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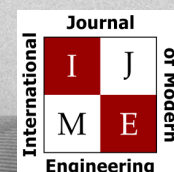
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# EDITOR'S NOTE: IJERI IMPACT FACTOR AND INDEXING



Philip Weinsier, IJERI Manuscript Editor

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## IMPACT FACTOR AND INDEXING

Faculty publication in academic journals is a key criterion for appointment, tenure and promotion at most universities. Furthermore, many universities weigh the publications according to the quality, or impact, of the journals. But what metrics do authors use in choosing a journal? And, how do we, as fellow researchers and/or readers in search of journal articles, find what we're looking for? Yes, doing an Internet search generally produces results; but such results just as often are so watered down with what we are not looking for that we waste valuable time or get frustrated and give up. For the savvy readers, though, they join indexing or abstracting service organizations. Here, one can find articles focused into discipline-specific topics. Examples of such organizations include ChemAbstracts (chemistry) and PubMed/Medline (medicine).

The most well-known of these abstracting and indexing organizations are Google and Thomson Reuters/ISI, which cover a broader mix of disciplines. Here, readers and researchers alike are able to home in on what they need, while at the same time receive a measure of the relative quality of the source journal. Google provides information about journal articles cited by other articles; information that can give researchers a sense of value in terms of how other researchers are using the studies published there. Thomson Reuters/ISI, for its part, provides a ranking of journals by what it calls its impact factor (IF). For years, the scientific community has used this as a measure of the average number of citations to articles published in a given journal. It has also become a common practice to use IF as a means of ranking the relative importance of a journal.

The Thomson Reuters/ISI Web of Knowledge is a larger platform that includes multiple databases and tools such as the Web of Science—which also covers the Science Citation Index—and the Journal Citation Reports (JCR), which reports all related analytical information as well as impact

factors. The Web of Knowledge indexes more than 11,000 science and social science journals. What you may not know is that besides ISI's impact factor, there are numerous other methods for ranking journals such as:

- Google Journal Metrics (using Google Scholar)
- Eigenfactor Search
- H-Index (available from Scopus and SCImago Journal Rank)
- Citations (available from Microsoft Academic Search)
- SCImago Journal Rank (SJR)

## IJERI: THE NUMBERS

The most popular ranking organization is Google Scholar Metrics (GSM), which is also available free to the public. According to GSM, the impact factor of IJERI, since its first issue in the fall of 2009, is .432 (with no self citation), which is rather remarkable for a relatively young journal. In comparison, most journals that are ranked by ISI have impact factors lower than IJERI. This places the journal among an elite list of engineering journals worldwide.

As noted above, impact factor of a journal is but one measure of its quality; another is indexing. While almost all journals seek indexing in indexing organizations, on rare occasions the major indexing organizations approach high-quality journals on their own to sign indexing contracts. We are proud that IJERI and its sister journals, IJME and TIJJ, have been invited to join EBSCO, one of the largest leading indexing organizations.

IAJC, the parent organization of IJERI, has also taken an aggressive approach to index the journal with other major indexing organizations in order to maximize its exposure and improve its quality and impact factor. At the time of this publication, IJERI is indexed by 15 major indexing organizations and under review by several more—visit our website ([www.ijeri.org](http://www.ijeri.org)) for a complete listing.

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Listed here are the members of the IAJC International Review Board, who devoted countless hours to the review of the many manuscripts that were submitted for publication. Manuscript reviews require insight into the content, technical expertise related to the subject matter, and a professional background in statistical tools and measures. Furthermore, revised manuscripts typically are returned to the same reviewers for a second review, as they already have an intimate knowledge of the work. So I would like to take this opportunity to thank all of the members of the review board.

As we continually strive to improve upon our conferences, we are seeking dedicated individuals to join us on the planning committee for the next conference. Please watch for updates on our website ([www.IAJC.org](http://www.IAJC.org)) and contact us anytime with comments, concerns or suggestions.

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# DEVELOPMENT OF A LOW-COST MOBILE EMBEDDED HANDHELD AIRCASTING DEVICE

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Pawel Obrok, Lunar Logic Polska LLP

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## Abstract

AirCasting devices represent an environmental sensing platform that allows participants, known as AirCasters, to record, broadcast and map air status updates in real-time using their Android smartphones and/or tablets. Initial development efforts in this study focused on recording variability in sound levels, temperature, humidity and carbon monoxide. The data collected and annotated by the AirCaster was uploaded to an interactive web-based map that displays both individual and aggregated routing information. Each AirCasting session allowed the user to capture real-world measurements, annotate the data to tell their story, and share the data with local and world-wide communities via a Crowd Map. The AirCasting platform also employs color-changing clothing accessories to communicate the status of the air in a particular place and time to both the AirCaster and people within the immediate vicinity.

## Introduction

Air pollution in the U.S. is estimated to cause in excess of \$78 billion in damages annually [1]. Of primary concerns are the human health effects of air pollution, including premature mortality and chronic illnesses such as bronchitis and asthma. Despite the tremendous economic costs and pervasive negative health impacts of bad air, air pollution often goes unnoticed because it is largely invisible. Much of what happens in our immediate environment passes without note despite the contribution that events such as recording and crowdsourcing might have on our understanding of us and our communities. AirCasting captures a spectrum of that lost reality and returns it to us as data that is consistent in its units of measurement and, therefore, easily meshed with data from other AirCasters. By making it possible for AirCasters to annotate specific environmental events in time and space, the authors supplemented the qualitative information reported through conscious human experience with the quantitative information from sensing handheld devices that observe and record aspects of our environment that are either impossible to perceive directly (e.g., pollutant gas concentrations) or difficult to quantify and communicate in a consistent manner (e.g., sound levels). AirCasting allows individuals to broadcast what is happening with their envi-

ronment, crowd source their own information with that from other AirCasters, and identify patterns and commonalities. Thus, this AirCasting device makes air pollution visible, thereby empowering communities advocating for healthy environments.

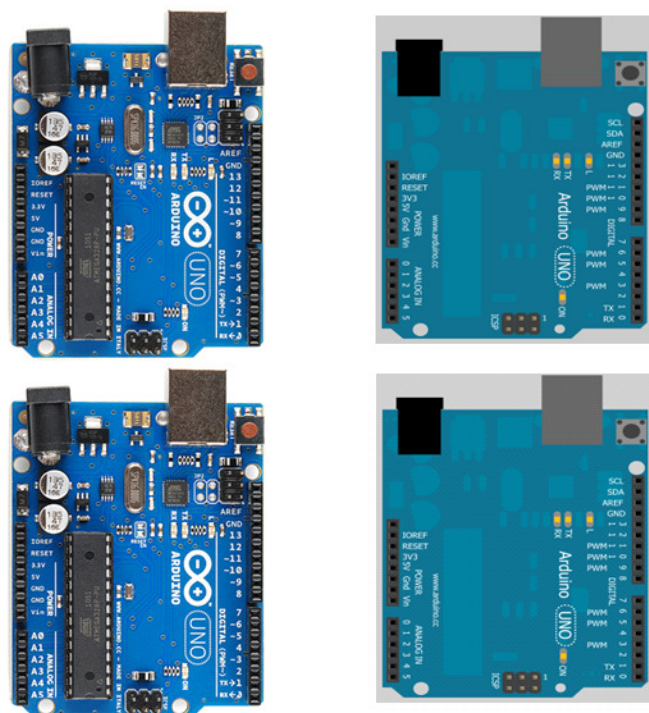
Unlike commercially available off-the-shelf chemical detection devices, the AirCasting device, with its novel design and small size, could potentially provide an advanced warning of impending danger. Comparing the AirCasting device to two commercially available off-the-shelf hazardous-vapor warning devices—the LCD 3.3 [2] and the Nose Gas Sensor [3]—the AirCasting’s Bluetooth modem allows it to communicate with the world-wide web by connecting to devices such as smartphones or tablets; whereas, the LCD 3.3 and Nose Gas Sensor have no way of connecting to the web. Additionally, neither the LCD 3.3 nor the Nose Gas Sensor is small or within the price-range of ordinary consumers. This makes the AirCasting device an improvement over currently available devices for use in a chemical detection or early warning system. Also, the AirCasting device is a low-cost environmental monitoring system that ordinary consumers can afford. The current custom-made AirCasting prototype costs about \$130-\$150 per unit to produce; whereas, current off-the-shelf monitoring devices start at around \$2,000 per unit.

## Microcontroller

Handheld AirCasting devices include a microcontroller. In general, a microcontroller is a small computer on a single integrated circuit containing a processor core, memory and programmable input/output (I/O) peripherals. There are many types of microcontrollers available on the market—PIC 18, ATmega 32, Arduino, Netduino, 68HC12, BASIC Stamp, VEX Cortex Microcontroller, NXT Microcontroller and the BasicATOM 28X, among others. In this study, an Arduino UNO microcontroller was used in the custom-designed handheld device due to its low cost. Figure 1 illustrates the physical Arduino UNO microcontroller and 3D Arduino hardware schematic layout. The 3D Arduino hardware schematic was created using the Fritzing software program [4]. The Fritzing software program is a freeware pro-

gram that is capable of making 2D and 3D schematic diagrams.

The Arduino has two power pins; one for 5V and the other for 3.3V. In addition, it has a Vin pin which is mostly from the input of the power supply, and it is around 9V. Further, the Arduino has two ground pins along with a reset pin.



**Figure 1. Arduino UNO Microcontroller and 3D Arduino Schematic Layout**

The Arduino UNO has I/O pins labeled on the right side of the microcontroller (see Figure 1). There are 14 digital pins of which 6 provide the pulse width modulation (PWM) output. PWM can be used as digital or as PWM itself. PWM pins act like variable analog outputs. Standard digital inputs and outputs, on the other hand, mean simply turning on/off an LED. In other words, digital means on or off, yes or no. These pins not only serve as outputs but inputs as well.

The Arduino UNO also has 6 analog input pins labeled on the left side of the microcontroller (see Figure 1). The analog inputs are generally used for sensors with analog outputs such as temperature, humidity or gas (CO, CO<sub>2</sub>, NO, NO<sub>2</sub>, etc.). It also has one set of communication pins (TX/RX). Communication pins are used for serial inputs and outputs for wireless communication between devices. Some examples of devices that use these communication pins are Bluetooth transceivers or ZigBee transceivers, which are useful

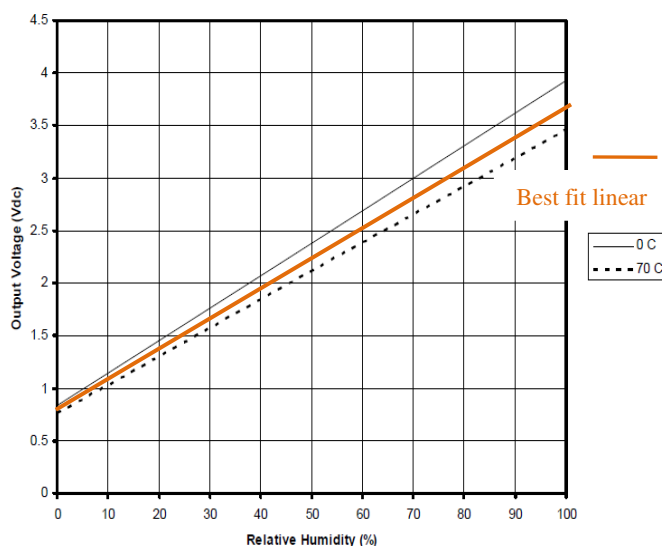
and practical in educational capstone projects. Heng et al. [5] provide some examples of capstone projects.

## Sensor Calibrations

The low-cost mobile embedded handheld AirCasting device has three different types of sensors: A temperature sensor (LM335A), a humidity sensor (HIH-4030) and a carbon monoxide (CO) gas sensor. The signal data acquisition from the three sensors is raw analog data. The raw data must be calibrated with respect to that sensor. For instance, the calibration for the raw analog value of the LM335A temperature sensor would be as follows:

```
float Kelv = (((analogRead(A2) / 1023.00) * 5) * 100;
// Kelv = Kelvin
float Cel = Kelv - 273.15; // Cel = Celsius
float Fah = (9.00/5)*Cel + 32; // Fah = Fahrenheit
```

Note that the analogRead() function reads the voltage applied to one of the analog pins from the Arduino UNO in Figure 1. In this case, the analog pin is A2. This analogRead() function returns a number between 0 and 1023 [6], which represents voltages between 0 and 5 volts (V). Also, the factor of 100 in the Kelvin equation comes from the fact that the LM335A works like a Zener diode with a breakdown voltage proportional to the absolute temperature at 10mV/°K [7]. Unlike the calibration of the LM335A, the manufacture of Honeywell Corporation provides a chart [8] on output voltage versus relative humidity, as shown in Figure 2.



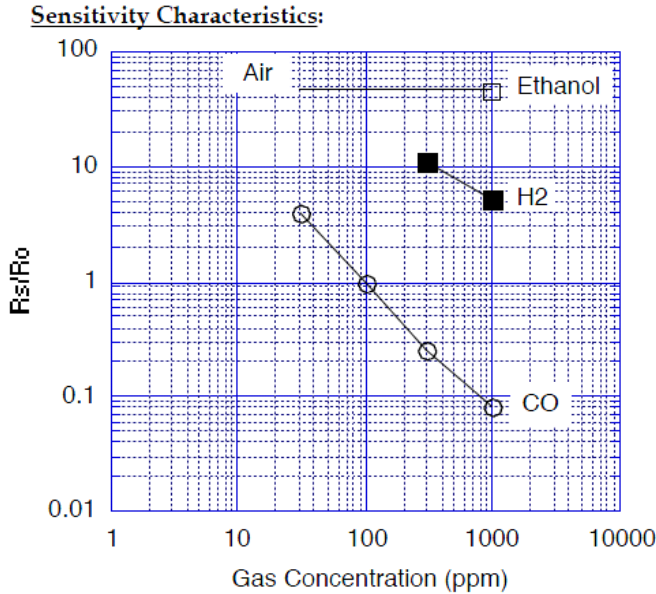
**Figure 2. Output Voltage versus Relative Humidity**

Based on Figure 2, the best linear fit and linear equation can be used to calibrate the relative humidity value from the raw analog value.

```
float MaxV = (3.27-(0.006706*Cel));
float RelativeHumi = (((analogRead(A0)/1023.00)*5)-
0.8)/MaxV)*100;
```

Note that the maximum voltage (MaxV) value drops to 0.006706 for each degree Celsius over 0°C. The voltage at 0°C is 3.27. This is corrected for zero percent voltage offset, which is approximately 0.8.

Similar to the calibration of relative humidity, the calibration for carbon monoxide (CO) is based on the sensitivity characteristics of the gas concentration chart. For instance, the gas concentration chart [9] in Figure 3 is used as part of the calibration for the CO concentration in PPM (parts per million).

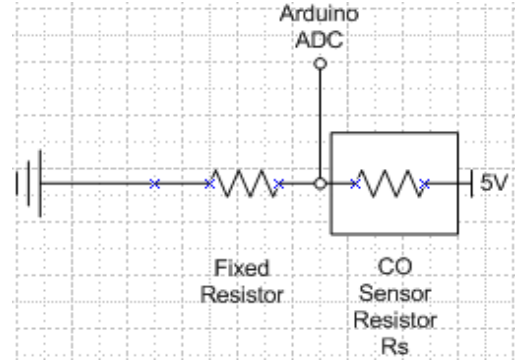


**Figure 3. CO Concentration in PPM**

The Y-axis in Figure 3 indicates that the sensor resistance ratio,  $R_s/R_o$ , is defined as follows:

$R_s$  = Sensor resistance of displayed gases at various concentrations  
 $R_o$  = Sensor resistance in 100 PPM CO

Figure 3 represents the typical sensitivity characteristics of the CO concentration level which increases as the sensor resistance decreases. As the value of the sensor resistor,  $R_s$ , decreases, the voltage across  $R_s$  decreases because the fixed resistor and the sensor resistor are connected in series. This is illustrated in Figure 4.



**Figure 4. CO Sensor Resistor**

Another way of looking at  $R_o$  in Figure 3 is the level of exposed gas to the sensor in a confined space. For instance, if 100PPM of the gas were poured into the container in a confined space, what would the  $R_s$  sensor read? It may read 98PPM or 102PPM. Using the voltage-divider concept, the formula for defining the sensor is as follows:

$$R_s = \frac{V_c \times R_L}{V_{out}} - R_L \quad (1)$$

From Equation (1),  $V_c$  is the voltage input, and it is the 5V from the Arduino UNO microcontroller.  $R_L$  is the load resistance (in this case, 39kΩ was used) that was connected to the CO gas sensor.  $V_{out}$  is a voltage signal from the CO gas sensor, which varied depending on the PPM CO concentration. The value of  $R_s$  in Equation (1) changes according to the amount of CO gas present—as seen in Figure 3; the typical detection range for the CO gas sensor is 30 to 1,000PPM. If the resistance value of  $R_s$  is the same as  $R_o$ , then  $100/100 = 1$ , which correlates to 100PPM in Figure 3. In theory,  $R_o$  represents the X axis in Figure 3, if conditions are perfect.

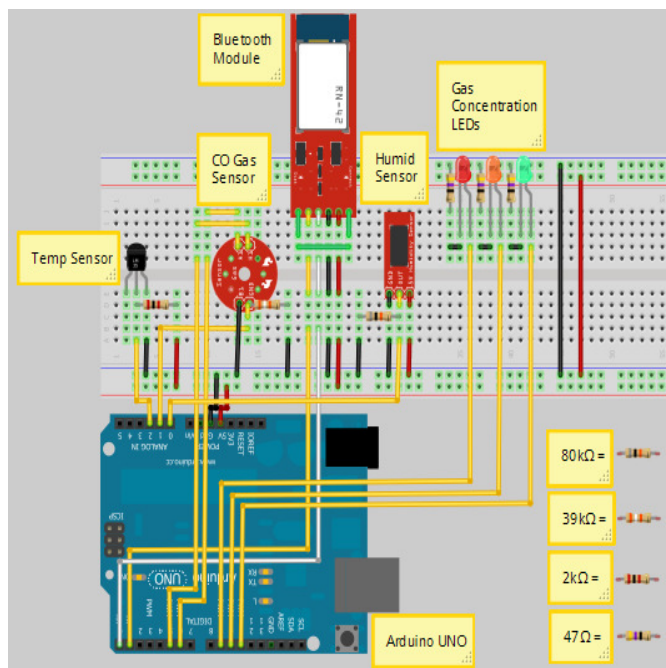
## Hardware Schematic of the Handheld AirCasting Device

Using the Fritzing software program, the overall schematic layout for the handheld AirCasting device was designed, as illustrated in Figure 5.

From Figure 5, the yellow, red, and black wires are used as data signal communication, voltage and ground, respectively. The signal lines for the three sensors (temperature, CO gas and humidity) connect to the Arduino analog pins A2, A1 and A0. The red and black lines are connected to the Arduino 5V and ground pins, respectively. The yellow and white wires from the Bluetooth module are used as the transceivers and are connected to Arduino pins TX (transmitter – yellow wire) and RX (receiver – white



wire). The use of a Bluetooth module provides the wireless communication lines between the AirCasting device and a smartphone or tablet. Also, the three color LEDs indicate the level of CO gas concentration. The green, orange and red LEDs indicate the least, medium and highest CO concentrations, respectively, making the AirCasting a unique mobile handheld device.



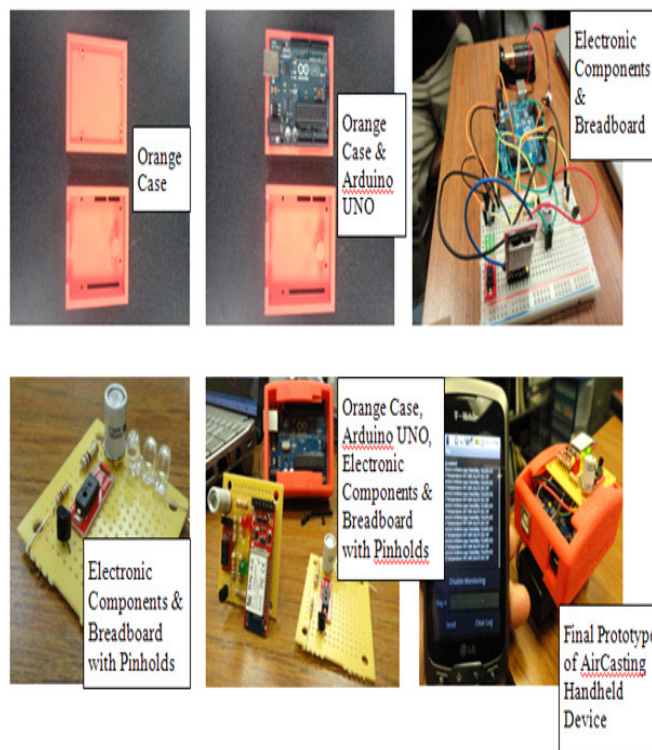
**Figure 5. Schematic Layout of the Handheld AirCasting Device**

## Prototyping of the Handheld AirCasting Device

Based on the hardware schematic layout of the handheld AirCasting device in Figure 5, the physical prototype for this device was made. Figure 6 shows the progress stages in designing the AirCasting device.

The custom-made AirCasting device cover (orange case) is used for holding the Arduino UNO microcontroller and electronic components (sensors, resistors, LEDs and Bluetooth) along with the breadboard. First, a computer model of the AirCasting device was created using Autodesk Inventor software. Figure 7 is a computer rendering of the device. Then, a physical prototype was made using a 3D rapid prototyping machine, as shown in Figure 7. The electronic components were soldered on the back side of the breadboard. After all of the electronic components were

soldered onto the breadboard, the completed breadboard was mounted into the orange case. This completes the design stages of the AirCasting prototype.



**Figure 6. Design Stages of the Handheld AirCasting Device**

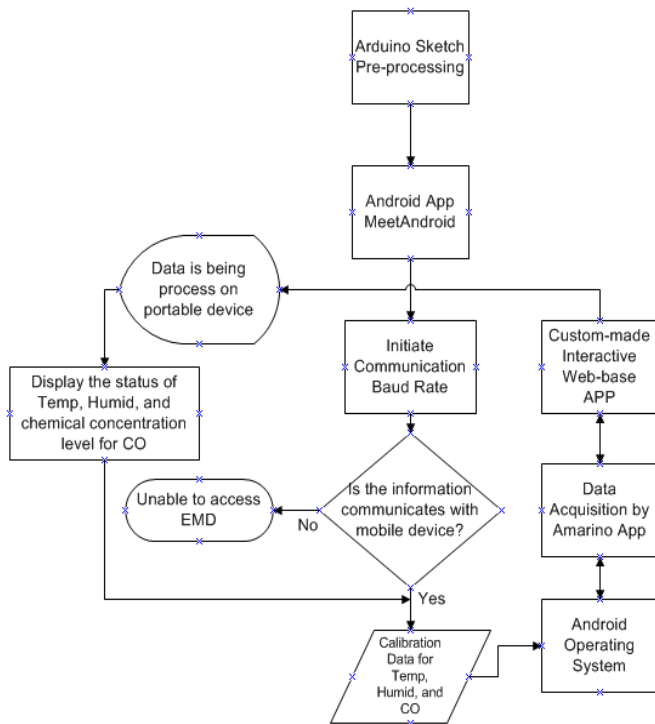


**Figure 7. Computer Rendering and Physical Prototype of the AirCasting Device**

## Software Design of the Handheld AirCasting Device

Following is a discussion of how the software program communicates and interfaces between the AirCasting device

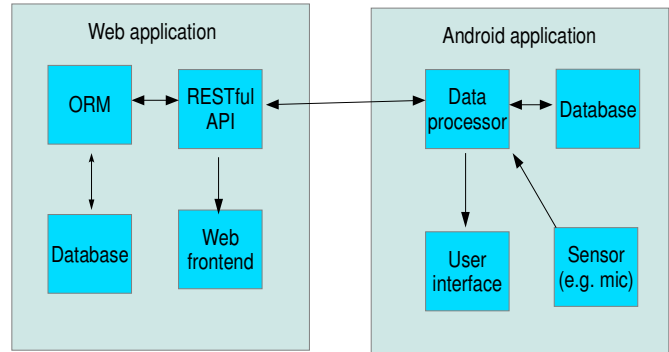
and mobile smartphones or tablets. The source code was written in Arduino Sketch to communicate and interface with the electronic components, such as the temperature sensor, humidity sensor, CO gas sensor and LEDs, as shown in Figure 6. Upon the success of interfacing with the sensors and LEDs in Arduino Sketch, the Android library MeetAndroid was imported into the Arduino library folder so that the data could be sent from the Arduino Serial Monitor to the Amarino Application (App) program. The Android library MeetAndroid is part of the Amarino driver device that must be imported into the library folder of Arduino Sketch. The Amarino program [10] is a freeware program that incorporates a plug-in mechanism which allows programmers and developers to integrate their events into Amarino. This, then, provides a gateway to communicate with smartphones or tablets based on the Android open-source operating system. Figure 8 illustrates the details of communication between Arduino Sketch, the Amarino App, AirCasting App and Android operating system.



**Figure 8. Flowchart of the Handheld AirCasting Device**

Since the Amarino program is capable of acquiring the data acquisition from the AirCasting device through Arduino, the AirCasting App was developed to retrieve the data from Amarino App. This AirCasting App is an interactive web-based map that displays both individual and

aggregated routing information on sound levels, temperature, humidity and carbon monoxide. It is written in the high-level Java and XML programming languages. The source codes of the AirCasting App are too long to be included here. Instead, the block diagram of the AirCasting App is introduced in Figure 9.



**Figure 9. Block Diagram of the AirCasting Application**

The system in Figure 9 is composed of two main parts: an Android App and a Ruby-on-Rails [11] backend. The main purpose of the Android App is to gather environmental data which is subsequently stored in the backend. It also allows the user to view data gathered and stored in the backend. The web application's purpose is twofold: it exposes an API which the Android App can use to submit data, and has a web user interface for a more comfortable way to browse the data.

## Android Application

The Android App (see Figure 9) accesses an environmental sensor connected to the phone (thus far, only the built-in microphone) and stores measurements obtained from that sensor (in the case of a microphone, sound volume levels). The measurements are annotated with the time and location where they are taken and form a sequence called a session. The users can add their own notes (to sessions) to indicate that some special events have occurred while measuring.

Sessions are stored in a database on the phone so that users are quickly able to access their data using the API. The application will also upload sessions to the backend when network connectivity is available. The application's user interface allows the user to view both their local data and aggregated data obtained from the web application's API.

## Web Application

The most important part of the web application is the API it exposes. A RESTful HTTP approach [12] was used in this study and all data were transmitted as JSON [13] for maximum simplicity. The most important functionalities of the API are:

- Uploading sessions
- Accessing raw session data - this is used, for example, when the user is viewing a single session
- Accessing aggregated data - this is used to generate a "crowd map" represented with color-coded averaged data overlaid on top of a map

The API uses an Object Relational Mapping (ORM) [14] layer to write and read data from a database; thanks to this, the sessions from various users are kept in one place and aggregate data may be calculated. The web interface is functionally very similar to the user interface available in the Android App; it uses the data exposed by the API and renders it for the user. The complete source codes for the AirCasting App are available on the following AirCasting website: <http://aircasting.org>. The sample of the AirCasting App for sound levels can be seen in Figure 10.



Figure 10. AirCasting App for Sound Levels

## AirCasting Device: Testing and Results

Several tests of the AirCasting device were performed at different locations to record temperature, humidity and CO. The test was done by using a laptop, a Xoom tablet and a T-Mobile Android smartphone. The preliminary results, an average of the tests, are shown in Table 1. Several tests were conducted and hundreds of data points were recorded on four different scenarios by using a laptop, a tablet and a smartphone. Each scenario was then averaged, as displayed in Table 1. Of the four different

scenarios, the worst case was placing the AirCasting device behind the car's exhaust pipe while the car engine was running. In this case, the average temperature, humidity and CO were approximately 85.7°F, 107.6% and 81.5PPM, respectively. Note that the wind factor was about 7 to 10 miles per hour while these outside tests were being performed. This is why the results of the temperature, humidity and CO were a bit low due to the wind factor.

Table 1. Testing and Results

Average	Temp (F)	Humid (%)	CO (PPM)
Indoor Tests	80.5	18.3	13.7
Outdoor Tests	42.3	31.5	8.1
Inside Passen-	57.3	22.1	22.2
Behind Car's	85.7	107.6	81.5

## Conclusion

The handheld AirCasting device is about crowdsourcing cybernetic systems. Seemingly, every day brings to market a new portable device that is capable of augmenting human sensory experience by tapping into phenomena that are beyond the limits of human perception. On any given day, the air may be bad in a particular place; or, our asthma may be flaring up. But sensing and communicating the quality of the air or the state of our bodies in precise and universal terms only becomes possible with the aid of scientific instruments. Previously, these instruments either did not exist or were too expensive or bulky to be purchased and carried on or in the human body. Currently, though, portable environmental sensors, tracking devices and bio-monitors are rapidly becoming ubiquitous. The output from these cybernetic systems is innately social as data-basing and crowdsourcing are fundamental to the way they record information and evolve through technological iterations. By creating a platform that crowd sources data from thousands or potentially millions of cybernetic devices, a handheld AirCasting device becomes an analytics engine capable of picking out emergent patterns in human environments and biology.

## Acknowledgements

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## Biographies

**DR. IEM HENG** earned his bachelor's degree from Providence College (Providence, RI) with double majors in Pre-Engineering Program and mathematics. In addition, he earned another bachelor's degree from Columbia University

(New York, NY) in mechanical engineering and master's in applied mathematics from Western Michigan University (Kalamazoo, MI); his Ph.D. in computational and applied mathematics from Old Dominion University (Norfolk, VA). Before joining the EMT/CET department at City Tech in fall of 2007, he was a faculty member and chair of the CET department at DeVry Institute of Technology (Long Island City, NY). He worked as a researcher for NASA Langley Base in Hampton, VA, for two years. His research activities include embedded systems, robotics, mechatronics, software development for embedded systems with real time simulation, real time gaming simulation programming, and web application programming.

**DR. ANDY S. ZHANG** earned his Master's in mechanical engineering from the City College of New York in 1987 and his Ph.D. in mechanical engineering from the Graduate Center of the City University of New York in 1995. Prior joining the Mechanical Engineering Technology department at City Tech in 2000, he served as an engineering instructor for the JUMP, an engineering training program sponsored by the New York State Department of Transportation. Professor Zhang's research area includes materials testing, composite materials, CAD/CAE, robotics and mechatronics, and engineering technology education.

**MICHAEL HEIMBINDER** is a community organizer, educator, and information designer. HabitatMap's community mapping and social networking platform is a direct testament to Michael's dedication to creating online platforms that engage the public and facilitate the sharing of news and information using geographic information systems. Since launching HabitatMap in 2006 he has worked with dozens of community based organizations and schools to create planning and advocacy maps that publicize the issues they care about most. In addition to running HabitatMap, Michael is Vice-Chair and Project Manager of the Newtown Creek Alliance, where he has made community knowledge sharing the keystone of the organization's successful efforts to clean up the Creek and improve quality of life in the surrounding neighborhoods. He is also a member of the New York State Environmental Justice Interagency Task Force Mapping Work Group and an advisor to the Organization of Waterfront Neighborhoods where he consults on solid waste management issues in New York City. Michael is a graduate of Colorado College and received his M.A. in International Affairs from the New School for Social Research.

**PAWEL OBROK** works for Lunar Logic Polska as part of web development team. He works on the programming aspect of AirCasting App and website to receive and display air quality data.

# IMPLEMENTING A SOFT-CORE NIOS II PROCESSOR FOR VGA APPLICATIONS

Saeid Moslehpour, University of Hartford; Kouroush Jenab, Society of Reliability Engineering-Ottawa;  
Balvinder Singh Pabla, University of Hartford

## Abstract

Today's embedded system designing industries use FPGAs for rapid prototyping, a demand of industry for development of precision and fast processing speeds with short turnaround times across a variety of applications. Board-level prototyping methods are described as a significant piece of the embedded system design flow. In addition, simulation, debug and reconfiguration prototyping tools provide functional and performance verification. This study used an Altera DE2 board as a platform to implement a game called air hockey (single slider) or pong game. The Quartus II 7.0 and Nios II 7.0 eclipse are used as software design tools. The Altera DE2 boards, which contain Cyclone II 2C35 FPGAs, were used as hardware to communicate with the peripherals, i.e. VGA and USB.

## Introduction

Engineering educational games and competitions—including events such as robotic events, egg drops, pumpkin launches and paper airplane design—help to educate students in the design of projects. Educational games have rapidly become popular. Many domestic and international experiences show that educational games have a significant influence on the growth of young people [1-4]. In electrical and computer engineering conferences and workshops, student competitions such as programming and robotics tend to dominate the landscape in the form of robot soccer and autonomous vehicle navigation. These challenge engineering students to reach a higher level of skill and knowledge. By configuring hardware with the soft-core Nios II CPU designed on the DE2 Board, the authors were able to create the sought-after game environment. Through the use of the system, one can immediately see that it is highly responsive to the user's hand movements, and the dynamics of the game emulate real experience exceptionally well.

## Applications

The user interactive virtual environment has a wide range of applications due to the advantage that the user's physical movements have interactions with the graphical world. It may be for fun, learning, exploring or making selections in order to find their key role. This makes virtual environments

useful in gaming, pilot training for using aircraft simulators, car driving, as well as selection of options on ATMs, cash registers, and industrial automation for setting the parameters for the equipment. The Graphic User Interface (GUI) has a wide range of applications and its areas are increasing due to the involvement of high-performance electronic hardware coming onto the market on a daily basis. The best example can be seen in surgical robotics, endoscopy and deep-water ocean research. These applications require fast and precise user hand movements to be transferred to the machine's robotic movements.

## Soft-Core Processor

A soft processor is a microprocessor core that can be customized and implemented logic descriptions that can be included with the rest of the design, compiled into a gate-level description, and routed onto the FPGA. Typically, a soft processor is described in Verilog or VHDL and then combined with the remainder of the Verilog or VHDL design [5]. The soft processor typically made of logical elements found in FPGAs and described in a Hardware Description Language (HDL), like VHDL or Verilog. The common soft-core include Nios, Nios II, Pico Blaze, Micro Blaze, Lattice Mic08 and so on, among which the Nios II develop by Altera Corp. and the Micro Blaze developed by Xilinx Corp [6]. In a soft-core processor, the designer has the flexibility to choose the instruction set, hardware features, and the data and address size as shown in Figure 1. Hardcore processors have a fixed instruction set and architecture, and can be designed for a specific purpose.

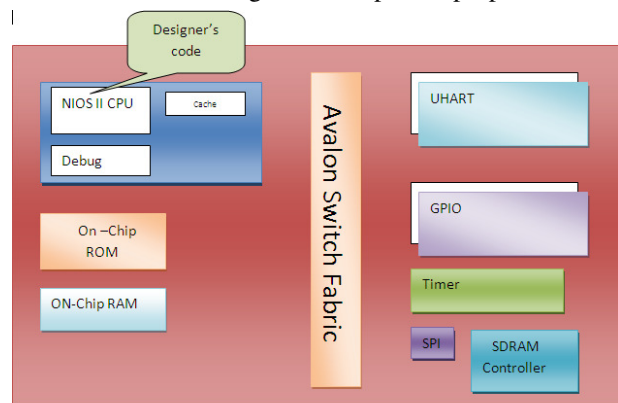


Figure 1. FPGA-Based Soft Core



## Nios II

This 32-bit soft-core processor architecture was developed by Altera Corporation. The older Nios was introduced in 2001 and was industry's first viable commercial processor created specifically for embedded system design in FPGAs. Nios II was embedded directly into FPGAs, which allowed for performance of more than 200DMIPS, and users could select more than 60 IP cores [7]. It also allows designers to include the available IP (Intellectual Property) modules during the design phase, which saves a lot of time [8].

The soft-core nature of the Nios II processors let designers integrate custom logic into the arithmetic logic unit (ALU) (Figure 2). The Avalon Switch Fabric (ASF) is one of the key features that differentiate the cyclone FPGA from other vendors' FPGA products. ASF is a high-bandwidth interconnect structure that offers greater flexibility than a shared bus. The switched interconnect structure of the ASF connects the master and slave ports. Nios II implements the function of the control and interpolation algorithm and the communication between the computer and the FPGA.

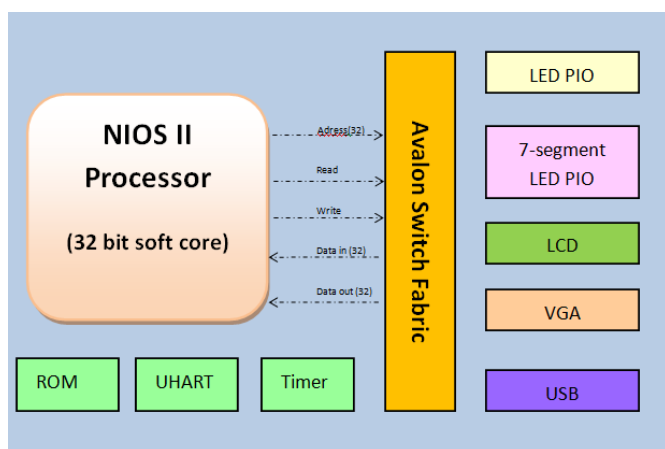


Figure 2. Nios II Soft-Core Processor

A master can connect to multiple slaves, and a slave can be connected to multiple masters. When a slave is driven by multiple masters, arbitration logic is automatically generated by Altera's System on a Programmable Chip (SoPC) Builder. Arbitration, by default, utilizes a round-robin master selection, but priorities can be associated with masters and used for selection. The DMA controller is given access to the data memory as well as the CPU. This allows data retrieval to take place without relaying the instruction through the system CPU. An interesting point is that the DMA controller accesses the VGA controller. The advantage of the Nios II processors is that they contain soft-core processors and there are numerous tools available for

them. The hardware-assisted debug module is especially useful for tracing applications. Ware-development environment easily allows the user to rapidly implement a prototype. For obtaining higher performance, the Nios II fast CPU core can be chosen. It contains a single-cycle hardware multiplier and dynamic branch prediction features that increase the performance of the application. Dynamic branch prediction means to perform pre-fetching of sequential instructions in order to keep the pipeline as active as possible.

Multipliers usually require more than one clock cycle, but with the single-cycle hardware multiplier, some highly mathematical applications can benefit from the optimization feature. The brief overview of the DE2 board displays the usefulness of the development board for rapid prototyping for a range of applications.

## Equipment and Software Package

### DE2 Board

On a Cyclone II EP2C35 FPGA chip, all important components on the board are connected to the pins of this chip to allow the user to configure the connection between the various components as desired (Figure 3).

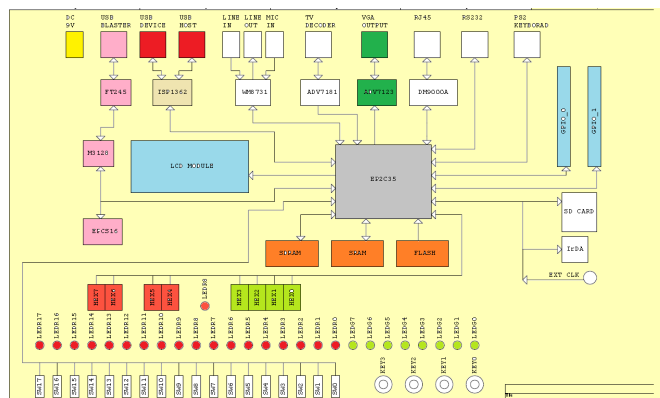


Figure 3. Region of the DE2 Board

Altera's DE2 board has become one of the most widely used FPGA boards for the development of FPGA designs (Figure 4) [8-10].

### Programming the DE2 Board

The Cyclone II FPGA can be programmed by way of the JTAG programming method or the EPCS16 Configuration Device programming method.

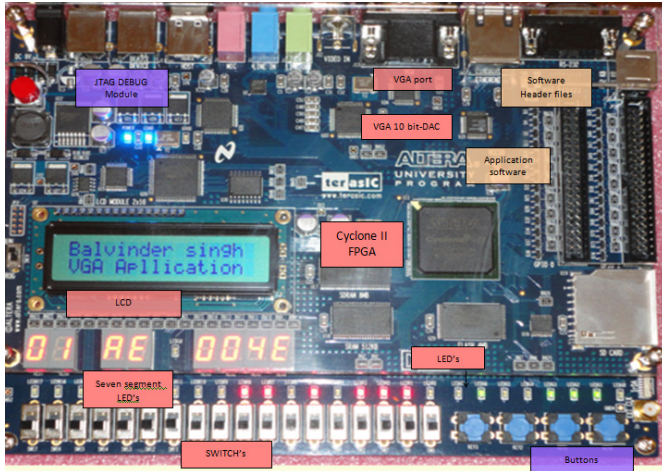


Figure 4. DE2 Educational Board

## JTAG Programming

JTAG programming is performed by downloading a configuration bit stream directly into the Cyclone II FPGA through a USB cable (Figure 5). In the JTAG mode, the FPGA stores the configuration data until the power is supplied. Figure 5 shows how JTAG programming is performed.

Quartus II programmers connect to the USB blaster circuit on the DE2 board such that when the switch on the board is set to "RUN," the configuration signals are sent to the FPGA. On startup, the default setting is for the serial configuration device to load the configuration files.

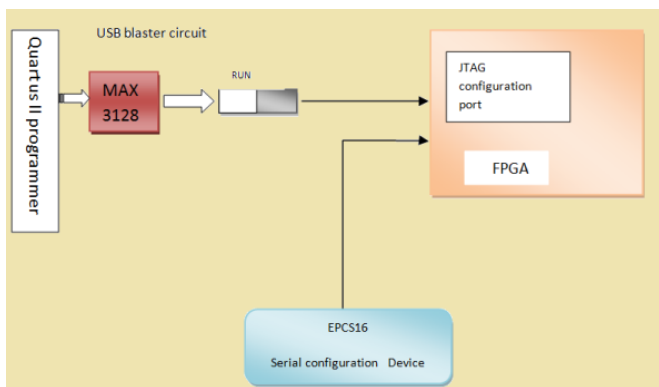


Figure 5. JTAG Programming of the Cyclone II FPGA

## Active Serial (AS) Programming

Active serial (AS) Programming is performed by downloading the configuration bit stream onto the Altera EPCS16 serial EEPROM chip. Using this mode, the data are retained

even when the circuit's power supply is off. This method of programming the FPGA ensures that the designer does not have to continually reload the design.

Figure 6 illustrates the process used by the designer to program the FPGA using the active serial method. The Quartus II programmer first has to be in the AS mode; the USB blaster cable is also used for this programming method. The switch on the DE2 board has to be set to the "PROG" mode in order for the serial configuration device to be programmed.

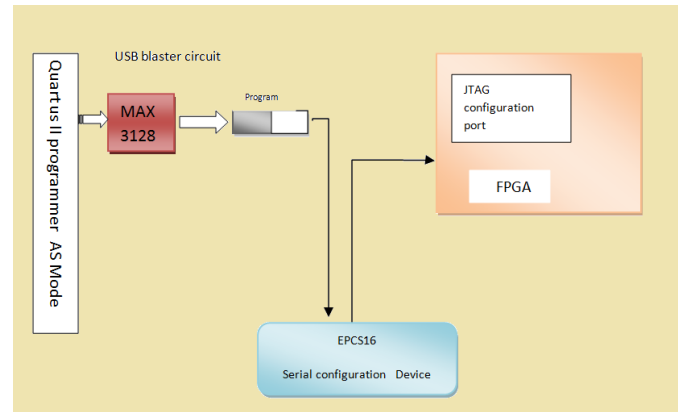


Figure 6. Active Serial (AS) Programming

## Design Tools

When designing an embedded system, either an ASIC or an FPGA is needed for hardware circuits. Designing one ASIC is very expensive, thus an FPGA is a more reasonable choice.

There are in general two options for FPGAs and their design tools. Xilinx and Altera are the market leaders in FPGAs, and together they control over 80 percent of the market [9]. However, there are several options for micro controllers, e.g., Atmel, Texas Instruments and ARM. The authors' choice of tools and hardware for this system was based on their availability in the department and the design tools with which they were already familiar.

## Quartus II

There are several EDA (Electronic Design Automation) tools available for circuit synthesis, implementation and simulation using VHDL or Verilog. Altera's Quartus II is one of them [5].

Quartus II is a Hardware Descriptive Language (HDL) programming tool. In this study, the authors used the Veri-

log language for describing the pin connections as they were selected. The following IC hardware pins on the DE2 board are mentioned here to indicate each input/output function and operating mode: ADV 7123, ISP 1362, EP2C35, LCD module, 7-Segment LED module, Red- Green LED's (see also Figures 7-9).

## SoPC builder

SoPC is a new concept and approach proposed by Altera Corporation [11]. It has features like combined programmable logic elements EDA, SOC, DSP and IP, which help in flexible design, ability to tailor the application, extension, upgradability and programmable software and hardware for system development. SoPC technology is an evolving synthetic electronic designing technology [12]. The designing technology of SoPC is the product of modern computer-aided design technology, the EDA technology and the enormous development of large-scale integrated-circuit technology (Figure 10).

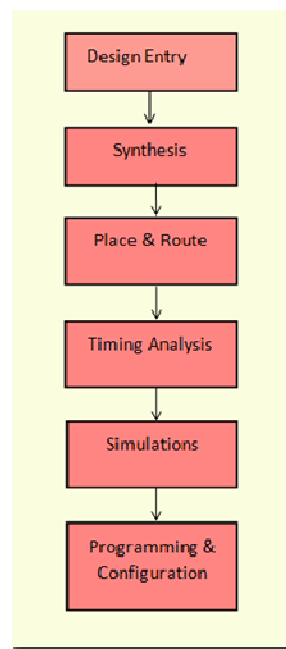


Figure 7. Quartus II Design Flow

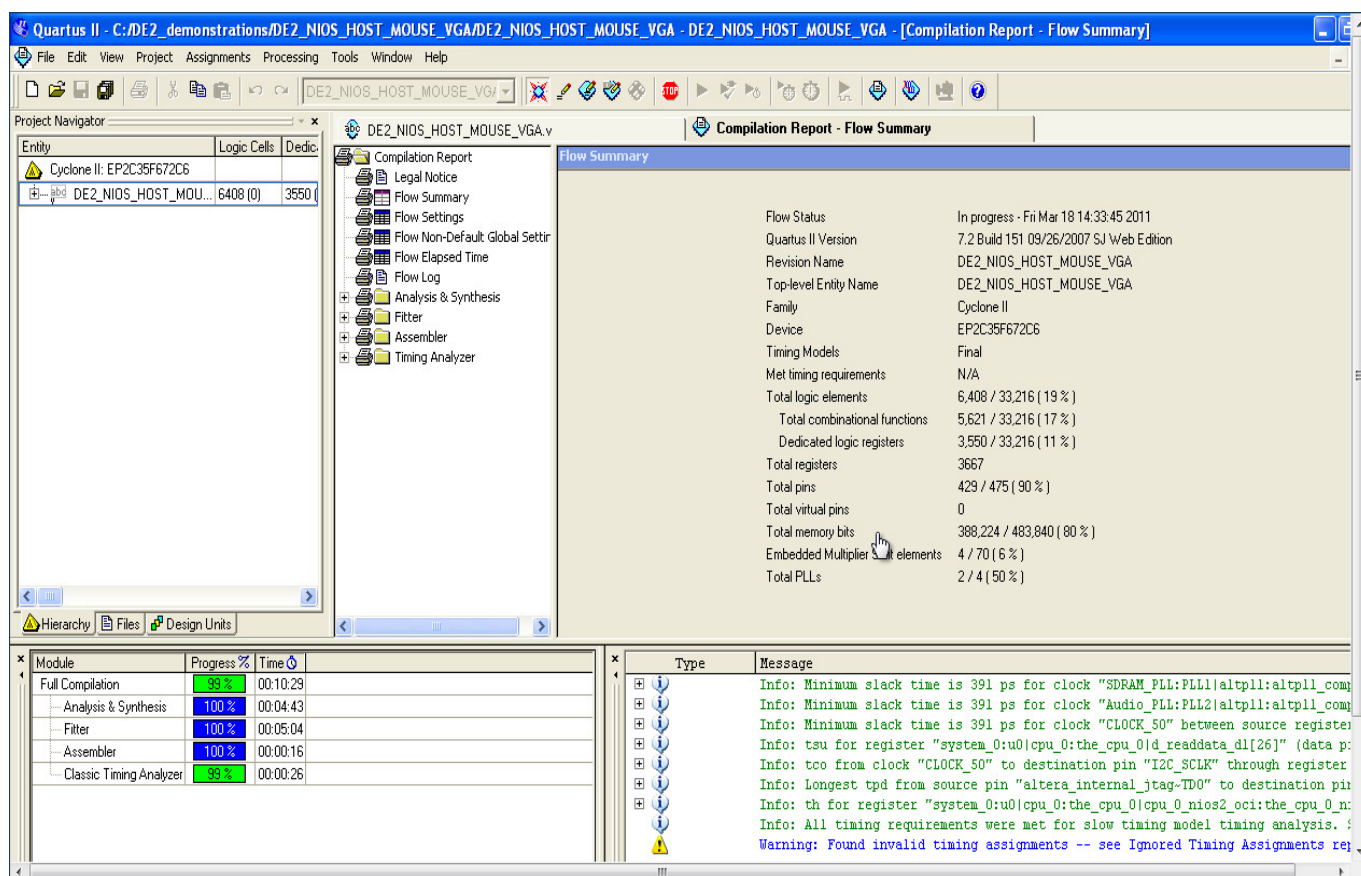


Figure 8. Quartus II

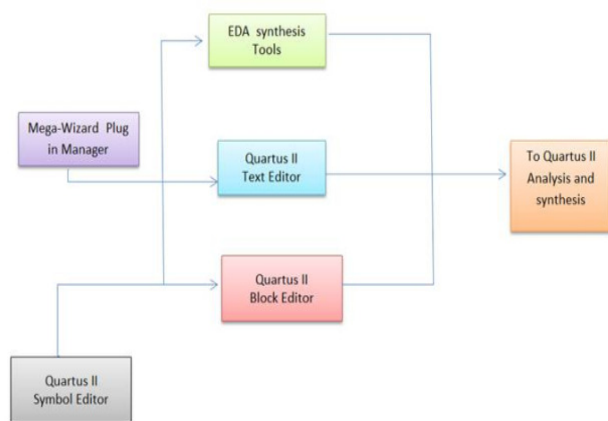


Figure 9. Quartus II Building Blocks

As show in Figure 11, it not only helps to select the hardware but also helps the designer to enrich it with required headers and supporting software. When SoPC Builder generates the hardware related to the core of the Nios II, it automatically generates a software development kit, including the peripheral device driver program, associated header files and software libraries. In the process of the design, it can call the software development kit in the header files and library files to easily complete the software design [13].

SoPC platforms are becoming more prevalent as a solution for the implementation of embedded computing systems [12]. This is due to their ease of implementation and highly customizable nature. It allows implementation of conceptual designs to practically target platforms. For many companies, mitigating the decision complexity at the conceptual design stage can result in succeeding on the compet-

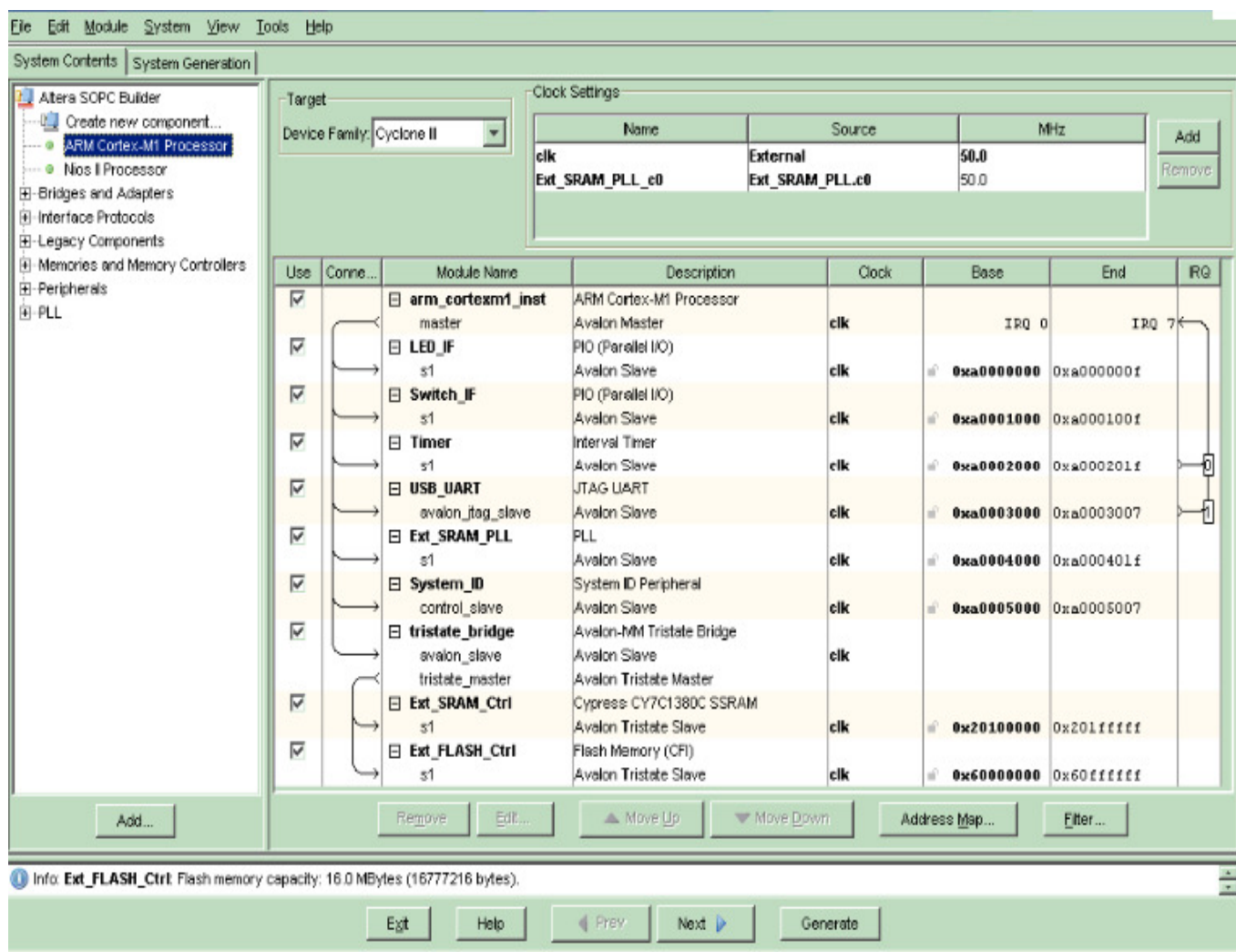


Figure 10. SoPC Design Environments



itive market. Therefore, having a robust decision-making tool embedded with conflict resolution for valuing potential new product investments helps to justify their development strategy [14]. It demonstrates a simple yet effective technique for accelerating an embedded RTOS running on a soft-core CPU on a SoPC platform.

## Nios II Embedded Design Suite

The Nios II EDS is a fully integrated development environment for developing software for Altera's Nios II embedded processor [15]. The environment is based on industry's Eclipse IDE (Integrated design environment). Figure 12 shows the Nios II EDS which describes the working environment screen. Nios II implements the function of the control and interpolation algorithm and the communication between the computer and FPGA [16].

The specific functionality of the Nios II is included as plug-ins. Following is a list of these plug-ins:

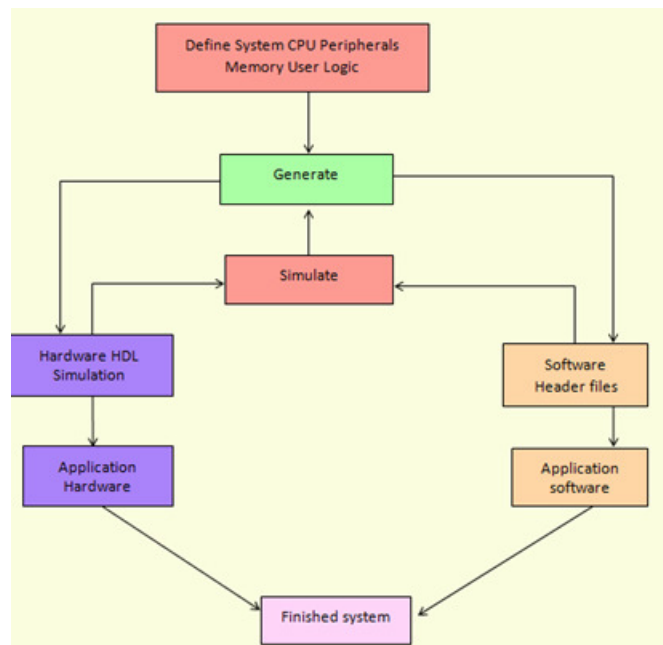


Figure 11. SoPC Design Flow

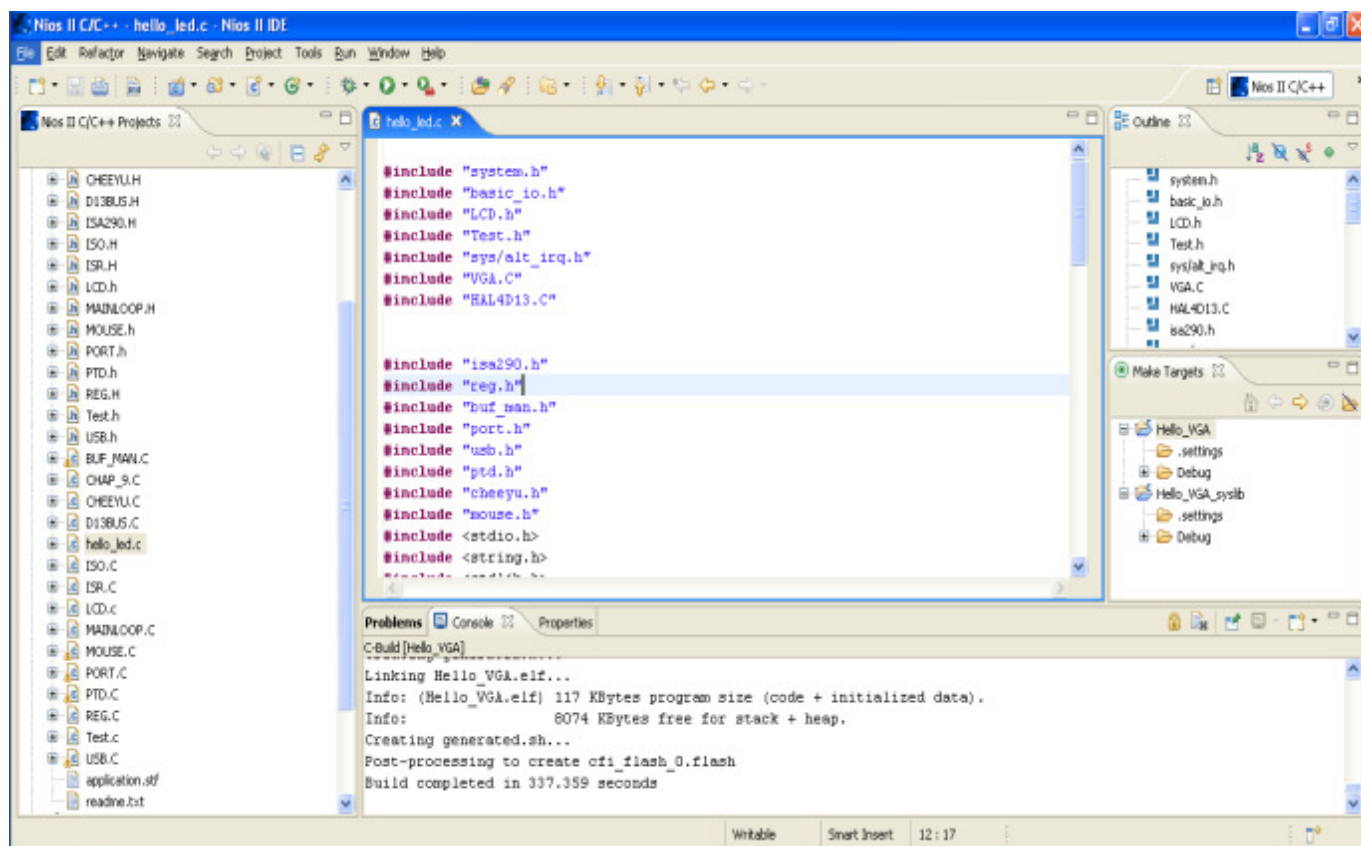


Figure 12. Nios II IDE Eclipse



- Nios II Project managers
- Nios II Software Templates
- Nios II Flash Programmer
- Nios II BSP Editor
- Quartus II Programmer
- Nios II Command Shell

The Nios II EDS provides two distinct development flows and includes many proprietary and open-source tools for creating Nios II programs. This platform is suitable for the software implementation of entire projects, since all development, debug and state diagrams can be done in a single window [15]. Eclipse IDE also provides different software templates or display messages and functions as a terminal when running code on a Nios II processor. The terminal will display any message printed using C library functions like print (). Print () is mainly used for transmitting data to the output devices such as an LCD, as was the case for this study. Quartus II helps programmers to program and implement code on FPGA chips. Software tools available with the Altera DE2 board include:

- FPGA logic design
- The SoPC Builder is used for customization
- Nios II IDE Eclipse uses C/C++ coding of the processor

In the Nios II IDE development flow, a Nios II C/C++ application project consists of a collection of source codes plus a make file. A typical characteristic of an application is that one of the source files contains the function main.o. An application includes code that calls functions in libraries and BSPs. The make file compiles the source code and links it with a BSP and one or more optional libraries to create one .elf file [17].

This design tool shortens the design processes, simplifies the circuits and increases data reliability. Simulation and testing results show that the data received are accurate, which confirms the validity of the design [15].

## Software Design

The software code is written in C language in the Nios II IDE environment. This study built on the 'DE2\_NIOS\_HOST\_MOUSE\_VGA' demonstration found in Altera's DE2 development board and educational CD. The main function in the software controlling the Nios II processor is in the hello\_VGA.c file. All of the .H header files and .C code files are in the software folder. The main file holds the majority of the code relevant to the game and there is another file that controls all of the functions of the

mouse in the mouse.c file. This file and the included .h files have the USB mouse connected and activated.

A function in the PTD.c or 'send\_int' file is called to continuously poll. It monitors mouse activities for any movement or clicking. Within this function there are other functions like 'move\_ball', which makes the ball bounce and other graphic activities. As the mouse is clicked or moved, the 'send\_int' function breaks out of a while loop and calls the 'play\_mouse' function. This function contains other functions for the lines and ball collision detection, location of the slider, ball erasing the sticks, etc. Also present in the .C files are the following codes and explanations (see Figures 13-16):

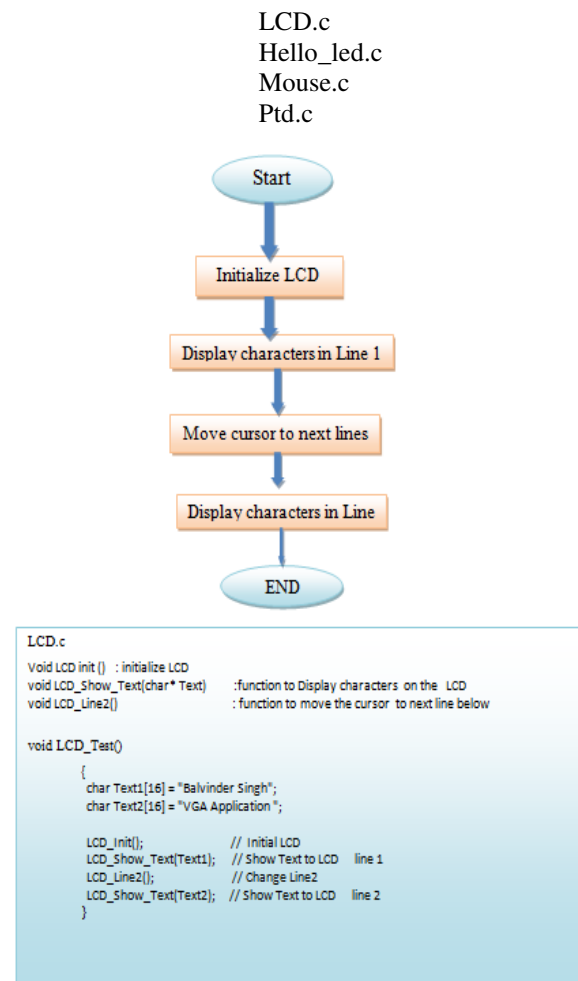


Figure 13. Flowchart of LCD.c

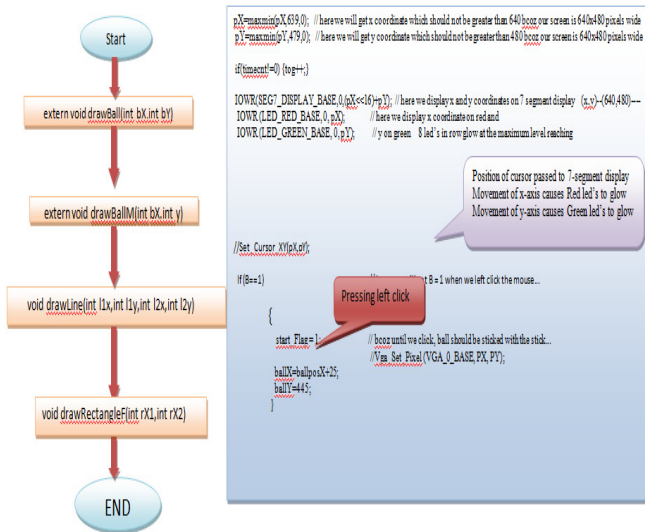


Figure 14. Flowchart of Mouse.c

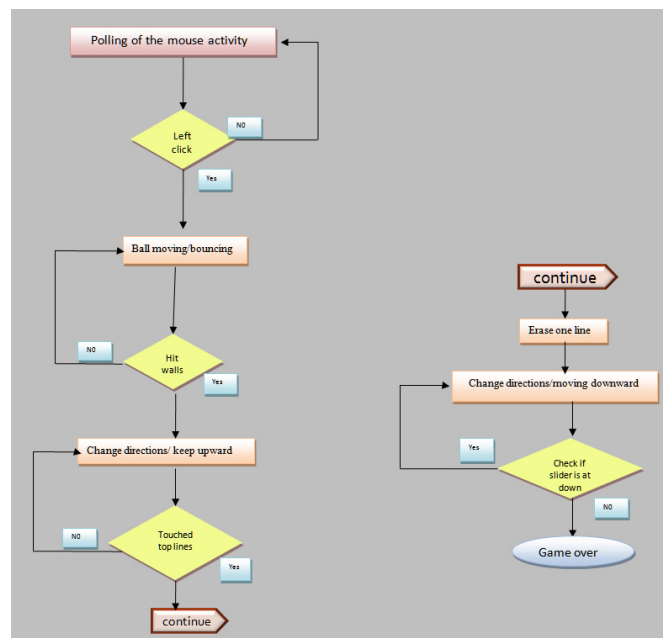


Figure 16. Flowchart of Ptd.c

## Setup

The Nios II soft-core processor is loaded with the software written in C++ language. The configuration bit streams from the computer (running Nios II IDE Eclipse) and is used to flash. This software configures the FPGA (Altera Cyclone II) as a CPU. The peripheral connected as an input is a USB-driven mouse via chip ISP1362. The output display device is a VGA Monitor screen via chip ADV7123. This on-board VGA controller chip (ADV7123) generates the VGA picture with a resolution of 640x480. The frame refresh rate is 60Hz.

The cursor movement of the USB mouse controls the left and right movement of the slider; this movement is indicated via a series of red and green LEDs on the DE2 board. A right click of the mouse starts ball bouncing. The screen location or (x, y) coordinates of the bouncing ball location is sent via software to the Nios II Eclipse. Also on the DE2 board, a 7-segment LED display indicates the x, y position within the 640x480 screen frame (see Figure 17).

Challenges faced during this study were related to memory and CPU usage of the program. During flashing of the program code on Altera's Nios IDE, it took a lot of time to transfer the configuration of the bit stream.

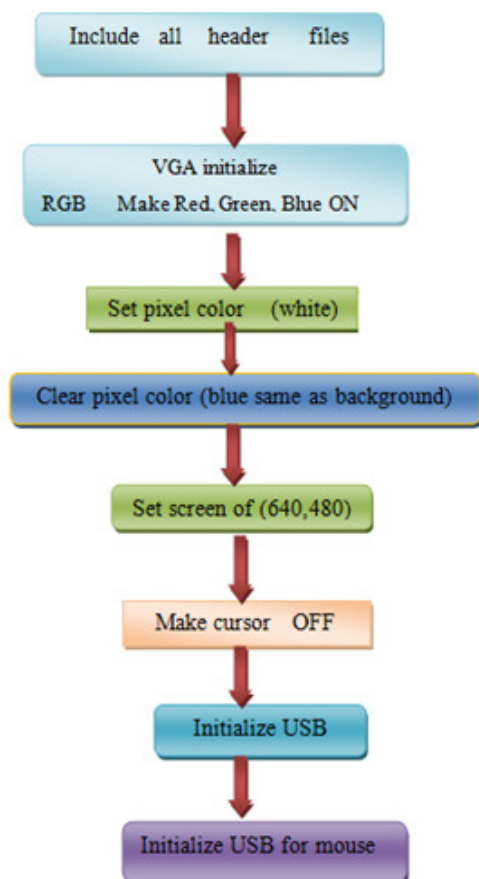
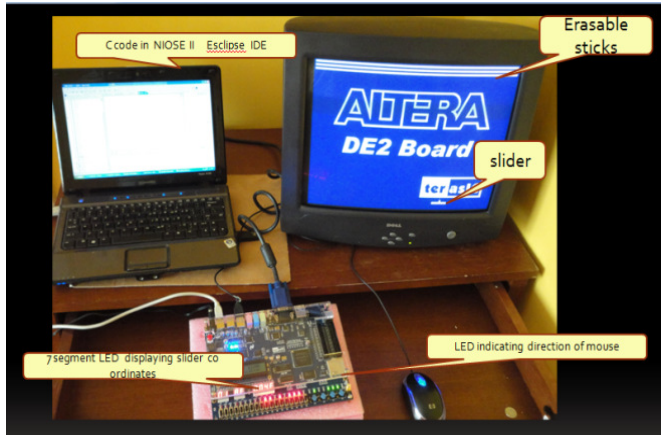


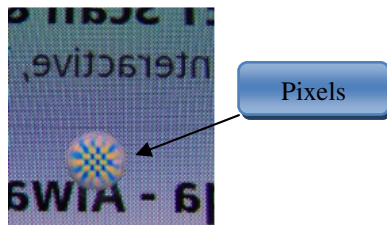
Figure 15. Flowchart of Hello\_Led.c



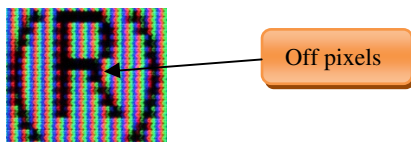
**Figure 17. Project Setup**

## Methodology for Formation of Structure

Structure gets displayed on a screen by the pixel arrangements. The address is nothing but the coordinates of a pixel indicating the location. The original image is represented on the screen with the arrangements of these dots or pixels (see Figures 18 and 19).



**Figure 18. Magnifications of the Display Showing Color Pixels**



**Figure 19. Letter R in a Bracket Formed of the Off Pixel**

All the objects are formed by pixel arrangement in order. The line is simply a row of pixels set in the x-axis direction. Thus, the code has to set pixels in the x-coordinates leaving y coordinates constant (see Figure 20).



**Figure 20. Formation of Lines by Pixel Arrangements**

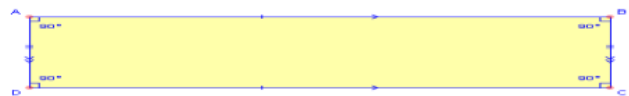
Thus, code can set or clear a row of pixels. This can be done by a variable inside a for loop which increments up to the entire length of the x-axis (Figure 21).

```
void drawLine(int l1x,int l2x)
{
    int lx=0,
    lx = l1x;

    for(x_Index=l1x;x_Index<=l2x;x_Index++)
    {
```

**Figure 21. Code for Formation of a Line**

A rectangle can be formed by the collection of all the lines. First, a line is formed which is only one pixel of the y-axis. Then, a cursor increments its position in the direction and again a row of a line is formed. Formation of a group of lines together leads to the formation of the structure of a rectangle (see Figures 22-24).



**Figure 22. Geometry of a Rectangle**



**Figure 23. Formation of a Rectangle**

```
void drawRectangleF(int rX1,int rX2)
{
    int lx=0,ly=0;

    lx = rX1;
    ly = 450;

    for(y_Index=0;y_Index<=8;y_Index++)
```

**Figure 24. Code for Formation of a Rectangle**

A ball is nothing but a circle filled with solid color and which has a constant radius circulating around a fixed point. A circle is a simple shape of a point's equidistance from a center (see Figure 25).

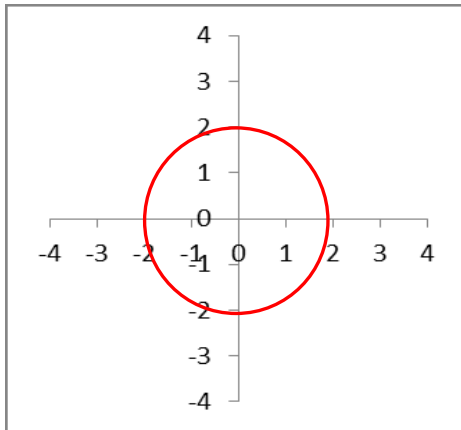


Figure 25. Circle

On the screen, a circle can be drawn with the help of a pixel arrangement. In the beginning, the code will start increasing the pixel number on the x-axis until the line of a certain diameter is reached. Thereafter, it starts to decrease the number of pixels until a single pixel is achieved, as shown in Figures 26 and 27. For simplicity, the authors only used a square of 5x5 pixels.

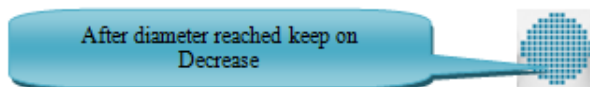


Figure 26. Circle Formed of Pixel Dots

```
extern void drawBall(int bX,int bY)
// this function will draw a ball (square) of the center (bx , by)
{
    int lx=0,ly=0;

    lx = bX;
    ly = bY;

    for(y_Index=bY;y_Index<=(bY+5);y_Index++)
        //height of the ball is 5 pixel
    {
```

Figure 27. C Code for the Formation of the Ball

## Initial Screen

In the initial stage, the ball is sitting in the middle of the slider which is 50 pixels in length and 5 pixels in width. So the x-coordinate of the slider will be half of that or 25. In this situation, the code is going to set the pixel at the ball  $X=ballposX+25$  (see Figure 28).

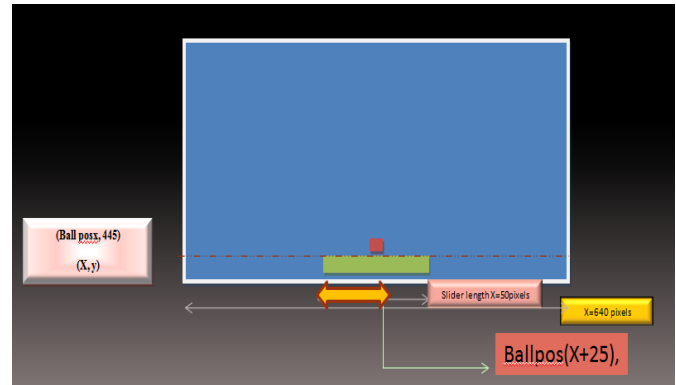


Figure 28. Initial Screen Before User Presses Left Click

This will draw a ball after 25 pixels correspond to whatever current cursor location is updated from the mouse polling function. In the initial stage, the code continues to monitor whether the user has clicked the left mouse button; e.g., *get B = 1*. If the left mouse button is pressed, the start flag becomes set: start Flag = 1. At this point, the ball bounces or the ball is in motion.

```
If (B==1).
{
    start Flag = 1; //because until clicking, ball
    should be stacked with the stick
    ballX=ballposX+25;
    ballY=445;
}
```

Once the left mouse button is pressed, the ball starts moving towards the upper right then it hits the wall and changes the direction to the upper left. Thereafter, the ball touches the first line it encounters and erases it.

## Upward Motion

This code uses the directional vector *diry*. “If *diry==1*” means that the ball is going up. The code will run for two loops of *y\_index* and *x\_index*. First, in order to make an object move, the screen has to clear its previous image and set the pixel for the current one. For example, assume the

ball has just left the slider and is moving towards the wall (see Figures 29 and 30).

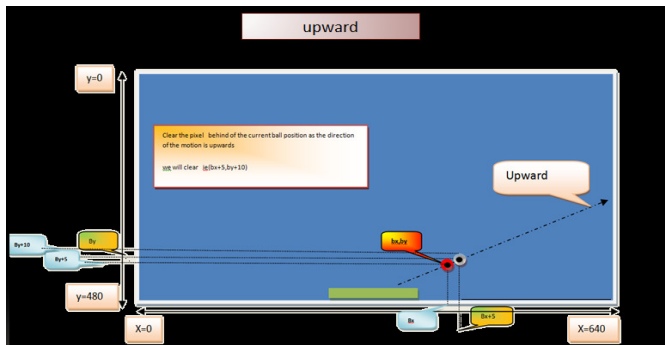


Figure 29. Motion of the Ball Moving Upward

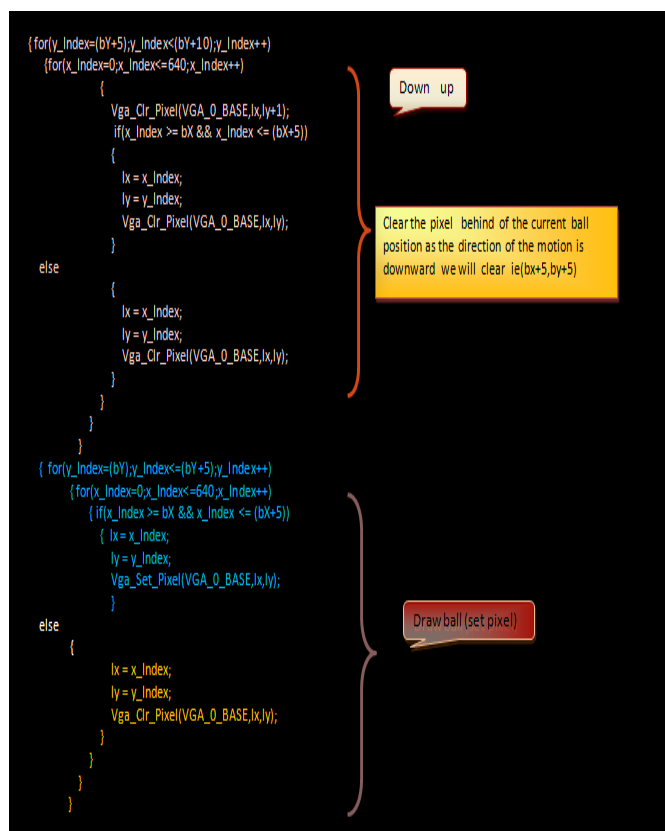


Figure 30. C Code Ball in Motion Upward

In order to create a future state code, it has to clear at x+5, y-5 as the x-coordinate of the ball increases and the y-coordinate of the ball decreases. Code will draw (set) the ball for x+5, y+5 coordinates. Once the ball hits the wall, it moves up and to the left. In that case, the x- and y-coordinates decrease. This process is repeated but now the code will clear the pixels at x-5, y+5 and set x+5, y+5.

## Downward Motion

As depicted in Figures 31 and 32, if the ball is moving in the downward direction, there will be a decrease in the y-coordinate. There will also be an increase or decrease in the x coordinate depending upon the location of the ball.

- If it has not yet hit the wall, there will be a decrease in the x-coordinate.
- After hitting the wall, there will be an increase in the x-coordinate.

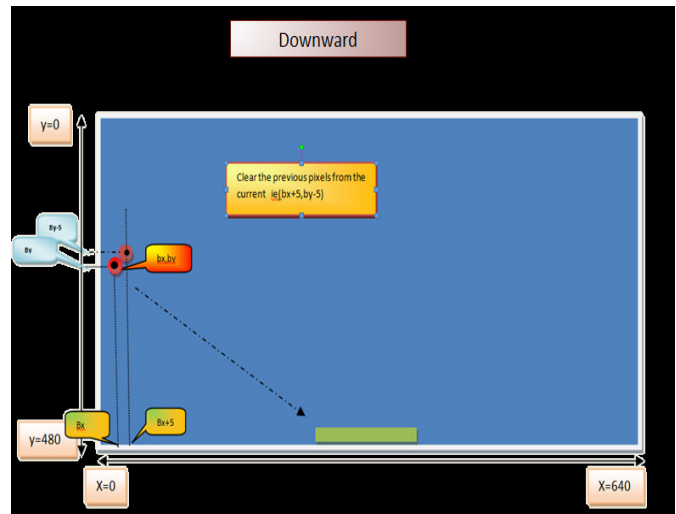


Figure 31. Downward Motion of the Ball and Pixel Formation

Let us assume the ball has just touched the top lines and it has not yet hit wall. In that case, the code will clear the x-5, y+5 pixels. After hitting the wall, the code will clear the x+5, y+5 pixels.

When the ball moves in the open space, there is an increase in the x-coordinate or y-coordinate depending upon which quadrant it is in. The code uses the dirX and dirY vectors which are set or cleared depending upon whether the x-coordinate has increased or decreased.

```

if(dirX == 0 && dirY == 0)
{
    ballX--;ballY--;
}
else if(dirX == 0 && dirY == 1)
{
    ballX--;ballY++;
}
else if(dirX == 1 && dirY == 0)
{
    ballX++;ballY--;
}

```



```

else if(dirX == 1 && dirY == 1)
{
    ballX++;ballY++;
}

```

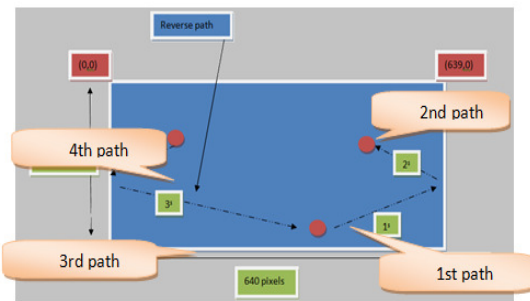
```

extern void drawBallM(int bX,int bY)
{
    int lx=0,ly=0;
    lx = bX;
    ly = bY;
    if(dirY==1)
    {
        for(y_Index=(bY-5);y_Index<bY;y_Index++)
        {
            for(x_Index=0;x_Index<=640;x_Index++)
            {
                Vga_Clr_Pixel(VGA_0_BASE,lx,ly-1);
                if(x_Index >= bX && x_Index <= (bX+5))
                {
                    lx = x_Index;
                    ly = y_Index;
                    Vga_Clr_Pixel(VGA_0_BASE,lx,ly);
                }
            }
        }
    }
    else
    {
        lx = x_Index;
        ly = y_Index;
        Vga_Clr_Pixel(VGA_0_BASE,lx,ly);
    }
}
else
{
}
}

```

**Figure 32. C Code for the Downward Direction of the Ball**

In this study, a video raster of 640x480 pixels was created. Technically, one wall is at x=0 and another is at x=640. From a software point of view, the code is checking via directional vectors (see Figure 33).

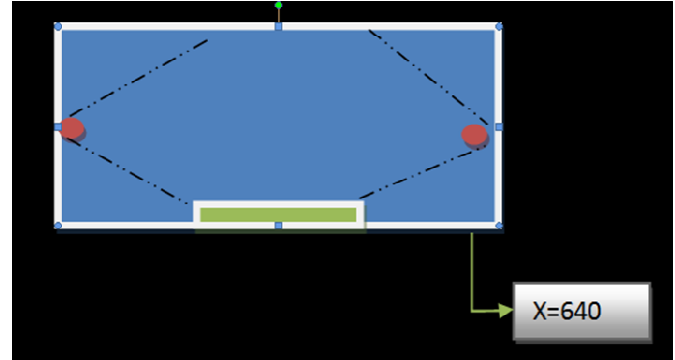


**Figure 33. Directions of the Ball Hitting Walls**

The path and direction vectors are:

§	1 <sup>st</sup> path:	x++	y—
§	2 <sup>nd</sup> path:	x--	y--
§	3rd path:	x++	y++
§	4th path:	x--	y++

If the current ball position is 635, then it is near the right-most wall (ballx<635) as our ball was 5 pixels wide. Or ballx<1 for the first wall; if this condition is satisfied then the code will make directional vector dirX change direction (see Figure 34).



**Figure 34. Ball Striking the Walls**

```

if(ballX>635)
{
    dirX = 0;    // stop motion in x axis up
}
else if(ballX<1)
{
    dirX = 1;
}

```

When the ball reaches the top, the code will clear the pixels for the entire length of the lines and make the ball change its y-axis direction and proceed moving downwards (see Figure 35).

```

dirY = 1;
if(Bottom_Line > 1)
    Bottom_Line = Bottom_Line - 1;
else
    Bottom_Line = 0;

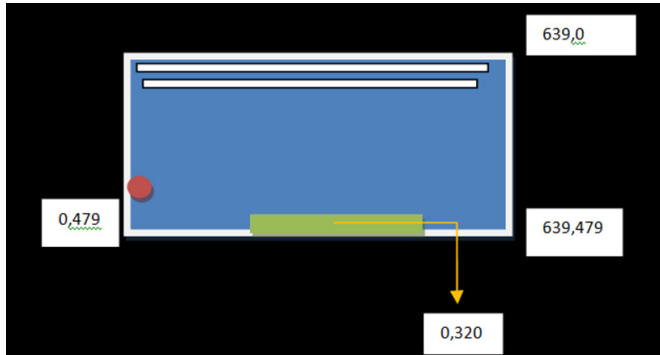
if(ballX < 320)
{
    for(y_Index=(Bottom_Blocks
[Bottom_Line]);y_Index<=(Bottom_Blocks
[Bottom_Line]+5);y_Index++)
    {
        for(x_Index=0;x_Index<=320;x_Index++)
        {
            Vga_Clr_Pixel(VGA_0_BASE,x_Index,y_Index);
        }
    }
}

```

```

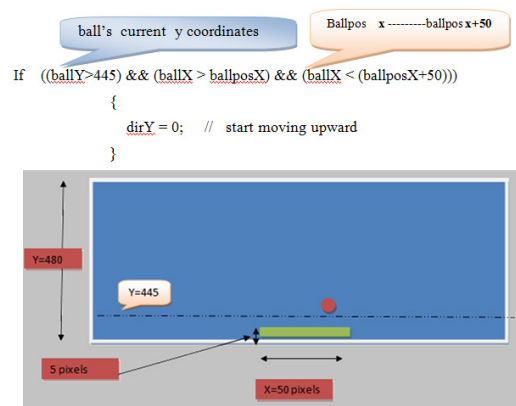
else
{
for(y_Index=(Bottom_Blocks
[Bottom_Line]);y_Index<=(Bottom_Blocks
[Bottom_Line]+5);y_Index++)
{
for(x_Index=320;x_Index<=640;x_Index++)
{
Vga_Clr_Pixel(VGA_0_BASE,x_Index,y_Index);
}
}
}

```



**Figure 35. Erasing of the Top Lines**

A loop check checks to see if the x-coordinate of the falling ball is equal to the x-coordinate of the slider ( $x_{\text{ball}} + 50$ ). If so, the direction of the falling ball is changed to up. If the condition is not reached, this means that the ball will fall down making the screen black; i.e., game over (see Figure 36).



**Figure 36. Ball Touching the Slider**

## Results

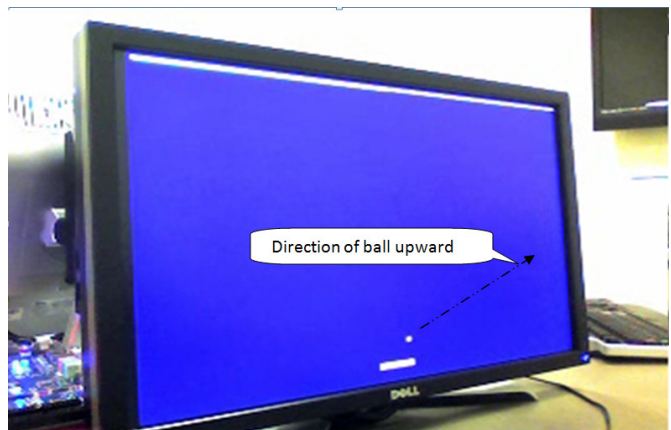
In this study, text in the LCD.c file was added. The text remains during the entire duration of code running on the

Nios II eclipse editor. Figure 37 presents the initial screen showing the Altera DE2 and Terasic logo before pressing the left mouse button so that the ball is sitting at the mid-point of the slider.



**Figure 37. Direction of the Mouse in the Leftmost Portion of the Screen Indicated by Full Green LEDs**

After pressing the left mouse button, the ball starts bouncing and moves towards the walls as it continues moving upward towards the sticks on top. As the ball advances, the screen frame refreshes, erasing the background, thereby making it dark blue, as shown in Figure 38.

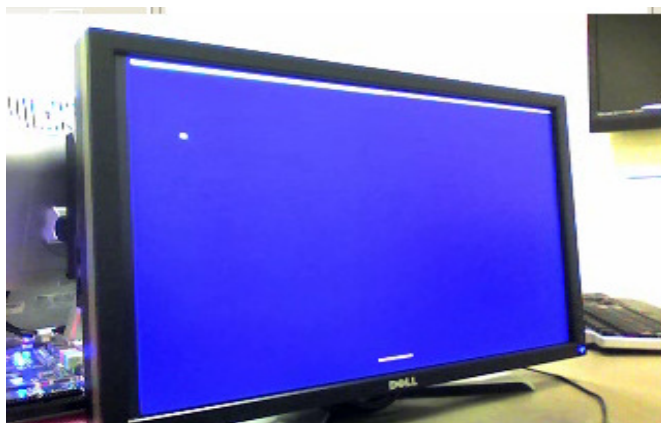


**Figure 38. Ball Going Up after Left Click is Pressed**

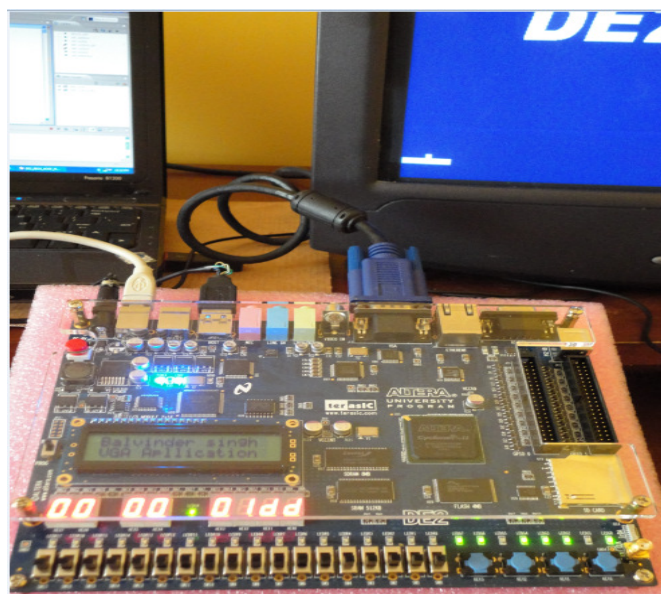
After erasing the stick, the ball moves downward as it makes its journey towards the slider, as shown in Figure 39. If it moves further down and hits the slider, it will bounce back upward, otherwise the game is over and the screen is turned black.

The direction of movement of the mouse is indicated with the red and green LEDs and location of the slider, as indicated on the 7-segment LED display shown in Figure 40. The authors were also successful in displaying the location

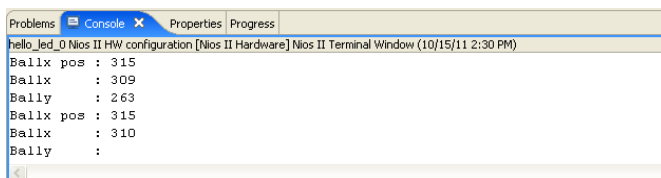
of the ball (x-y coordinates) and the slider's x-coordinate on the console of the Nios II IDE, as shown in Figure 41.



**Figure 39. Ball Coming Down After Erasing One Stick**



**Figure 40. Location of the Slider at the Leftmost Portion of the Screen Indicated by a 7-Segment Display**



**Figure 41. Locations of the Ball and the Slider Indicated in the Nios II IDE**

## Conclusion

The purpose of this study was to design a VGA-based application using a Nios II as the core CPU. The authors used USB, red/green LEDs and a 7-segment display, though the device in this study had a primitive level of graphics and no audio. This design tool shortens the design processes, simplifies the circuits and increases data reliability. Simulation and testing results showed that the data being received were accurate, which verified the validity of the design. Future work could include a software upgrade of animations to increase the sharpness of the graphical objects.

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# DESIGN AND DEVELOPMENT OF A MULTIPLE CONCEPT EDUCATIONAL RENEWABLE ENERGY MOBILE MINI-LAB FOR EXPERIMENTAL STUDIES

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## Abstract

When students are introduced to the concept of science and engineering projects, one of the instructor's first tasks is to help students understand the difference between non-experimental and experimental projects. In general, non-experimental studies with theory only are not sufficient to prepare a future workforce in engineering and technology fields because this method does not teach the skills of critical thinking, troubleshooting and problem solving. Hands-on experimental projects in addition to the theory of a topic involve the students in critical thinking and engineering processes, developing models of engineering concepts, collecting and recording data, analyzing and presenting data and drawing conclusions. Experimental work of this type focuses on discovery and investigation and aids the students' understanding of concept in details. In the field of alternative energy technologies, there has been a recent demand for a qualified workforce that understands the engineering concept and practical applications.

For renewable energy technologies, students should have a background in energy, electricity and mechanically related topics in order to properly understand renewable energy concepts so that they can enter the field of management and building systems. For students to have a grasp of both theory and experimental knowledge of renewable energy technologies, a laboratory environment is mandatory to conduct related labs. There are many ways to involve students with lab experiments. However, to offer a renewable energy related program, there are additional costs to purchase lab equipment for these classes. Those schools that cannot afford to buy equipment to conduct lab sections may consider building the training equipment themselves. This will reduce the overall costs and give students an excellent opportunity to apply the concepts they learn in the classroom. This current project describes the implementation of a stand-alone and cost-efficient hybrid educational training mobile lab to teach lab sections of renewable energy classes.

## Introduction

Dependence on limited energy resources such as fossil fuels results in issues that present generations must address in order to ensure that future generations are able sustain their energy needs. The subject of renewable and clean energy is the main force driving nations to become more environmentally conscious. As a result, there is increased awareness of the delicate balance between the consumption and maintenance of world's energy resources. The new trend in this century is all about "going green" and promoting clean energy, which refers to increasing awareness of the environment. Community attention is focused on current lifestyles which use resources inefficiently and destroy or pollute the environment. According to the Energy Information Administration (EIA), the share of residential electricity used by appliances and electronics in U.S. homes nearly doubled over the past three decades [1-3]. The use of renewable energy sources will help decrease the dependence on energy produced by fossil fuels. Recent attempts from government, academia and organizations have increased energy awareness and promoted use of alternative energy sources. Renewable energy today provides about 9% of the world's energy and 8 - 10% of the U.S. needs [4].

According to a 2011 projection, only 8.2% of the energy supply comes from renewable energy. However, in many parts of the world, these percentages are increasing significantly. Based on current data on global warming, as well as on the current U.S. dependence on overseas oil, there is increasing interest and urgency in the use of alternative energy sources [5-7].

As Sam Houston State University moves toward an environmentally friendly green campus, energy harvesting projects are getting more attention from students and college administration. Recent projects supported by various departments on campus include the use of new LED security lights powered by solar panels with a tracking system, a 2kW hybrid wind and solar system powering LED parking lights and development of an electric boat, among others. The number of renewable energy (RE) projects has been increasing in order to promote RE technologies at school

---

campuses [8-12]. This trend is not limited to on-campus projects, there are also classes developed online to offer energy awareness for the students. In order to offer hands-on experiments to students along with theory, technology program faculty have attempted to purchase laboratory equipment to improve the courses and offer hands-on training. Due to the high cost of laboratory equipment on the market, students and faculty built ten renewable energy training stations with departmental, college administration and local utility company support.

The majority of alternative energy educational training units are built and sold by companies that offer custom-made systems according to their customers' needs; this increases the cost of the training units [13-17]. Alternative energy teaching tools help students to fully comprehend complex concepts with interactive educational training equipment and are very important for the hands-on laboratory sections of energy education. Due to the high costs of educational training units, it becomes a budget concern when equipment is purchased for the laboratory sections of energy related courses. The costs of such equipment range from \$10,000 to \$50,000 per unit [18-21]. If there is a budget concern for a department, the only option to the instructor is to teach only the associated theory of the course, but not the actual application. Even if energy courses are taught in business and education programs, it is imperative to conduct laboratory experiments using equipment and materials, especially in engineering, science, and technology courses.

Students and faculty in the Industrial Technology program designed, developed, built and tested ten multipurpose RE mobile training units for alternative energy related education. The units were designed to be used in hands-on activities to provide opportunities for students to engage in experiments that would reinforce the material covered. More importantly, students experienced a real-life design and production process ranging from purchasing, requests for donations, writing proposals, generating reports, metal working, wood working, electronics, computer-aided design, painting, market and literature search, team work, and working with industry to complete the project. This paper reports all of the details for building a mobile system for educational purposes along with the curricular materials. The materials in this study were to be used for educational purposes only; the authors can be contacted for further information and collaboration.

## Design

Usually, educational training equipment is manufactured to educate students on a specific topic such as rotating machines, power electronics systems, refrigeration, plants, con-

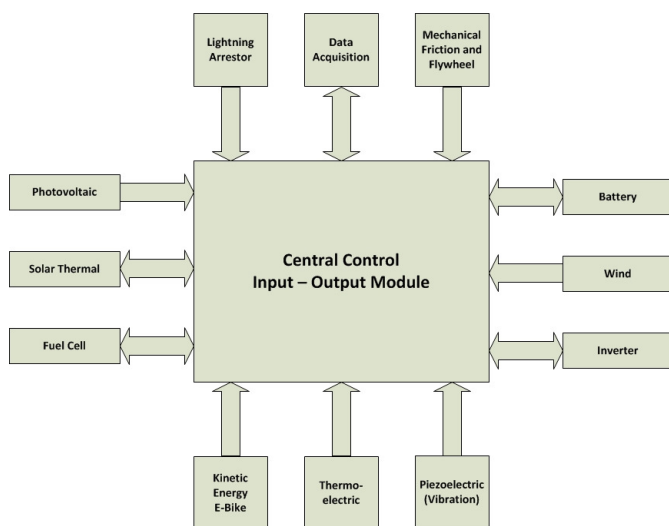
trols, HVAC, instrumentation, hydraulics, etc. This is also true in the field of renewable energy education; usually an educational training unit presents a single energy source topic such as solar, wind or biomass energy system. As a consequence, the educator is forced to buy separate units to teach each alternative energy technology such as wind technology, human power, biomass, solar energy or hydrogen fuel cell systems. It is very rare to see combined training units to teach multiple energy sources in one integrated system. One of the main reasons for this is that energy systems typically are taught separately for topics such as photovoltaic systems, wind energy systems, geothermal energy, fuel-cell systems, etc. General energy courses cover most of the renewable energy topics but usually only theory is taught with a minimum of lab experiments. For example, business- and economy-based energy courses only cover the theory of energy systems. Engineering technology programs are more application-based to offer more hands-on experiments as compared to engineering programs.

Another reason for a lack of hybrid trainers is the space and cost issues present—except in cases where the system is custom made. If the training equipment is hybrid, this increases the size of the unit, which may cause problems if lab space is limited. The design concept in this study covered a custom design for the schools and teaches both general renewable energy systems and specific energy systems such as photovoltaic and wind energy. However, these topics cause the establishment of an alternative energy program and laboratory to be more expensive and difficult to implement. In the implemented prototype for an integrated educational training system, six energy sources were combined in one training unit that included wind, solar, human power, passive water heating, passive air heating and hydrogen fuel cell technologies. The unit serves to compare the efficiency and reliability of each source using a data-acquisition system. The block diagram of the energy harvesting central module is shown in Figure 1.

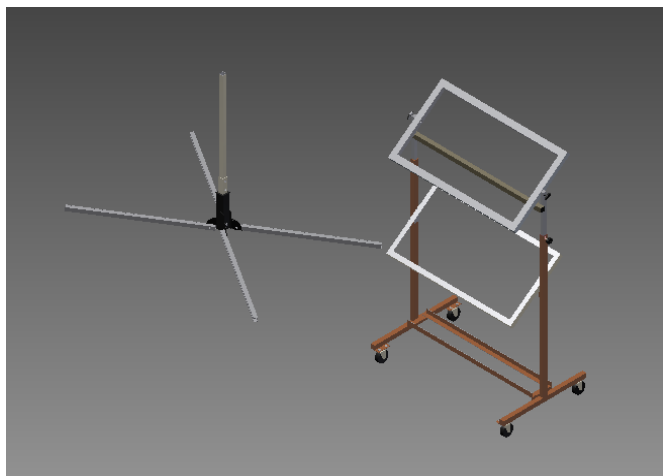
Besides the modules in the block diagram, there are energy-related modules available to mount on the central unit for study. These modules include data acquisition, thermoelectric, piezoelectric, friction, flywheel and rotary units; human-power kits; and, temperature, light, sound, mass, rotary, force, VI, rainfall, anemometer, wind vane, humidity, irradiation, barometric pressure, heat-index, wind-chill and dew-point sensors.

A 3D CAD (Computer Aided Design) model of the mobile metal stand was created using Autodesk Inventor [22] to estimate the number of metal parts (tubing and brackets), bolts and nuts, wheels and paint of the training unit. The design of the mobile frame and wind turbine stand are

shown in Figure 2. The upper portion of the stand has a rectangular frame to mount the solar modules. This frame can be manually adjusted to study seasonal sun energy as it reaches the earth's surface. It allows users to tilt the frame with the solar panels attached in order to study -15 to +15 degrees, depending on the location and season. The frame can be tilted 180 degrees to study tilt angles and the efficiency of the solar module relationships [23]. The total price of materials to build ten metal stands was \$654.40 (based on a discounted quote from a local business). This amount can change dramatically depending on building materials of the training unit housing.



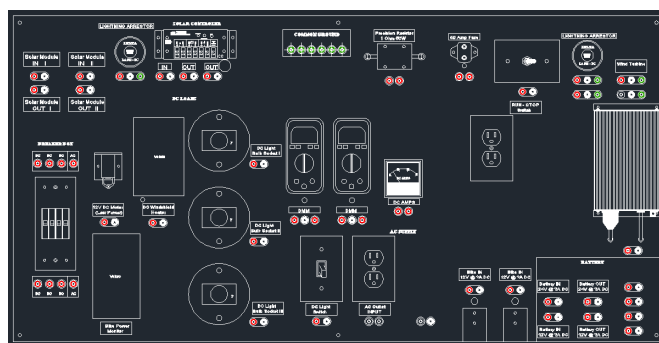
**Figure 1. General Block Diagram of the Central Module**



**Figure 2. CAD Model of Stand Frame and Wind Turbine Stand**

The training unit components were identified after extensive market research. The compatibility of the parts was confirmed, and specification sheets were stored in a data-

base to draw components using the Autodesk-AutoCAD software tool. The design layout helps to locate drill holes and to make cutouts to place and align the components on the module board. After getting dimensions of all the parts from either specification sheets or by measuring the parts, they were put into digital form so that they could be used for the CAD design. The following CAD file is just one of the concepts that were developed using this method. There are many components that make up this training board; all of these components were drawn on a 1:1 annotation scale, which allowed us to properly place the components onto the board as if it were in a real application. This made for optimum assembly of these parts allowing for maximum space utilization of the training board. The AutoCAD design layout is shown in Figure 3.



**Figure 3. The AutoCAD Design of the Training Control Unit Layout**

In order to reduce safety concerns, Pomona electronics panel-mount jacks for sheathed plugs were used so that there would be no contacts readily available to users of the module. The wire connections between the contacts of the jacks are located behind the panel where users have no access [24-26]. Banana Plugs with patch cords and panel-mount jacks are all sheathed types and contacts and are not exposed to users. This reduces the safety concerns of the unit, which was tested under various conditions. For this design, the AutoCAD layout was used, including all of the drilling and component specifications. The CAD layout was shared with a local small business that does woodworking so that a prototype of the module could be made for test purposes. After revisions and updates on the prototype module, ten identical units of modules were built using CNC (computer numerical control) operated machines. The overall work was done including machining from the design layout and furnishing the melamine of 5/8" thickness. Also, a PVC edge banding of 3mm slightly radiused edges were applied for durability purposes of the units. Ten units cost \$425.00 (discounted price) including all of the materials, design work and prototype module.

Each unit can accommodate two to three students at a time. This mobile mini-lab is capable of using wind and solar technology, active/passive human power, passive water heating systems, passive air heating systems, and hydrogen fuel cell technology. The unit includes two solar panels, a wind turbine connection, a charge controller, measuring devices, circuit breakers and fuses, lightning arrestors, a battery, an inverter, switches, a DC generator, a temperature sensor, irritation sensor, an anemometer, two power sensors, and data acquisition peripherals. The system has the capability to accept several different RE sources at a time and convert those intermittent voltage sources to constant voltage to charge a battery. The charge controllers handle the charging process of the battery at different input voltages that vary by intensity of light energy, wind speed and human kinetic energy.

## Production and Testing

The prototype training unit project had four phases and was finished in a year. The first phase of the project used a 3D CAD design system with 3D parametric modeling software tools. After the design of the system, all of the necessary parts for one unit (prototype unit) were determined and ordered from various manufacturers or vendors. Then, the wheeled metal frame, which is the housing of the training unit, was built in the production lab. The balance of the housing (frame) was important because of the heavy components placed on it, such as a battery, solar modules, inverter and computer case. All of the components were mounted on the board (5/8" MDF) which is the actual training unit. The board was then fastened to the wheeled frame and all necessary wiring was done to test the system in different locations on campus and for use in renewable energy education. The prototype unit was extensively tested to eliminate or reduce any safety issues, and improvements were applied before the production of the remaining ten units. The remaining units were built quickly since the completed prototype model could be referenced, with the remaining parts acquired with support from internal/external funds.

Building a reliable system to eliminate safety concerns is of importance because of the variable voltage outputs from different alternative energy sources. Special attention was given to the location of battery and circuit breakers/fuses to eliminate any hazard caused from short circuits in the system. The training unit and all of the peripheral equipment around it are shown in Figures 4 and 5.

The wind turbine is mounted separately from the training unit; it was placed on a separate stand in order to avoid any accidents due to spinning wind turbine blades. The wind

turbine output was connected to the training unit module through a long cable for power reading and data acquisition purposes. A hydrogen fuel cell unit and hydrogen gas canister was placed near the training unit frame and a connection was established via cables with connectors. The fuel cell unit was kept in a separate metal box instead of on the metal stand housing for safety purposes. Both solar thermal air and water heating units were also placed near the training unit and wired to the training unit module with connectors. Two of the electric bikes—for studying energy generation through human kinetic energy—were connected to the training module through wires with connectors. Detailed information about hydrogen fuel cell unit, solar thermal air and water heaters, and electric bikes are not shared in this paper because it is not within the scope of this project.



**Figure 4. Renewable energy training unit**



**Figure 5. Renewable energy training unit with peripherals**



A single 12V@75A deep-cycle battery was used as a storage unit. The voltage level of the wind turbine, electric bike, fuel cell unit and solar panels was 12V and can be easily connected to the battery without any buck (step-down) converters. The project investigators avoided using multiple batteries for safety reasons. Due to the knowledge level of potential users (high school students, teachers and college students), using multiple batteries may cause an unexpected short and create a potential hazard. Instead, a single battery protected with a fuse, insulated connector switch, and circuit breaker was used as a storage device. In the future, multiple batteries and super capacitors will be added and will be used to teach senior-level engineering and technology students.

## Experiments for Workbook

Several basic laboratory experiments were written in order to conduct the lab experiments. All of the experiments were prepared to be conducted in the potential RE-related education classrooms and workshops using the mobile mini-lab. There are already fifteen basic laboratory experiments written but they are not combined in a booklet to be used as lab workbook yet. The number of experiments can be extended using additional modules available on the market. For example, a small hydrogen fuel cell kit can be added to the training unit for demonstration purposes to teach science concerning fuel cell technology to K-12 students. Complexity and level of experiments can be extended according the knowledge level of the students by adding more modules to the training unit.

- Training Unit Guide
- Overview to Photovoltaic Technology
- Basic Electricity & Measurements (Voltage, Current, Resistance, and Power)
- Solar Panel Output Measurements (Voltage, Current, Power, Temperature)
- Series-Parallel Connections of Solar Modules
- Effects of Temperature, Irradiation, Humidity, Wind to Solar Module Output
- Solar Panel Efficiency – Shading Effects
- Solar Path Finder - Side Shading Analysis and Solar Tracking
- Overview to Wind Power Technology
- Wind Turbine Output Measurements (Voltage, Current, Resistance, and Power)
- Series-Parallel Connections of Wind Turbines
- Wind Power Efficiency – Wind Speed vs. Turbine Efficiency
- Wind Speed and Direction Measurements
- Battery Charging & Protection
- AC/DC Load Characteristics and AC/DC Conversions

- Hybrid Systems - Wind and Photovoltaic
- Energy Generation from Human Power – Electric Bike and Hand Crank Generators
- LED (Light Emitting Diode) Technology and Comparison to Traditional Lighting
- Energy Harvesting from Piezoelectric Materials
- Flywheel Energy Harvesting and Storage
- Energy Harvesting from Friction Technology
- Thermoelectric Energy Harvesting Technology
- Energy Harvesting from Hydrogen Fuel Cell
- Measurements I – Light, Temperature, Sound, Mass, Rotary, Force, VI, Rainfall
- Measurements II – Humidity, Barometric Pressure, Heat Index, Wind Chill

The experiments contain pictorial connections of the modules instead of standard schematics in order to provide visual connections between components. This simplifies the level of understanding of the experiment connections; otherwise, all of the participants of the workshops would have to be taught the meaning of the each symbol on the circuit schematics. Although it may be easy for college students majoring in engineering and technology programs to learn the symbols, this can create frustration for students and teachers at the K-12 level or for community members to learn the meaning of the symbols. However, experiments are being revised to include schematics with standard symbols along pictorial drawings. Based on feedback from past workshops, it is very helpful to use pictorial connections when conducting experiments.

Its mobile structure extends the use of the system in various locations for training, troubleshooting and testing purposes. The system contains all equipment usually required for a remote residential installation of complete wind and photovoltaic energy systems. The main equipment in the system are two 60W photovoltaic modules (to study series and parallel connections), a charge controller, batteries, AC and DC disconnects and breakers (fuses), an inverter, a 400W wind turbine (mounted on a separate stand), switches, receptacles, digital and analog meters, a battery analyzer, lightning arrestors, a step-down transformer as well as AC and DC loads. The system also contains equipment for laboratory purposes to study energy systems including a data acquisition unit, a computer, kinetic and potential energy systems kits (thermoelectric, friction, flywheel, rotary, human power), various sensors (temperature, light, sound, mass, rotary, force, VI, rainfall, anemometer, wind vane, humidity, irradiation, barometric pressure, heat index, wind chill and dew point).

There is also external equipment available to study hydrogen fuel cell technology, solar thermal energy (water and air

heating), kinetic energy (electric bike) and thermoelectric and piezoelectric technologies. Due to the size and weight of this equipment, for each system, a mobile metal structure was built to move these units between training equipment to offer students more flexibility using all of the equipment. This mobile system can be used to teach renewable energy systems for sixth through twelfth grade levels in K-12, or for teachers, college-level educational systems and workforce development. For specific knowledge levels, the mobile unit comes with a variety of experiments developed by senior students and faculty. These experiments are being revised in order to publish all of the experiments in a workbook as a future goal.

## Discussion and Conclusions

This project idea came to light due to budget limitations to purchase commercially available training equipment. Project coordinators still prefer to have commercially available products because of the prepared lab manuals and technical support by the companies. However, especially for undergraduate research institutions, this type of project offers excellent hands-on training opportunities for the students. Students involved in this project learn stripping/crimping of wires, reading specifications of the components, contacting companies for technical support where equipment is purchased, drilling holes with a variety of drill bits, cutting square/circular holes with routers, creating 2D/3D layouts and drawings for drilling and component orientation purposes, welding and metal and wood working to build the module frame. Students also experience troubleshooting and connections between various RE components such as charge controllers, batteries, lightning arrestors, circuit breakers and fuses, rectifiers, inverters, wind turbines, switches, AC and DC loads, grounding rods, thermoelectric generators, piezoelectric materials, measuring and data acquisition tools. Since the spring 2009 semester, approximately 35 students (mostly undergraduate and three graduate students) have been involved in this experience.

Students involved in this project conducted structured independent research, used creative thinking, and shared hands-on experiences, which was beneficial to them. The training units were used to develop an understanding of the way that energy is collected and stored. Establishing alternative energy teaching and research interactive training units involved our undergraduate and graduate students, faculty and community for future alternative energy projects and training. A fully functional training unit provides for applied energy education workshops for local community colleges, secondary/high school science/technology teachers and students, as well as for interested citizens who have not been exposed to state-of-the-art renewable energy. Students

can obtain valuable knowledge by doing research related to their major/minor.

The outcome of this project was an efficient, easy approach to building and operating a cost-efficient and mobile alternative energy training unit that works as a stand-alone mini-lab. It is an interdisciplinary project because this study gathered students from a variety of disciplines and merged their knowledge in this experimental project. The project engaged student participation from disciplines such as construction management, design and development, safety management, agricultural engineering technology, industrial technology and electronics. The results of the reliability of these types of projects will lead other institutions to develop their own systems. Students involved in this project were able to participate in hands-on experiments that will benefit their future careers. Building a renewable energy teaching and research training unit as a mini-lab will help to establish a laboratory and involve our undergraduate/graduate students, faculty and community as they learn about alternative energy. A fully functional laboratory training unit will augment applied energy education workshops for local community colleges, secondary/high school science/technology teachers, students, and especially interested others not already exposed to state-of-the-art renewable energy.

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# THE IMPACT OF CHANNEL DOPING DENSITY ON NANO-SCALED MOS DEVICES

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## Abstract

As Metal Oxide Semiconductor (MOS) channel length shrinks into the nano-scale regime, the impact of channel doping density has become more pronounced on transistor drive current, the threshold voltage and the leakage current. This work focused on understanding the impact of channel doping density on nano-scale metal oxide semiconductor devices. Two channel doping concentrations of  $5 \times 10^{16}$  atoms/cm<sup>3</sup> and  $5 \times 10^{14}$  atoms/cm<sup>3</sup> for N-type devices with 90nm and 900nm channel lengths were evaluated. The experimental results demonstrated that the threshold increases with the higher channel doping concentration, and the variation in figure-of-merit parameters ( $V_t$ ,  $I_{off}$  and  $SS$ ) are much greater for the lower channel doping concentration devices.

## Introduction

The Metal Oxide Semiconductor Field Effect Transistor (MOSFET) has been the major device for integrated circuits over the past five decades. With technology advancement and the high scalability of the device structure, silicon MOSFET-based Very Large Scale Integrated (VLSI) circuits have continually delivered performance gains and cost reduction to semiconductor microchip manufacturers of data processing and memory devices [1]. The impact of channel doping density on MOS nano-scaled devices is vital to the design and application of devices. Since the creation of the first transistor, inventors have been trying to find ways of making devices ever smaller for economy of scale. The applications for ICs have increased, their sizes have decreased and functionality has increased. Channel length is important in the determination of off-state current [2], [3]. In this study, the average off-state leakage current for the n-channel metal oxide semiconductor (NMOS) 90nm device was 10nA and 1.1nA for the 900nm device. The transistor off-state current is defined as the drain current when the gate-to-source voltage is 0V [3]. The data presented represent an average of 244 sites at room temperature.

## Experimental Methodology

The MOSFETs were fabricated using 90nm process technology. Processing was performed on 200mm diameter wa-

fers. Lightly doped drain regions were implanted along with halo implantation in order to control the short channel effects (SCE). Threshold variation was given by way of threshold voltage implants that allowed a threshold range between low channel doping concentrations (LCDC) and high channel doping concentrations (HCDC), respectively. Two n-type devices with aspect ratios of 4500nm/90nm (W/L) and 4500nm/900nm (W/L) were tested. The high channel doping (HCDC) devices had  $10^{16}$ cm<sup>-3</sup> impurity concentrations in the channel, while the lower channel doping (LCDC) devices had  $10^{14}$ cm<sup>-3</sup> impurity concentrations in the channel. The average threshold voltage for the 90nm lower doping concentration device was 0.14V, while the value virtually doubled (0.25V) for the high channel doping concentration device. The average threshold voltage for the 900nm lower channel doping concentration devices was 0.15V, with 0.21V for the high doping concentration device. All of the devices had equal widths of 4500nm.

The data for this study were collected at the Advanced Device Characterization Laboratory of Prairie View A&M University. All measurements were performed on an Agilent 4155C Semiconductor Parameter Analyzer. Static current/voltage characteristics of front channel  $I_d - V_g$  were measured with medium integration time and single sweep. The gate voltage for the n-type devices was swept from -0.20V to +1.2V in 100mV increments.

## Background

In contemporary integrated circuit design, sources of power dissipation in CMOS circuitry can be attributed to sub-threshold leakage currents and dynamic switching power [3]. The largest contributor to this power-consumption challenge is dynamic switching power. This is attributed to very high speed gate capacitance charge fluctuations during signal switching. However, continued advancements in low-power voltage scaling will bring about an increase in sub-threshold leakage. This increase may be large enough in magnitude to potentially dominate overall power dissipation. In addition, this becomes more important as sub-threshold leakage current is a strong function of, and exponentially impacted by, the threshold voltage [4], [5].



## Threshold Voltage Adjustment

Silicon transistor technologies have been particularly attractive for low-power applications. The challenge, as mentioned, is to minimize power dissipation while maintaining high-performance operation. The primary approach for improved energy efficiency is power supply scaling. In order to preserve circuit speed, scaling of the power supply should be accompanied by a threshold voltage reduction [2], [4]. However, the lower limit of the threshold voltage is set by the amount of tolerable off-state leakage current. This consideration becomes increasingly important with added geometric scaling to deep sub-micron regimes. Also, with power supply scaling comes a relational downward scaling of threshold voltage, which therefore makes threshold voltage control progressively important [5], [6].

The main enablers of threshold voltage adjustment can be seen in the influence of the acceptor concentration in Equation 1. The threshold voltage controlling mechanism is a function of substrate doping ( $N_A$ ), substrate bias via ( $\phi_s$ ) and oxide thickness ( $t_{ox}$ ). The primary contributor to leakage current and transistor threshold voltage will be variation of the channel doping concentration:

$$V_T = 2\phi_F - \frac{Q_s(2\phi_F)}{C_{ox}} + V_{FB} \quad (1)$$

where  $C_{ox}$  is the oxide capacitance,  $V_{FB}$  is the flat band voltage,  $Q_s$  is the bulk charge,  $V_T$  is the threshold voltage and  $\phi_F$  is the internal potential.

The channel doping concentration can be modified using ion implantation with two limiting cases considered: the very shallow heavily doped surface layer, and the general ion-implanted impurity profile. The very shallow surface layer is modeled in Equation 2, while the effect on threshold voltage is described by Equation 3:

$$N_D(y) = N_A + D_i\delta(0) \quad (2)$$

$$\begin{aligned} V_G &= \phi_s + \frac{q}{C_{ox}} \int_0^W [N_A + D_i\delta(0)]dy + V_{FB} \\ &= \phi_s + \frac{qN_A W}{C_{ox}} + \frac{qD_i}{C_{ox}} + V_{FB} \end{aligned} \quad (3)$$

where  $V_G$  is the gate voltage at threshold,  $W$  is the maximum depletion width,  $\phi_s$  is the surface potential,  $D_i$  represents the change to the channel impurity, and  $N_D$  and  $N_A$  are the donor and acceptor concentrations, respectively.

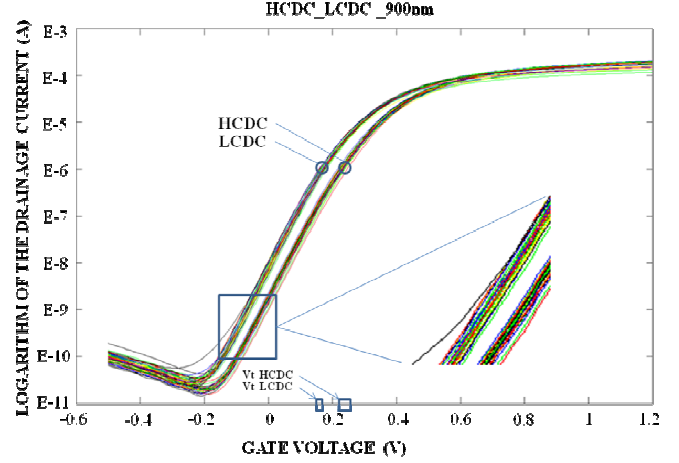


Figure 1. Current-Voltage Characteristics of HCDC and LCDC Devices of 900nm Channel Length

## Results and Discussion

The data presented represent an average of 244 site measurements. As shown in Figure 1, the current-voltage characteristics of the high channel doping concentration (HCDC) and the lower channel doping concentration (LCDC) 900nm devices exhibited standard characteristics. As expected, LCDC showed higher drive current,  $4.3\mu A$  for LCDC and  $1.10\mu A$  for HCDC, due to less impurity in the channel. Comparatively, Figure 2 shows similar current-voltage characteristics for 90nm devices. It can be argued that both HCDC and LCDC exhibited higher variation as depicted in the figure. The average drive current of  $4.3\mu A$  for LCDC and  $1.10\mu A$  for HCDC remain unchanged; however, the standard deviation doubled to 6% from 2.8% for 900nm channel devices. As the voltage approached the off states, more variation was observed with the LCDC devices. This variation was attributed to larger depletion extrusion into the channel region. Although the average current was not significantly different, the variation was apparent between the 900nm (Figure 1) and 90nm (Figure 2) devices. This was expected since depletion is inversely proportional to the channel doping concentration (see Equation 4) [7], [8].

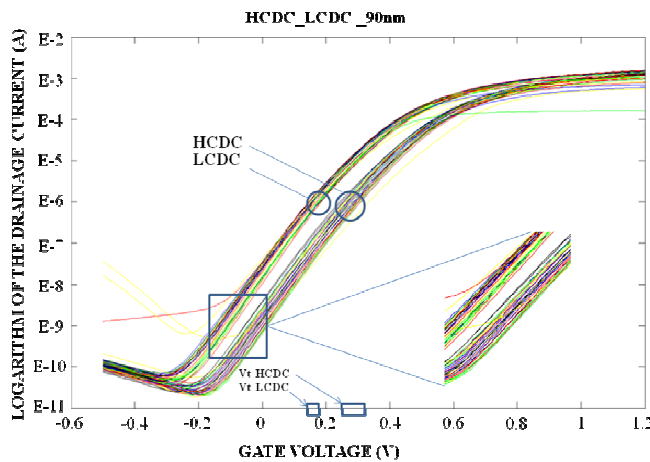
$$W_{dep} = \left[ \frac{2K_s\epsilon_0}{q} \left( \frac{N_a + N_d}{N_a N_d} \right) (V_{bi} - V) \right]^{1/2} \quad (4)$$

Consistently apparent in Figures 1 and 2 is the higher drive current of LCDC over HCDC, both at 90nm and 900nm channel length at a given gate voltage. This is due to lower carrier mobility in HCDC channel because of the higher impurity concentration; the opposite will be the case for the LCDC devices. As shown in Figure 3, the effect of channel doping concentration on mobility is further demon-

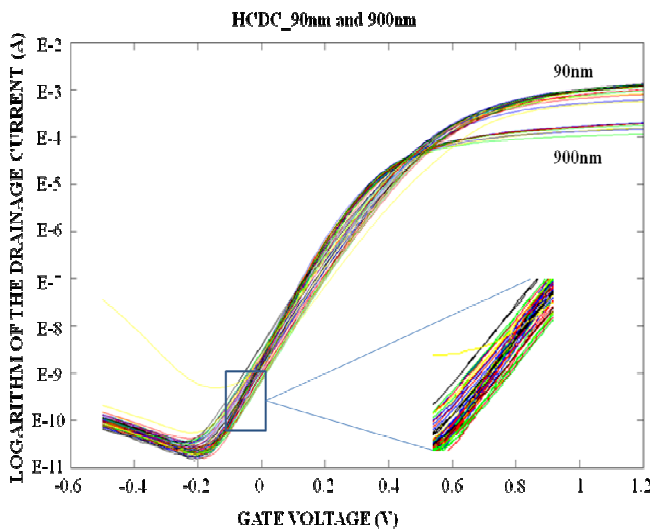
strated. The drive currents of 90nm and 900nm channel devices are almost identical for HCDC except at higher gate voltages where 90nm drives higher. This higher drive current can be directly attributed to a higher electric field for 90nm devices and an inverse relationship between the drive current ( $I_D$ ) and the channel length (see Equation 5):

$$I_D = q \frac{kT}{q} \sqrt{\frac{\epsilon_s}{2qN_a\phi_s}} D_n W \frac{1}{L} \frac{n_i^2}{N_a} e^{q\phi_s/kT} \quad (5)$$

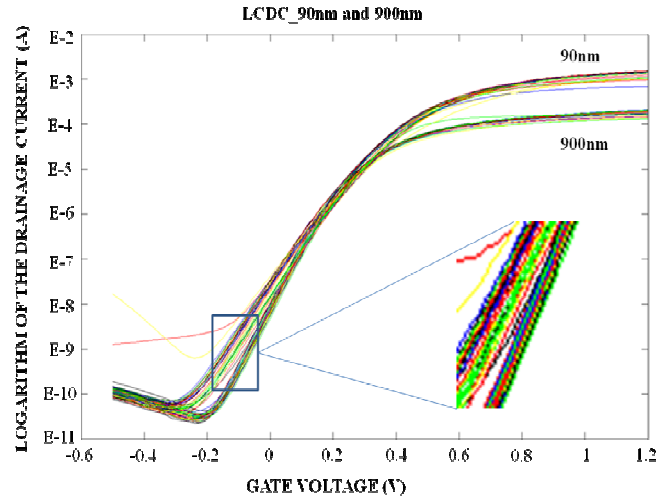
where L is the channel length, k is the Boltzmann constant, q is the electronic charge and T represents absolute temperature. A similar argument holds for LCDC 90nm and 900nm channel length devices, as shown in Figure 4.



**Figure 2. Current-Voltage Characteristics of HCDC and LCDC Devices at 90nm Channel Length**



**Figure 3. Current-Voltage Characteristics of 90nm HCDC and 900nm HCDC devices**



**Figure 4. Current-Voltage Characteristics of 90nm LCDC and 900nm LCDC devices**

It can be seen that a few sites of the 90nm devices are beginning to show higher current at very low gate voltage. This may be attributed to the higher carrier concentration in the source and drain and the associated diffusion gradient, though more drive current and more leakage current will be generated by the smaller channel devices. The sub-threshold slope for the smaller devices ranges between 96.3mV/decade and 128.6mV/decade, and between 78.2mV/decade and 102.8mV/decade for the 900nm devices.

## Conclusion

Two channel length (90nm and 900nm) devices with two channel doping concentrations were characterized. At room temperature, a lower doping concentration exhibited higher leakage when compared to the high channel doping concentration device. As the channel length decreases, the  $I_{off}$  increases due to source and drain junction proximity, diffusion gradient and the higher electric field. The threshold voltage of the high channel doping concentration device is clearly much greater than the lower channel doping devices. As the channel doping concentration increases, the threshold voltage increased. The results showed that 90nm devices turn on faster with a steeper current curve. So, for a large change in  $V_g$ , there is a smaller change in the logarithm of the drain current and, consequently, a larger sub-threshold slope. In future studies, the focus will be on understanding current leakage mechanisms; specifically, gate-induced drain leakage (GIDL) and gate-edge direct tunneling and the associated quantum effects.

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## Biographies

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# COMPARATIVE ANALYSIS OF THE RESIDENTIAL ENERGY EFFICIENCY POLICIES OF SIX MIDWESTERN STATES OF THE U.S.

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Suchismita Bhattacharjee, Nicholas Emmons, Tarek Mahfouz and James Jones, Ball State University

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## Abstract

This study looked at the need for energy conservation and the use of renewable sources of energy, energy efficiency and renewable energy policies implemented by state governments in order to accelerate the development and deployment of energy efficient and renewable energy technologies. This research task represents an initial step in a line of research projects aimed at developing an automated methodology for decision support in the field of energy efficiency policy development and evaluation. As a first step, a solid point of departure for this research line should be established through a literature review and a comprehensive understanding of the current standing of energy efficiency policies in the United States. Consequently, the current research task focuses on residential energy efficiency policies in six Midwestern states, namely Illinois, Indiana, Michigan, Minnesota, Ohio and Wisconsin, due to their proximity and familiarity to the authors.

This study employed a cross-sectional analysis to understand the components of energy efficiency policies in the aforementioned six Midwestern states in the U.S. Policy priorities were identified and predictions put forward about possible future directions of energy efficiency policy in these states. To that end, the Database of State Incentives for Renewables & Efficiency (DSIRE) has been used for data collection. The database provided detailed information about each policy, both at the state and municipal levels. The study provides the groundwork for more specific research targeted toward individual policies implemented across the states, identifying possible trends and conducting policy analyses to test policy efficiency.

## Introduction

Energy conservation and the use of renewable sources of energy have gained increasing importance subsequent to the oil crisis of the 1970s. In recent years, the world has been faced with a serious shortage of energy which has heightened the need for energy efficiency. “Governors, state legislators, regulators, and citizens are increasingly recognizing that energy efficiency—the kilowatt-hours and gallons of gasoline we don’t use as a result of improved technologies

and practices—is the cheapest, cleanest, and quickest energy resource to deploy” [1]. As a result, energy efficiency policies are targeted towards creating necessary conditions to speed up the development and the deployment of energy-efficient equipment. These policies encourage people to use energy more efficiently; that is, get the maximum output from a minimum input of energy.

In the U.S., various energy efficiency policies have been developed and implemented at the federal level as well as at the state level. Usually, following the policies implemented at the federal level, each individual U.S. state implements its own set of policies, which are guided by the broader aspects of the federal policies. Some states such as California (ranked first among the 50 states in 2010 and second in 2011), Massachusetts (ranked first in 2011) and New York (ranked third in 2011) are more advanced compared to others with respect to the type and the number of energy efficiency policies implemented [1]. The world is undergoing vast changes that create unique challenges for development and implementation of efficient energy policies. In 2010, a total of \$5.5 billion was allocated to support electricity and natural gas efficiency programs in the U.S. [1]. These challenges and their manifestations in societies are often very complex in nature and require integrated approaches to solve them.

Although energy efficiency policies represent a pressing demand for our communities, the literature does not include a lot of comparative or explanatory analysis to the ones currently in place. In one of the most recently developed reports, the American Council for Energy Efficient Economy (ACEEE) ranked the 50 states in relation to energy policies with respect to six areas: 1) utility and public benefits programs and policies; 2) transportation policies; 3) building energy codes; 4) combined heat and power; 5) state government initiatives; and 6) appliance efficiency standards [1]. To that end, this study presents a focused comparative analysis of the energy efficiency policies implemented at the six Midwestern U.S. States surrounding the Great Lakes. This research represents a point of departure for a research line aimed at developing a comprehensive decision support methodology for energy policy portfolio analysis.



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## Background

Over the past 30 years, several energy efficiency policies have been implemented in the U.S., which were guided mainly by three drivers [2]. The first major driver was the economic concern that evolved during the oil embargo of the 1970s. The second factor was the environmental movement that started in the early 1970s in response to urban smog and acid rain, and more recently to climate change. The third driver was the increasing energy cost for the consumer [2]. According to the 2011 ACEEE report, nearly every state implements a kind of energy efficiency program nowadays. "Driven by effective regulation from state utility commissions, utilities and third-party program administrators in some states have been delivering energy efficiency programs for decades, and offer various efficiency services for residential, commercial, industrial, and low-income customers." [1]. Policy-makers responded to the aforementioned market drivers by formulating two types of policies: (a) supply-push policies and (b) demand-pull policies [3]. Supply-push policies encouraged technological innovations while demand-pull policies created a market for emerging energy efficient technologies. Supply-push policies were mostly in the form of mandatory regulations, economic incentives and financial help for industries to promote energy efficiency or energy efficient products. Demand-pull policies were, for example, environmental regulations, regulations related to utilities, information and awareness programs, and subsidies for specific energy saving technologies.

## Research Goals

The goal of this study was to perform a comparative analysis of the energy efficiency policies implemented in the six Midwestern states of Illinois, Indiana, Michigan, Minnesota, Ohio and Wisconsin. Content analysis was used to comprehend and arrange large volumes of data collected from the Database of State Incentives for Renewables & Efficiency (DSIRE). The outcome of the analysis would assist in understanding the dynamics of currently implemented policies.

## Rationale

The need for this study was justified by the following reasons. First, a majority of the existing literature in this area was survey-based. Therefore, this study focused on policy content and available socioeconomic information in order to gain an in-depth understanding of how instituted policies directly relate to state and local constituents [4-7]. Second, an analysis of energy efficiency policies imple-

mented at the state level was an uncommon phenomenon. Several studies analyzed the effectiveness of energy efficiency policies at the national or international level [8-12]. Third, this study provided information to social scientists, such as political scientists and sociologists, to better understand the requirements of the efficiency policies. Finally, much of the available research was conducted at larger and advanced states, like California and New York, but never on the Midwestern states [13-15].

## Methodology

This section provides a description of the adopted research methodology illustrated in Figure 1. To that end, the study included only the states in the Midwest region of U.S. surrounding the Great Lakes, namely Illinois, Indiana, Michigan, Minnesota, Ohio and Wisconsin.

The method employed for this study was content analysis, which was used to analyze the explicitly mentioned components of each policy. Content analysis permitted the authors to develop a better understanding of energy efficiency policy portfolios of these six Midwestern states. To that end, 341 municipal energy efficiency policies listed under the six Midwestern states in the DSIRE database were first collected. Next, the authors went through the descriptions of all of the policies and shortlisted a total of 274 policies which focused only on the residential sector.

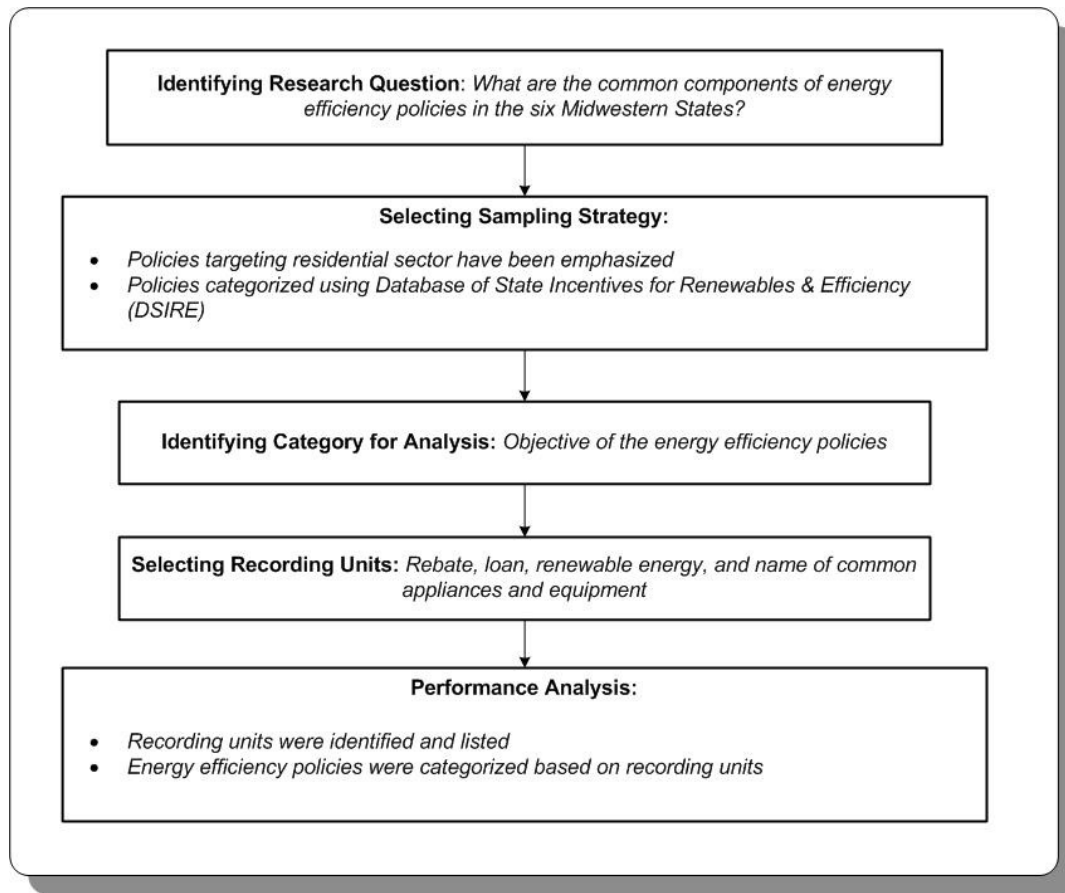
## Content Analysis

Content analysis is a useful technique used to sort qualitative data and categorize them into a more methodological and systematic manner [16-18]. The study adhered to the rigorous process of content analysis as outlined by Robson [19]. After identifying the research questions, the sampling strategy was chosen, followed by identification of the recording unit. Subsequently, the analysis was conducted using the recording units.

The specific steps described here were performed in conducting the content analysis in order to analyze the residential energy efficiency policies in the states of Illinois, Indiana, Minnesota, Michigan, Ohio and Wisconsin. Each of these steps is described below, providing a detailed representation of how the data for this study were collected.

## Research Question

The primary research question for the analysis was: What are the common components of energy efficiency policies in these six Midwestern states? A number of initiatives have



**Figure 1. Research Methodology**

been implemented at the state and local levels with the aim of increasing energy efficiency in the residential sector. This study evaluated these components in order to develop a better understanding of the incentives that are offered along with the types of appliances that are targeted by the policies.

## Sampling Strategy

Energy efficiency policies targeting both residential and commercial sectors, and energy efficiency policies targeting only residential sectors, have been included. Based on the target sector, categorization of policies was performed using an energy efficiency policy online database, the Database of State Incentives for Renewables & Efficiency (DSIRE). DSIRE, a comprehensive source of information on state, local, utility and federal incentives and policies that encourages renewable energy and energy efficiency, was used for this study [20].

## Category Analysis

The categories for analysis were based on the research questions. According to Holsti [21], there are several types of categories: subject matter, direction, values, goals, methods, traits, actors, authority, location, conflict and ending. For this study, the category for analysis was the objective of the energy efficiency policies. The categories were exhaustive and mutually exclusive.

The primary objective of residential energy efficiency policies is to generate the required conditions that can expedite both advancement and deployment of market efficient equipment through the following means: (a) knowledge for and interaction with the end users, (b) potential threat shared with both distributor and producer, (c) research, development and diffusion of the skill inherent in energy efficiency sectors, (d) operation of particular mechanisms pertaining to finance, and (e) parameters for the consumers and/or of equipment used [22].

## Recording Unit

Apart from defining the categories to be used, another important task was to select the recording unit. Individual words were used as the recording unit for this study. Each time a particular word occurred, it was counted as one, and counts of these occurrences were made and compared. Due to the simplicity of the approach, authors could distinguish between words with multiple meanings and code phrases that constituted a semantic unit. For this study, units of interest were “incentive”, “rebate”, “loan”, “renewable energy”, and names of particular appliances or equipment.

## Analysis

The analysis of the information followed three steps. Consistency was considered to be the key for this study, so the standards were strictly met. The three-step process of analysis was:

- Each policy description was studied once to find the recording units. Generally, exact words or phrases were not found; instead, the understood meaning was considered. Brief notes were made when something containing relevant information appeared.
- The policy descriptions were studied again and a list of all of the identified recording units was finalized.
- Finally, the energy efficiency policies were categorized based on the recording units.

## Results

The four analyses that were conducted for this study were: (a) type of policies (residential alone and residential with other audiences), (b) the types of appliances that were included in the policies, (c) the policies that have either an energy efficiency or renewable energy focus, and (d) the types of incentives offered. The background of policy content and purpose provided by the analyses would act as a foundation for subsequent investigations.

In an attempt to validate the forthcoming outcomes of the adopted research methodology, an investigation of the underlying probability distribution of the addressed populations (six Midwestern states) was performed. To that end, a one-way ANOVA and a correlation analysis were performed on data gathered from these states. The aforementioned analyses were performed using 20 factors:

Median household income  
Median age of people  
% Male

% Female  
Population  
% White  
% African American  
% American Indian  
% Native Hawaiian  
% of two or more races  
% Hispanic or Latino  
% White, not Hispanic or Latino  
Number of households  
Number of industries  
% HS Diploma  
% Bachelor's  
Per Capita Energy Consumption -- Million Btu  
Number of heating degree days  
Energy Price -- per million Btu

Table 1 includes the outcomes of the correlation analysis, while Table 2 identifies the results of the ANOVA analysis. A closer look at these outcomes shows that there is a strong correlation between the six states. The values ranged between a maximum of 0.999987 to a minimum of 0.999613. Furthermore, the achieved an F value of 0.246 compared to a critical F value of 2.29 illustrates that there is an overlap between the underlying sampled populations. This was expected due to the fact that the analyzed states operate under one major governmental policy that supports the development and implementation of efficient energy policies at the state level. As defined by Elizabeth Doris, Jaquelin Cochran, and Martin Vorum in the Energy Efficiency Policy in the United States: Overview of Trends at Different Levels of Government report [23], the efficient energy policies in the U.S. aims at lowering energy bills, improving air quality, reducing greenhouse gases, increasing energy security and deferring the need to invest in new infrastructure. This finding is further supported by the notion that the analyzed states are Midwestern ones, which mandates similarities of the underlying distributions.

**Table 1. Correlation Analysis of the 6 States**

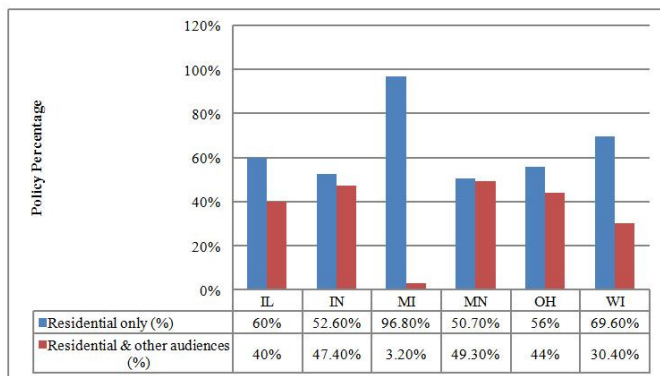
	<i>IL</i>	<i>IN</i>	<i>MI</i>	<i>MN</i>	<i>OH</i>	<i>WI</i>
IL	1					
IN	0.999945	1				
MI	0.999757	0.999876	1			
MN	0.999933	0.999858	0.999757	1		
OH	0.999626	0.999802	0.999983	0.999613	1	
WI	0.999905	0.999987	0.999931	0.999861	0.999872	1

Within the first analysis (Figure 2), it was found that Michigan had the highest percentage (96.8%) of programs targeting residential audiences only, with nearly every policy aimed at energy efficiency of residential users. Indiana

had the highest percentage (47.4%) of programs targeting both residential and other audiences, including businesses and schools. Illinois and Ohio had an equal distribution in both categories, whereas two-thirds of programs implemented in Wisconsin were aimed at residential audiences.

**Table 2. Outcomes of ANOVA Analysis of the 6 States**

Source of	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P</i> -	<i>F crit.</i>
Between	5.59E+12	5	1.12E+12	0.246	0.94	2.29
Within	5.19E+14	114	4.55E+12			
Total	5.25E+14	119				



**Figure 2. Policies in the Six States Targeting Residential Audiences**

The second analysis explored the types of appliances that were targeted by the energy efficiency policies of all the six states (Table 3). A majority of the energy efficiency policies of Indiana, Ohio, Minnesota and Wisconsin targeted heat pumps and water heaters, whereas the policies of Illinois focused on water heaters and furnaces. The primary focus of the policies of Michigan was clothes washers. In all of the six states, central air conditioners were targeted by approximately 48% of the policies. Overall, Indiana and Michigan had the greatest number of policies targeting appliances, whereas Illinois had the lowest number of policies.

The third analysis examined whether the policies had an energy efficiency or a renewable energy focus (Figure 3 and Table 4). Table 4 explains various types of policies that were in demand. There was an overlap in some cases where both energy efficiency and renewable energy were focused within the same policy. However, the vast majority (85.6%) of all programs focus on energy efficiency and more than half (59.8%) also featured incentives for renewable energy technologies. Michigan had the highest percentage (93.5%) of energy efficiency programs; however, a little more than one in ten (12.9%) of those focused on renewable energy. Indiana was most likely to support the use of renewable

energy policies with more than three-fourths of the programs encouraging their use.

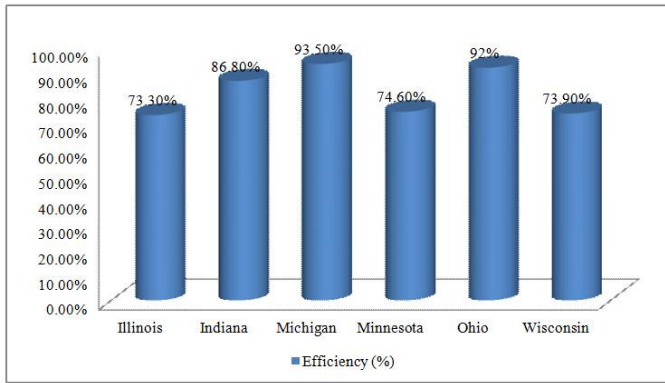
**Table 3. Percentage of the Policies Implemented in the Six States Targeting the Different Residential Appliances**

Appliances	IL %	IN %	MI %	MN	OH %	WI %
Water heater	75.0	75.0	37.0	55.7	63.2	72.2
Space heater	25.0	3.1	0.0	3.8	15.8	16.7
Heat pump	50.0	84.4	11.1	68.9	68.4	57.9
Pool heater	8.3	3.1	0.0	1.6	0.0	16.7
Refrigerator	25.0	3.1	29.6	63.9	21.0	33.3
Freezer	0.0	0.0	0.0	0.0	0.0	5.5
Dehumidifier	8.3	0.0	14.8	44.3	5.3	11.1
Ceiling fan	8.3	0.0	7.4	29.5	15.8	0.0
Furnace	58.3	15.6	44.4	31.1	47.4	50.0
Central air condi-	41.7	43.8	63.0	67.2	36.8	50.0
Room air condi-	16.7	0.0	14.8	36.1	5.3	5.5
Clothes washer	8.3	15.6	70.4	62.2	5.3	16.7
Clothes dryer	0.0	0.0	3.7	0.0	0.0	0.0
Boiler	33.3	9.8	18.5	24.6	21.1	50.0
DE super heater	8.3	0.0	0.0	0.0	0.0	0.0
Back-up genera-	0.0	3.1	0.0	0.0	0.0	0.0
Dishwasher	0.0	0.0	7.4	55.7	5.3	16.7
Total number of	12.0	32.0	27.0	61.0	19.0	18.0

**Table 4. Percentage of the Policies Targeting Renewable Energy**

State	Renewable (%)
IL	53.3
IN	76.3
MI	12.9
MN	56.3
OH	48.0
WI	60.9
Total	59.8

To gain further insight into the topic, a comparison of the types of incentives that were offered within the policies was performed (Table 5). The majority (76.5%) of residential energy efficiency programs were rebates for using energy efficient or renewable technologies. Loans were the least popular (9.1%), except in Wisconsin (21.7%) and Ohio (20%). Michigan dominated the rebate category (93.5%) and offered no residential loans. Other forms of incentives were present in all states. Those that were not rebates or loans accounted for a relatively small portion (14.4%) of overall energy efficiency policies.



**Figure 3. Percentage of the Policies Implemented in the Six States Targeting Energy Efficiency**

**Table 5. Percentage of the Policies Implemented in the Six States that are Either Rebates, Loans or Other Types**

State	Rebate	Loan (%)	Other (%)
IL	66.7	6.7	26.7
IN	86.8	2.6	10.5
MI	93.5	0.0	6.5
MN	77.5	14.1	8.5
OH	68.0	20.0	12.0
WI	52.2	21.7	26.1
Total	76.5	9.1	14.4

## Discussion

The aforementioned findings are encouraging because of the potential implication. This means that the Midwestern states recognized the need to offer financial incentives to constituent homeowners. Large areas of rural communities could be the reason for the greater number of policies targeting appliances in Michigan and Ohio compared to Illinois; the larger the influence of rural communities, where homeownership is higher, the more relevant the need for financial assistance for energy efficient appliances. Indiana and Michigan have larger areas of land that is mostly rural, whereas the influence of Chicago often sways decision-making in Illinois. Indiana's support to increase the use of renewable energy is most likely a result of the movement within the state to harness ethanol-based fuels. Additionally, it is encouraging to notice that a high proportion of the policies implemented in the six Midwestern states focus on renewable energy and energy efficiency. At the same time, the policies should continue increasing their focus on renewable technologies.

Although these outcomes might not fully comply with the outcomes of the 2011 ACEEE report in regards to the rank-

ing of states, this fact contributes to the focus of the current research. As mentioned earlier, the ACEEE report considers six area of energy efficiency, namely Illinois, Indiana, Michigan, Minnesota, Ohio and Wisconsin. On the other hand, this study provides a more focused look at policies targeting residential construction and energy saving appliances.

This study helped to identify the possible methods to enhance energy efficiency policy at the local and state levels, in addition to serving as a model for the development of federal energy policy. Beyond the environmental benefits gained from enhanced energy efficiency policies, human health and well-being will likely improve as a result of better financial incentives built into energy efficiency policies and the shift from conventional energies to renewable technologies.

## Conclusion

The purpose of this study was to create a preliminary understanding of the focus of energy efficiency policies implemented in six Midwestern states. This study can possibly serve as a model in the study of energy policies at the local, state and federal levels. The analyses identified the types of financial incentives for residential users and found that an overwhelming majority of these incentives was in the form of rebates. It would be interesting to analyze the evolution of these types of policies to better understand how incentives have changed. In addition to the rebate programs in these six states, the economic market for loan programs is still alive.

Directions for future research would include further analysis of environmental and energy policies in the United States. There also exists the opportunity to compare domestic residential energy efficiency policies with international energy efficiency policies. Studies reflecting on the evolution of energy policy in the United States—at the federal and state levels—will assist in developing a broader concept of projected trends for the future. Finally, it would be of special interest to stakeholders to look at how climate change affects the incentives and incentive types of these policies.

The results of this study should be considered carefully due to possible limitations. First, this was a cross-sectional analysis of a convenience sample of six states only, posing a threat to external validity. The results cannot be generalized to the entire United States policy scenario. Second, researchers could have made errors in interpretation of policy content. However, this was controlled by assessment of all policies by two independent researchers. The study was



delimited to the DSIRE database, which may not be up-to-date, resulting in some missing elements of policies. Finally, due to a small number of states considered in this study, in-depth quantitative analyses could not be conducted. There may be more insights that can be revealed with a larger sample that would allow for a detailed quantitative analysis in addition to content analysis.

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# PREDICTING MANPOWER REQUIREMENTS FOR A TRUCK-BUILDING FACILITY USING SIMULATION TECHNIQUES: A CASE STUDY

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## Abstract

Simulation is one of the most frequently used techniques in operations research and industrial engineering. Simulation can be applied in many critical areas and enables one to address issues before they become problems. The effective generation, verification and validation of simulation models is an important challenge. Due to the rapid increase in computing power, it is now possible to simulate significantly larger systems. In this study, simulations are used to predict the manpower requirements for a local truck-building facility. Here, the authors developed two simulation models. The first, Model I, was used to identify the bottlenecks in the facility and study their impact on truck production. Later, an interactive simulation model (model II) was built using commercially available software (Extend 6.0) to predict the manpower requirements for every station depending on the planned truck production. A time-study analysis of the facility was also conducted in order to obtain the data required for the simulation models. These models predicted the manpower requirements depending on the user's input to the model for the planned truck production and the desired operator utilization. This study served as a demand-based decision-making tool for resource allocation.

## Introduction

In today's competitive environment, decision making and strategic planning are becoming more and more important. Computer simulation is one of the most important analysis tools that can help to increase operational understanding and decision making for managers [1]. Simulation is an imitation of the operation of a real-world process or system over time. Simulation is used to describe and analyze the behavior of a system, ask what-if questions about the real system, and aid in the design of real systems [2]. In the field of mechanical engineering, simulations have been used for a variety of applications ranging from evaluating airborne radar applications [3] and analyzing solar-panel efficiency [4] to path planning and navigation for unmanned surface vehicles [5].

In principle, by experimenting with different configurations of the system, engineers can evaluate and compare any

number of system designs. One of the largest application areas for simulation modeling is that of manufacturing systems [6], with the first uses dating back to at least the early 1960s. Following are some of the specific issues that simulation addresses in manufacturing:

- The need and the quantity of equipment and personnel for a particular objective [7]
- Labor-requirement planning [8]
- Performance evaluation such as throughput analysis, bottleneck analysis, time-in-system for parts, utilization of equipment and/or personnel [9], [10]

Factory simulation can provide insights into various issues of a manufacturing firm before significant time and cost has been invested [11], [12].

The purpose of this research study was to develop and validate a visual interactive simulation model that represents the manufacturing flow of a local truck-body building facility. This model was used to predict labor requirements for every station depending on the truck production planned on a given day. Figure 1 presents the process flowchart describing the process used in the simulation model for this truck-building facility. The process chart is a device for recording the processes in a compact manner as a means of better understanding and improving it [12]. The chart graphically represents the separate steps or events that occur during the performance of a task. The chart begins with the raw material entering the factory and follows it through every step—such as transportation to storage, machining, assembly and inspection—until it becomes a finished product or a part of a subassembly. In the case of this study, raw materials entering the factory are truck chassis along with various parts, assemblies and subassemblies required to build a truck box. The finished product is a truck ready for dispatch to the dealers.

An extensive time study was conducted to get cycle times for various stations. Time-study analyses involve timing every operator for every operation. In the real world, different operators work at different paces based on their skills, ability and experience. New operators may take more time to finish their tasks than experienced, trained operators. Because of the time and scheduling constraints in conducting the time study, a time-study dataset based on a skilled oper-

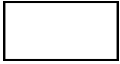


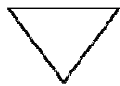
ator was used in the project. The cycle-time data collected from the time study were used as an input to the simulation model.

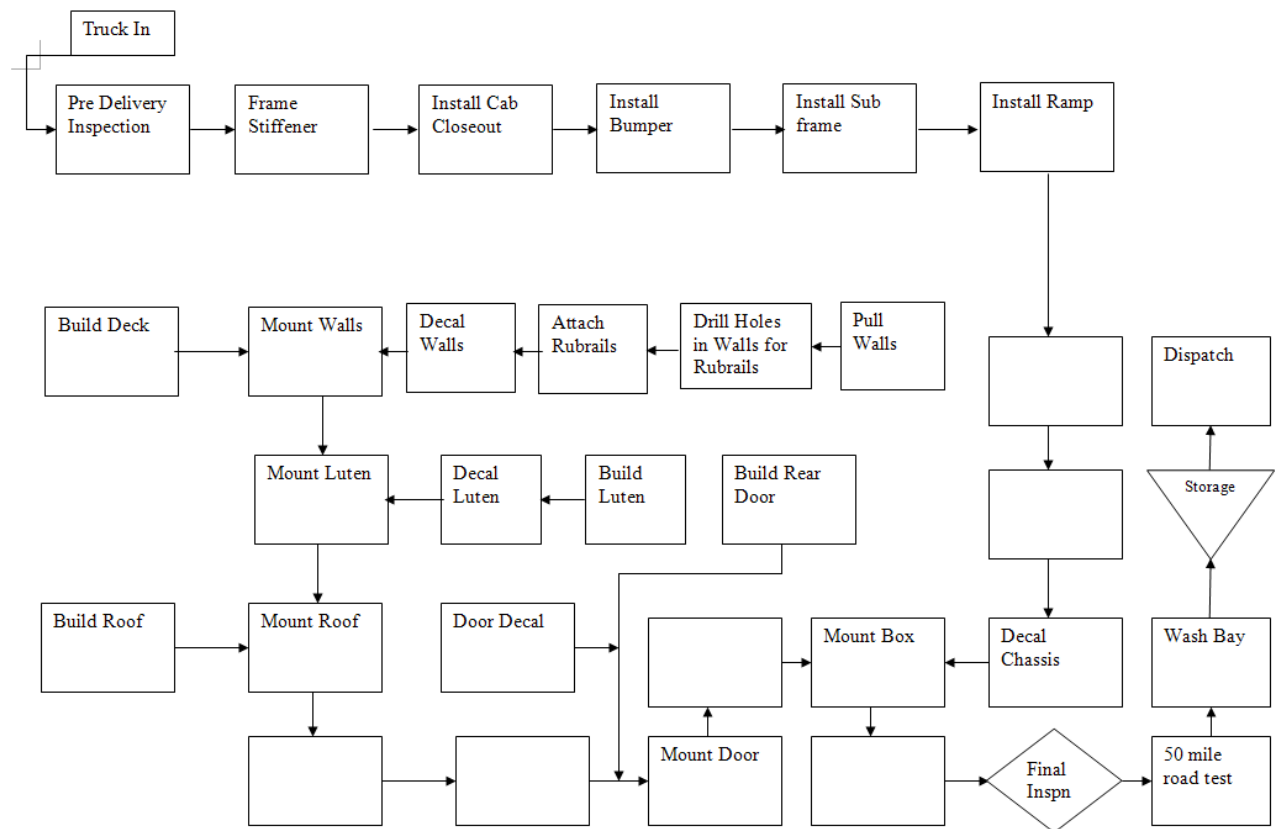
In this paper, the authors present the development and validation of this factory simulation. The symbols used in the process chart (shown in Figure 1) are described in Table 1.

## Industry Application

As stated earlier, the main objective of this study was to develop a methodology for predicting manpower requirements for every station, depending on the truck production output planned for a given day. Two simulation models using Extend 6.0 [13] were developed. First model was used to identify the bottlenecks of the facility, while the second model was used to predict the manpower requirements. For the first model, supervisor feedback about the cycle times for all stations was considered based on their knowledge and experience about the facility. The second model used data collected from time study for manpower prediction.

**Table 1. Symbols Used in the Process Chart**

Symbol	Name	Description
	Operation	An operation occurs when an object is intentionally changed in one or more characteristics. It represents a major step in the process and usually occurs at a machine or a work station.
	Transportation	Transportation occurs when an object is moved from one place to another, except when the movement is an integral part of an operation or inspection.
	Inspection	An inspection occurs when an object is examined for identification or is compared with a standard as to quantity or quality.
	Storage	Storage occurs when an object is kept under control such that its withdrawal requires authorization.



The next step in the project was to study processes taking place in the body building plant. This truck-building facility buys truck chassis from leading truck manufacturers. The body-building facility then builds truck boxes and installs them on the chassis. During this stage, various operations taking place at every station and sub-station were observed and recorded. With the help of this input, the process flowchart shown in Figure 1 was created and used to represent the truck-body building facility.

To construct any simulation model, the basic requirement is to have appropriate data. For the simulation model used in this study, the authors needed data such as operation sequence, operational job details, number of workers and cycle times for each and every station [6]. Since no historical data were available for the cycle times of stations, the important part of the simulation project was data collection. Operations taking place at every station were divided into small elements [14]. A document containing detailed list of activities performed at every station was prepared by the manufacturing department. This document contained a list of 372 operations performed at 22 stations. This document had information such as station name, operation number, operation performed, number of operators performing the operation and cycle time in seconds (see Table 2).

**Table 2. Time-Study Format**

Station Number	Station Name	Sub Station Number	Sub Station Name	Opn No.	Operations Performed	Operation Performed by # of Operators	Cycle Time in secs.	Performed by Operator No.
6	Pull Walls			68	Install hole alignment fixture and clamp.	1	88	10
6				69	Drill 2 holes top of the wall	1	43	10
6				70	Un-clamp and remove hole alignment	1	31	10
6				71	Drill 5 holes in bottom of the wall	1	56	10
6				72	Lift wall and slide into wall line	1	165	10
6		5.1	Clamp Rubrails	73	Clamp rub rails into position	1	74	10
6				74	Using fixture drill holes on rub rails	1	111	10
6				75	Remove fixture and drill 3/8" holes	1	122	10
6				76	Countersink all 40 holes	1	75	10
6				77	Make a set and put aside for later use	1	40	10

Time-study techniques were used to record the data for every station and sub-station in the format developed by the manufacturing group. The two commonly used methods for time studies are [14]:

- **Continuous Timing:** In this method, the observer starts the watch at the beginning of the first element and allows it to run continuously during the period of the time study. The observer records the watch reading at the end of each element. The time for each element is subsequently determined by subtraction.
- **Repetitive Timing:** In repetitive timing, the observer reads the watch, resets the watch, and then records the reading at the end of every element. This method gives the direct time without subtractions.

Time-study techniques used in this project followed the repetitive timing method where the operators were instructed to start performing the operation when instructed by the observer and stop when finished. This time study was per-

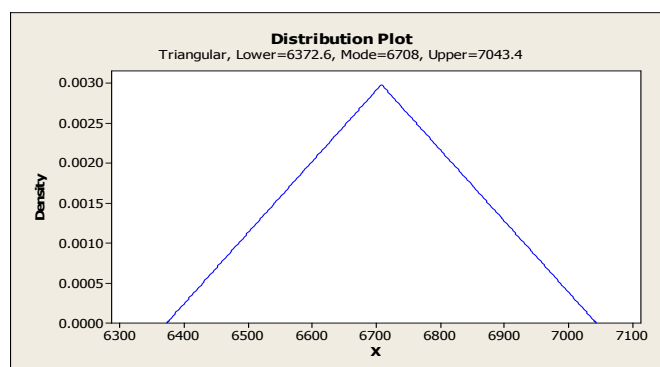
formed just before providing input to simulation. Before the actual time study, operators and supervisors were briefed and asked for suggestions, and trial runs were carried out to ensure that realistic data were collected.

## Model Development

### Model I:

After gathering the data, the next step of the project was model development. As noted above, two simulation models were developed. Both of the models used Extend 6.0 simulation software. The first model was used to identify the bottlenecks in the facility. This model had an associated notebook that displayed information such as station utilization, number of arrivals, number of departures and average processing time for every station. The notebook also showed truck production status at given times. Stock blocks were used in the model to store parts and supply them to the respective stations as requested. Various stations in the facility were represented by using station blocks. This model used the data based on supervisor feedback about processing times for various stations. All of the station blocks operated with random processing times.

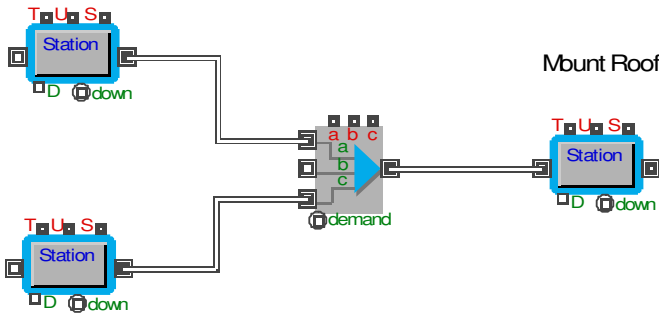
The distribution chosen for random processing was triangular. Triangular distribution is often used when little or no data are available [12]. It also has 3 parameters: minimum and maximum range definition and the more likely, or peak, value. The distribution has a triangular form (see Figure 2). It starts at the minimum value, increases linearly to peak at the mode, and then decreases linearly to the maximum value. The triangular distribution is often used in business decision making, particularly in simulation. As an example, the batching process joins one unit of roof with one unit of luten; the assembly then travels as one item. Figure 3 shows the block representation and Figure 4 shows the input to the block. Finally, the exit block was used to count the number of trucks built at a particular time.



**Figure 2. Example of Triangular Distribution**



Mount Luten



Build Roof

Figure 3. Example of Batch Block Used in the Model

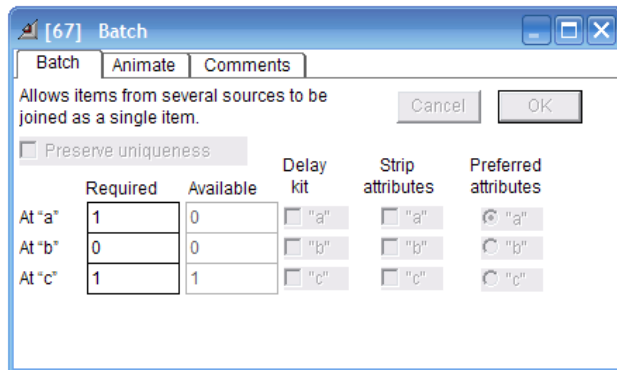


Figure 4. Batch Block Dialog

## Model II:

Figure 5 shows the architecture developed for the second simulation model. Through Excel, users can give the following input (as shown in Table 3) to the simulation model: a) Planned Production per Day, and b) Desired Operator Utilization. The desired operator utilization input will be explained later.

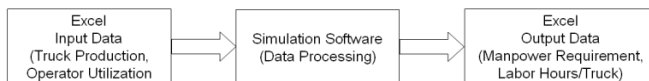


Figure 5. Model II Architecture

Table 3. Simulation Model Input Parameters

Planned Production per Day	5
Desired Operator Utilization %	70

Figure 6 shows how the different blocks are used in the second model, and represents a PDI I station used to model activities performed by operator #4. The cycle-time data collected from the time study are entered into respective blocks for respective activities of a particular station. The various activities performed at a station are represented by individual activity delay blocks. This model takes into consideration the number of workers at a particular station at the time the time study was performed. The activities performed by every worker are put into the model using separate activity delay blocks.

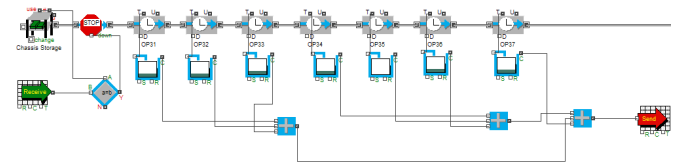


Figure 6. PDI I Station –Showing Different Blocks Used

Depending on the user input of planned production per day, the simulation model processes the data. The model calculates the total man-hours spent by every worker in the facility, based on the activities performed. These data are sent back to an Excel spreadsheet for further calculations. The Excel spreadsheet developed for manpower calculations shows the station number, station name and planned station production per day (see Table 3). It also displays information such as operator number, total time spent by the operators in performing their set of activities for building x trucks in a day, which is specified by the user. Total available hours in a day for production are also displayed. The spreadsheet then calculates the total number of man-hours required for a particular station for building x trucks in a day. It then predicts the total number of operators required for a station to achieve the desired utilization, which is entered as an input parameter by the user before running the model.

Operator utilization is calculated by the formula:

$$\text{Operator Utilization} = \frac{\text{Total Operator Hours}}{\text{Available Production Hours in a Day}}$$

Operator utilization indicates how much time per day each operator is utilized and how long he remains idle. Production hours (7.5 hours) are calculated by subtracting the lunch break of 30 minutes from the total shift time of 8 hours. The operator-utilization figure automatically changes to red if operator utilization is less than the desired operator utilization for a user-entered planned production per day. A utilization figure marked with a gold background indicates that operator utilization is greater than the desired utilization and overtime, or an extra operator, would be required in

**Table 3. Excel Spreadsheet -Format for Manpower Calculation (PDI I Station)**

Station Num- ber	Station Name	Planned Station Production/Day	Operators Hours @ Planned Production				Total Man Hours for PID I Station	Total Operators Required @ Planned Production @ Desired Utilization
			OP1	OP2	OP3	OP4		
1	PDI I	5	3.5	5.0	5.5	5.33	19.3	3.7
		Available Hours in a Day	7.5	7.5	7.5	7.5	30	
		Operator Utiliza- tion @ Planned Production	47%	66%	73%	71%	64%	
* <b>Figure in red bold letters indicate that operator is underutilized for current planned production</b>								
*Figure marked with this background indicate that utilization of the operator is above Desired utilization (Overtime or extra operator/s needed to achieve planned production @ Desired Utilization)								

order to achieve the planned production at the desired utilization level.

Desired Utilization: A separate input tab for desired operator utilization is provided in the simulation model. The main purpose of doing so is to see how the manpower requirement changes based on the user-specified desired utilization. This gives the management a clear picture of the manpower requirement.

Based on the data received from Extend, the Excel spreadsheet calculates total man-hours required at a particular station for building x trucks in a day by adding the man-hours of all operators working on that station. Depending on the desired utilization input, the spreadsheet calculates ideal man-hours for that utilization. For example, for a desired utilization of 70%, the ideal man-hours would be  $(0.7 \times 7.5)$  5.25. The total number of operators required for the planned production at the desired utilization level is calculated by dividing the total man-hours for that station by ideal man-hours.

$$\text{Total Operators Required} = \frac{\text{Total Man Hours}}{\text{Ideal Man Hours}}$$

## Data Analysis and Results

### Model I:

Model I uses the data obtained by line supervisor feedback about the cycle times based on their experience and knowledge. The data are shown in Table 4. With the given input data, the facility was supposed to build 4 trucks per day. Simulation Model I was run for a year to observe the results. After running the model for a year, it was observed that the facility produced 963 trucks. This means that, on

average, the facility produced 3.73 trucks per day. Utilization of various stations is presented in Table 5.

**Table 4. Approximate Cycle Times-Supervisors Feedback**

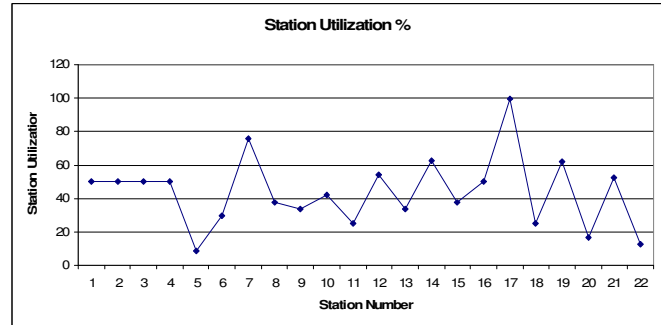
Sr.No.	Station Name	Approx. Cycle Time (min)
1	PDI Line Stations	60
2	Pull Walls	10
3	Drill Holes in Walls/ Attach Rub Rails	35
4	Decal Walls	90
5	Build Deck	45
6	Mount Walls	40
7	Build Luten/Decal Luten	50
8	Mount Luten	30
9	Build Roof	75
10	Mount Roof	40
11	Build Door	75
12	Door Decal	45
13	Mount Door	60
14	Mount Box	120
15	Decal Chassis	20
16	Cab Decals	75
17	Inspection	20

It can be seen from Figure 7 that the highest utilized station is station 17—Mount Box (99.7%)—followed by station 7—Decal Walls (75.5%). Station 5—Pull Walls (8.4%)—is the least utilized followed by station 22—Wash Bay

(12.5%). Mount Box station is the bottleneck in the facility. The following graph shows that utilization of the Mount Box station increases rapidly from the 0<sup>th</sup> hour to 241<sup>st</sup> hour. After that, the utilization remains stable to almost 100% until the end of the year. Similarly, the graph shows utilization for PDI I, Wall Decals, Build Roof and Build Door stations. The blue line represents PDI I, the red line represents Wall Decals, the green line represents Build Roof, and the gray line represents Build Door. The Wall Decals station utilization increases to 97% until the 67<sup>th</sup> hour and then stabilizes at 75%. A parallel station was added to the Mount Box station and the model was run again for a year. Now, with the additional Mount Box station, the facility produced 1,285 trucks in a year (4.98 per day). This means production could be increased by 33.4% by adding a parallel Mount Box station.

**Table 5. Station Utilization**

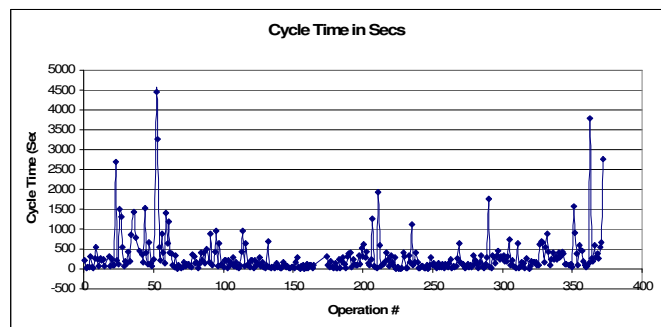
Station Number	Station Name	Station Utilization %
1	PDI I	50.3
2	PDI II	50.2
3	PDI III	50.2
4	PDI IV	50.2
5	Pull Walls	8.4
6	Drill Holes in Walls/Attach Rub Rails	29.4
7	Decal Walls	75.5
8	Build Deck	37.71
9	Mount Walls	33.4
10	Build Luten/Decal Luten	41.9
11	Mount Luten	25.1
12	Build Roof	54.15
13	Mount Roof	33.3
14	Build Door	62.59
15	Door Decal	37.6
16	Mount Door	50
17	Mount Box	99.7
18	Decal Chassis	25
19	Cab Decals	61.8
20	Inspection	16.6
21	Road Test	52.3
22	Wash Bay	12.5



**Figure 7. Station Utilization-Graphical Summary**

## Model II:

Model II uses the data obtained from the Time Study. The graph of Figure 8 summarizes cycle times for all of the operations performed at the various stations. It can be seen from the graph that operation number 52, which is install rear bumper/draw bar, has the highest cycle time (4,444 seconds). Some of the other higher cycle-time operations are ramp track assembly (3,265 seconds), enter the data of PDI line into computer (2,700 seconds), install rivets (Build Roof station—1,937 seconds) and install Door Decals (1,766 seconds).



**Figure 8. Cycle Times for All Operations**

Simulation Model II was run for various planned truck production cycles from 1 truck per day to 20 trucks per day. After running the simulation model, a summary macro was run in order to generate the results summary in Excel. Figure 9 shows utilization of all the stations in the facility, which is calculated by effective utilization of the operators working at a particular station. Only the stations Mount Walls (115%), Build Roof (142%) and the Chassis-Van Box Decals (111%) have utilization above 80%. This means that these stations need more manpower than the currently assigned manpower in order to achieve truck production of 4 trucks per day.

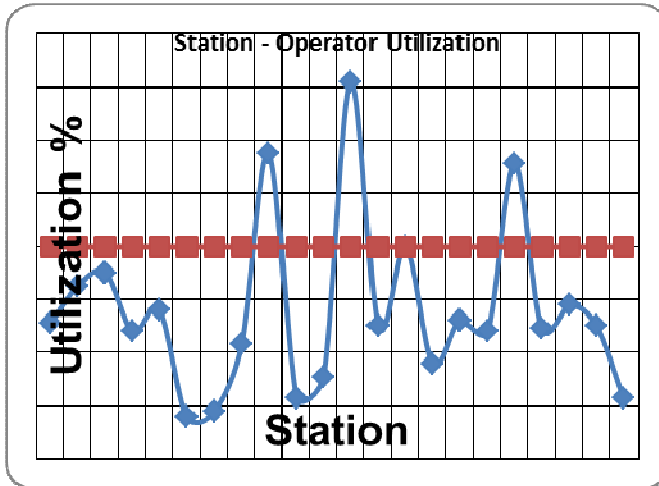


Figure 9. Station-Operator Utilization (4 trucks per day)

Figure 10 shows utilization of the operators working at various PDI line stations for truck production of 4 trucks per day. Utilization of all the operators is less than 80%, which means that PDI stations need fewer operators ( $4.8 \approx 5$ ) than the currently assigned 7 operators in order to make 4 trucks per day at 80% utilization.

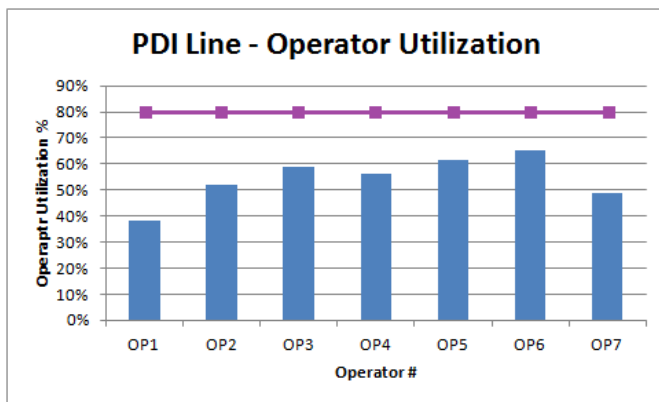


Figure 10. PDI Line Operator Utilization (4 trucks per day)

Various stations need a different number of operators depending on the work content. For building 4 trucks in a day, assuming operators are 80% utilized, the PDI I station requires 2.6 operators, whereas 1.7 operators are required at the Mount Box station, as shown in Figure 11. When this time study was conducted, 27 operators were working in the facility for building 4 trucks per day. Results provided by the simulation software showed that the facility would have needed only  $21.6 \approx 22$  operators for building 4 trucks in a day at 80% utilization. The graph shown in Figure 12 summarizes the total manpower required for the body-building facility for truck production from 1 to 20 trucks per day.

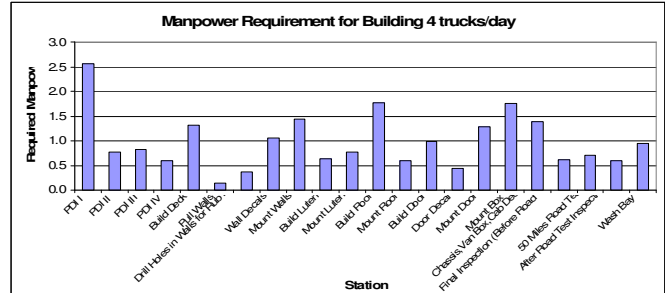


Figure 11. Manpower Requirements for Building 4 trucks per Day @ 80% Desired Operator Utilization

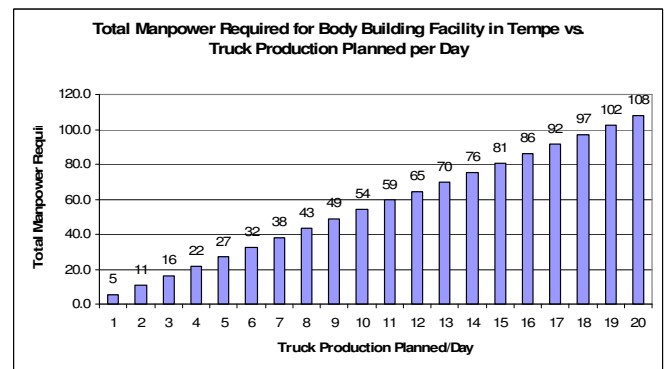


Figure 12. Manpower Requirements versus Truck Production

Verification and validation of the simulation models is an important step. There are various ways that the model could be verified. In this study, the authors used peer review for an initial verification. The models were presented in front of workers and supervisors, who were asked for their feedback. It is important to note that the feedback from the workers who have worked on particular operations was very helpful in verifying the models. Workers' feedback was studied along with the supervisors' and engineers' feedback. This exercise resulted in very positive group dynamics and helped us understand workers' concerns and answer their questions. Some sanity checks, such as consistency in input and output data, were also carried out in order to verify the models.

For validation, the authors decided to use peer evaluation, sensitivity analysis and historical input data. It should be noted that the results from this simulation matched very closely with the actual as well as historical factory production data. Interestingly, this truck-building facility has three identical manufacturing units across the United States. These plants also follow the same manufacturing flow (shown in Figure 1). The time-study analysis and simulations performed at other locations also showed similar trends. However, the bottlenecks identified at those facilities indicated by low utilization were different. The simulation



models were very useful in identifying underutilized and/or understaffed stations. Based on the results of this work, the supervisors allocated the resources as indicated by this simulation at two locations which have shown substantial improvement in production and resulted in significant cost savings, operating efficiency and revenue generation. Currently, the approach presented in this case study is being developed further to improve the process efficiency.

## Conclusion

This research study developed two valid simulation models of a local truck body-building facility. The company management can use these tools to assign manpower at various stations in the facility depending on the truck production planned. These models can be used to explore alternative techniques to lower production costs and increase production capability.

Simulation Model I used the data based on the production supervisor's feedback. The model was run for one year. This model identified Mount Box as the bottleneck in the facility as the utilization of this station was almost 100% throughout the year. A possibility of adding a parallel Mount Box station was explored in the model and its impact on the production was studied. Model I showed that by adding a parallel Mount Box station in the facility, truck production could be increased by 33.4%.

Simulation Model II was developed for predicting manpower requirements for the facility depending on the truck production planned and desired operator utilization specified by the user. One of the issues faced at the start was collecting the information about the total time worked by the operator and sending this information to Excel. This issue was sorted out with the use of activity delay, accumulate, add and send blocks. This model identified the maximum number of operators required at the PDI I station followed by the Mount Box station. The model also recognized that the facility had a 23% larger workforce when 4 trucks were built in a day at the time the study was done.

With the help of results obtained from Model II, manpower could be assigned to various stations in such a way that the operators were efficiently utilized. The time-study data could be used to target the operations that had maximum cycle times and explore new techniques for reducing them. It should also be noted that these simulation models have been validated and are currently being used for resource allocation. Several extensions and generalizations of the approach presented here are in progress.

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# DESIGN OF REUSABLE EMERGENCY RELIEF HOUSING UNITS USING GENERAL-PURPOSE (GP) SHIPPING CONTAINERS

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## Abstract

The natural disasters that have occurred during the last decade have shown the need for temporary emergency housing that could be quickly dispatched and placed. The modular designs of the shipping containers make them very simple to be transported using ship, rail, air or truck transportation. Temporary housing designed using shipping containers would be easy to prefabricate at an off-site location or factory which could cut costs on traditional construction while increasing quality control and consistency. Shipping containers are readily available and, since they are built to adhere to strict standards, could be utilized for the purpose of relief housing. The solution proposed here is to utilize shipping containers as a shell to build durable and reusable emergency relief units that can be quickly dispatched to disaster areas. The use of shipping containers for housing would bring the advantage of modularity, ease of transport and assembly. These units can be arranged in multiple layouts and built to be self-sufficient in terms of water, power and waste disposal. The design includes considerations for reinforcement for windows and door openings, connection between modules, design of framing and partitions, insulation and flooring, design of foundations and the selection and placement of systems of water management and power generation and supply. This design considers small clusters or camps, each self-sufficient in terms of water and power management.

## Introduction

The natural disasters that have occurred during the last decade have shown the need for temporary emergency housing that could be quickly dispatched and placed. The Asian tsunamis and earthquake of December, 2004, affected twelve countries causing over 150,000 deaths and at least a half million injured, and leaving five million homeless or without adequate access to safe drinking water, food or health service. After this event, the World Health Organization (WHO) issued a declaration entitled “focus on life”, which states that the response to any disaster has one primary focus: enabling those who are affected to live, sustain their lives and enrich their livelihoods [1]. Sheltering and housing are indispensable to meeting this objective.

Researchers have identified three phases of rebuilding after disaster: emergency housing, temporary housing and permanent reconstruction [2], [3]. The function of temporary housing is to provide a covered, healthy living space with privacy and dignity during the period between the occurrence of a natural disaster and the achievement of temporary housing [4]. Ideally, this type of housing will be upgradeable, reusable and/or re-sellable.

Immediately after a disaster, when houses have been rendered inhabitable by its effect, the initial approach may be in the form of large emergency shelters such as gymnasiums and other facilities, or through the use of hotels to accommodate large numbers of victims [5]. In August, 2005, when Hurricane Katrina hit the southern coast of the U.S., the city of New Orleans made available a sports stadium as a shelter. The occupancy reached an estimated 12,000 people with insufficient water and food supplies, while high winds and flooding limited access by road to the stadium during the first days to provide additional supplies and management. During the weeks following the hurricane, tent cities were established in Biloxi, Mississippi, to shelter victims (Figure 1) [6].



Figure 1. Tent City in Biloxi, Mississippi [6]

After the January, 2010, earthquake in Haiti, the office of internal migration and its partners delivered more than

6,000 tarps, 3,345 items of plastic sheeting and 400 boxes containing a 10-person tent, blankets, water purifiers and materials for children to 36,000 people (Figure 2) [7], [8]. The displacement sites sheltering victims are in danger of becoming permanent slums [9].



**Figure 2. Refugee Camp In Petionville, Haiti [8]**

After four months of being sheltered in provisional locations, an estimated 85,000 victims of the earthquake and tsunami that hit Japan in March, 2011, temporary housing facilities that required skilled labor to be built started to be occupied (Figure 3) [10], [11].



**Figure 3. Temporary Housing in Schichigahama, Japan [11]**

The term housing indicates more extended help than temporary sheltering. The provisions of temporary housing in the form of mobile homes and travel trailers taken after Hurricane Katrina were considered inadequate, provoking

complaints from residents and congressional hearings to determine the adequacy of the procedures [5].

The solution proposed in this study is to utilize shipping containers as a shell for building durable and reusable emergency relief units that can be quickly dispatched to disaster areas. These units can be arranged in multiple layouts and built to be self-sufficient in terms of water, power and waste disposal. The use of shipping containers for housing would bring the advantage of modularity, ease of transport and assembly. Each unit is designed from a container as a module with most of the major components needed for the emergency housing units pre-assembled off-site before its transportation. Modules can be combined to make up different complete housing units offering versatility to the design to meet the needs of different family sizes.

Construction of complex foundations would not be typically required, thus eliminating the need for major ground-work or excavation processes. Because of its original intended use and unibody design, cargo containers are able to carry large loads offering durability in harsh environments [12], [13].

The two most common sizes of shipping containers are 20-foot and 40-foot long containers. These containers are commonly referred to as TEUs (twenty-foot equivalent units) and FEUs (forty-foot equivalent units). There are less commonly available lengths on the market including 10-, 30- and 45-foot units. The standard width for shipping containers is 8 feet, with 8.5 feet and 9.5 feet as standard heights [14]. Shipping containers are constructed of weathering or Cor-Ten® steel, which is characterized by forming a stable layer of oxides on the surface of the metal which provides resistance to weather conditions and slow deterioration in harsh environments. The steel panels are corrugated with a typical depth of one inch to provide extra rigidity and a larger moment of inertia [15].

According to estimates given by the World Shipping Council (WSC), as of May, 2011, there were approximately 28,535,000 TEUs representing roughly 18,605,000 units worldwide. The ratio of loaded TEUs to container inventories was reported as ranging from 4.5 to 4.7 between 1990 and 2002, before rising above 5—except for a dip to 4.97 in 2009—with a forecasted ratio of 5.52 for the year 2012. The average annual container disposal rate during the last decade has been approximately 5% of the fleet. This rate fell to 3.8% in 2010 and 4.5% in 2011, only rise to 5.3% in 2012 [16]. These estimates still represent a large number of containers to be disposed of. This overabundance of shipping containers is due to several factors; e.g., trade imbalances, repositioning costs, revenue generation, manufacturing and



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leasing costs and usage preference. A large number of these containers remained stored and unused in ports around the world [17]. These unused containers take up valuable space at shipping docks while waiting to be loaded, repositioned to different locations, resold or disposed of [18]. Given the abundance of these unused shipping containers, it seems logical to try to solve this issue while addressing the overarching issue of emergency relief housing.

The use of shipping containers as housing presents both advantages and disadvantages. On the one hand, shipping containers are essentially large uninsulated boxes with no openings to allow light and air to enter and circulate. Although there are some insulated containers called Refers used for temperature-controlled product transportation, the vast majority of containers has no insulation and is referred to as GP containers, or general-purpose containers. Since there is no insulation and the walls are relatively thin, these containers are not soundproof. GP shipping containers may also present other disadvantages, based on their previous use, if they encountered cargo spillage or chemicals used to paint and seal their plywood floors. However, these setbacks can be easily overcome. On the other hand, shipping containers allow for modular design providing ease of transport by ship, rail or trucks. Used shipping containers are available anywhere around the world from many distributors and they are built to adhere to strict rules of the International Organization for Standardization (ISO) [19], [20].

Dwellings incorporating shipping containers have been considered since as early as the mid-1960s as a result of an architectural interest in merging mobility and manufacturing into building construction. Attempts in Australia and Europe have shown how universal and flexible these shipping containers can be in creating homes and sometimes offices. Even though the history of reusing containers for housing in the United States is very short, they have been used in the design and construction of homes and offices [21], [22] demonstrating that the use of GP shipping containers may provide a valuable alternative as longer-term reusable emergency relief housing units.

## Philosophy of Design

The Department for International Development of the United Nations on its transitional settlement and reconstruction after natural disasters report [23] states that affected communities should not be displaced or resettled unless it is absolutely essential in order to avoid risks from physical hazard since displacement is likely to exacerbate the impact a disaster has on their livelihood. Planned camps are places where disaster victims find accommodations on purpose-built sites and a full-service infrastructure is

provided [23]. It is also recommended that the size of the camps be manageable to facilitate assembly, placement and removal in stages or phases.

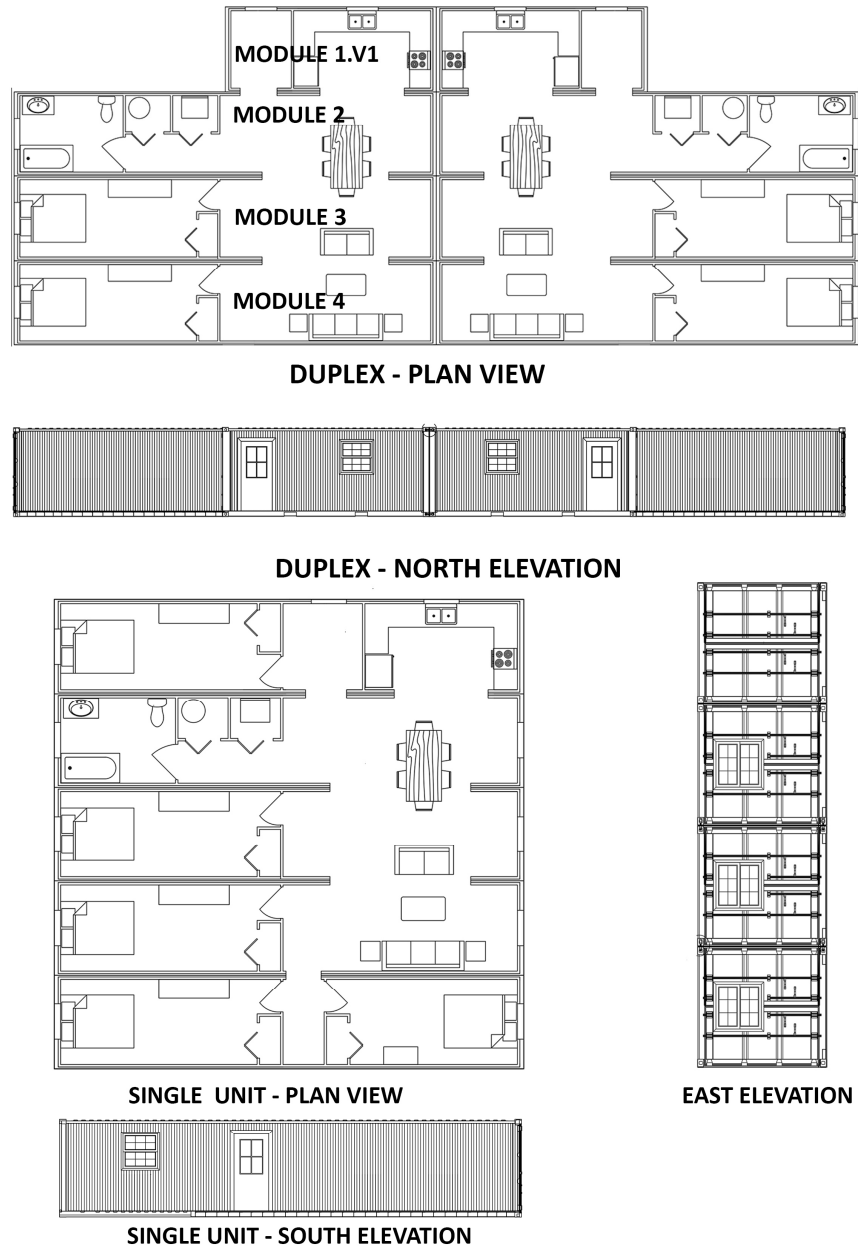
The use of GP containers and the arrangement of units into camps that can accommodate different size families is the objective of this project. Factors like strategic planning, selection of sites, camp management, versatility and options for phasing, development and expansion, water, power and health management were considered for the design and proposed layout. Particular attention was given to minimize the disruption of the livelihood of victims.

The unibody construction and the size of the GP containers presents various challenges. The design must take into account that these structures may be used for reasonably long periods, depending on the required amount of reconstruction and the time and resources required to perform it. The idea of increasing to a maximum the ratio of occupancy per unit area cannot be taken lightly, even though it may result in a decrease in the costs. Similar consideration may be taken when addressing the amount of modifications to the initial structure. The importance of keeping families together, preventing social conflicts and the spreading of disease and crime control are of paramount importance and could result in a minimization of the need for constant monitoring by emergency personnel which could distract them from other important duties [23].

In this design, different size units are considered in order to accommodate different size families consisting of two to six people. Each unit incorporates a small kitchen, bathroom and common area. The use of public showers was discarded due to the presence of minors which would have created the need for close monitoring of these areas. Although the possibility of using two-story units was initially considered, this option was discarded due to several reasons: 1) the area required for the placement of stairs; 2) the decreased capacity due to alterations would require large reinforcements in lower-level units; 3) the need for larger equipment for the erection of the top units; and, 4) the preference for standardization of the type and size of the foundations.

In general, the floor layouts were designed to simplify the fabrication and erection stages. The units were designed to be modular. The individual modules were designed to be put together in different arrangements or layouts and for interchangeability. A total of five different modules were designed and are presented here, combined in three different arrangements for single-family units (see Figure 4).





**Figure 4. Module Design with Single and Duplex Units Alternative of Combination—Top Views and Elevations**

The layout of the camp shown in Figure 5 accommodates up to 264 people using a combination of twenty-four duplex units and twenty single units; this layout is flexible and can be modified on demand. The layout was kept to this occupancy—with the single family units arranged in a combination of single separated or duplex units—to optimize the area and to meet the capacity of the power, water supply and waste treatment systems. In extreme cases, however, occupancy could be increased to 392

people—for example on the initial days after the disaster. The use of only duplex units without any need for modification of the standardized infrastructure is also possible.

Researchers have investigated the structural integrity of shipping containers [12], [13]. Transmission of loads through the walls was considered when openings were created for windows and doors as well as openings

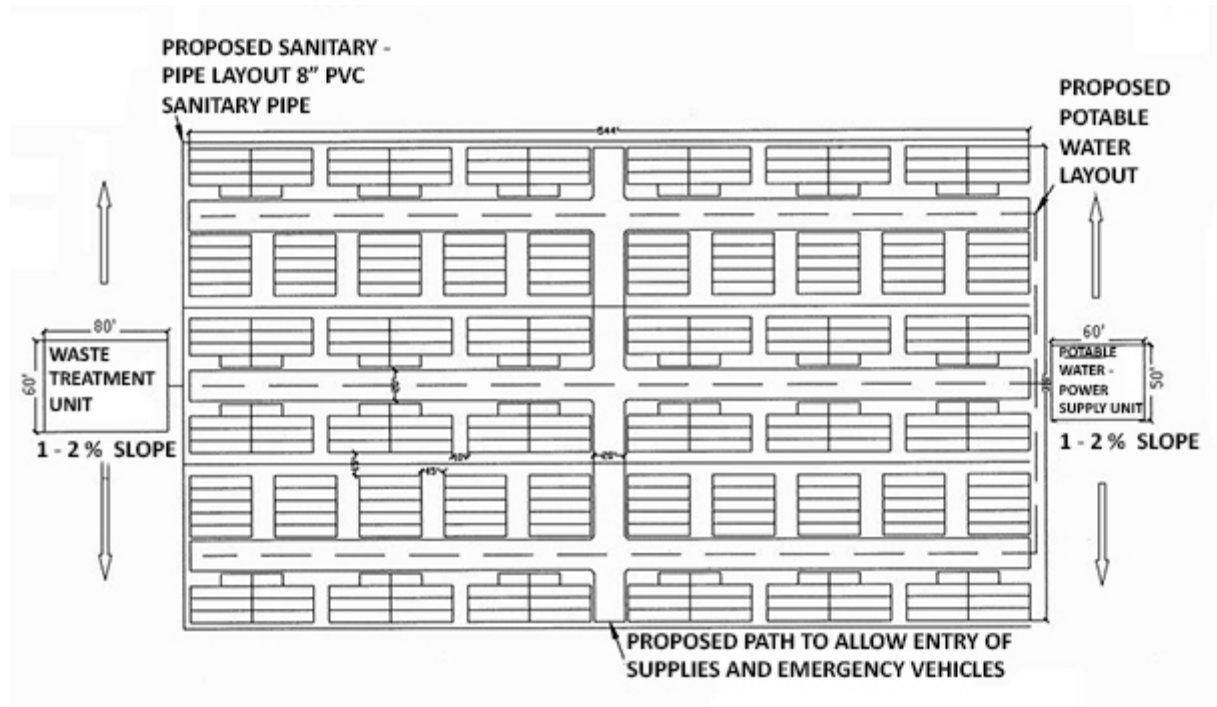


Figure 5. Emergency Relief Camp Layout Proposal with Power/Water Supply and Waste Treatment Systems.

inbetween the containers for an open concept making the interiors feel less box-like and claustrophobic. Due to the size of the openings, and in order to keep the integrity of the structure, reinforcement was found to be required. The use of steel tubing was selected for this purpose (see Figures 6 and 7).

## Foundations

The floor of the containers is constructed of steel-beam boxes, C-channels or I beams, six inches deep, using corrugated metal and 1-1/8" thick plywood flooring [19]. The great majority of shipping container strength comes from their four corner posts, which transmit the loads from the corners to the support surface. These posts were kept intact to maintain the structural integrity of the container regardless of the desired configuration.

The size and style of foundations used in the emergency relief units were selected to carry stresses to different types of soils. The four corners of each container are designed to carry the loads of the container and its cargo. The type of foundations chosen were spread footing style shallow foundations with piers set on top to keep foundation layout simple and reduce time and costs. This type of foundation

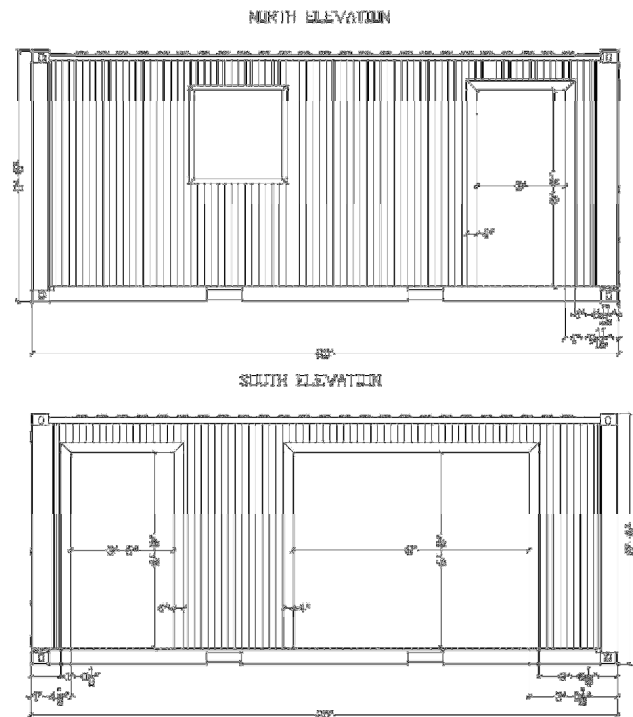
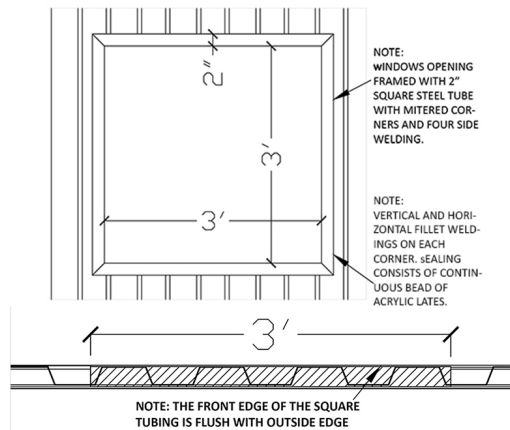


Figure 6. Doors and Windows Openings Dimensions.

provides overall flexibility in different soil conditions, as well as ease of placement.



**Figure 7. Detail of Window Reinforcement.**

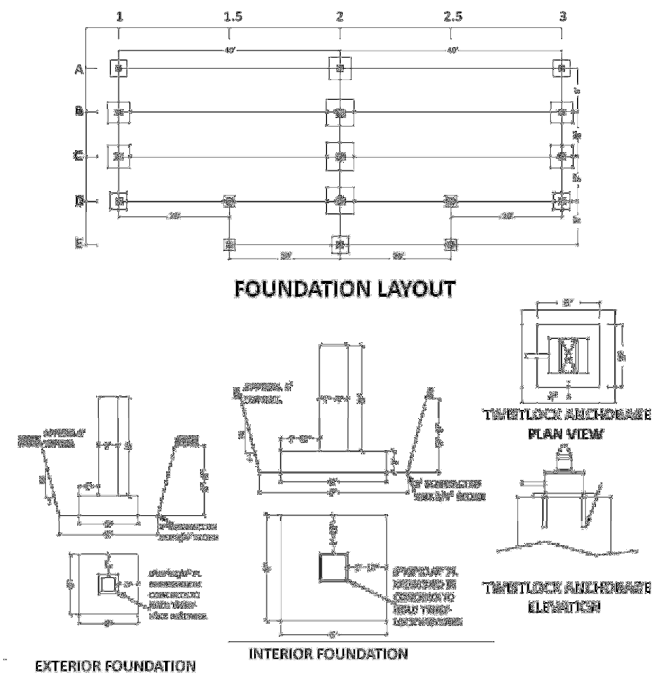
Soil-bearing capacity plays a vital roll in the design of the size and shape of the footings. Soil-bearing capacity can vary drastically from location to location. Given the unknown environmental conditions in which emergency relief units will be utilized, the worst possible soil conditions were used to design the footings; a soil-bearing capacity of two thousand pounds per square foot was used for the design.

The possiblity of these foundations being needed in regions with frost lines was considered in the design. The foundations used in the emergency relief units were designed for a frost depth of 48 inches. The total finished height of the pier was set at six feet to allow for a distance of two feet between the ground and the bottom of the modules. Keeping the units off the ground would help in preventing pest and insect infiltration, and reduce corrosion and deterioration (see Figure 8). The use of precast concrete elements will drastically reduce erection time and reduce time of installation. The proposed style of precast pier can be seen in Figure 9.

## Module Connections

The fastening of the modules to the top of the piers needs to be strong but removable. The current method of securing GP shipping containers, whether on a ship, rail car or truck, is by twistlock-type fasteners that lock into each of the four corner castings. These fasteners are manufactured in various configurations. Steel plates were designed to be inserted in the top of the piers to carry and transmit the applied stresses and to serve as flat support surfaces for the twistlock mounts (see Figure 8). Once in position, the twistlock

fasteners are locked. This method not only meets the requirements of strength and serviabiility but also the condition of being removable and reusable.



**Figure 8. Foundation Layout—Dimension and Details of Exterior and Interior Foundations**

The modules will be fastened to each other near the adjoining roof lines' removable connectors in the form of uni-versal bridge clamp hooks with a maximum force capacity of twenty thousand pounds. This device eliminates the need for onsite welding to join the containers and reduces the time of assembly and removal.

The openings that had been cut in the sidewalls will be sealed using inflatable seals with a capacity of creating 20,000 pounds of force using air or water as an inflation medium. The seals are available in various shapes, sizes and materials (see Figure 10) [21]. Various options are also available to hold the seals in place such as an aluminum extrusion or retention clips. A non-reinforced DR4 foot base profile seal was selected for the sealing.

The seals include mitered corners and inflation valves that are accessible from the interior of the module. This method of sealing the gaps between modules is air and watertight, removable and reusable. To decrease assembly time onsite,

these seals are attached to all openings of modules two and four, chosen because of their interchangeable nature with all units. To protect and hide the seals after inflation, a renewable composite lumber—comprised of 95% recycled and natural materials requiring no finishing and which are rot and split resistant—was selected. The composite lumber spans across adjoining modules to close the openings on the sides and the top while an epoxy-coated steel plate covers the bottom of the opening.



**Figure 9. Precast Concrete Piers [20]**



**Figure 10. Dynamic Rubber, Inc. Foot Base Profile Seals [21]**

## Interior Framing and Partitions

The interior framing selected is non-carrying load used solely for running mechanical and electrical components as well as a fastening point for insulation and drywall. In order to frame the interior spaces, 2-1/2", 20-gauge metal drywall studs separated 24 inches on-center were chosen due to their recyclable nature as well their reduced weight used with 1/2" thick drywall.

## Insulation

Closed-cell polyurethane spray foam was selected as insulation as it provides extra sealing to openings and a high R value (R15.75) in the limited 2-1/2" depth, almost 50% higher than fiberglass [22-24]. Closed-cell polyurethane insulation also provides several other benefits such as being waterproof, durable and renewable.

## Floor Covering

In an unaltered state, a typical GP shipping-container floor is made of 4'x8' 19-ply plywood, approximately 1-1/8" thick, secured to the cross members using self-tapping screws (see Figure 11) [19]. To decrease fabrication time and cost of the emergency units, the plywood floors will be sealed and leveled first with a skim coating of thinset, and then painted with "green" polyurethane coating to completely seal them [25].



**Figure 11. Typical Shipping Container Flooring [19]**

## Site Infrastructure

In situations where there is no water or power available, as is usually the case in disaster areas, these types of infrastructure are necessary for the operation of society. Typically, infrastructure refers to roads, water supply, sewers and

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electrical grids. The basic site layout shown in Figure 5 indicates the proposed locations of the potable water and power generating systems, and the location of the waste treatment system for the designed camp.

## Wastewater Treatment

Perhaps the most important piece of infrastructure in any disaster is waste treatment. Bacteria, viruses and parasites are types of pathogens that can be found in wastewater that are hazardous to humans. Bacteria are microscopic organisms that are responsible for several wastewater diseases, including typhoid, paratyphoid, bacillary dysentery, gastroenteritis and cholera. Like bacteria, viruses are found on a microscopic level, but they are parasitic and can infect people through wastewater. Well-known diseases such as Hepatitis A, polio and viral gastroenteritis can be contracted from viruses in wastewater [26].

The options for waste treatment for this type of camp are limited, considering the characteristics of the site and the conditions of the area. A septic field is an impractical option in this type of development since the size of the area required would be too large and the cost of installation and closing too high. The use of composting toilets could be selected as a solution for the few days right after the disaster strikes, but it can be sustained for longer periods.

A mobile wastewater treatment system was the ideal system for the emergency camp shown since it offers the advantages of being portable, modular and customizable for any required demand whether large or small. It was determined that a system with a capacity of 90,000 gallons per day works for the layout shown. This type of mobile wastewater treatment system was specifically designed for remote camps, disaster relief and temporary events [27]. The other major advantage of using the system is its low maintenance requirements. The system contains only a few pumps, filters and distribution mechanisms that must be maintained on a regular basis [27]. The treatment technology referred to as AeroCell requires no chemical additions for proper operation, and no monitoring of controls testing of the AeroCell media has shown effective treatment to secondary and tertiary wastewater levels. Tertiary treatment levels are optimal because the water effluent can be released back into the most sensitive and fragile ecosystems.

## Potable Water

Besides waste treatment, the second most important piece of infrastructure in a disaster is potable water. As previously mentioned, in wastewater, parasites can find their way into

potable drinking water. Two of the typical types of parasites found in drinking water are protozoan and helminthes, which are more commonly referred to as parasitic worms. If ingested, these parasites can cause severe diarrhea and illness [26].

The selection of the potable water system could depend on the location and type of disaster. Several types of devices could be considered to meet specific demands. A containerized desalinization plant, which could take water from nearby sources such as the sea, rivers or lakes and turn it into potable water, could be considered. This type of system could also meet the calculated demand of 15,477 gallons per day, but would be a secondary option in the emergency layout if access by ground or air were not possible. Instead, a 20,000-gallon hydro-pneumatic storage tank would be used with a containerized reverse-osmosis unit. By using a pressurized water storage tank, no onsite water towers would need to be erected. This system would also eliminate the need for pumps to feed the individual units as well as a water tower.

In order for this system to function properly, the potable water would have to be brought in by ground or air, which may cause problems, depending on terrain. The water would first be put into a holding tank that would then be piped to a containerized reverse-osmosis unit that would feed the hydro-pneumatic tank. If water could not be brought to the site due to terrain restrictions, the containerized desalinization unit would take the place of the holding tank before the containerized reverse-osmosis unit.

## Power Generation

Electricity is a key element in the layout of the emergency subdivision as well as the layout of each individual unit. Without electricity the wastewater and potable water systems would not be able to operate. Several forms of power generation such as wind and solar were researched for possible use in the emergency units, but due to the calculated 600KW daily demand, they proved to be insufficient.

A layout like the one shown in Figure 3 requires 900 kilowatts of power per day (including the standard 1.5 safety factor). A 900-kilowatt diesel generator pre-installed in a 40-foot GP shipping container was selected. The generator would also require less specialized maintenance, and be easily transportable with the emergency units. The power would be distributed to the individual units through overhead transmission lines similar to traditional homes.



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## Site Grading

Grading the site properly as well as placing provisional roadways between the emergency relief units is the last major piece of site infrastructure. Without proper grading, the site could experience water “pooling” which would be detrimental for sanitation. To promote proper runoff, the site will be graded at a minimum slope of 1% from the center outwards north and south to keep water runoff away from the emergency relief units as well as the waste treatment, potable water and power generation facilities. This also becomes a major design consideration if multiple sites are to be placed next to one another. By having the runoffs going in only two directions, if multiple sites are placed next to each other, only the north and south sides would need a drainage ditch to transport the rainwater runoff away from the site(s), instead of on each of the four sides.

The pathways between the units are to be compacted  $\frac{1}{2}$ " stone or, if possible, a single layer of asphalt surfacing material sloped at minimum 1%. The paths will be a minimum of twenty feet in width to promote efficient means of egress from the site, whether in a vehicle or on foot. By keeping the paths at a minimum of twenty feet in width, vehicles will be able to enter when the site is under construction; emergency vehicles will also be able to enter if needed during the life of the emergency relief unit.

## Conclusions

The design of emergency relief housing units using GP shipping containers represents a feasible solution for housing of victims of natural disasters. The solution presented here presents several advantages among which are: the versatility of the system to be arranged according to the needs of the disaster area; the modularity of the system which allows for modification of the units presented here; the ability to be built off-site; the ease of transportation to the required area; and, the ability to be reusable and/or resellable.

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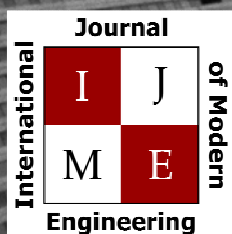
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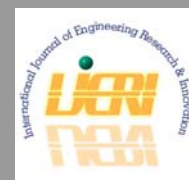
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