Life-Cycle

Bicycle health monitoring system

Team: Eagle Application Team

California State University - Los Angeles (CSULA)

Guided Wave- Based System for cure Monitoring of Composites using Piezoelectric Discs and Fiber Bragg Gratings (FBGs)

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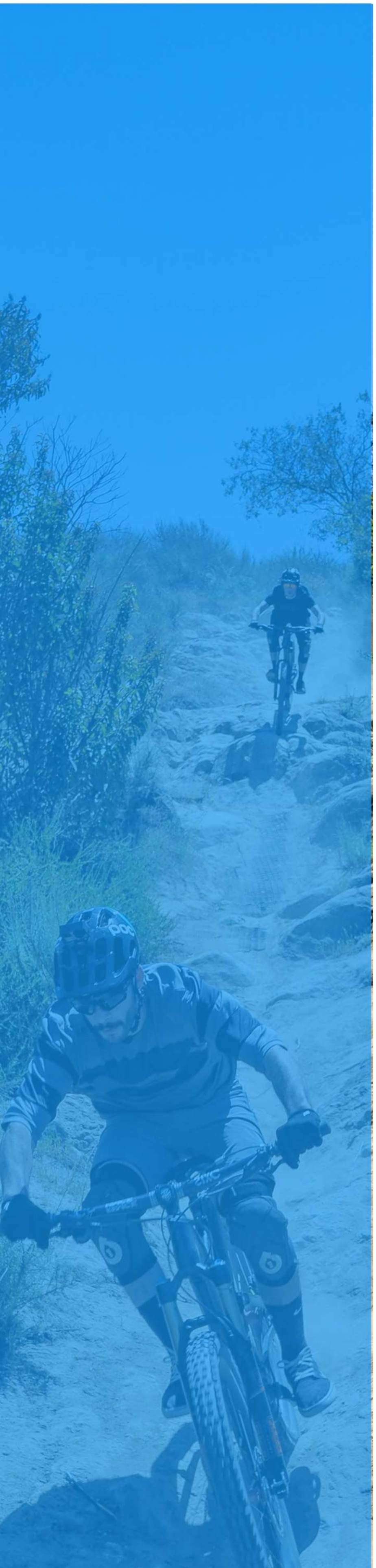
This proposal will demonstrate the commercialization of one of NASA's intellectual properties; Guided Wave-Based System for cure Monitoring of Composites using Piezoelectric Discs and Fibers Bragg Grating (FBGs). The application chosen was to embed these sensors into a carbon fiber bicycles frame both to monitor its life cycle by periodic stress and strain testing, as well as to diagnose defects through thermal monitoring during cure in the manufacturing process. In the last thirty years, the bicycle industry has seen drastic changes, such as front and rear suspensions and disc brakes. These new technologies are now being implemented across all models of bicycles. Carbon fiber is a relatively new material that has taken many industries by storm, including the bicycle industry. Carbon fiber has been used to build frames, forks, seat posts and other components. Although it made bicycles lighter and stiffer, it had drawbacks such as possible defects during the lay-up of the carbon fiber and if it fails, it will completely shatter. Applying the sensors to carbon fiber bicycles will aid the rider to identify problem areas before they happen, and help manufactures detect defects during curing. The data collected will also assist in the design, and increase the speed of frame optimization, to creating a faster and lighter product. Most of the contribution to the carbon fiber bicycle industries and products come from Taiwan and sometimes China. These carbon fiber frames are manufactured by layering sheets of pre-impregnated carbon fiber in a bicycle mold and depending on the type of use or design of the bicycle, the strength of the frames can be custom made by changing the orientation of the fibers. There is a $6.2 billion annual market, in the United States, with an expected global growth rate of 5.2% Compound Annual Growth Rate (CAGR). The growth plan takes into the manufacturing process the number of operators needed and advertising on different social media platforms. The Eagle Application Team (EAT) has designed deliverables to meet the standards of the competition and will explore and explain the MSI's capabilities along with a detailed manufacturing plan. EAT created a spreadsheet with the time every development process of the bicycle would take. The long-term plan is to set a new standard in the composite bicycle industry, which increases safety of the customers and should appeal to the riders. EAT has worked out a planning sequence of operations that would provide optimal value to the customer and mapped out a value stream with steps of production control, receiving, ply cutting, and the lay-up. Using value stream map as a guideline, EAT was able to make educated decisions in the type of equipment that would be necessary to produce a bicycle frame with an integrated life monitoring system. Currently, the carbon fiber industry is growing and found its way into many other industries such as aerospace, automotive, safety helmets, and bicycles.



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IDENTIFICATION AND SIGNIFICANCE OF THE INNOVATION

The Eagle Application Team (EAT) proposes to use NASA's Intellectual property (IP): Guided Wave-Based System for cure Monitoring of Composites using Piezoelectric Discs and Fibers Bragg Grating (FBGs) on composite (carbon fiber) bicycles. The application of the FBGs on the bicycles can change the bicycle industry, which is no stranger to change. FBG monitoring sensors would ideally replace current testing that are not limited to non-destructive testing, quality control, thermal monitoring, and stress and strain testing after the rider's use.

The bicycle industry has drastically changed in the last thirty years. Not long ago, cycling magazines wrote articles about the feasibility of suspension and disc rotor brakes. Today these innovative components are considered standard on bicycles, including the most economical bicycles. As new technologies and materials become more accessible, the cycling industry incorporates these advances to provide a superior rider experience. The objective for the cycling industry is in making the bicycle feel as though it is an extension of the rider's body. The composite materials, without a doubt, have taken the industry by storm. Carbon fiber, a relatively new material, provides an optimal strength to weight ratio, an increased stiffness, and vibration dampening characteristics. In addition, since the material is molded, the aesthetics of the frame are only limited by the imagination of the designers. All the material's properties provide an extreme appeal to consumers in a market. The industry was valued at $59.9 billion dollars as of the year 2021.However, the benefits of composites do not come without stipulation. Composite manufacturing is extremely costly and unforgiving. Unlike metal bicycles, composite bicycles are anisotropic; meaning the strength from the material is directional. While this anisotropic property is a benefit for design's optimization, it can be frustrating selecting the adequate composite material for the application. Fortunately, because of its prolific use in aerospace many readily available resources exist under ASTM D30 Composite Materials Committee. The ASTM D30' Composite Materials Committee provides years of testing data and verification methods. Although, the occurrences are rare, in which these resources are ever utilized in the design or manufacturing processes by bicycle manufactures. This decision is uncertain in why this is the case for the design process. An assumption about the decision is to reduce the total production costs. Another assumption, it may be that because the usage of composites in bicycles is a new application, and standards, test, and regulations for manufacturing are laxed or not required. Since the bicycle industry, does not make standard to consider material, this reality does pose a concern for safety of the rider. Most defects in composite structures are below the surface and are not visible. The defects can proliferate until catastrophic failure occurs creating a serious safety risk for the consumer. Dr. Scott W. Beckwith is the president of BTG Composites Inc. and the global technical director for the Society for the Advancement of Materials and Process Engineering. Furthermore, she serves as a consultant in forensic investigations, that involves composite failures in bicycle structures. Dr. Scott W. Beckwith has said "I have not seen a stress analysis or set of material strength allowable or an applied safety factor for any of roughly 50 carbon fiber high-performance bicycle failures. That needs to change, manufacturing, structural analysis, quality control, testing and inspection are all important considerations in controlling a labor-intensive molding and composites manufacturing process."

The FBGs would replace a variety of testing sensors. There is a need to not only monitor the manufacturing process of the material, but also to monitor the stresses and strains that occur during use. While simulated analysis in CAD programs are useful for simulation testing, there is no substitute for the instant information of the material reaction. Although there are several ways to test the material, these can be costly, time consuming and might need heavy equipment. FBGs sensors present a revolutionary process of monitoring the structural integrity of a design. Through integration of the sensors throughout the frame of the bicycle one can record the stress and strain in a bicycles frame during actual use. Although the sensors are not a standard now, these sensors can become requirements soon. The application of the sensors would allow for massive data collection of the bicycle's performance relating to the frame design during customer use. The massive information collection can assist in the design, and increase the speed of frame optimization, to creating a faster and lighter product. This technology would also benefit the customer by giving them the ability to check the structural integrity of their bicycle after use. Potentially in the future user-based interaction with such sensors can be used with a smart phone. The data could be uploaded and understood by a user in the palm of their hands. The data gathered by the sensors would ideally send instant alerts to the rider, during the use.

EAT aims to solve this increasing problem with little to no increase in manufacturing costs, by applying a technology developed at NASA to internally monitor the "health" of composite structures. The proposed technology should use fiber optic sensors embedded within the carbon fiber that can monitor stress, strain, and temperature all in real time throughout the product's lifecycle. By applying this array of sensors from within the laminate, the structure has a simulated nervous system that further achieves the goal of making the bicycle an extension of the rider. The benefits of this technology are not limited to bicycles, but this application can extend further. By incorporating FBGs sensors, weak points in the carbon fiber could be easily identified and the cause of the imperfection could be traced. Thus, speeding up the process of constructing a carbon fiber product, that is adapt to industry standards. Figure 1 Sensors could potentially monitor different sections of the demonstrates the different parts in the bicycle that can be monitored.

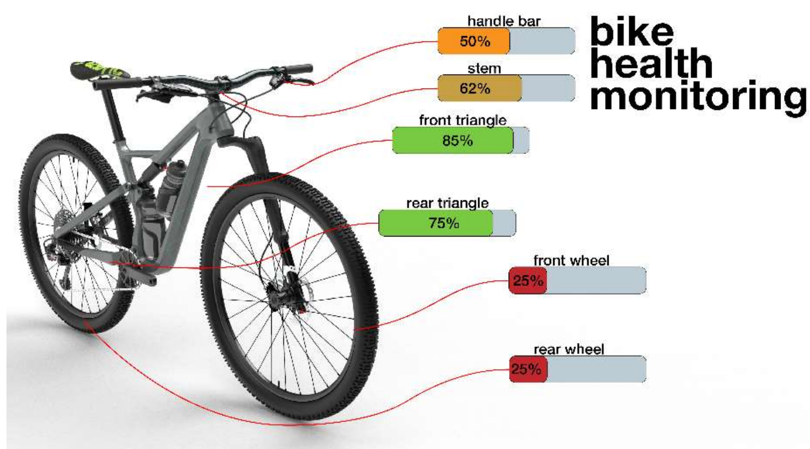

Figure 1 Sensors could potentially monitor different sections of the bicycle.

INDUSTRY ANALYSIS AND TRENDS, TARGETS MARKET AND COMPETITION

Currently, the carbon fiber industry is growing and found its way into many other industries such as aerospace, automotive, safety helmets, and bicycles. Companies began manufacturing bicycle frames from carbon fiber to improve the connection between the rider and the bicycle. Road and mountain bicycles serve as a bridge connecting the rider with the road, giving the rider an extension to their bodies. Most of the contribution to the industries' carbon fiber products come from Taiwan and sometimes China. Although, there are some companies like Trek (bicycle company), who manufacture in the United States. These carbon fiber frames are manufactured by layering sheets of pre-impregnated carbon fiber in a bicycle mold and depending on the type of use or design of the bicycle, the strength of the frames can be custom made by changing the orientation of the fibers [1]. Mountain bicycles have a huge advantage with the layering of carbon fiber because its fine tunes areas that will experience higher stresses, creating a highly durable and lightweight bicycle. Bicycles made from this material can expect to have a life of approximately 3 – 6 years depending on usage, storage, and the manufacturers recommended maintenance [2]. Although carbon fiber bicycles provide the rider a much better riding experience, it comes with disadvantages when involved with unintended forces. These bicycles are designed and manufactured to ride well and withstand impacts, but a crash can significantly compromise the integrity of the frame.

If the bicycle is involved in a crash, then the rider should visually inspect the bicycle and look for noticeable chips or cracks. However, a visual inspection is not sufficient in most cases because there could be internal damage [1]. A carbon fiber bicycle can break as shown in Figure 2 Broken Carbon Fiber Bicycle Typically, the rider will have to bring the bicycle to a professional to have it inspected as well as using specialist techniques of non-destructive testing, such as ultrasounds and X-rays to determine if there is any deeper damage [3]. Although carbon fiber is a tough and strong material, it is susceptible to catastrophic failure. Unlike bicycles made from other materials such as aluminum, it can be extremely difficult to detect signs of damage in carbon fiber. Damage like cracks or dents are visible in other materials but with carbon fiber, it is hidden beneath the surface and thrives within the structural layers. If the damage is not found, the bicycle will fail causing it to unpredictably shatter into pieces and potentially injure the rider, which can lead into lawsuits. The bicycle manufacturer, Giant, received a lawsuit in 2013 over a defect in their carbon fiber forks which led to the injury of a rider [4]. This raises questions of quality control and the sustainability of carbon fiber bicycles. If companies do not have a set standard for their bicycles or other parts, then there is little to no guarantee in receiving a good quality product.

Figure 2 Broken Carbon Fiber Bicycle

In the United States bicycle market overall, there is a $6.2 billion annual market [5]. The target market will be in mountain and road bicycle sales which are estimated to be $577.7 million and $412.8 million respectively [5]. Within these categories there is approximately a total of 48 million potential buyers with an expected growth of the global carbon fiber bicycle market of 5.2% CAGR through the year 2025 [6]. When consumers purchase carbon fiber bicycles, they not only have to worry about the frame but also worry about high impact areas such as the forks, seat post, and handlebars that some manufactures recommend replacing every 3 years. As mentioned earlier, when carbon fiber bicycles fail, they shatter and could injure the rider. What would be sold is safety as well as bicycle frame well-being and peace of mind. Although there are steps taken to maintain the bicycle, there is not a definitive way to know the actual state of it without taking it to a specialist to perform the techniques mentioned.

Typically, to check on the state of the bicycle the rider would have to either visually inspect it or if a crash occurred, they would have to take it to a specialist. There, the specialist performs ultrasounds and X-rays to reveal any internal damage. Another novel technique is using infrared thermography, which is a form of non-destructive testing [7]. The intellectual property of fiber optics sensors will be integrated with the bicycle frame. Thus, it will reduce the need for expensive equipment to test nondestructively. If the rider suspects something is wrong with their bicycle, they would connect their bicycle to a computer to read the sensor and gauge the severity of any damages that might have occurred as well as estimate how much life is left in the frame. This technology will also help the manufacturers optimize their designs when curing the frame or other carbon fiber parts. Since there is not anything much like it on the market, the risk, and barriers to enter will be minimal such as creating a prototype and being able to market the new technology well.

WORK PLAN

The Eagle Applications team decided to set the following milestones to meet the proposal requirements and then the execution of the plan. The first step was to separate the milestones into 3 phases. The first phase consists in creating a plan. The second phase was to establish a network to assist the Eagle Application Team to meet the requirements of the competition. The third phase is the manufacturing process for the prototype. For a better visual in the deliverables view appendix Table 3 Deliverables and Milestones for Project.

Phase 1 – Develop a Plan: The Eagle Application team was formed on December 9th. In the first phase the goal was to establish a plan. The team took a couple of days to explore all the intellectual properties for this competition. After lightly researching NASA's Intellectual Property, the Eagle Application team decided to research on the Guided Wave-Based System for cure Monitoring of Composites Using Piezoelectric Discs and Fiber Bragg Gratings (FBGs). The team investigated possible sectors in the industry with a wide range that consists of Aerospace, automobile, windmills, and others. In this phase every member is expected to contribute 15 hours per week to research. Research shall be conducted in three sectors, cars industry, aero, and civil. After the research is conducted, a meeting ranging from 2 to 3 hours shall be conducted to have a spin off concept. The work and sections of the paper shall be divided amongst the members.

Phase 2- Network: The second phase consists of establishing new networks or contacting current networks for the purpose of the competition. Phase 2 was divided into 3 stages: 1st stage is to seek a Principal Investigator (PI) to support EAT, 2nd stage is to contact businesses to support EAT, 3rd is to address local schools for the opportunity of presenting the information to the students. In 1st stage EAT sent an email to Dr. Landsberger and Dr. Castillo. Dr. Landsberger and Dr. Castillo agreed to support the team. The time allotted to find a PI was estimated to take two weeks. EAT took 1 week to find a PI. In the 2nd step EAT will start contacting and establishing new network connections, specifically in the bicycle industry. EAT shall start contacting the local businesses for both road and mountain bicycles. The team also discussed the possibility of helmet applications. In the 3rd stage, the team started to contact local k-12 schools, community colleges, and student organizations to have an informational session. The team asked for written agreements to have an opportunity to present each of the team's experience and information on the competition. EAT is expected to allocate 10 hours per week to research various companies, contact the business, and will continue until a business support is established. Outreach allocation of time will vary. EAT is expected to participate in at least one outreach event. The events time will be 30-45 minutes.

Phase 3 – Manufacturing: Phase 3 is the development of EAT's concept, and for this it is also divided into 3 sections. The first stage is to obtain CAD files to modify for EAT's objective. The second stage is to implement the sensors into the frames of the bicycle. The third is to test the bicycles once constructed for four weeks. The manufacturing process of the bicycle is divided into 9 main development stages. Time for the development of one bicycle is calculated to 68.95 hours and estimated 2.88 days calculations are in Appendix Figure 22 Time Calculated to Produce Bicycle . Due to COVID restrictions 1 to 3 members are expected to work on the manufacturing of the bicycle.

Growth Plan: The growth plan takes into the manufacturing process the number of operators needed and advertising on different social media platforms. EAT created a spreadsheet with the time every development process of the bicycle would take. The Spreadsheet was used to calculate the number of operators necessary to develop 4 bicycles as awareness to the product will be a slow start. Two operators with cross-training with different machines are needed but 3 operators are optimal. Advertising plans are to establish social media accounts to influences consumers. The second step is to bring awareness to the bicycling community. Outreach, with different institutions, will also bring awareness to the new product. The last step is to save enough money to purchase equipment to produce the bicycles.

Long Term: The long-term plan is to set a new standard in the composite bicycle industry. The safety of the customer should appeal to the riders. The goal is to have the testing in an integrator that is portable to carry and is affordable. Research has been conducted and cheap integrators are possible. Another possibility is to have the testing capabilities to the user in cellphone applications. The next possible application is to explore other type of bicycles. Another application is to set the sensors into the helmets.

INSTITUTION CAPABILITIES

EAT's goal is to collaborate with an existing bicycle manufacturer who will support it in the design and manufacturing of the bicycle prototype. While communication between several bicycle manufacturers is ongoing, EAT does have an additional plan to fabricate a prototype with the support of its university, faculty, and small business collaborator. With such assistance, a prototype could be made, which could then be demonstrated to those in the bicycle and cycling industries to appeal to the larger producers and manufacturers of the market.
Eric Oakes was referred to EAT by the team's IP, Dr. Landsberger. Mr. Oakes is a senior mechanical engineer for bonding in composite manufacturing who currently works at Jet Propulsion Laboratory (**JPL**). He has worked at JPL for over 20 years and has helped design and build composites for several flight projects like MSL, Mars 2020, Juno, and Insight. Eric Oakes has offered his guidance and assistance to EAT as well as provided beneficial information on current manufacturing techniques in **SpaceX** and JPL.
Dr David Raymond is an associate professor of Mechanical Engineering specializing in impact biomechanics. He is the responsible for the Applied Injury Biomechanics Lab on campus. Prior to joining CSULA, Dr. Raymond spent approximately nine years working in forensics engineering in the fields of injury biomechanics and accident reconstruction and four years as a Crashworthiness and Occupant Protection Engineer at General Motors [8].
The work of the Applied Injury Biomechanics Laboratory is to advance the state-of-knowledge on the mechanical response and tolerance of the human body and to use such information to create novel technology for injury prevention and for the progression of forensic science [8] Equipment available at the noted lab include, but not limited to several drop towers, drop apparatus, drop stand, low-crash sled, DTS SLICE data acquisition system, Pneumatic projectile launcher, M-1 Master chronograph, universal material testing machines, and environmental scanning electron microscopes. Dr. Raymond's experience with experimental methods and data analysis utilizing six-degree-of-freedom (6DOF) sensors, which provide analog outputs for three axes of acceleration and three axes of angular rate, could support the team's project. If granted the ability to able build a prototype, Dr. Raymond's *familiarity with sensors* and their readings could help the team properly assess the stresses and strains that occur during the use of the frame.
Dr. John "Chris" Bachman is an assistant professor of Mechanical Engineering who is director of the Innovation and Design Center overseeing the ECST Makerspace at CSULA. The ECST Makerspace was formed by students, faculty, and staff to provide access to equipment and training for students to create and manufacture [9]. The Makerspace has facilities intended for design and development, prototyping, computer aided design and simulation, manual and CNC machining, laser cutting, waterjet cutting, and welding [9]. Dr. Bachman is also the leading faculty advisor for the university's Baja SAE and Formula SAE teams. Both teams usually fabricate all parts and components that go into their projects on campus [10] . Many of their components are *constructed with the use of carbon fiber*, therefore, if given the opportunity to design a prototype for future commercialization, the team would have access to the Makerspace, along with the Baja and Formula SAE workspaces. Dr. Bachman has also offered to be an advisor for EAT's prototype in case it would need to be manufactured without the assistance of a bicycle company.
Dr. Mauricio Castillo is a professor of Technology department. He is involved in engineering new ideas to teach STEM education. He has offered to connect EAT to various connections to *present information* on the competition.

Aside from the institution, EAT has contacted several companies and individuals. EAT would also have the assistance of a Jet Cutting Solutions, local manufacturer. The small aerospace shop owner has agreed to allow EAT to utilize any of the equipment available on the premises for the design and manufacturing of the bicycle prototype. Emails have been sent to various manufacturing bicycle companies. Interest from bicycle manufacturing companies has occurred, but the team is still waiting on written agreements. The equipment available to EAT are in the appendix ***Error! Reference source not found.***.

FACILITIES/EQUIPMENT/BUDGET

A state-of-art bicycle needs a state-of-the-art manufacturing process. For this reason, EAT has created a planning sequence of operations that would provide optimal value to the customer. Below in **Error! Reference source not found.**, a value stream map outlines the optimal state for production. EAT made a concerted effort to leverage lean manufacturing practices to design a leveled pull production system where manufacturing is directly proportional to customer demand. EAT can reduce wastes in the form of work in progress (**WIP**) inventory throughout the value stream. The reduction in WIP not only improves available cashflow of the business but increases the quality of the product by creating an environment where defects are discovered and remedied swiftly. Value Stream Map is shown in Appendix Figure 21 Value Stream Map*, and is used as a guideline*. The Eagle Application Team was able to make educated decisions in the type of equipment that would be necessary to produce a bicycle frame with an integrated "Life-Cycle" system.

Production Control: The initial step is to begin with the brain of the operation, Production Planning. Since the team is manufacturing end use products, it is important to ensure to have proper traceability and material tracking capabilities. Therefore, implementing an ERP system is critical to the success of the organization as well as meeting the international requirements for production; ISO9001 certification.

Receiving: Once materials are ordered by production control; they are then delivered by suppliers Hexcel (carbon fiber prepreg) and Luna (fiber optic sensors). Each roll of material is weighed and tagged with a unique identifier and lot number. At the same time, each fiber optic sensor is continuity tested using an optical interrogator and given a unique organizational part number. The integrator relays light to the sensors and with the feedback of the light data is interpreted. Now that the material and components have been received, they are released to production by placing them in FIFO Kanban storage racks which initiates the pull production system. It is important to note that due to carbon fiber prepreg's storage constraints, the material must be stored below 0˚ F to retain its mechanical properties. This constraint makes it imperative to keep material handling outside of a freezer to a minimum as well as tracked. With this information the equipment that is needed for the receiving department is: Storage racks for optical sensors, Industrial Freezer with a minimum volume of 20 ft^3.

Ply Cutting: Producing carbon fiber bicycles requires that the fabric be cut into patterns, these patterns are called plies and each ply is created to match with the surface of the bicycle. Using CAD, the team created a ply pattern kit by applying a mesh surface shown in *Figure 4 EAT Ply Pattern Kit Mesh Application* to a generic bicycle model shown in Figure 3 Generic Bicycle Model*.* Therefore, the team could quantify the number of plies needed. From the team's simulation, it was determined that a total of 275 unique plies would be needed. With the two-dimensional patterns, view *Figure 5 Two- Dimensional Pattern,* the team applied a nesting algorithm, view *Figure 6 Nesting Algorithm applied to Two-Dimensional Pattern,* to simulate the most efficient use of material given the team's constraints, as well as determine the amount of material needed per bicycle frame. The total length of material needed from a 48" wide roll is: 192".

Figure 3 Generic Bicycle Model

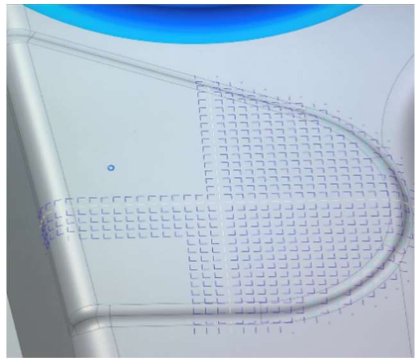

Figure 4 EAT Ply Pattern Kit Mesh Application

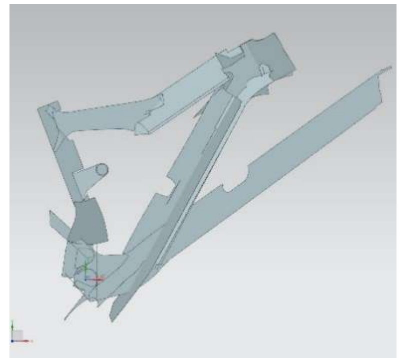

Figure 5 Two- Dimensional Pattern

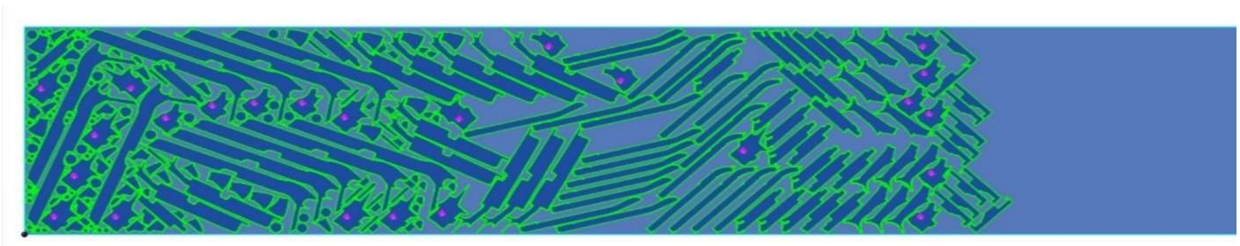

Figure 6 Nesting Algorithm applied to Two-Dimensional Pattern

From the analysis, the team ascertained that the magnitude of cutting required to build a bicycle would extremely be costly for technicians to cut by hand, therefore using an automated solution is needed for producing the ply kits efficiently. The team has determined that the Gerber DCS 2500 is the most cost-effective solution due to its cut speeds, accuracy and scaling capabilities. The logistical proximity to service and spare parts was also a factor in the consideration of this equipment and Gerber's service center operates within California.

Lay-up: Once the plies are finished being cut and kitted, a lay-up operator will pull the kit from the freezer Kanban. The lay-up tech will also pull a lay-up mold and clean it with methanol and cheese cloth. After, a chemical release agent is applied to the mold cavity surfaces and then buffed. When the mold is finished being prepped, the lay-up process begins. Lay-up technicians pull the plies from the kit, which are labeled with the orientation and ply sequence number. Ply number one is located from inside the kit and placed onto the mold surface. Immediately after ply layer one is applied, a debulk takes place to ensure adhesion to the mold surface and reduce the chances for voids, wrinkles or bridging of the fabric. The process of placing plies and debulking is repeated until the operator is at half of the ply kit. At this point the operator pull HD6s ODiSi fiber optic sensors and places them onto the fabric in the mold, by using a heat gun the resin becomes tacky and allows for accurate placement of the sensors. Lay-up is shown in *Figure 7 Lay-Up Process for creating a Bicycle .*

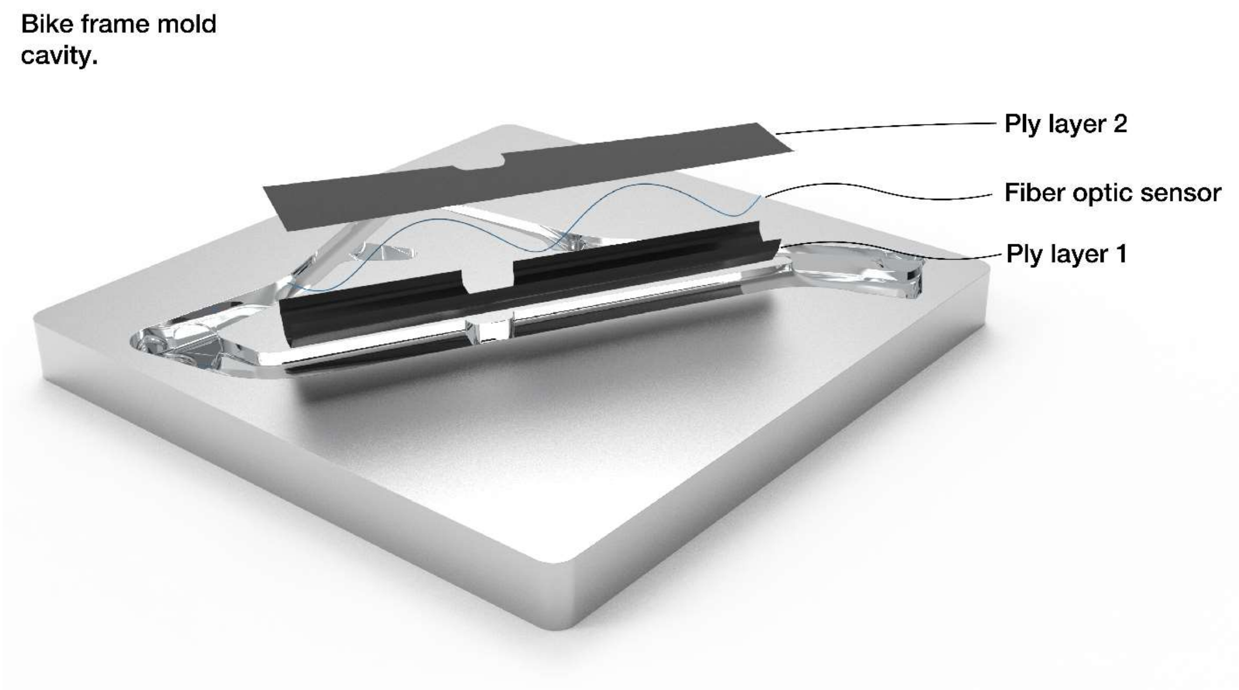

Figure 7 Lay-Up Process for creating a Bicycle Mold.

Due to the legal implications and costs that are associated with manufacturing products using NASA's intellectual property in the international arena. EAT has determined that a manufacturing facility in the United States of America would be in the best financial interest to the organization. Because of its tame seasonal weather and proximity to shipping ports and material suppliers the team believes California is a clear choice for a manufacturing facility with the capability to provide the market with an uninterrupted supply of the team's product.

The process in which the team would produce a bicycle frame with embedded "life cycle" sensors involve 9 operations. Shipping/Receiving, Ply cutting, Lay-Up, Cure, Trim and Drill, NDI, Paint, and assembly

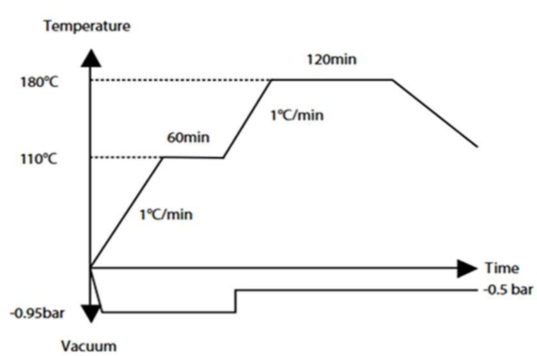

Figure 8 Time for the Cure Process

Cure: The cure process is largely determined by material selection to which the manufacture provides the specified cure recipe. From the analysis, EAT were driven to choose an "out of autoclave" resin formulation. Ultimately, the Hexcel m56 UD epoxy prepreg met all the mechanical needs while being convenient with its ability to do standard oven cures. The out of autoclave pre-preg reduces the complexity of the cure process and reduces the initial equipment investment cost in expensive autoclaves. Since EAT must incorporate sensors into the laminate there is no need for traditional thermo couples to monitor and record the temperature gradient throughout the cure process. Not only does this reduce the setup time it also provides the ability to accurately monitor the cure, improving quality and reducing defects.

Trim and Drill: After the bicycle frame is completely cured it moves onto the next process "trim and drill" where it is mounted to a fixture on a 5 axis CNC router. The machine will proceed to accurately remove any flashing, mill any bonding surfaces to accurate dimensions and drill holes for brake and shifter cables.

NDI: Because composite defects are not visible it is important to place a quality gate in the manufacturing process that specifically checks for subsurface defects. Typically, this is a time consuming and costly process, however using “life cycle” sensors EAT can inspect every bicycle frameset by simply connecting the frame with embedded sensors to an interrogator.

Paint: During the painting process the frame is inspected for any surface imperfections and sanded to a smooth finish. The frames surfaces are then cleaned of any dust and primed with a 2-component epoxy primer. Once the primer is applied the paint of choice is added to the frame and clear coated.

Assembly:

Table 1 Calculations for Assembly Process

Process	Time (Min)
Receiving	38
Ply Cutting	115
Lay-Up	197
Cure	507
Trim and drill	44
NDI	21
Paint	3134
Paint	3134
Assembly	50
Shipping	31
Cycle Time	4137
Hours	68.95
Days	2.872917

Customer Demand Monthly	4
Monthly workdays	20
Daily demand	0.2
Total Daily Available time	430
TAKT time	2150
Customer Demand Monthly	4

In the assembly process, shown in Table 1 Calculations for Assembly Process, the front triangle and rear triangle are united through the fastening of the suspension linkages. The linkages are then lubricated and inspected for full range of motion.

Workforce requirements: Time Studies for each process were conducted to get a baseline estimate on the cycle time required to produce 1 unit with the current projected equipment. EAT also used this data to calculate the available production time divided by customer demand (Takt) time that allowed the team to estimate the workforce necessary to produce bicycle frames at a rate of 4 per month as well as 44 per month as shown Table 2 Calculate Time for Rate of 4 Bicycles and 44 Bicycles.

Table 2 Calculate Time for Rate of 4 Bicycles and 44 Bicycles

Type of Operator	Time (Min) Rate 4 Bicycles	Time (Min) Rate 44 Bicycles
Receiving Operators	0.02	0.194
Ply Cutting Operators	0.05	0.588
Lay-Up Operators	0.09	1.008
Oven Operators	0.24	2.594
Trim and Drill Operators	0.02	0.225
NDI Operators	0.01	0.107
Paint Operators	1.46	16.034
Assembly Operators	0.02	0.256
Shipping Operators	0.01	0.159
Sum	1.92	21.17
Minimum Operators Needed	2	21.2
Realistic operators needed	3	22

Facility: Due to the legal implications and costs that are associated with manufacturing products using NASA intellectual property in the international arena. EAT has determined that a manufacturing facility in the United States of America would be in the best financial interest to the organization. EAT believes California is the best location for a manufacturing facility due to the proximity to the shipping ports, material suppliers, and tame seasonal weather.

Floor plan: Using the dimensions of the equipment, EAT has generated a floorplan to determine the square footage of the facility needed. The floor plan design is a concept based on an ideal state, where the team designed material to flow in a “U” shaped direction to minimize waste in the form of unnecessary material transportation and motion.   Visual Floor is in Appendix Figure 23 Manufacturing Assembly Line.

Scaled Prototype: The team consulted with a composite expert at JPl Eric Oakes. Mr. Oakes advised the team to begin the prototyping by first making a scaled model to fully understand the intricacies of the manufacturing process. The team was fortunate enough to receive support from Jet Cutting Solutions, an aerospace machine shop, to develop a cost analysis for creating the scaled model. The team provided a bicycle frame to be 3D scanned using a laser coordinate measuring machine. After the bicycle frame was scanned the team was returned a 3D model with a point cloud to create a mesh body and solid body. Once the geometry was established, the team designed a mold to be 3D printed using the Formlabs form3 SLA printer available to the team in the makerspace on campus. The material chosen for the mold is a high temperature resin that can withstand multiple cure cycles in a composite’s oven.

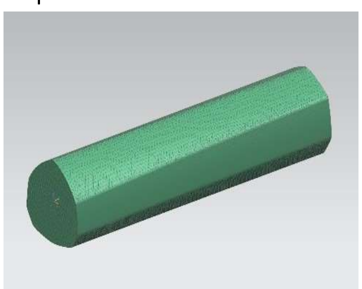

Figure 9 Cloud Mesh Body

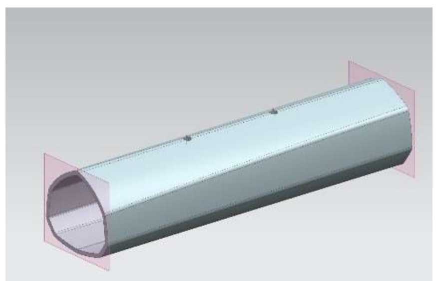

Figure 10 Solid Body

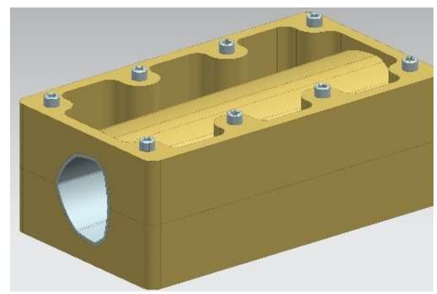

Figure 11 Assembled Mold

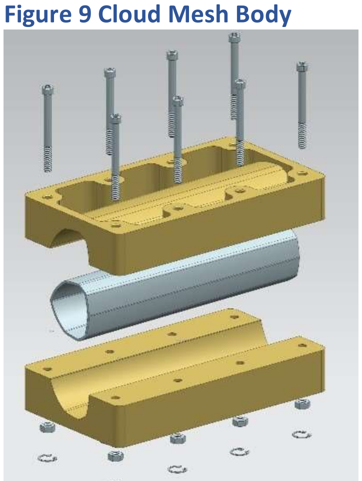

Figure 12 Assembly of the Mold

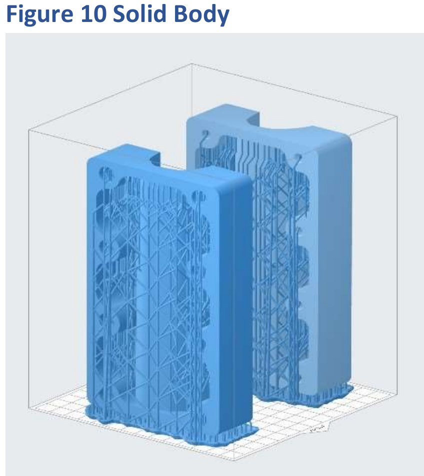

Figure 13 3-D Printer Simulations

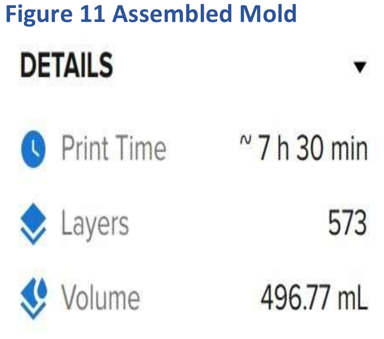

Figure 14 Estimated Printing Time

Cost Analysis: EAT has determined the cost of all the equipment, material, labor, cost to build a single bicycle unit, Table 9 Cost Per Bicycle Unit. It was determined that approximately 4 units/month will be produced initially but once interests increase, production is estimated to increase to 44 units/month. In Table 2 Calculate Time for Rate of 4 Bicycles and 44 Bicycles in the appendix, there will be an initial $172,007.53 in overhead costs calculations. Following an annual operating cost of $65,743.63, Table 5 Cost Expected for the First Year. The total cost of materials to produce the bicycle frame will be $406.20 Table 6 List of Materials Needed, Quantity, Cost. Labor per hour was given at $17.5 an hour and calculated the manufacturing a bicycle labor cost at a total of $1206.975,Table 7 Calculations for Cost of Labor. Calculations for the materials need per frames were also calculated, Table 8 specific Calculations for Materials needed and . The total cost per unit will be $1,737.51 Table 9 Cost Per Bicycle Unit. According to the estimates done, EAT needs a total of 38.94 units to break even, Table 10 Calculations to Determine Bicycle Units to Break Even. For a visual representation view Figure 15 Visual Representation demonstrating the Number of bicycles needed to break and Figure 16 Months to Break Even.

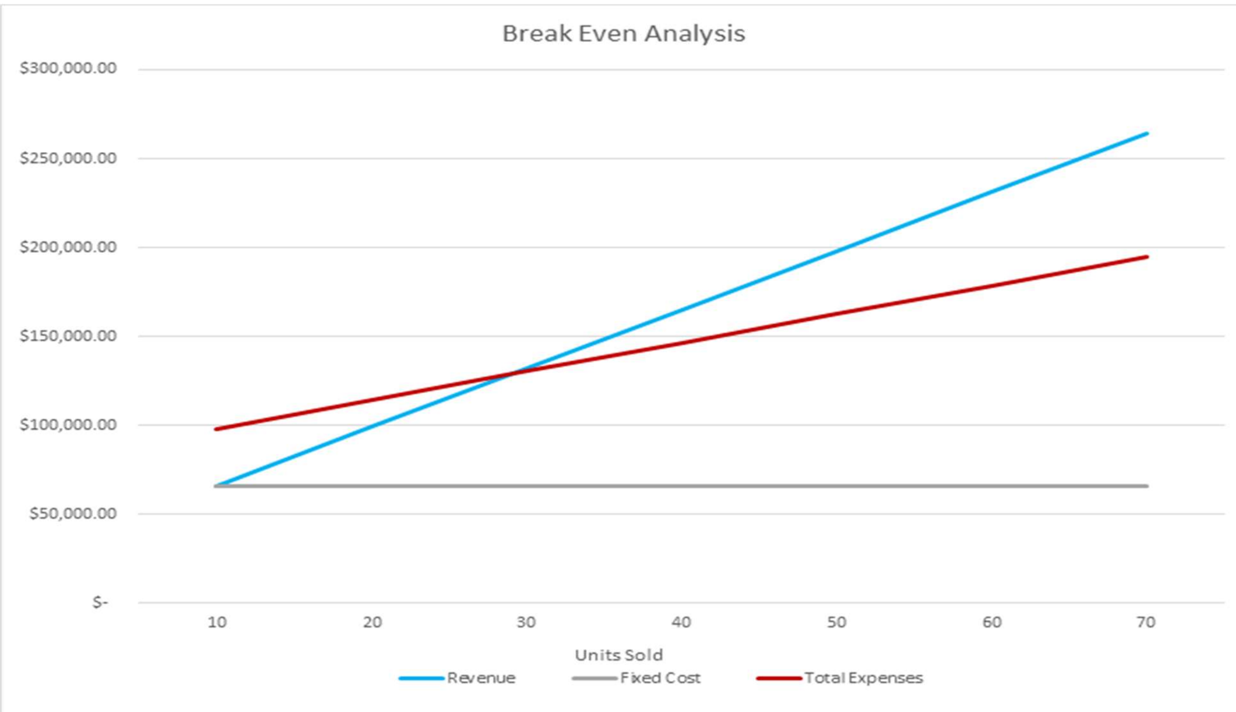

Figure 15 Visual Representation demonstrating the Number of bicycles needed to break even.

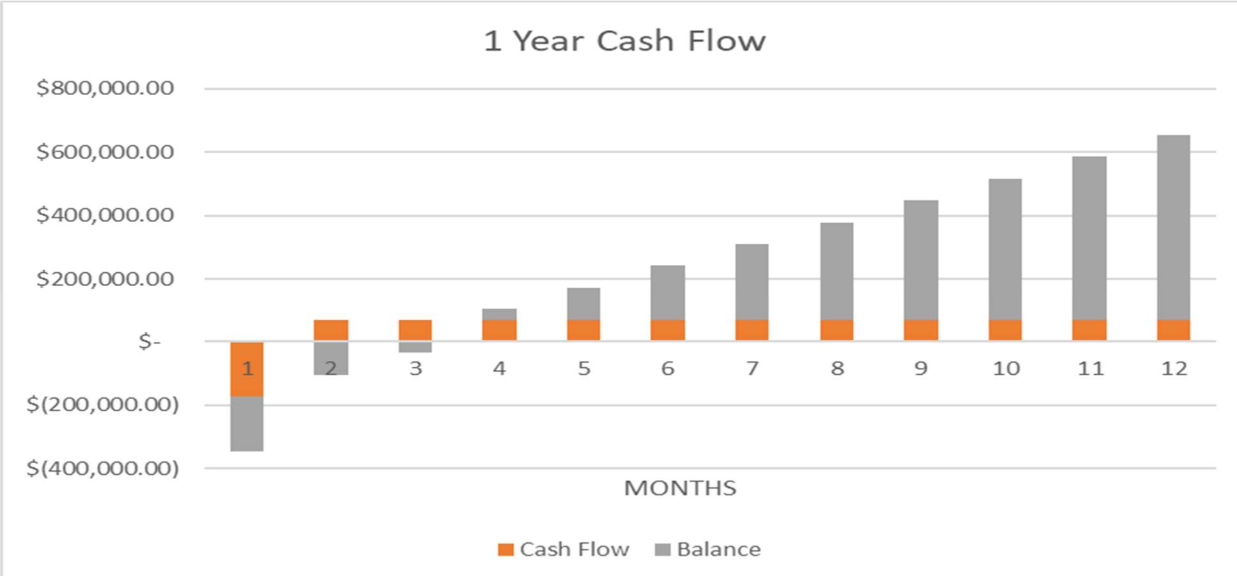

Figure 16 Months to Break Even

COMMERCIAL APPLICATION

The targeted application is the use of embedded fiber optic sensors for use in the manufacturing of bicycle frames to increase the efficiency of the manufacturing process and the simultaneous creation of smart parts. Other potential applications include automobile crash tests using composite parts, aircraft component lifecycle monitoring, wind turbine blade lifecycle monitoring, and prosthetic limb integrity monitoring.

In the aviation industry, a practical use for these optical fiber sensors is to collect real time stress and strain data that can be beneficial to verify predictions computed by the 3D computer models. Especially due to the broad array of flight situations a plane may experience that may not be easily modeled in a simulation. With the optical sensors ability to monitor an uninterrupted stretch of distance, engineers will be better able to monitor minuscule stress concentrations that may propagate into fatigue failure. There is a massive interest in reducing the weight of aerospace parts such as fuel tanks. When constructing a fuel tank out of a material such as carbon fiber, the positioning of every single strand of carbon is of upmost importance in maintaining the structural integrity. There can also be an improvement in life management of wind turbine and helicopter blades. However, there are other industries that will benefit from this technology such as formula 1. The engineers will be able to better improve the aerodynamics of the vehicle while monitoring the stresses during testing as well as during cure.

Potential customers for the targeted application include bicycle frame manufactures. Current manufacturing techniques require manufacturers to test their composite products post cure, increasing the time and therefore the cost of manufacturing the product. With embedded sensors, the entire curing process can be monitored, reducing the time necessary to manufacture and test a composite product. By curing the composite part with a sensor embedded, a smart part is created, allowing for future monitoring of the bicycle frames, adding a new safety feature for customers, and a new data pool for bicycle frame designers for improvement.

Initial commercialization can be achieved by acquiring the necessary sensing components, including fiber optic cable and interrogator, and creating a prototype frame alongside a manufacturer to demonstrate the capabilities and business value of the technology. The team is proposing that the cost of the fiberoptic cable used per component is less than the cost of time and money resulting from being required to test post-cure. The product can then be sold as a smart part, allowing users to monitor the integrity of their frame throughout its use by returning to the shop for a reading.

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OUTREACH

The Eagle Application Team (EAT) is focusing on implementing NASA Intellectual Property and commercializing the product. The Guided Wave-Based System for cure Monitoring of composites using Piezoelectric Discs and Fiber Bragg Gratings (FBG). After much consideration, EAT felt an application to the bicycle industry would benefit from the FBGs. The technology has tremendous potential to increase safety for consumers, reliable data for manufacturers, and potentially saving time in the quality control sector of the bicycles.

EAT will separate the target audience into four categories based on age and expected knowledge. The categories are as follows: elementary, middle school, high school, and college. The events will vary depending on the category and how the event is formatted in the school. The events and activity are planned based on the categories. Unfortunately, due to COVID-19, most events are schedule through zoom calls, but EAT is prepared for in person events. The intention for outreach is to inspire young minds to pursue stem careers, motivate students to continue to follow their dreams, and encourage different majors to come up with innovating ideas.

Many groups have been contacted to present information on the competition, and in explaining the intellectual properties. Due to the short notice, and the semester beginning in some of the school's letters of agreements have not been reached. Verbal agreements were made but these are excluded due to no written agreement between the institution, club, or organizations. There is a possibility that more groups and events might be created in the future. The plan for the written agreements is describe. EAT is prepared to do more outreach, if presented the opportunity.

Elementary: The team contacted a teacher at an elementary to do an outreach event. The teacher forwarded the email to the principal who forward the email the coordinator of school district. After several emails, there was an agreement for two outreach events, and these are scheduled for elementary. The coordinator of school district had a template to follow to present on Career Day event.

Career Day Event: An estimated 30 students (per class) with 30 to 45minutes will be present when the information is presented. The presenter(s) will present background information of themselves. The presenter(s) will then state their major and life as a mechanical engineering student. Afterwards the presenter will discuss the competition. The technology shall be explained to the young minds with the help of a board game, example candy land or twister. The spin of the wheel shall indicate the level of stress or strain that is occurring. The students shall then be asked a question, “If we have red what does this color state about the bicycle?’’ The small activity will give the students an opportunity to understand the information while not being overwhelmed by the complications of the science.

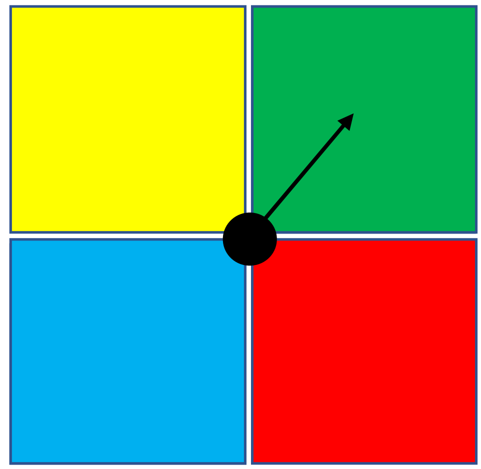

Figure 17 Color Pattern Light

After COVID Restrictions Lift: There have been several conversations to the school’s principal to help the STEAM Education Lab. The conversations are to help provide several experiments to engage the young minds. EAT shall explain how the properties of lights in the cable can tell the rider of the health of the bicycle. To demonstrate these concepts several toys will be lined up. One of the toys will be covered in glow in the dark paint that will glow under a black light. The student will be asked which toy is about to break and needs to be fixed. Then the black light will be pointed at the toys. The student will be asked the same question after the demonstration. For the older kids in elementary the experiment shall be slightly different. The toys will be covered in different glow-in-the-dark paint and will be placed on a mat with its matching color as shown in Figure 17 Color Pattern Light. One of the several toys shall be moved so that it will not fit the matching color. This action will indicate that stress is occurring in the bicycle. As the toy moves, so will the stress, as molecules move, and the light given off from the glow-in-the-dark paint shall indicate movements in the bicycle. The sensors will tell the rider that something has moved in the bicycle and this needs to be fixed.

Figure 18 Colors Can demonstrate to kids if an object is moved.

Middle/High School: Through contacts of EAT's Co-PI, EAT was able to establish outreach events. Verizon Innovative Learning for Minority Males has agreed to have an outreach event for their students. Go STEAM LA Program has also agreed to collaborate with EAT.

Guest Speaker: The outreach event for the middle school shall be like the one with the elementary. An estimated of 30 students (per class) with 30 minutes to 45minutes shall be used to give the information. The presenter(s) will present background information of themselves. The presenter(s) will then state their major and life as a mechanical engineering student. Afterwards the presenter will discuss the competition. The experiment will demonstrate how light travels in a straight-line using make-shift platform as shown in Figure 19: Light Traveling Demonstration. The presenter(s) will then explain how the light being blocked by slide B is like how the sensor works. This sends information to the eyes telling the individuals cannot see the other side of the "tunnel" meaning, there's something in the way. Once the understanding of light travel is solidified, it will then be time to demonstrate how waves act very similar. When an object is in the way of a sound wave or even a ripple on a puddle, it comes back faster rather than completing its full path. This will then lead to explaining how FBGs work and how it will help in the application: The bicycle feels these "waves" throughout the frame when going down hills and over bumps, the sensor can see the location of where the waves or the light is blocked which will help to identify breaks/fractures in the frame.

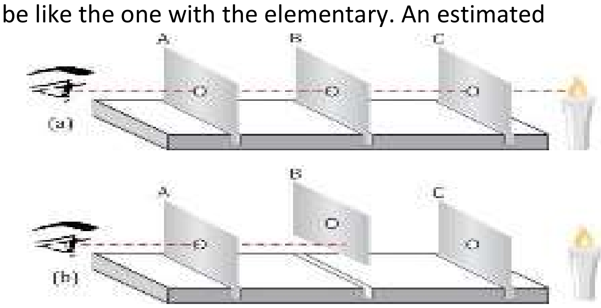

Figure 19: Light Traveling Demonstration

After COVID Restriction Lift: Activities for middle schoolers are a little more engaging. Information is presented to the students' level of understanding. Once the information is presented to the students, several activities can be conducted. One activity is to divide the team into groups. The teams will compete in a light maze. Reflective material will be used to get to the target objective. This will give the students an opportunity to engage in the reflective properties of other material.

Figure 20 Sample of a Maze

Community College and Student Organizations: EAT members contacted previous community college professors for the opportunity to do outreach. Through EAT's PI, contact was made with student organizations at the home university. The students are targeted STEM major's majority are over the age of 18.

Guest Speaker: EAT is composed of all transferred students. As students with similar backgrounds to the community college, EAT hopes to inspire other students to participate in events, locally, statewide, and nationwide. In the community colleges most students do not participate in competitions and are not aware of the of opportunities for college students. EAT will communicate during the event to the current students on how to participate in future competitions. An event is to have a zoom conference video to show case the student's work and spin-off to the NASA's Intellectual Property. Current LATTC students will ask questions related to the competition, or about transferring. For the student organizations similar steps will be taken but an emphasis in establishing networks and participating in opportunities will be emphasis. Eat will encourage students to take advantage of competitions like MITTIC. Since most schools and organization are MSI this will meet the requirements of the competition. Depending on the even around

After COVID: The second possibility depending on the circumstances is to have a small event in which the team can present the information to the students. The goal is to inspire current students to participate in competitions. Depending on the class the details will vary. For the engineering classes, information specific details will be given. In a Statics class a force equilibrium equation will be demonstrated with a finite element analysis done in solid works or other programs. The sensors also determine the strain stresses that occur in the bicycle and that can be explained in a Strength of Materials class. For a Material Science class, the properties of composites and the effects of the curing process can be mentioned. As the project are dependent on various engineering from the beginning to curriculum this will be beneficial to mention during the events. The need to engineer creative applications. The ability to demonstrate the knowledge being applied to a project will also encourage students to engage in classes.

APPENDIX

Table 3 Deliverables and Milestones for Project

Task	Time
Phase 1 – Develop a Plan	
Research	2 Weeks
Application	2 Weeks
Phase 2 – Network	
Principal Investigator	2 Weeks
Business	5 Weeks
Outreach	4 Weeks
Phase 3 – Manufacturing Process	
Sensors	
Bicycle Frame Construction	1 Week
Testing	4 Weeks

Table 4 Equipment Available to EAT

Equipment Provided to EAT	
ThermWood 5 Axis Router	Utilized for trimming and drilling with a diamond endmill.
Haas VF9 50 Taper	Utilized for molding machining with tooling boards and aluminum.
Gerber DCS 250	Utilized for Ply cutting with Hexcel M65 UD prepreg
Clean room (1400 ft^2) and Facility Vacuum	Utilized for lay-up with a vacuum bag, N10 breather, PTFE, non- perforated release film, Chromate tape, Kapton tape, heat gun, vacuum ports, and vacuum gauge.
Paint booth (800 ft^2)	Utilized for painting with paint, sandpaper, masking tape, paint gun, and compressed air
80 In^3 industrial Oven with Ramp and Soak	Utilized for curing with TC wires (K type)

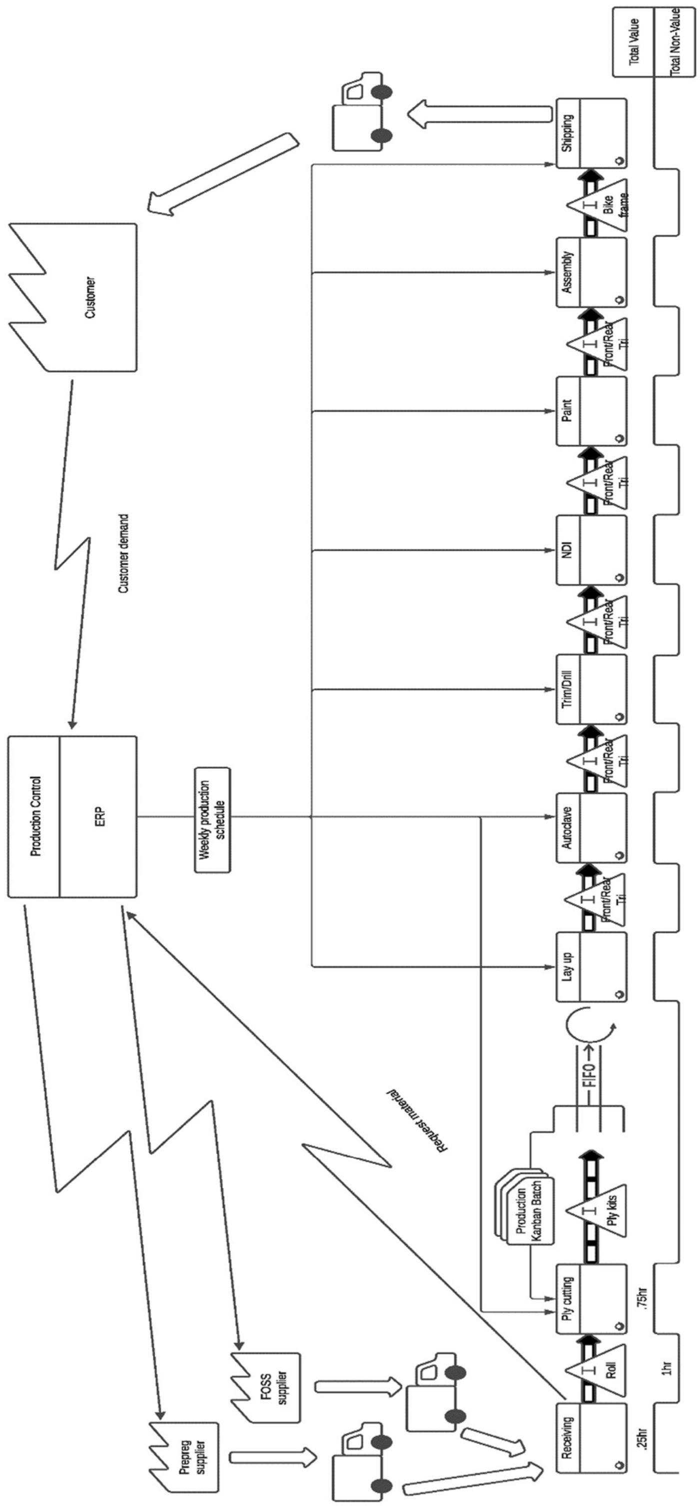

Figure 21 Value Stream Map

Process	time min	process subtotal
Receiving		
sign packing slip	2	
Weigh and tag material	10	
store in freezer kanban	7	
	19	38
Ply Cutting		
retreive roll from freezer	5	
Thaw roll in bag prevent condensation	30	
wipe off moisture	2	
remove roll from bag	1	
load roll onto plycutter	4	
load program on controller	2	
roll out material to specified length	5	
align and tape down edges	6	
turn on vacuum	1	
set machine work offset inside of material selvedge	2	
run program	16	
turn off vacuum	1	
pick up plies	10	
remove scrap	5	
kit plies	10	
store plies and kits in freezer kanban racks	15	115
Layup		
Retrieve tool	3	
clean tool with methanol and cheese cloth	2	
retreive ply kit from freezer	5	
make debulk bag	5	
apply ply_0	15	
apply non-perforated release film	2	
apply n-10 breather	2	
debulk_0 (final bag created in this time)	10	
remove debulk bag save all bag mat'l for later	2	
apply ply layer 1 - 3	35	
apply non-perforated release film	2	
apply n-10 breather	2	
debulk_1	10	
remove debulk bag save all bag mat'l for later	2	
reterive fiberoptic sensors	2	
use layup stencil and mark with silver pencil optical sensor placement	8	
place optical sensors along stenciled area	15	
apply non-perforated release film	2	
apply n-10 breather	2	
debulk_2	5	
remove debulk bag save all bag mat'l for later	2	
apply ply layer 4-6	35	
apply non-perforated release film	2	
apply n-10 breather	2	
apply envelope final bag	15	
perform leak check	10	197
Oven		
place tool in oven	3	
connect Fiberoptic sensors to interrogator	5	
connect vacuum lines	2	
cure to hexcell m56 profile	420	
disconnect sensors	5	
disconnect vacuum lines	2	
remove tool from oven	3	
remove vacuum bag	7	
remove bike frame from tool	15	
post cure bike frame	45	507
Trim and drill		
place bike frame in fixture	6	
load program	2	
set work offset	10	
run program	20	
remove frame from fixture	6	44
NDI		
Connect fiber optic sensors to interrogator	5	
set calibration baseline for fiber optic sensors	6	
serialize frame	10	21
Paint		
abrade surface with 220	15	
clean with methanol and cheese cloth	3	
fill and fair using E-120HP Hysol	25	
cure	60	
wet sand till frame is smooth	15	
clean with methanol and cheese cloth	3	
apply mask and plugs on frame	7	
apply 2k epoxy primer	15	
cure	45	
wet sand till frame is smooth	15	
clean with methanol and cheese cloth	3	
apply 2k paint	15	
cure	1440	
wet sand till frame is smooth	15	
clean with methanol and cheese cloth	3	
apply 2k clearcoat	15	
cure	1440	3134
Assembly		
assemble linkages with bearings	15	
attach rear traingle to front triangle	20	
perform cycle test inspect for defects	15	50
Shipping		
create box	10	
Scan box	1	
locate corresponding frame to box	3	
place frame in box with packaging material	15	
seal box	2	31
	Cycle Time	4137
	hours	68.95
	days	2.872916667

Customer Demand Monthly	4
monthly work days	20
Daily demand	0.200
Total Daily Available time	430
TAKT time	2150
Receiving operators	0.018
Ply Cutting operators	0.053
Layup operators	0.092
Oven operators	0.236
Trim and drill operators	0.020
NDI operators	0.010
Paint operators	1.458
Assembly operators	0.023
Shipping operators	0.014
Sum	1.924
Minimum operators needed	2.000
Realistic operators needed	3.000

Figure 22 Time Calculated to Produce Bicycle

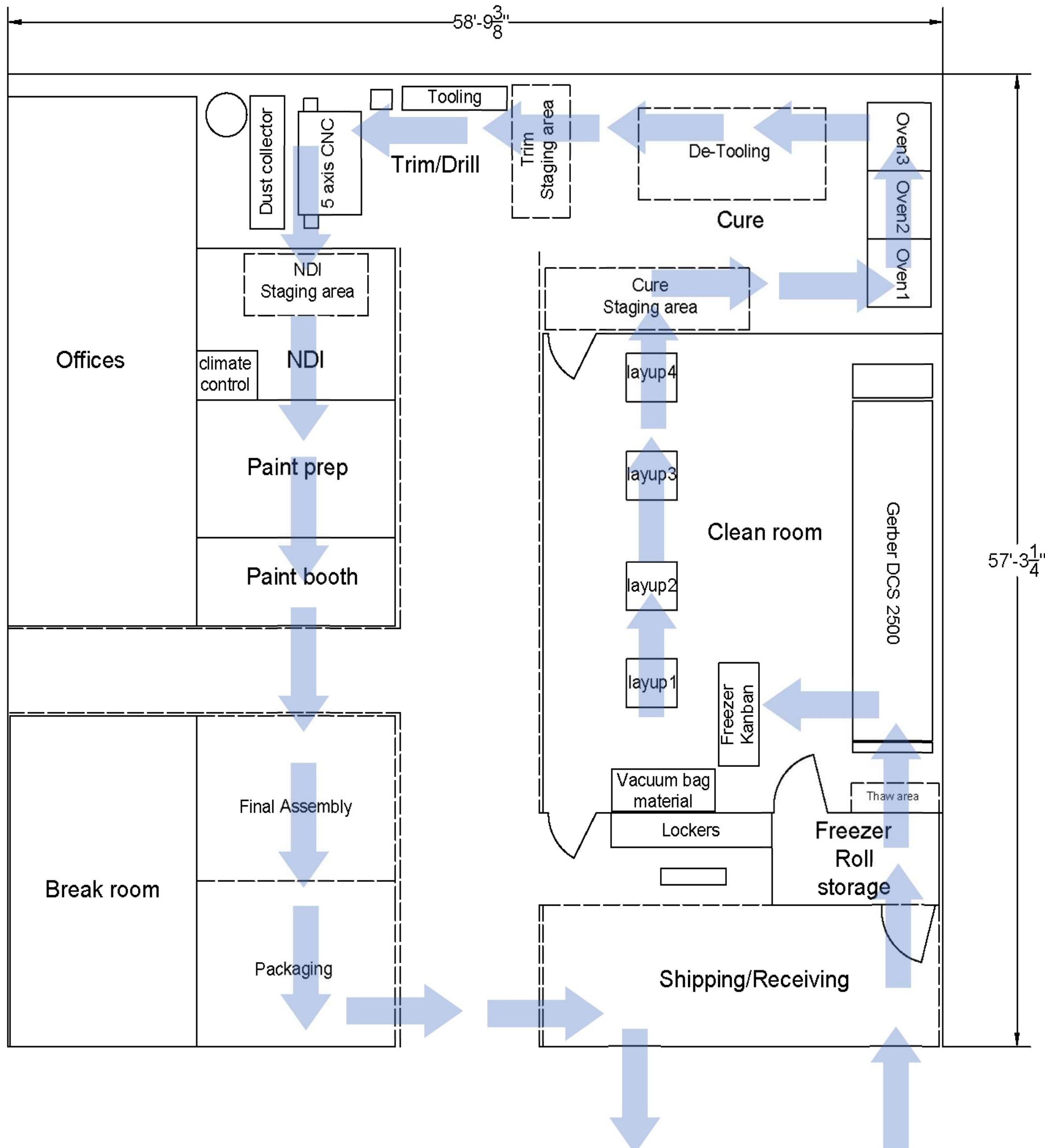

Figure 23 Manufacturing Assembly Line

Table 5 Cost Expected for the First Year

Equipment	Initial cost	Annual Operating Cost
Industrial Freezer 10x16x7	$13,300.00	$ 1,995.00
Chest freezer 34 cu ft	$1,859.53	$278.93
Gerber DCS 2500	$45,000.00	$9,000.00
SV300B Vacuum Edwards Busch Becker	$9,989.00	$2,497.25
Blue M Burn-In Oven	$8,510.00	$ 2,127.50
Thermwood Model C 67	$49,500.00	$7,425.00
HBM Optical Interrogator	$25,000.00	$250.00
Down Draft Paint booth with fire suppression	$15,399.00	$769.95
Rent	$3,450.00	$41,400.00
Total overhead Costs	$172,007.53	$65,743.63

Table 6 List of Materials Needed, Quantity, Cost

Material	Cost	Quantity ft	Unit cost/ft
Hexcell M56 out of autoclave epoxy prepreg	$1,813.23	600.00	$3.02
VB200 Vacuum Bagging Film LFT	$528.45	900.00	$0.59
Self-releasing Tubular Bagging Film	$80.00	656.00	$0.12
N10 Breather Cloth	$110.00	600.00	$0.18
Chromate tape	$5.89	25.00	$ 0.24
Vacuum connector	$4.52	1.00	$ 4.52
Release Ply - Hi Temp 450F - Non-Perforated Film	$2,149.79	501.00	$4.29
Luna ODiSi Fiber optic sensor	$300.00	16.50	$ 18.18

Table 7 Calculations for Cost of Labor

Type of Labor	Estimated Cost
Labor cost per hour	17.5
Labor hours per bicycle	68.97
Total labor costs	1206.975

Table 8 specific Calculations for Materials needed and Cost.

Materials Needed for Production	Quantity Needed	Cost
Hexcell M56 out of autoclave epoxy prepreg	16	$ 48.35
VB200 Vacuum Bagging Film LFT	4	$2.35
Self-releasing Tubular Bagging Film	6	$ 0.73
N10 Breather Cloth	12	$2.20
Chromate tape	4	$0.94
Vacuum connector	2	$ 9.04
Release Ply - Hi Temp 450F - Non-Perforated Film	12	$ 51.49
Luna ODiSi Fiber optic sensor	16	$290.91
Total Cost of materials/bicycle frame		$406.02

Table 9 Cost Per Bicycle Unit

Bicycle Unit Cost	
Item	price
Total Cost of materials	$406.02
Total Labor Costs	$1,206.98
Total Overhead costs/bicycle	$124.51
Total cost/bicycle	$1,737.51

Table 10 Calculations to Determine Bicycle Units to Break Even

	Unit	**Total**
Units sold	528.00	
Price	$ 3,301.26	
Revenue		$ 1,743,066.11
Variable costs	$1,612.99	$851,659.59
Contribution Margin	$1,688.27	$891,406.52
Fixed Expenses	$124.51	$65,743.63
Profit		$825,662.89
Break Even (units)	38.94	