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Doing the impossible in a pandemic: Delivering student-designed fabricated parts to an industry client

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Doing the impossible in a pandemic: Delivering student-designed fabricated parts to an industry client

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Abstract

March 2020 was a turning point for the world and for the education sector. While the semester started with the conventional face-to-face teaching mode, suddenly, there was total shut down and teaching had to be continued only in the virtual mode (online). This change in teaching mode posed particular challenges for lab-based and hands-on courses that require significant skill development through experiential learning. The challenges were further compounded by the requirement to work on industry-sponsored projects to design and fabricate needed parts based on clients' requirements. This paper describes how a team of senior engineering students successfully designed a fixture for a critical automotive component for basic utility vehicle for developing countries, even in the midst of a pandemic. The basic utility vehicles feature robust and simple designs that enable them to survive the harsh environment while meeting the low-cost requirements in such markets. The project was a part of the course requirements for a manufacturing processes course. The paper highlights how the students successfully worked in a virtual environment, engaged the client, designed the part and had the designed parts fabricated and shipped to the clients. In addition, the critical role of technical staff in providing hands-on learning experiences as well as in completing a project, particularly in a pandemic, is highlighted. Key lessons learned from the perspectives of students, instructor, technical staff, and client were gathered through reflections and interviews.

Key words: pandemic, projects, design, online, virtual environment, manufacturing processes, online learning, pandemic

1.0 Introduction

Three mechanical engineering students at the R.B. Annis School of Engineering, University of Indianapolis were tasked with designing a fixture for the Institute for Affordable Transport (IAT) Basic Utility Vehicle (BUV). BUV produces basic transportation and vehicles for developing countries that feature robust and simple designs. The project involved a service component because the BUV is being used for critical applications including agricultural, water and medical transportation in developing countries (Figure 1). Exposure of students to such open-ended and real life projects will help the students to develop critical professional and technical skills such as leadership, communication, teamwork, problem solving, project management, entrepreneurial mindset and engineering design [1-4].

Figure 1: Different applications of BUV in developing nations a) agricultural and construction, b) mobile dental clinic

In order to simplify the assembly process, BUV asked the student team to create a fixture so that their assembly process has repeatable and simple locating points to lay the foundation for the frame of their vehicles. More specifically, the team was tasked with designing a fixture for the assembly of the motor deck. The motor deck holds two components, the motor and the transmission. Both of these components can be installed on the motor deck before (or after) the motor deck is bolted to the vehicle frame. The student team was asked to design the fixture for the motor deck by incorporating their knowledge of jig and fixtures, design for manufacturing, manufacturing processes and additive manufacturing.

The project was designed to be executed as part of the traditional face-to-face course delivery format. Then the Covid-19 pandemic struck. Due to the COVID-19 pandemic, the student team did not have access to the workshop on campus, and instruction and guidance have to be moved into the online learning environment. Also, access to the client's facility for site visits was cut off. Consequently, the project metamorphosed into an online project-based learning (PBL) with its associated challenges.

Figure 2: (a) Basic Utility Vehicle (BUV)

2.0 Literature Review

Project-Based Learning (PBL)

Project-Based Learning (PBL) is a pedagogical approach that was first used in Italian Architecture schools and later adopted by engineering schools in the United States [5]. PBL gained traction in the 1990s as a result of seminars organized by the Buck Institute for Education (BIE) and their publication of the Project Based Learning Handbook in 1999 [6].

Kow (2019) [7] defined Project-Based Learning (PBL) as the practical acquisition of knowledge and skills through effective direction from an instructor and the response to feedback from students to solve real life problems through a group setting. PBL is a student-centered pedagogical approach with which students supposedly gain knowledge on a certain subject through projects [6]. The students are largely responsible for the organization of the activities, which include research, writing, discussion, presentation and time management. PBL encourages students to make meaningful arguments (communication skills development) while developing ways to solve the assigned real-world problems [6, 8]. It is characterized by developmental feedback and assessment through the cautious layout of evaluation and analysis that integrates formative responses, particularized directions and multiple sentiments [7].

Unlike lecture-based learning which is instructor-centered, PBL is student-centered with students having more collaborations and interactions among themselves while the instructor acts more as a coach or a facilitator. The instructor supports and guides the students through a successful project by addressing any issues that may arise [6, 7]. The instructor is responsible for ensuring that the students have the material and equipment necessary to execute the project and learn. In addition, the instructor is responsible for evaluating the final project presented by the students [9].

Savery (2006) [10] identified the key differences between project-based learning and problem-based learning as follows [7]:

• Project-based learning has its goals structured in the process of teaching. On the other hand, outcomes of problem-based learning are often shared, and the goals jointly set by the students and the teachers.
• Project-based learning involves real-life problems while problem-based learning uses scenarios or cases such as mathematical problems generated by the teacher.
• Project-based learning follows a more general procedure while problem-based learning uses a specific or laid down procedure.
• Project based learning is often multidisciplinary and takes a longer time. On the other hand, problem-based learning is more related to one subject and takes a shorter period.

Online PBL

Online learning, a subset of distance learning, is the acquisition of knowledge via the internet with the use of computers and appropriate mobile devices [7]. A number of research has shown that the incorporation of PBL in an online classroom may be more difficult compared to the traditional face-to-face classroom environment [11]. Some of the challenges that have been identified include: students usually lose out on the opportunity of finishing projects in groups and there is difficulty in effectively assessing the competences of students' projects instantaneously [12]. On the other hand, a research study to investigate the role of technology in PBL showed that students in the online environment exhibited higher understanding as opposed to the face-to-face environment [13]. The study also revealed that assessment and comments on individual and group performance were easy to capture for further review and reflection [13]. In addition, it has been shown that an Online PBL environment supports self-efficacy, a key element for students' success in the online environment [12].

According to (Kow, 2019) [7], the online PBL model is not different from the traditional classroom model, only the environment changes. The PBL model employed for this course follows that by Peffers et al, 2007 [14] as shown in Figure 3.

Figure 3: Project-Based Lesson Structure Model [14]

3.0 Method

The Project Assignment

The team of three mechanical engineering students were given the project description below. The method to be employed in executing the project included site visits, customer interviews, engineering design, fabrication and testing. The assessment included final presentation and report as well as student reflections.

Project Description

Your manufacturing company, MENG Manufacturing Inc, has assigned your team of mechanical engineers a project with a very important client, Basic Utility Vehicle. Your mandate includes understanding the client's requirements, designing viable solutions within set constraints and applicable standard, as well as applying appropriate manufacturing processes to fabricate the product.
You will be delivering the fabricated product as well as report and presentation to your client.

Required Tasks

1. Assign roles and responsibilities to your team members.
2. Develop a project management plan (meeting time and venue, minutes of meetings, etc); activity/duration/precedence table; and a Gantt chart for the project.
3. Create a questionnaire with open-ended questions to understand the needs of your potential customers.
4. Identify key technological, social, cultural, economic, and global factors that you will consider as you design and create the solutions (PI 4b)
5. Discuss how these factors influenced your decisions as you created the solution for the client (PI 4b).
6. Design and fabricate the solution to meet the customer's requirements.
7. Highlight the different manufacturing processes you employed and the justification for their use (PI 6d).
8. Explain strategies and techniques you employed to ensure the fabrication of a quality product.
9. Identify knowledge from other disciplines apart from mechanical engineering, you needed to successfully execute the industry-based project and how you use those knowledge in the project (PI 1c)
10. Describe how the ethics of your profession guided you as you executed the project.
11. Reflect on your personal experiences and lessons learned from the project.
12. Prepare report and present project result to your client and your management team.

Deliverables

Your team is required to submit the following to your client and CEO (submission on learning management system):

1. A concise report with executive summary (maximum 15 pages excluding appendix, Times New Roman font size of 12); appendix should be used for data sheets, etc.
2. Presentation slides for presentation to your client.
3. Fabricated product to be delivered to client.

You will also have the opportunity to present your findings/experience at a conference.

Assessment

The report and presentation slides are to be submitted to your CEO (professor) via ACE (learning management system) on Tuesday April 21 by 11:55 PM for assessment. You will present your findings to your CEO and client on Thursday April 23, 2020 at 9:00 am where each team member will be assessed.

In addition, apart from students' reflections, reports and oral presentations, feedback were obtained from the client during the team's presentation as well as after the delivery of the fabricated fixtures. The instructor and the lab manager also reflected on lessons learned from the project.

4.0 Fixture Design

Defining the Customer Requirements

In order to gain a good understanding of the client's needs, the student team visited the BUV facility in Indianapolis, Indiana (Figure 4). The visit was done before the Covid-19 Pandemic lockdown. The students were able to see a BUV under fabrication, learned about the company and her customers, as well as ask questions on the motivation for the project and operations of the BUV.

Figure 4: Mechanical engineering senior students at the client facility at the beginning of the project before the Covid-19 pandemic

The main function and requirement of the fixture for the power platform is that it supports, locates, and allows for easy assembly of the power platform. Assembly must be consistent with the desired part specifications, repeatable, and provide a platform to maintain high quality. In terms of specific features to locate, there are five essential to the fixture. First, the main power platform plate must be set in a consistent position for every assembly. Second, the left and right tubes are essential features to locate because they hold the bushings that connect to the chassis frame. Third, the middle or top mounted tube holds another bushing that connects to the chassis frame. Fourth, there are pipe support plates for the main structural pipe that runs the length of the power platform. Lastly, the transmission needs support plates to hold it securely, which need alignment features on the fixture. The positions of each key feature on the power platform are essential to understanding the desired locates on the fixture. Moreover, they are customer requirements that are critical for the functionality of the fixture.

Key Design Factors

The team must consider many factors when designing the fixture. If the team fails to identify the important factors for the design, it will not meet the needs of the customer and the client, BUV. The team focused technology, social, cultural, economic, and global factors.

<u>Technological</u> - All technology used in the fixture must be relatively simple to prevent complex training requirements for workers in developing countries.

<u>Social</u> - Limited education in areas where this fixture will be used should be considered during design. The fixture should be easy and foolproof to use.

Cultural - Because there are different social expectations with the use and maintenance with machinery in third world countries, the design must be robust. Most likely, the design will be used in ways unintended so the team plans to make it simple and with high safety factors.
Economic - Due to the economic state of some of the third world countries that the vehicle will be used, the fixture must be inexpensive to obtain for all technicians that will be assembling the power platform. This economic consideration must include shipping, handling, assembly, material cost, energy usage, and maintenance of the fixture.
Global Factors - The fixture must be easily assembled in available workshops abroad or will need to be assembled in the US and shipped internationally. Fixture fabrication should be accomplished with common machines and manufacturing operations that are easily available.

3D Model of the Power Platform

Before the team was able to design the fixture, the team needed to get the 3D model of the power platform itself. Having the 3D model of the power platform provided the team with the accurate dimensions to create the fixture. The team took the individual components provided in the compressed file from the client, oriented them in the 3D model, and constrained them together. The team was also able to create part drawings for the assembly, highlighting the main dimensions for the key features.

Figure 5: (a) BUV power platform and **(b)** 3D model of power platform

3D Model of Power Platform Fixture

Because most of the essential features on the power platform are on the underside of the design, the team thought it would be most simple to have the power platform sits on the fixture upside down. This way, fabricators don't have to fight against gravity when welding and assembling parts together. The fixture design features locating plates and holes in the plates for pin alignments with the tubing. Additionally, the main support includes vertical supports and the power deck locating plate. All methods of assembly and material choice used in the fixture are discussed in future sections. The team was able to create part drawings for the fixture model for fabrication at a later date in time. The part drawing includes the most important dimensions for fabrication as well as the weld callouts.

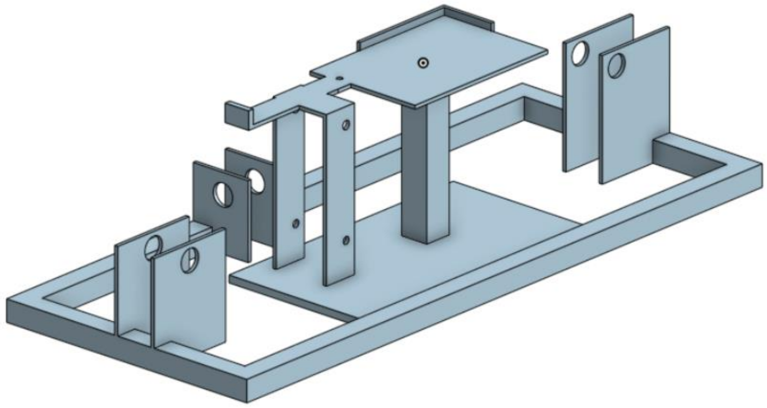

Figure 6: The power platform fixture 3D model

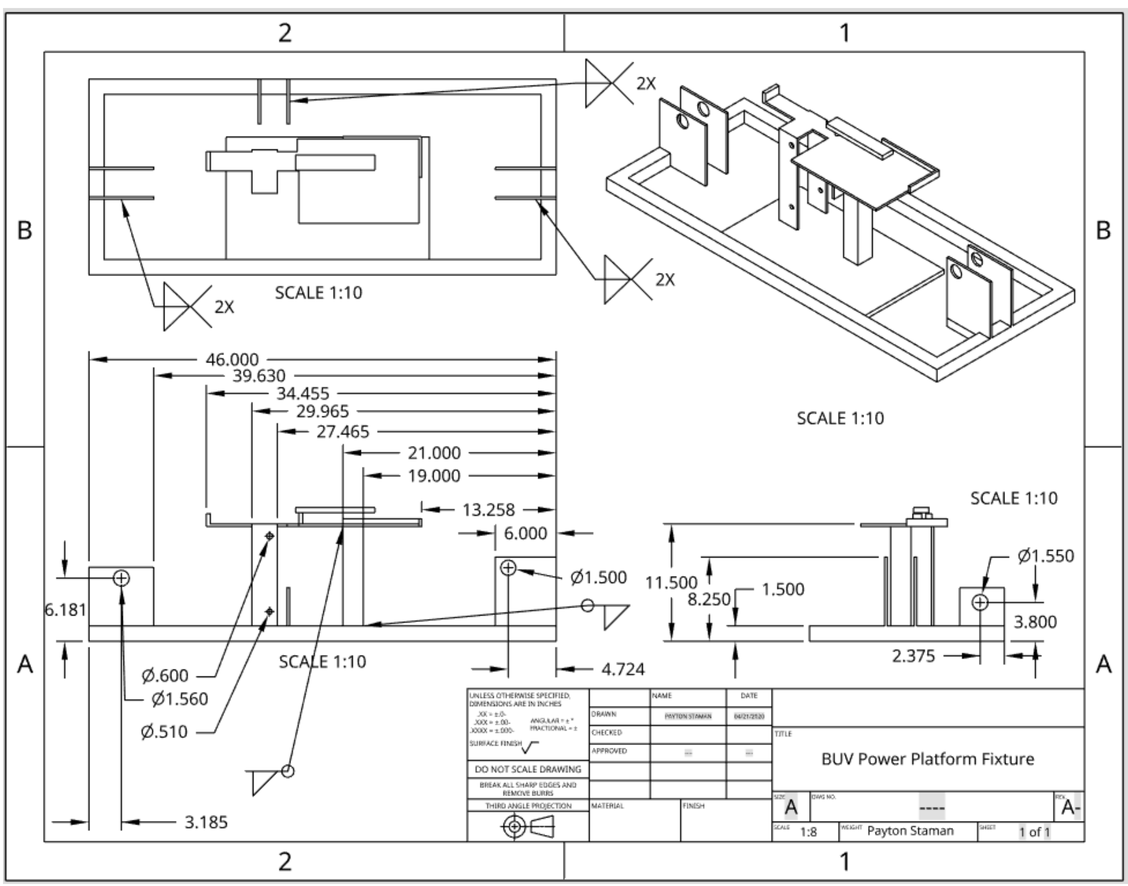

Figure 7: The power platform fixture part drawing

Assembly and Operation

The assembly order of operations of the power platform is crucial for a consistent build. To begin with, the power deck plate is aligned against the two corners on the main fixture plate component. The right angle should align with the power deck plate properly to provide location and geometry guidance.

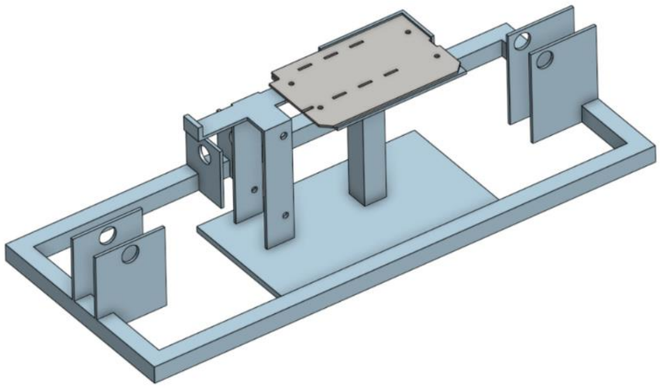

Figure 8: Assembling the power deck plate onto the fixture

After the power deck plate is installed, the plates for transmissions can be installed into the puzzle-piece slots in the power deck plate. The transmission plates should align so that the vertical face interfaces with the vertical support structure in the fixture. The top and bottom pins can be installed in the vertical faces of the transmission and vertical fixture plates. After the proper alignment is achieved, welding occurs to solidify the location and connection.

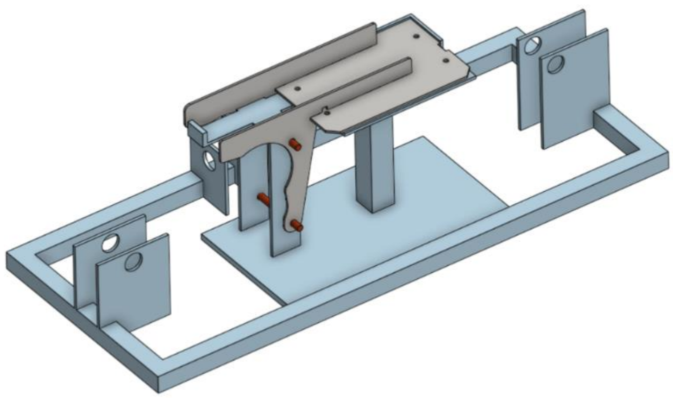

Figure 9: Installing Plates for transmission

With the transmission plates installed, a proper guide is available for the main pipe to be installed. The pre-bent pipe can be installed between the transmission plates and aligned with the right side plate. After the proper alignment is achieved, welding occurs to solidify the location and connection.

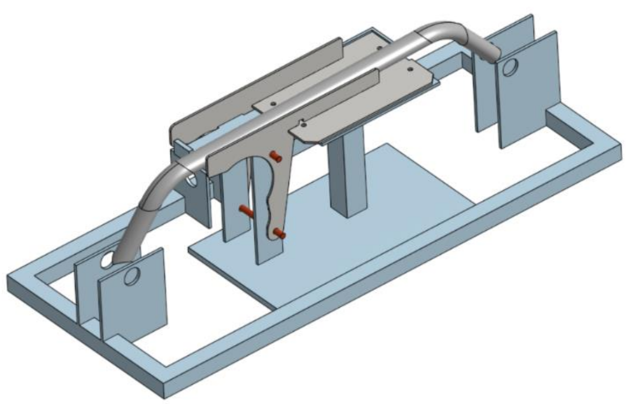

Figure 10: Installing the bent pipe

After the bent-pipe is installed in between the transmission plates, the bushings tubs must be welded into place. The tubes align with the holes in the fixture and are held into place with the wooden doll rod pins. Once the bushing tubes are held into place, they should interface loosely with the main bent pipe. The left and right bushing tubes can be welded to the main pipe and the pins left installed into the fixture.

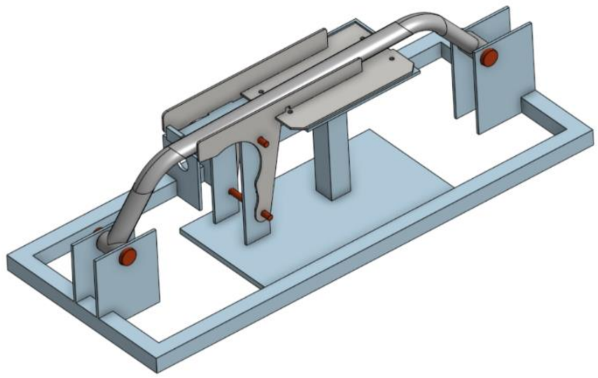

Figure 11: Installing the left and right bushing tubes

After the left and right bushing tubes are installed, the middle / top bushing tube assembly can be installed. The top bushing tube is fabricated and assembled off of the right transmission plate. The first piece to be installed is the pipe that connects the bushing tube to the transmission plate. This piece is welded to the transmission plate. Next, the bushing tube can be installed like the previous bushing tubes, utilizing the holes in the fixture and the bushing tube pins for alignment. To reiterate this process, first the tube is held by the pin through the hole in the fixture. Next it is welded to the connection tube that connects to the right transmission plate. The whole assembly can be left with the pin in place to maintain proper position.

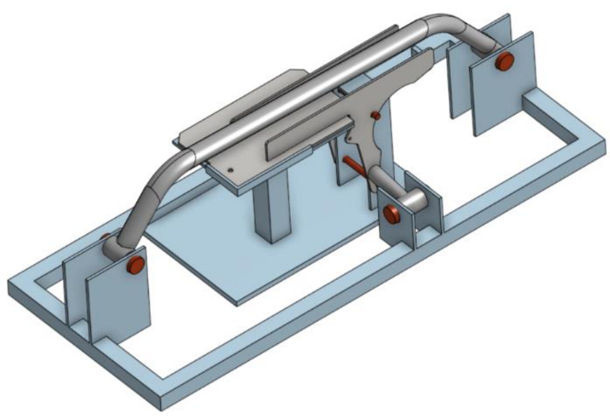

Figure 12: Middle Bushing Tube and Pin Installation

The last step of the assembly process involves securing the bent pipe in place. Three support plates are installed between the two transmission plates. To begin the process, the plate alignment tool (Orange in Figure 12), is used to space the first two plates the right distance apart. This tool is installed by aligning the alignment pin into the hole in the power platform deck. The two plates are aligned against the tool on either side and welded onto the power platform against the transmission plates. Finally, the third support plate can be aligned against the fixture and welded as shown in Figure 13.

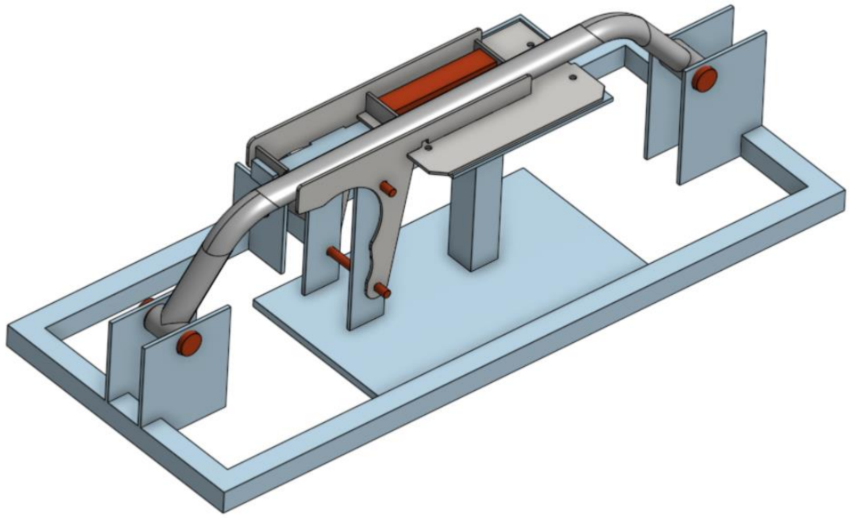

Figure 13: Installing the bent-pipe support plates

Finally, the power platform is assembled upside-down on the fixture. All pins can be removed once the welding process is finished and the components have secured connections. The power platform is ready to move to the next stage of assembly with the chassis.

Additive Manufacturing Prototype

A 3D printed prototype of the fixture was fabricated. The prototype shows proof of concept and proves that the fixture design allows for an easier assembly of the power platform. It was a minor challenge to remove all the support material off the model, but the fixture-power platform interfaces were accurate enough for the proof of concept demonstration.

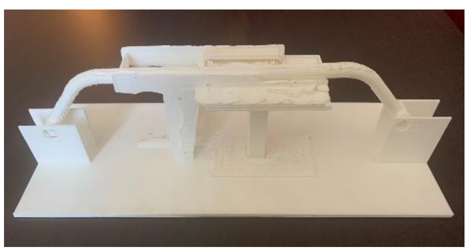

Figure 14: 3D printed fixture and power platform assembly

4.0 Engineering Changes and Design Iterations

<u>Hollow Tubing</u>

The original 3D model did not represent the square tube as hollow, but instead as a solid square block of aluminum. This was updated following client feedback to provide a better weight estimate from the modeling software and improve one of our key performance indicators.

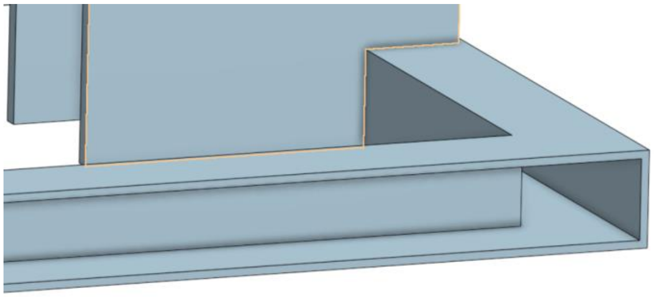

Figure 15: Hollow Tubing Section View

Plate Extensions

Bushing pipe alignment plates were extended to allow for an additional hole to be located an inch above the currently used hole. The additional hole was added when the client mentioned that the location of the bushing pipes will likely move upwards in future design iterations.

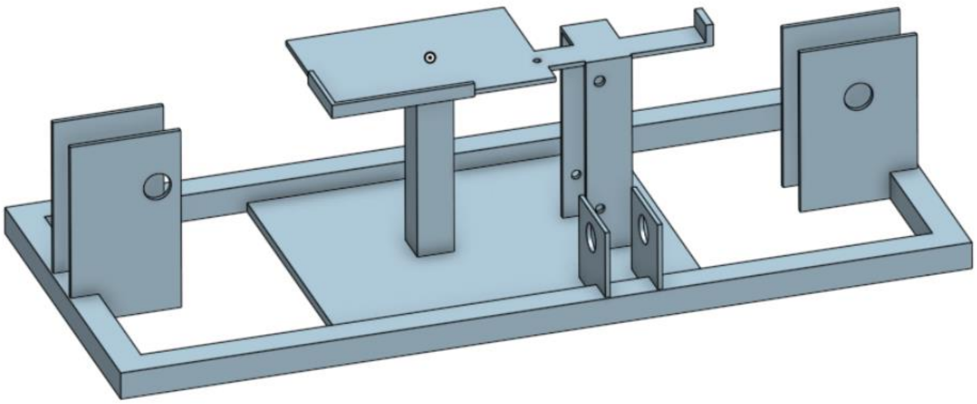

Figure 16: Plate Extensions for future power platform design iterations

Fixture Support for Rugged Handling

Client feedback showed that reducing the area of the baseplate would allow for easy handling by operators, but without a connection on both sides of the frame the plate would be weak and susceptible to damage in a manufacturing environment. Another modification was made to extend the baseplate to be joined to the frame at both sides, improving the strength of the fixture while keeping the overall weight down.

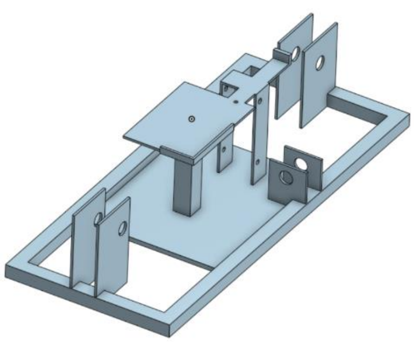

Figure 17: Extension of base plate for a stronger base support

Alignment Pin Handles

Alignment pins were given handles to provide operators with a stop to ensure the pin is pressed in fully and also allow for a "head", similar to a nail. This will allow operators to use a mallet to insert or remove pins in the case of significant warpage or misalignment.

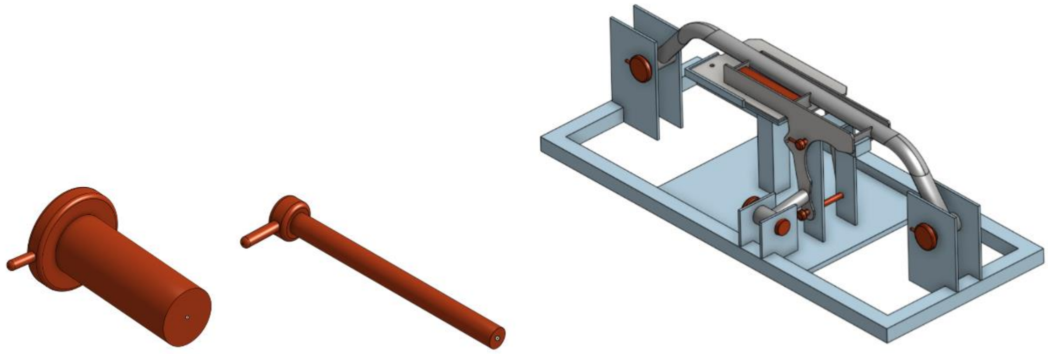

Figure 18: (a) bushing tube pin, **(b)** transmission plate pin, and **(c)** fixture with updated pins

5.0 Performance Indicators

<u>Weight Estimate</u>

The team was able to use OnShape CAD software to estimate the total weight of the fixture. Assuming aluminum is used for the tubing and a steel is used for the plates, the final weight metric ends up being around 35 lbs. The team worked hard to reduce this weight for operator ergonomics and think it is reasonable to carry. Additionally, the round tube stock provides easy handling and places to grab for transportation of the fixture.

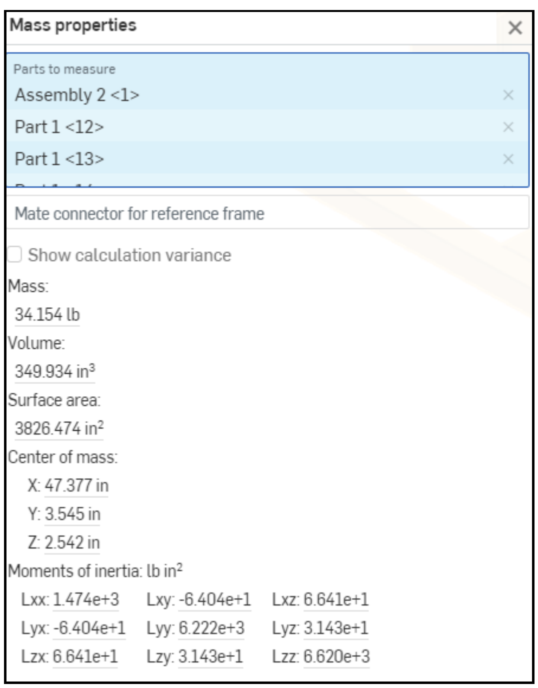

Figure 19: Onshape Geometry Metrics

Cycle Time / Fabrication Time Estimation

Because the team was not able to fabricate the physical design during the semester, it was challenging to get a cycle time for the fabrication of the fixture. In order to combat this obstacle, the team created an operations flowchart to estimate the total cycle time. The lab manager also reviewed the flowchart to ensure that it is a realistic estimation for the total cycle time. The estimated cycle time was determined to be about 5 hours. The flowchart is depicted below.

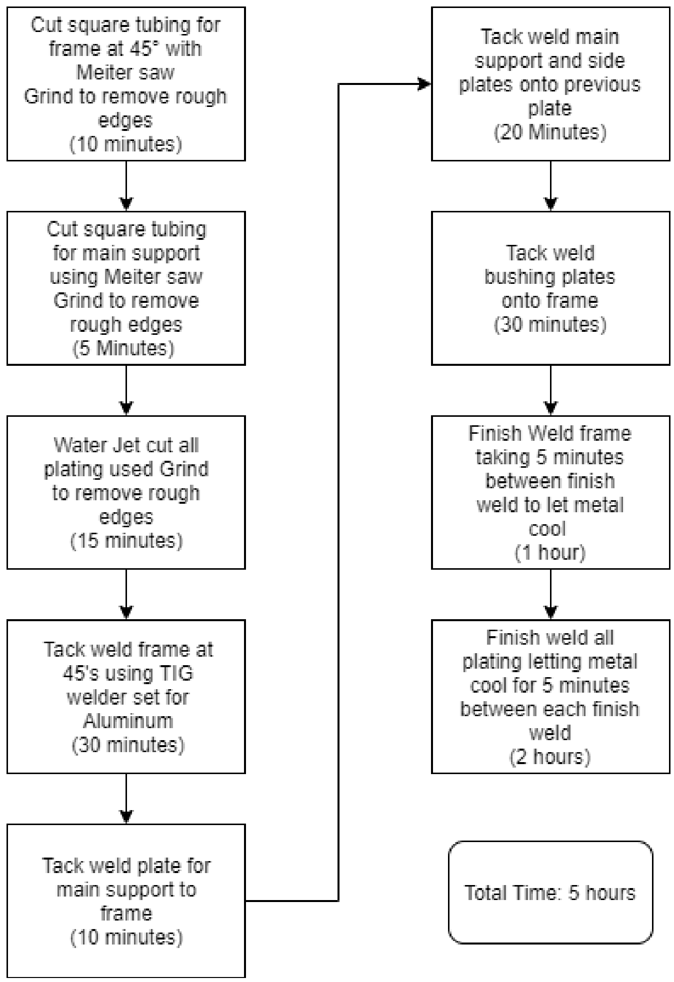

Figure 20: Operation Flowchart with time estimations

6.0 Addressing Covid-19 Pandemic-Imposed Constraints and Key Lessons Learned

3D Printed Model and Full Scale Model Fabrication

Fabrication options were limited due to the COVID-19 pandemic. Consequently, a ¼ scale model was created on a 3D printer with ABS plastic as a proof of concept prototype. The plan evolved for the lab manager to fabricate the full model of the design when the campus opens. Part and assembly drawings were provided for full scale fixture fabrication. Fixture framing and center column will be made from 1.5” aluminum square tubing to reduce weight as much as possible while still keeping the fixture balanced during use. Plating will be constructed from ⅛” aluminum plates, while all pins for part locating will be wooden dowel rods. Manufacturing processes required for the full scale model included: metal cutting miter saw (cutting the square tubing); waterjet cutting (cutting all the plate components); CNC lathe machining (making the steel bushings for locating the pipes for the completed bushings); and welding (frame and plates welded to produce fixture). The fixture was assembled using a customer supplied cross-member to ensure proper fitment.

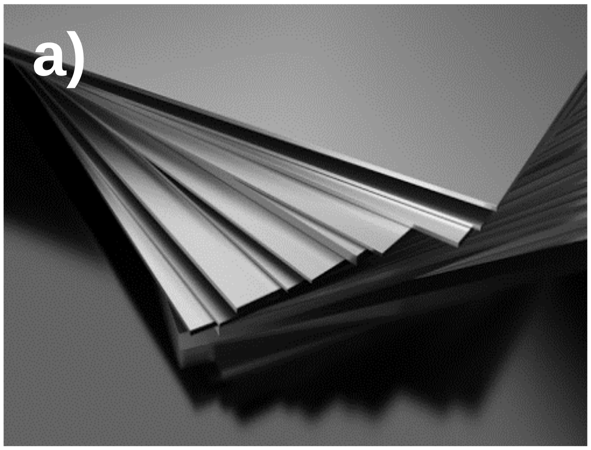

Figure 21: (a) aluminum and steel plates for full scale model, and **(b)** ABS plastic used in the mini model

Shortcomings as a Result of the Covid-19 Pandemic

The Covid-19 Pandemic resulted in a delay in the fabrication of the full scale fixture for the client. Due to safety concerns and the shutting down of the campus, fabrication of the fixture had to be delayed until the summer. Consequently, the students did not have the opportunity to engage in the actual fabrication of their design in the workshop. Engaging in the fabrication of the full scale model would have provided additional and important learning opportunities for the students to use different fabrication equipment as well as gain hands-on experience from the expertise of the technical staff (lab manager). The innovation and learning that accompany fabrication is evident by some changes in the students' design during the fabrication of the full scale fixture.

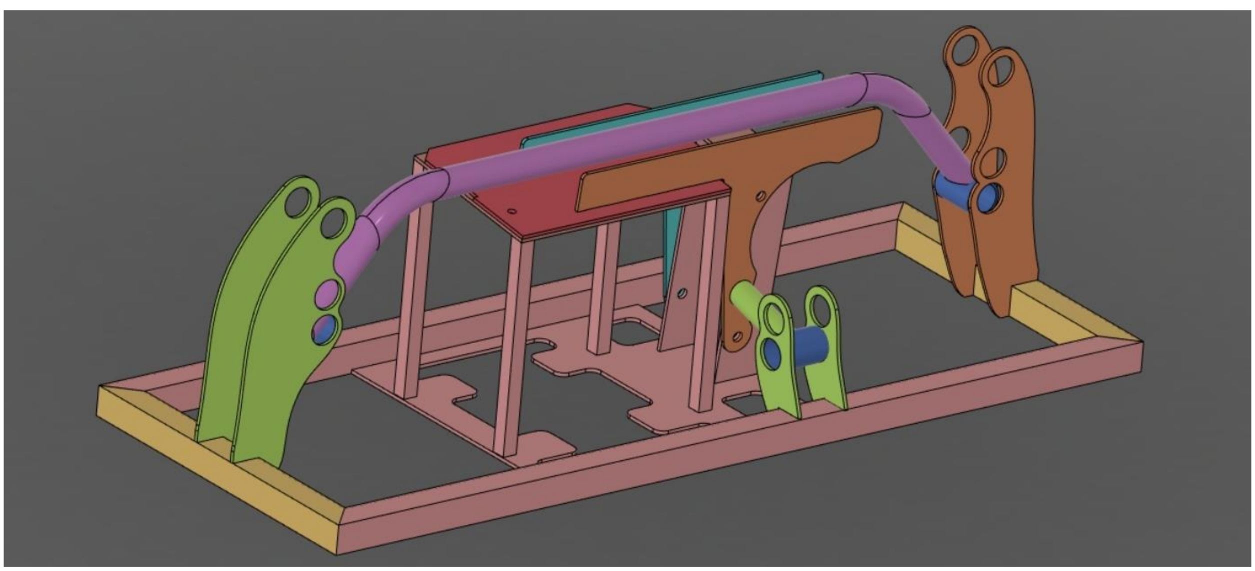

Figure 22: 3D Model of the modified design fabricated for the full scale model

Role of Technology for Successful Online PBL

While in-person interactions and access to campus as well as client's facilities were greatly limited as a result of the Covid-19 Pandemic, the use of relevant technology helped to reduce the drawbacks and facilitated student learning and project success. Communication tools like videoconferencing technologies, particularly Zoom, helped to facilitate students-instructor interactions as well as client interviews. The student team were able to communicate in real time with messaging apps on their phones. Real time file sharing and collaborative technologies like Google Drive facilitated real time collaborative team work, file sharing and documentation. Cloud-based technologies like OnShape computer Aided Drafting software facilitated team collaboration and file sharing with instructor and the lab manager.

Effect of Service Component of Project on Student Motivation

During the project presentations and in the students' reflections, the students repeatedly expressed that they found the project inspiring and motivating because of the service component involved. They stated that the fact that their work was going to impact and make the lives of other people in different parts of the world better, was a great motivational force for them to apply their knowledge and find creative ways to meet the client's requirements. During their site visit to the client facility at the beginning of the project before the pandemic, they saw pictures and learned from the client how different customers in developing nations were using the BUV for critical functions including agricultural, water and medical supplies transportation. They learned how the BUV was being use to alleviate poverty and enhance the healthcare of many in the developing nations. This information at the beginning of the project provided great motivation to the students for the project.

Fabrication and Manufacturing Processes: Critical Role of Technical Staff

Due to the limited access to the workshop because of the Covid-19 pandemic, the strategic decision was made that while the student team will focus on the design of the fixture to meet the client requirements and specifications, the team will work with the shop manager and engage his service in the fabrication of the full scale design. This process works similarly to contracting or outsourcing for real world projects. The modification in the project approach provided the students with another unique learning opportunity where they have to effectively communicate their design to production personnel. In addition, during the face-to-face mode of the course, the lab manager was heavily involved in the selection and design of the labs for the course. The instructor drew heavily on the lab manger's industry experience and knowledge of industry needs to create the lab component of the course that would add the most value to the students. The lab manager assisted the instructor in providing hands-on training on the use of different fabrication tools and equipment in the manufacturing lab (Figure 23).

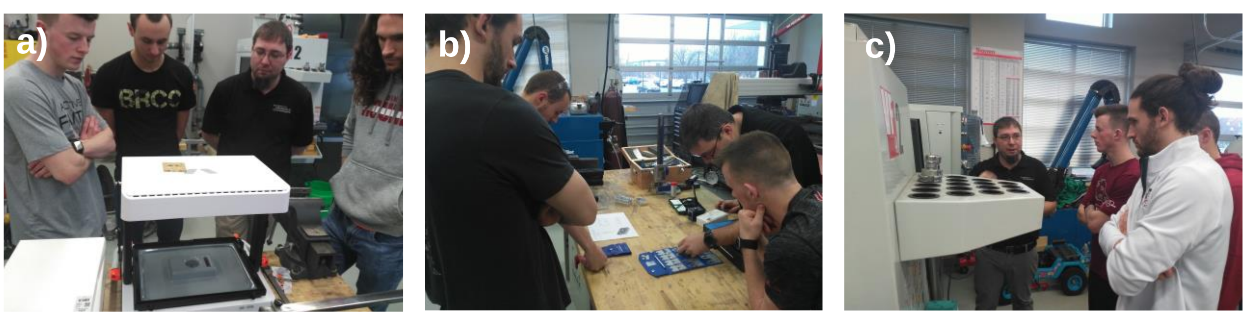

Figure 23: Lab manager working with students in the manufacturing lab

Student Team Reflections

Overall, the team enjoyed working on the project. COVID-19 had a significant effect on everyone's personal situations, at times making it nearly impossible to make progress with our progress goals. The team struggled with finding opportunities to meet in person, fabricate physical prototypes, and complete any form of testing. Due to this, the team had to stay proactive in finding means for how the fabrication would be done in the midst of the pandemic. Below are quotes from the student team based on their reflections on the project:

"I enjoyed working with the team on this project. The project allowed us to apply coursework from multiple courses as well as our own creativity to the fixture design and creation of manufacturing instructions. BUV was a fantastic client to work for and we were able to overcome the challenges posed by the COVID-19 pandemic and deliver strong first and second design iterations to the client." - TJ

"I enjoyed this project because it aligned closely with my interests and previous internships. The COVID-19 virus issued us challenges that we were able to overcome to the best of our abilities and deliver a first and second prototype." - Jake

"At a personal level, I enjoyed this project because it aligned with my values to serve and provide opportunities for people in less fortunate situations than myself. I enjoyed the mission of the company and allowed it to drive my passion for the project, even when COVID-19 tried to slow the team down." - Payton

Impact of University Support on US Small Businesses' Product Development and Competitiveness

The monetary value of the support provided by the university in supporting the IAT through this project is huge. A conservative estimation of the cost of producing one prototype if we factor in the engineering time the students spent on designing the fixture as well as the machining, materials and labor costs totaled $1500 per fixture. This estimate is based on an estimated shop rate of $50.00 per hour which is equivalent to $800.00 in labor alone. CNC labor could be $70.00 per hour and our lab manager used about 2 hours of labor on the CNC. The waterjet has a rate of about $100.00 per hour and about one hour was spent in fabricating a part. In total, the lab manager spent about 16 hours to make a complete fixture from start to finish. The client only paid $160 per fixture.

This project exemplifies the great value that universities can add to US small businesses, particularly during product development and prototyping. The use of university students, professors and technical staff can help US small businesses to significantly lower the cost of product development which can help them to be competitive against their global counterparts. It will also enable them to access world class facilities and personnel to develop innovative and competitive products in term s of quality and price. On the other hand, universities will benefit from such collaborations by providing their students with real life industry-based projects that will enhance their graduates' professional and technical skills. Their graduates will stand out and be competitive in the market place. Such industry-academia collaboration is mutually beneficial to both parties involved.

Client's Feedback

The following questions were asked the client after the completion of the project.

1. Share your experience working with the mechanical engineering students, faculty and lab manager on the project in the midst of the Covid Pandemic

2. What is the relevance of the work done or project to IAT and IAT customers?

3. What is the importance of such academia-industry collaboration for US small (technology) companies and for future workforce development?

Response from the Client, Executive Director, Institute for Affordable Transportation (IAT)/ Basic Utility Vehicle (BUV)

1. I really enjoyed working with the UIndy students. They were very prepared for the calls and kept me updated on developments. The engineers made good progress on the project despite Covid setbacks. At the end of the semester, the lab manager James Emery did a great job pulling the student's work together for a finished project. The end result was an excellent fixture that will be used with our next factory partners. The first of these partners is in northern Benin, West Africa. We have already shipped them equipment and they will be starting in the summer 2021.

2. The project is very relevant to us in that it is on the main product that we will be promoting in 2021. We are using the fixture now to build a consistent engine module for the BUVs. The power platform holds some of the most expensive parts of the BUV (the diesel engine, the continuously variable transmission CVT, and gearbox) in proper alignment for long life and strong performance. This fixture is a portion of the Technology Transfer Package that we pass on to partner businesses that manufacture the BUV in the developing world. It is one key step that makes it possible to produce low volume, high quality, farm-to-market vehicles in Africa. The BUV creates jobs for the driver entrepreneurs, for mechanics, and for the factory worker.

3. Academia-Industry collaboration is very important to the Institute for Affordable Transportation. We view the engineering universities as a critical part of our R&D work. Students bring a fresh mindset and a strong methodology to the problem solving effort. I also think this is a great tool for developing our future engineers. They work with real customers on real problems. It is a great opportunity to emphasize the importance of good communication to the engineering students. I want the student team to feel the responsibility for good communication on their project. They are to manage the relationship. As the customer, I emphasize the importance of the deliverables and try to help them understand the context of the problem. I admire how the UIndy professors emphasize communication as a key part of the students' engineering work. We have completed over 50 engineering projects with 20 different universities during the last 20 years. Sometimes we learn a simpler or more cost-effective solution. Sometimes we merely learn what not to do. In the case of UIndy, we are using their fixtures in BUV production, and we are very pleased with the performance of the fixtures.

7.0 Concluding Remarks

The Covid-19 Pandemic forced a traditional face-to-face project-based learning manufacturing course to metamorphose into an online PBL one. The change resulted in some challenges in executing an industry-based project that involved the design and fabrication of fixture for an automotive component for the BUV for customers in developing nations in harsh driving terrain. Some of the challenges the student team led to overcome included limited assess for site visits to client facilities for observations and interviews as well as inability to access campus workshops and resources.

In spite of these challenges, the use of key technologies like videoconferencing and design technologies like cloud-based computer aided design software enabled the team to communicate and collaborate effectively with team members, instructor, technical personnel and client for the project execution. Based on the student team design, a 3D printed scale model of the fixture was presented to the client at the end of the semester. The client was so impressed with the students' work that he ordered four full scale model to be fabricated by the R B Annis School of Engineering staff to be sent to the client's customers in Africa.

The students reported that they were inspired and motivated to work on the project because of the service component involved. In addition, close collaboration between the instructor and the university's technical staff was crucial fir students' learning and success of the project, particularly as an online PBL in the midst of a global pandemic. Finally, industry-academia collaboration is a mutually beneficial one. The use of university students, professors and technical staff can help US small businesses to significantly lower the cost of product development which can help them to be competitive against their global counterparts. It will also enable them to access world class facilities and personnel to develop innovative and competitive products in term s of quality and price. On the other hand, universities will benefit from such collaborations by providing their students with real life industry-based projects that will enhance their graduates' professional and technical skills.

This is the first time the course was taught as this was the first graduating class from the RBASOE. Reflection analysis and client's feedback were used to assess the students' experience and project success. The teaching team will adopt other methodologies to assess students' experience and learning in future cohorts of the course.

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