018; Knime, 2020) along with various datasets to accurately predict network traffic. Finding the relevant dataset for this task was quite difficult; hence, the authors tested ML models with various datasets and found various level of success. The first phase of experimentation was started with a dataset (Rojas, 2018) that was created using Cicflowmeter and had 87 features and 3,577,296 instances. Network traffic prediction was performed on this dataset using linear regression, time-series analysis, ARIMA, and artificial neural networks; however, the results were inadequate, since the dataset was too small for the model to learn and capture data that were extremely random and without any trends or patterns. Figure 6 shows the linear regression model workflow.

In the second phase, the authors utilized another dataset, which was comparatively new and more relevant for the creation of traffic prediction models. This data set was called the "Dartmouth campus dataset" and contained syslog, SNMP, and TCP dump data (Kotz, Henderson, Abyzov, & Yeo, 2009). Algorithms were applied on this Dartmouth dataset and it was found that the results were inadequate, as this dataset was also insufficient for the algorithm to learn upon. In this workflow, linear regression was used to predict usage of data. In the third phase, a dataset was chosen that had campus DNS network traffic consisting of more than 4000 active users (in peak load hours), for 10 random days, organized in hourly PCAP files in the dataset. (Singh, Singh, & Kaur, 2019; Singh, Singh, & Kaur, 2019). To predict the traffic, six features were analyzed: month, week, the day of the week, daily download traffic for the one previous day, the average daily download traffic for the two previous days, and the TSC for the download internet traffic data.

The authors concluded that the time-series analysis detected patterns in the data to learn upon for prediction. It was very accurate for long-term network traffic prediction, where it did not matter whether the data were at the very next instance, and tried to learn the routine of short-term network traffic in spite of the difficulty in finding a pattern, as a spike in network traffic could occur at any time and throw off the results.

Future Work

The authors of this current study intended to utilize the novel idea of the intelligence plane framework of SDN and tools such as Mininet for network simulation, an OpenDayLight SDN controller to build network topologies, and demonstrate the system response each time a network load is placed on the system. The same environment will be used to demonstrate that an on-going cybersecurity attack can be mitigated in real-time.

Conclusions

In this study, the authors employed the principles of technology management to develop a solution for network traffic prediction, which is a very complicated problem faced in the internet-connected world. Many services rely on the stability of networks that can be broken down if the congestion is not controlled or the traffic on the network is unpredictable. The authors presented here the design of a novel intelligence plane in SDN that resides as the top layer on the control and user plane. The addition of such an intelligent plane provides network traffic prediction in real time for both linear and non-linear traffic by using real network devices such as routers, switches, firewalls, and load balancers to manage and control these devices. This implementation of an intelligence plane framework helps in improving the quality of service for users, decreasing congestion, and improving resource control by altering network parameters based on traffic characteristics.

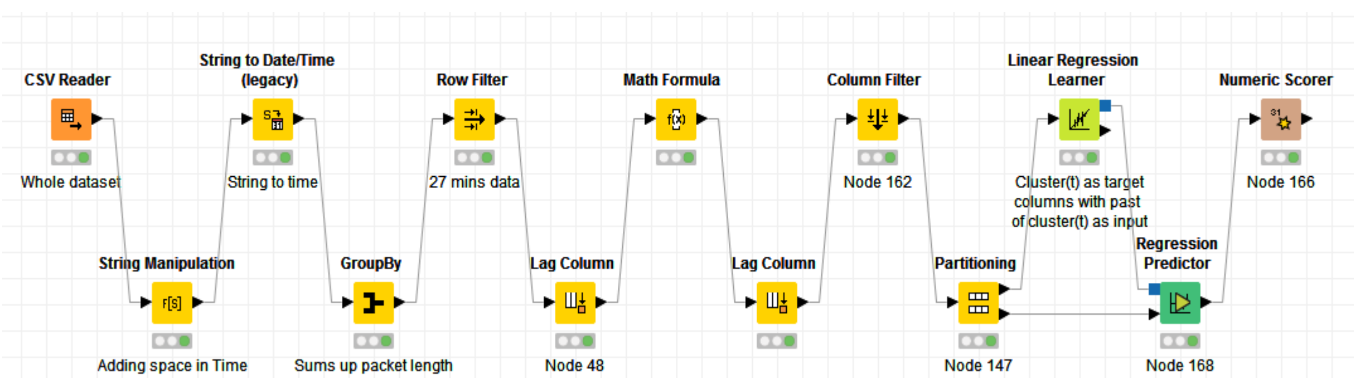

Figure 6. Linear regression workflow model created in Knime analytics.

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An Integrated Approach for an Introduction to Mechatronics Engineering

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Abstract

An introduction to engineering education always plays a definite role in the future careers of students. In this context, they should be acclimated to all steps of the entire product lifecycle (Standard 1). Specifically, the mission statement must be outlined from the beginning of the engineering task in order to focus their active thinking and save on the cost/time ratio. For this current project, the focus was to design and engineer an electric wheelchair for disabled persons. Each team consisted of 3-4 students, assigned by the instructor, to investigate the demand of certain wheelchair types (Irish wheelchair Association, 2014) in the community. After the market data were acquired, all teams adjusted their opinions in order to finalize their aims and reassemble the electric wheelchair accordingly. The data produced from the study indicated that a series of CDIOs (Conceive, Design, Implement, Operate) were needed to be integrated into the curriculum in order to help sharpen the graduates' engineering and entrepreneurial acumen. Thus the need for the integrated approach (Standard 3) in teaching the technical discipline, namely manufacturing processes.

Students must be acquainted with production design and CAD, metalworking processes, dynamic calculation drivers, industrial esthetic design, and skills testing with the patient. The workspace also covers the on-site practice (Standard 6), so it would be attractive and very useful for the development of production skills for engineers. The general purpose of this outline of the mechatronics discipline was to encourage students to seek out and solve urgent socio-economic problems. This was done through integrating various skillsets to create feasible answers to the problems presented and select the most ideal one based on their learned design and implementation knowledge. In this paper, the authors present the details of this study, in the hopes that the knowledge gained will benefit colleges and universities looking to improve on their introductory technical procedures.

Introduction

The integrated approach is one in which students work in a learner-centered environment where the context of activities is focused on the learners and their interests. It encourages students to engage in purposeful, relevant learning. Knowledge knows no boundaries. But the fragmented approach has a narrow approach for learning and does not ensure psychologically sound learning, whereas the integrated approach provides a larger canvas for student discourse and interaction as well as strong inter-linkage between interdisciplinary concepts (Kaur, 2019). Other authors described the organization and the impact of the mini-conference on the project with the creation of a software product and its introduction onto the market (Fernandez, Hattum-Janssen, Ribeiro, Fonte, Santos, & Sousa, 2012). The distinctive point of this study was to apply simultaneously many standards of CDIO to teach students in technical disciplines to formulate a sense of community and social obligations, the so-called human side of university education. Based on the mission of Duy Tan University—"… focus on in-depth training and research of technologies and sciences in order to produce graduates with recognizable levels of patriotism, confidence, creativity, flexibility, humanities, community…"—teaching staff often organize activities that allow their students to network with local companies and the community.

This also encourages the students to form a bond with their community from the beginning of their engineering curriculum. In doing so, the students are encouraged not only to follow coursework that interests them, but also their community. This is a new way to integrate "human education" into technical disciplines. The end goal of these activities is to have students focused on their intended areas of study, and the realization that the project idea is the centerpoint of all inspiration and creative endeavors. For this, the instructor must be required to not only present simple slideshows, but also demand a product forecast for each project in their market area. This was the driving factor for the teams to allow them to create a rough draft of their entrepreneurship plan. (Duong & Dang, 2017).

Objectives

The objectives of this study were to introduce, discuss, and implement a new approach for integrating engineering education disciplines in a technical way to help students in order to help them identify solutions for urgent socio-economic problems. This integrated-discipline approach helps students gain different skills for solving these problems in a practical way and to find an optimal solution.

CDIO Standards 2 and 3 Refocused for the Conceive and Design Stages

During the "Conceive" stage of the CDIO project, the students were encouraged to discuss the general theme that they wished to pursue in their group. The ideas presented might initially be impossible to complete, but if the proposal followed the base guidelines and had a practical application based on the CDIO syllabus, then the instructor could encourage them to follow it. More advanced CDIO projects required further personal and communication skills (in terms of English), as well as enhanced development abilities, systematic and creative thinking, and problem solving and teamwork (CDIO, 2010) that students must gain through the conceive-stage activities.

- The first task for students was to describe and outline their plans using a mind map (Johnson, 2001). The instructor would ask the students to present information gained from their meetings with companies, or other outside links they may have formed, in order to specifically identify practical problems related to mechatronics. To complete and improve this mind map, all students needed affective cognitive development, as well as creative and critical thinking. In this context, attention was paid to professional ethics as the important side of "human education." Pertaining to Standard 2, this procedure facilitated learning outcomes.
- The first draft of the students' designs rarely remained static, and the students were encouraged to be open to changes in their plans, based on the several meetings they would have with companies and associations. This presented a unique opportunity for the students and allowed them to sharpen their communication and analysis skills, as well as promote creative thinking in order to complete the learning outcomes and mind maps.
- This type of flexible model allowed the students to engage in discussions and reveal their personal views on the information presented. These views, however, were often likely to change, thus the students were encouraged to reorganize their teams. The problem focus had to pertain to the field of mechatronics and could be social in nature or company demand. The end goal of these discussions was a focus on delivering a complete product that was narrowed down to a single operation in the assembly line, a regulation of some product, or a humanitarian project like the one outlined in this paper.

The instructor's role in this process was essential to the students' success. The instructor worked to link all information from students and help them create the idea, as well as guide the more advanced engineering and technical aspects of the project in order to help them accomplish their engineering goals. In addition to the technical aspects of the project, the instructor also guided the teams' workloads and helped manage their time so that they could complete all scheduled meetings, seminars, workshops, and presentations required of them within the assigned time frame. This helped take some of the managerial workload off of the students and let them focus more on the technical aspects of the project. The final project focus was determined by the students, and the project was to develop a wheelchair for disabled persons. The concept not only applied to the people of Vietnam, but also served to satisfy practical global demand. Statistics show that 7% of the total population of Vietnam is disabled; they need a motorized wheelchair that could be disassembled quickly and smoothly. Also, the equipment had to be available at a reasonable price for moving not only on a street, but also in an indoor environment. This, all students worked hard on the design of a dismantling mechanism so that a user could assemble and disassemble it in a matter of seconds. Figure 1 shows their design.

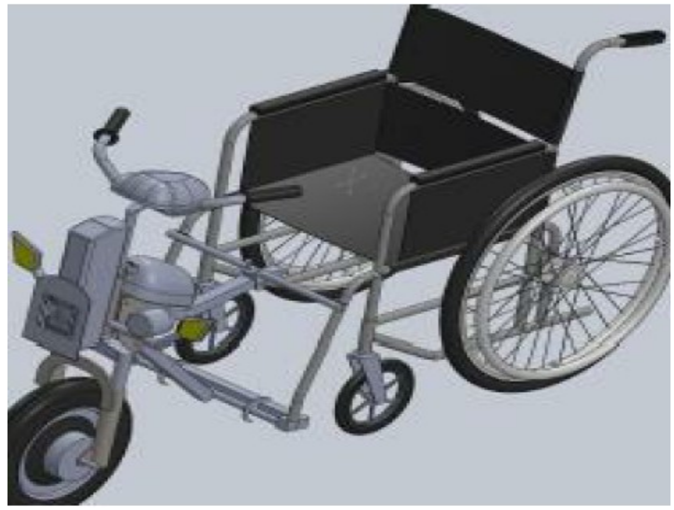

Figure 1. Disassembled locomotive drive.

In this community, though many people have lost their mobility, their mental and physical wellbeing are strong factors in their quality of life. They have to face daily many difficulties with moving and working, and their dream is a wheelchair that can help them move freely and work at home. The mind map below is an example of how all information gathered by a team can be collated together in a readable format (CDIO, 2010).

Figure 2. Mind map providing data on a low-price electric wheelchair for disabled persons.

In the concept stage, this student team was contacted by the association for disabled persons and families for approaching disabled people to gain insight into customer needs and to consider the technology needed in order to develop the technical and business plans. During this stage, the students also began design work on the wheelchair and collected related reference materials. On the managerial side of the project, the students relied on the instructor to arrange meetings with the local associations for disabled persons, their families, and local governments to ensure that the students' surveys and investigations would be welcomed and encouraged.

The second stage of the design began with the data collected from onsite investigations. The students analyzed the data and proposed some design and engineering details for the wheelchair. Figure 3 shows students working in the lab. The emphasis of this stage was on proficiency with certain software packages, such as *Microsoft* Visio, AutoCAD (Tickoo, 2016), Autodesk Inventor (Tickoo, 2015), as well as the completion of the project's teamwork requirement. The overarching goal of this stage was to finalize a well-thought-out technical solution that satisfied the specification required of the wheelchair. The instructor's role in the phase was to monitor, consult, and answer questions about the mechanical and dynamic calculations, which included more technical aspects such as data processing from sensors and the regulation of limb movements. This served to support the student learning in engineering prototyping, process, and system design.

Figure 3. Student from DTU in onsite learning.

The communication layer provided help to the students—regarding the people with disabilities and the communities that represent them—in learning important skills such as interviewing, data collection, observation, evaluation, and the creation of technical proposals. Prototyping within the groups was highly encouraging, and students could use both AutoCAD and Autodesk to create 3D models for prototyping. This was the most basic integration of the skills required in the curriculum (Enelund, Wedel, Lundqvist, & Malmqvist, 2012) to design and implement the product (Standards 2, 3 - CDIO Standards v2.0 - 2010). This project served to satisfy a continuous-improvement model by having the students constantly working together and with their intended users (people with disabilities) to reduce costs, when compared to traditional methods.

In the third stage—implementation—all students from the Department of Mechatronics, under the guidance of the instructor, worked hard in the university's workshop, where they used machines such as laser cutters, CNC mill, and lathes to fabricate the prototype of the wheelchair. Since they were juniors in the mechatronics program and had manufacturing processes skills, all were involved in making the prototype. The students also applied their knowledge of mechanics, statics, and machine elements to calculate the power of the driver needed for wheelchair and choose the electric power and battery charger. Figure 5 depicts a schematic drawing of the theoretical system and its variables.

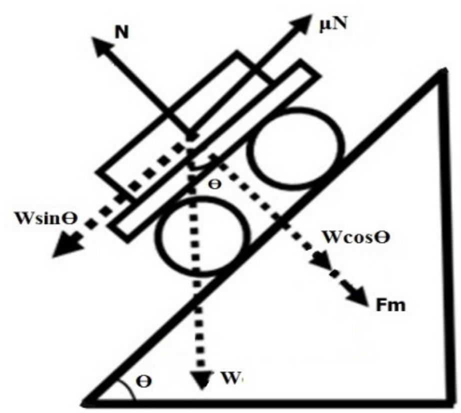

Figure 4. Variables associated with the system.

Several equations were derived from the system. The normal force from the ground is given by Equation 1:

$$N = W * \cos(\theta) \quad (1)$$

where,
W = 100 kg (the weight of the wheelchair)
θ = 30º (the angle of inclination)

Using the normal force, N, found in Equation 1, the torque could be found using Equation 2:

$$T = \left(-W\sin(\theta) + W\cos(\theta) + \mu N\right) * \left(\frac{D}{2}\right) \quad (2)$$

where,
μ = 0.6 (the coefficient of friction of rubber on concrete)
D = 0.53m (slope distance)

The required amount of torque for this scenario, given these values for variables, was found to be T = 230 Nm. Using this value, the power required to move the wheelchair must be calculated in order to choose a proper motor for driving the system. The power required was calculated using Equation 3:

$$P = \frac{T * V}{9550 * \pi * D} \tag{3}$$

where,
V = 60 km/H (the linear velocity required by the motor)

Given these parameters, the minimum amount of power that the chosen motor had to produce was 230W. For safety, and so that the motor would not always be operating at 100% of its capacity, one was chosen with a power capacity of 450W, driven by a voltage of 48V. This would bring the maximum current consumption, I, to 9.4A. Using these values, a battery with optimal capacity was chosen using the following method: the battery capacity is equal to the power requirement (in watts) multiplied by the backup hours (in hours) divided by the battery voltage (in volts). In this case, the solution would be (240*2) /48 = 10Ah. Through practice, the students would be able to improve their implementation of these processes. All of the students who joined this project fulfilled many tests in order to produce the quality of wheelchair, especially the safety in operation.

Figure 6 shows the final stage of the project—operation—which would help the students deliver their product directly to the people with disabilities. The students would also instruct them on how to operate the wheelchair, under all conditions, and strongly commit to the repair service.

Figure 5. Final design of wheelchair.

Refocus of Standards 6-8 (CDIO Standards V2.0) in the Implement and Operate Stages

After a series of training exercises, the students actively participated in suggesting models for implementation, proposing to fabricate them, and designing products to analyze in small team collaborations, while providing feedback in the process. This stage focused on the fabrication of the wheelchair, providing the students with the practical and professional skills associated with it (Standard 8). The instructor only provided guidance and offered suggestions through their connection with the Center of Electrical Engineering—CEE (one engineering division of the university, having facilities for mechanical manufacturing, programming, simulation, etc.) so that experts from the CEE could be available to support and help them realize their ideas.

The students took sole ownership of their project, including the analysis and engineering phase, and took on the social obligations that came along with the project. This method of teaching is quite unique, and the learning activities (Standard 7) provided in the CDIO project could not be implemented in previous semesters, due to space restrictions. The students took it upon themselves to contact technical staff to demonstrate their proposal and also prove certain aspects using technical instruments and modern software. The methodology used has many advantages as follows:

- The space requirement of the CDIO program was extensive and provided the students with ample workspace as well as the opportunity to move to workshops and laboratories in the Center of Electrical Engineering. Open-space learning has helped students effectively comprehend more than what would be capable in a traditional classroom environment.
- The direct communication and teamwork with the instructor (Erekson & Shumway, 2006) allowed the students to improve their professional experience. The project advancement, under the supervision of the instructor, had few mistakes and shortcomings, due to the supervision, while also allowing the students to gain practical experience in the field with minimal setbacks. The end design was intended to be used in the real world, exactly from the students' designs.
- The university allows students to use well-equipped technical facilities as research tools as well as development and training tools. The students were allowed to take advantage of the available machinery and materials from the Center of Electrical Engineering, which helped them save research expenses.

Figure 6 shows that, in the operation stage, the students were required to test the wheelchair under normal working conditions within the company workshop. In past projects, students were not required to do this, as the CDIO project requirements were limited to the completion of the target and not necessarily a deliverable project, which was due to certain constraints within the university. Within this advanced CDIO project, the students developed more experience and entrepreneurial skills, allowing the instructor to apply better criteria in evaluating practicality, fullness, and flexibility in the production aspect of the project. Normally, one project is evaluated by a complex set of criteria, such as relevance, fulfillment of the objective, efficiency, effectiveness, impact, and sustainability. As an instructor, we follow all criteria, but we pay more attention to entrepreneurial skills and an integrated approach in assessments.

Figure 6. Students testing mechanical components and electronic automation of the wheelchair.

Conclusions

The project, engineering a wheelchair for persons with disabilities, was a typical example used to strengthen the students' professional skills, especially in mechatronics and mechanical engineering, by integration and simultaneous implementation of complex CDIO standards. This is one new approach to set the social obligation for students in the market to study and constructively implement inter-branch knowledge in an integrated educational environment, extended space, and technology improvements. Its target was for a reasonably priced, practical product, paying attention to a humanitarian application.

This is important, as it prepares students before joining the labor market. In all stages of this unique CDIO project, the junior students in the mechatronics program, as well as the instructors and the research staff of CEE from Duy Tan University, applied CDIO standards to create a working product (see Figure 7) that was integrated with teaching typical technical subjects. This CDIO project once more gives evidence of how the university implements CDIO methodology, not only in the preparation of the syllabi, but also in all stages of the education process.

Figure 7. Delivery ceremony in Duy Tan University.

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