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EML4551-2

Team 515: JTEKT Part Painter

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Abstract

The abstract is a concise statement of the significant contents of your project. The abstract should be one paragraph of between 150 and 500 words. The abstract is not indents.

Keywords: list 3 to 5 keywords that describe your project.

Disclaimer

Your sponsor may require a disclaimer on the report. Especially if it is a government sponsored project or confidential project. If a disclaimer is not required delete this section.

Acknowledgement

These remarks thank those that helped you complete your senior design project. Especially those who have sponsored the project, provided mentorship advice, and materials. 4

- Paragraph 1 thank sponsor!
- Paragraph 2 thank advisors.
- Paragraph 3 thank those that provided you materials and resources.
- Paragraph 4 thank anyone else who helped you.

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AAA	American Automobile Association
AARP	American Association of Retired Persons
AHP	Accelerator Heel Point
ANOVA	Analysis of Variance
AOTA	American Occupational Therapy Association
ASA	American Society on Aging
BA	Back Angle
BOF	Ball of Foot
BOFRP	Ball of Foot Reference Point
CAD	Computer Aided Design
CDC	Centers for Disease Control and Prevention
CU-ICAR	Clemson University - International Center for Automotive Research
DDI	Driver Death per Involvement Ratio
DIT	Driver Involvement per Vehicle Mile Traveled

Difference between the calculated and measured

Difference	BOFRP to H-point
DRR	Death Rate Ratio
DRS	Driving Rehabilitation Specialist
EMM	Estimated Marginal Means
FARS	Fatality Analysis Reporting System
FMVSS	Federal Motor Vehicle Safety Standard
GES	General Estimates System
GHS	Greenville Health System
H13	Steering Wheel Thigh Clearance
H17	Wheel Center to Heel Pont
H30	H-point to accelerator heel point
HPD	H-point Design Tool
HPM	H-point Machine
HPM-II	H-point Machine II
HT	H-point Travel
HX	H-point to Accelerator Heel Point
HZ	H-point to Accelerator Heel Point
IIHS	Insurance Institute for Highway Safety
L6	BFRP to Steering Wheel Center

Chapter One: EML 4551C

1.1 Project Scope

Project Description

The objective of this project is to automate the process of painting needle bearing retainers. The sponsor company, JTEKT, currently paints needle bearing retainers with dykem layout-fluid ~~a metal paint~~ by hand. This is done with a brush by a plant operator and must be done one part at a time across hundreds of parts. To avoid ~~wasted~~ inefficient use of employee time, the sponsor has requested an automated solution to this problem.

Key Goals

The following key goals of this project will help create a device whose functionality matches the project description and appeals to our sponsor. The first key goal of this project will be to accurately apply metal paint (Dykem) to retainer surfaces. The second key goal will be for our project to accommodate a wide range of bearings between 7/8” to 2 ½” inches in outer diameter. The third key goal of our project will be to automate the process for painting bearings and use the least amount of extraneous human effort and time as possible.

Markets

This project is rooted in **Industrial Manufacturing**, as it aims to solve a problem in one of the more tedious tasks in the industry, as such, any painting task may be solved via alteration of this project. The project also offers development in Automation, building on principles designed to make a task require less human oversight. **Mass Production** industries (such as automakers), also stand to benefit from more efficient, higher quality processes, such as this one. On that note, **Quality Control** principles are better upheld by a system that removes human error.

Assumptions

Throughout the project, there are assumptions that will need to be made. It is assumed that the project will only need to accommodate bearings within a 7/8”-2 ½” outer diameter range. The project will only be loaded with 1 type of bearing/ paint color for each process and will need to let the parts adequately dry before beginning the next cycle. It is also assumed that the project will need to be manually loaded and unloaded. The project will also be powered by a standard 120V wall outlet.

Stakeholders

This project is being advised and supervised by Dr. Shayne McConomy as the Mechanical Engineering advisor and professor of Senior Design. JTEKT, centered in Cairo, Georgia is the sponsor of the project, giving the primary driving goal and purpose of our design.

Affected companies include the Toyota Motor Corporation, Caterpillar Inc., and Allison Transmission, for whom this would affect the price and quality assurance of the bearings they receive.

1.2 Customer Needs

JTEKT has given us the task of creating an automated machine that successfully paints bearing retainers for the indication of the type of bearing. Based on this, we generated some questions to ask JTEKT in the table below.

Question/Prompt	Customer Statement	Interpreted Need
1. How is the process currently done?	A technician is pulled from duty at another portion of the plant to sit and manually paint on the stripes.	Automate the process so it takes a technician the least amount of time possible.
2. What size bearings will we be expected to work with?	7/8”-2.5" Outer diameter width.	Project will be able to process retainers between 7/8” and 2.5 inches in diameter.
3. At what rate do you expect the machine to complete parts?	We would like a cycle time of 3 seconds.	A finished part has to be produced every 3 seconds.
4. What type of paint will be used on the bearing?	Dykem Layout Fluid is the current method of marking the bearing bars.	Dykem Layout Fluid is the current method of marking, but other options are available.
5. How automated do you expect this to be?	Loading and unloading will be done manually but everything else will be fully automated.	Automation of painting process without human interference is ideal. Loading

Question/Prompt	Customer Statement	Interpreted Need
		and unloading of device can be manual.
6. Are the retainers painted separate from the bearings or as a singular unit?	Retainers are painted separately.	Retainers are painted separately from bearings.
7. Where on the retainers need to be marked?	A singular stripe only on the lower bar, while avoiding transition angle. Avoid excessive paint on the sidewall.	The painting mechanism will avoid applying marking solution to transmission angles and working surfaces.
8. What type of drying process will be needed?	Dykem dries fully in <2 minutes.	Drying is quick compared to average paint and will not need to be accounted for that heavily.
9. Will we be able to use a standard wall 120V outline?	There is a wall outlet available outside of the Fume hood, but not inside.	120V wall outlet allows for power input, negating the use of batteries.
10. Are we expected to accommodate for any fume control?	There is a fume hood at the current workstation that the device can be integrated into.	Fumes are handled by a fume hood on-site.
11. Are there any size requirements for the project?	The fume hood is 2’ x 3’ x 3’	We will need to make sure that any part of our project that involves the Dykem is underneath the hood in those dimensions.

After meeting with our sponsor, we determined that JTEKT needed an automated machine that accomplished the following: Has the capabilities of painting bearings around 1-3 inches, able to paint the lower bar of bearing retainer at a rate equal to or exceeding 100 retainers per hour. This would be accomplished with minimal human interaction during the painting process, and while avoiding elements of the retainer other than the lower bar. The project will fit into an existing fume hood on-site and will not have to deal with the drying of parts.

1.3 Functional Decomposition

Introduction

Using function decomposition, our group has broken a complex problem into a handful of basic functions. From these basic functions smaller tasks are created to show how these functions are accomplished. As a reminder, these functions are created in a manner that isn't specific, allowing any possible solutions to accomplish the basic functions created. Further into the design process more sub-tasks will be made based off of the initial functions.

Data Generation

The generation of functions for the project originated from the project scope and customer needs. The functions that were created describe what the project needs to do without taking into account any physical concepts for the project. The customer needs were interpreted from the project sponsor, JTEKT, and used as the foundation for the functions, along with the assumptions and key goals in the project scope. Figure 1 shows the functional hierarchy chart. The main systems of the project are shown in yellow and are broken down into the green sub-systems, which are then broken down into the essential functions in blue.

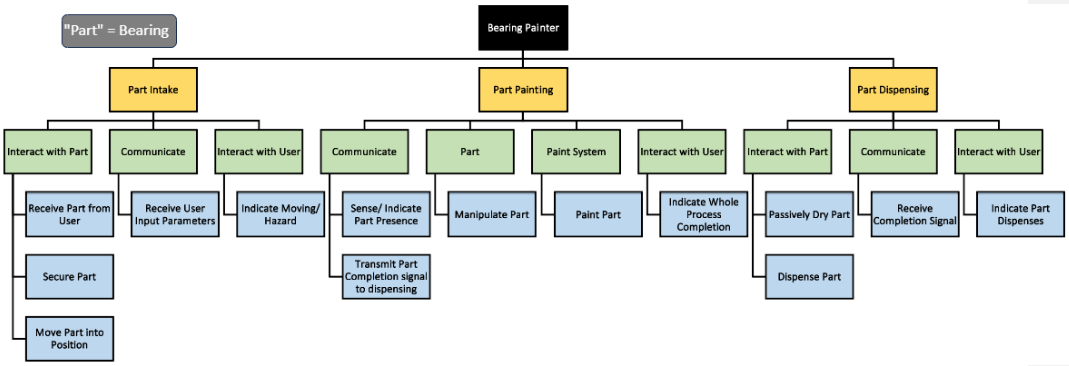


Figure 1: Functional Hierarchy Chart

Discussion

The primary goal of this project is to create a device that is responsible for painting stripes on the lower bar of needle roller bearing retainers. From our discussion and analysis of Customer needs, the device generally has three major functions; Storing and intaking unpainted bearing retainers, painting the bearing retainers, and dispensing the painted parts.

The Intake portion of the device would be responsible for storing the current, unprocessed bearing retainers in the batch, as well as bringing them to the next functional area in a controlled manner. On top of this, interacting with the user to determine the type/size of bearings being put into the device is to be communicated with the other two systems to ensure they use the correct parameters.

Part painting is the most involved process, taking information from the intake system to use the correct paint color on the bearings in the correct position. It will also be required to display the status of the machine, indicating the hazard of the processing. When completed, the painting system will communicate with the dispensing system that a finished retainer is awaiting dispensing. It will also be responsible for indicating that the current batch is completed and signaling as such to the user.

The Dispensing system is responsible for retrieving the finished parts when given the completed signal from the painting system and placing them into a retrieval area in an orderly manner. This system will have to work closely with the part painting in order to effectively cycle through parts.

Functional Relationships

Table 1: Cross Reference Table

Functions	Systems		
	Part Intake	Part Painting	Part Dispensing
Recieve Part from User	x		
Secure Part	x	x	
Move Part Into Position	x		
Recieve User Input Parameters	x		
Indicate Moving/Hazard	x	x	x
Sense/Indicate Part Presence		x	
Transmit Part Completion Signal to Dispensing		x	
Manipulate Part		x	
Paint Part		x	
Indicate Whole Process Completion		x	x
Passively Dry Part			x
Dispense Part		x	x
Recieve Completion Signal		x	x
Indicate Part Dispenses			x

The functional decomposition cross-reference chart, displayed in Table 1, shows how the functions relate to the three main systems. The cross-reference table is a valuable tool to show how some functions can exist in more than one system, showing the relationships, as well as ranking the importance of the systems. After our evaluations the main systems ranked from most to least important are part painting, part dispensing, and part intake. Using this information, the part painting system will be focused on, making it the “brain” of the project that will influence the other systems.

Some of the functions overlap into multiple systems. These functions will be carefully evaluated because they have more of an influence on the project. An example of one of these functions is “indicate moving/ hazard.” This function appears in all three systems because the project will need to accomplish this as the whole process is carried out. Other important functions include those that deal with communication between systems. This will be the key to developing a successful project because the different systems need to be in-sync while carrying the whole process out.

1.4 Target Summary

With analysis of our customer needs and the various functions that we find vital to our project we assigned a set of targets to aim for, whether that be numerical or subjective in nature. These targets were made to be tangible marks that will guide our design during the prototyping stage. While it is not essential, surpassing the targets is preferable, if the effect on the cost and other targets is not affected significantly, as balancing the cost and efficacy of all our targets is ideal. Table 1 defines the targets of the project; however, the full target catalog can be found in the Appendix.

Table 1: Project Targets

Targets Table		
1. Shall accommodate 7/8 to 2.5 inches outer diameter bearing retainers	2. The device shall accommodate a load of 5.1 Newtons	3. Move part into device within 2 seconds
4. The project shall have a setup time within 5 minutes	5. The project shall have a setup time within 5 minutes	6. Shall indicate Operation in progress with green
7. Part presence will be sensed in 0.1 sec	8. Dispensing system shall be notified of painting completion within 1 sec of painting completion	9. The part shall have less than $1mm^2$ of paint on the working surface
10. The part shall have 360 degrees of paint coverage	11. Shall indicate Operation completion with red & green	12. The parts shall be dried to the touch before being dispensed
13. The device shall have a 3.5 second cycle time	14. Machine shall begin dispensing within 1 second after painting	15. The project shall increase part count by 1 per part completed
16. Any system exposing paint shall fit within the 2ft x 3ft x 3ft fume hood	17. Besides loading new parts, the process shall run for 30 minutes before user interaction is needed	18. Shall support 2 different colors of Dykem

Critical Targets

With the many targets listed above in the table, there are some key targets that will be fundamental for the success of this project. Starting with a machine that has the capability of accommodating bearings of about 7/8 of an inch to 2.5 inches in outer diameter. This was a customer requirement and represents the smallest and largest parts that are currently painted by hand. In addition, having the machine's cycle time at 3.5 seconds is a requirement requested by the customer and means that the machine shall present a finished bearing every 3.5 seconds. Also, another critical target is limiting the surface area of the extraneous painting on the working surfaces to 1 mm^2. This helps to ensure that the painting will only be applied to the non-working portion of the bearing and will not hinder the performance of the bearing. Next, the target of having the paint cover the full 360 degrees of the surface for the bearing's non-working area is a critical target because the customer needs to make sure the part has a paint stripe around the whole circumference. Developing a device that fits under a pre-existing fume hood at the sponsor's facility is also a critical target that relates to the size constraints of the project. This is important because the Dykem fluid used to paint the parts needs to be applied under the fume hood. While these are a few of the critical targets, all the targets have a significance in the project and shall be met with a tolerance of ±5% to ensure efficiency.

Method of Validation

The testing and validation of the targets will be performed using various tools, as well as visual or physical inspections for some. A measuring tape will be used to verify the size-related targets, such as the need to fit in the fume hood. A stopwatch will be used to measure the targets that are verified by time. This will be a sufficient method of measurement, however, if a more accurate time is needed, a slow-motion camera can be used in addition. The quantity and visual inspection metrics will be sufficient to validate the appropriate targets as anyone can inspect the paint on the parts or count the number of parts being dispensed. The physical inspection that will be used to check if the paint is sufficiently dry will be completed by touching the paint with a nitrile glove on, if no paint appears on the glove, the part is sufficiently dry.

Derivation Targets and Metrics

Our targets and metrics stem from customer requirements given by our sponsor, JTEKT, and the intended functions of our project. For our critical targets, the focus was to define critical benchmarks which are necessary for system operation. Targets relating to the overall part completion rate were communicated to be important, especially in a factory/production setting. Thus, many of the targets are governed by time metrics. In doing this, the goal was to provide a concise time wherein each subsystem of the machine should be able to finish its operation. This leaves a blueprint of machine operation, outlining the exact amount of time a part should spend in the machine. These time targets were, in large part, derived from the overall target of a 3.5 second cycle time, as well as reasonable expectation for any sensing/mechanism motion. Another key target, the overall bearing size to be accommodated, was derived directly from the sponsor's request. The range specified is designed to accommodate the smallest and largest bearing retainer the machine will be used to paint.

1.5 Concept Generation

In order to develop a design that meets the customer's needs and requirements, 100 concepts were generated by our team in order to think of all the possible solutions for the project. The complete list can be found in Appendix B. Different methods were used in order to generate all 100 concepts. First of all, our team utilized brainstorming to come up with ideas, in which we collectively came up with any possible concept, even if it did not sound feasible. We then began organizing all of our ideas into 4 categories of concepts relating to the processes of our project. The categories were receiving, painting process, dispensing, and processing. Coming up with ideas for a specific process allowed us to piece together these ideas to make concepts for a full system. The generated concepts were discussed and 5 were chosen as medium fidelity concepts and 3 were chosen as high fidelity. The medium fidelity concepts are realistic and viable solutions, however, there may be 1 aspect that lacks making it a complete concept. The high fidelity concepts were chosen as the strongest concepts that were the most realistic to use for this project.

High Fidelity Concepts

Concept 1

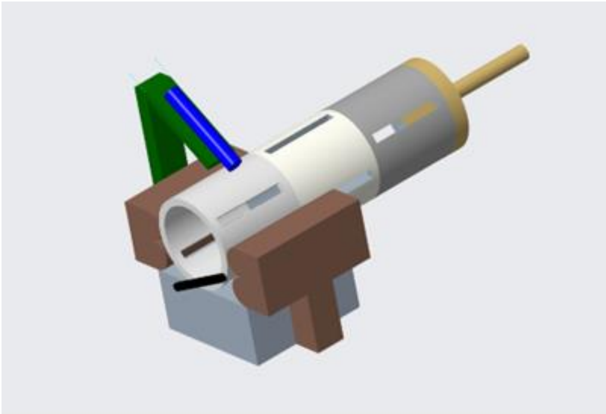


Figure 1: High Fidelity Concept 1

The first high fidelity concept that was chosen is shown in Figure 1. This concept would allow the user to load the device with up to 10 bearings (only 3 shown), and a linear actuator (gold) would push the bearings to the painting area. A treadmill under the bearing ready to be painted will rotate the bearings and a mechanical arm (green) will pivot a marker (blue) onto the bearing to paint it. When painting is complete, the stopper (black) will move out of the way and the linear actuator will push the finished bearing into the completed area or bin of parts. Free rolling bearings (brown) will be used to stabilize the part while it is undergoing the painting process but will not add extraneous friction on the part.

Concept 2

Figure 2: High Fidelity Concept 2

The second high fidelity concept is shown in Figure 2. The concept uses a treadmill (black) to both load and push bearing retainers (white) along through the painting mechanism. Two curved rails steer the retainers through the machine and center the retainers over a paint application strip (red). Features on the bearing retainers (not as pictured above) rest on the outside off the rails and keep the retainers from derailing. To accommodate different sized bearings, the rails can be swapped or adjusted to change the distance between them and the treadmill. The speed of retainer advancement can be changed by changing the speed of the treadmill.

Concept 3

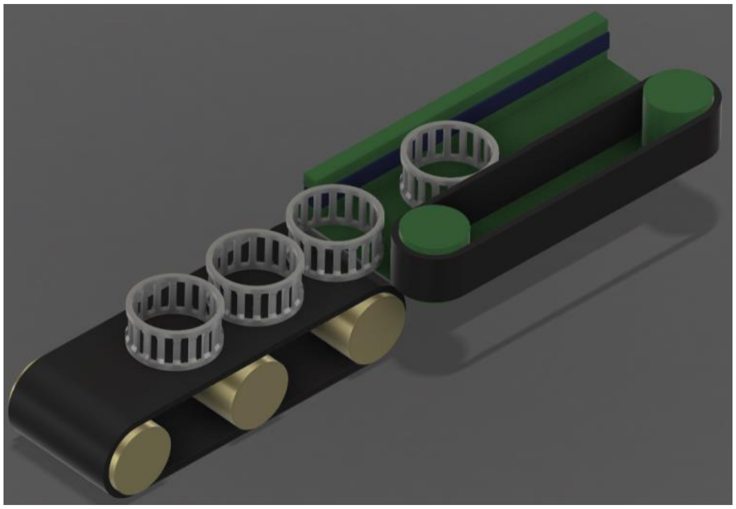
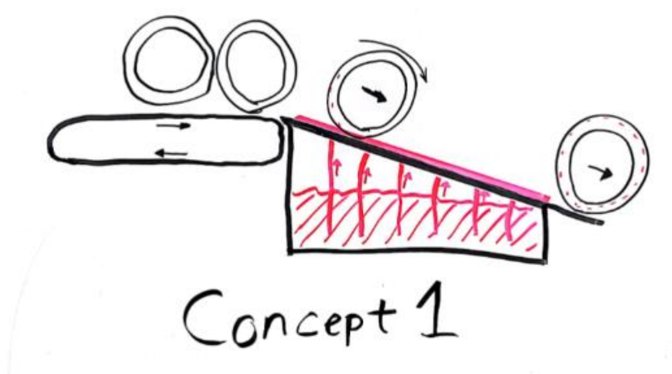


Figure 3: High Fidelity Concept 3

The third high fidelity concept is shown in Figure 3. Like a machine that applies labels to bottles, the machine uses a set of two conveyor belts. The first conveyor belt is used for the intake and output of the bearing, while the second conveyor belt is used to paint and rotate the bearing retainer on its axis. Starting off the bearings will be loaded onto the conveyor belt taking to the painting segment of this design. As the bearing encounters the second conveyor belt the bearing retainer will move laterally while spinning on its axis from the second conveyor belt. During this process there will be several brushes of Dykem on the other side of the wall holding the bearings that paint the bearings circumference. As the part continues to move laterally, it will enter the holding area with the first conveyor belt. The size of the largest retainer would determine the length of the painting apparatus, being equal to the circumference, but smaller retainers would be unaffected, as the Dykem would not be dry if a bar contacted the painting surface more than once and would just receive a single coat of Dykem. Adjusting the rails on either side of the painting surface as well as the protrusion of the surface would allow for different retainer sizes to be painted and would be pre-set by the machine. The main difference between this and high-fidelity concept two is that the retainers are much more controlled, less likely to roll away due to gravity.

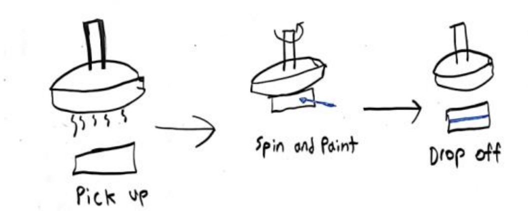
Medium Fidelity Concepts

Concept 1



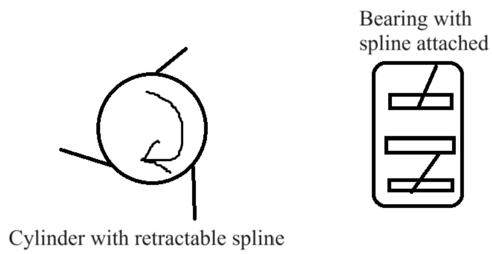
The first medium fidelity idea would utilize a conveyer belt to feed part intake to a ramp. Once a part reaches the ramp it will roll down it via gravity and the non-working surface will come in contact with a felt strip that is saturated in Dykem that will paint the retainers. The parts will continue onto a conveyer belt that will facilitate part drying and dispensing.

Concept 2



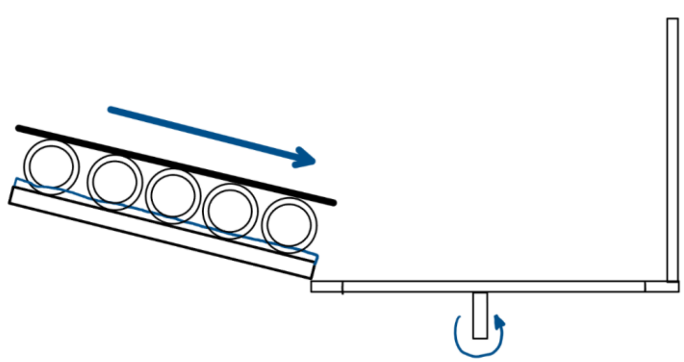
The second medium fidelity concept is using a vibrating system to feed part intake from a loading hopper. An electromagnet will be used to grab retainers so they can be manipulated through the painting process and will deliver them to a conveyer belt for dispensing by demagnetizing.

Concept 3



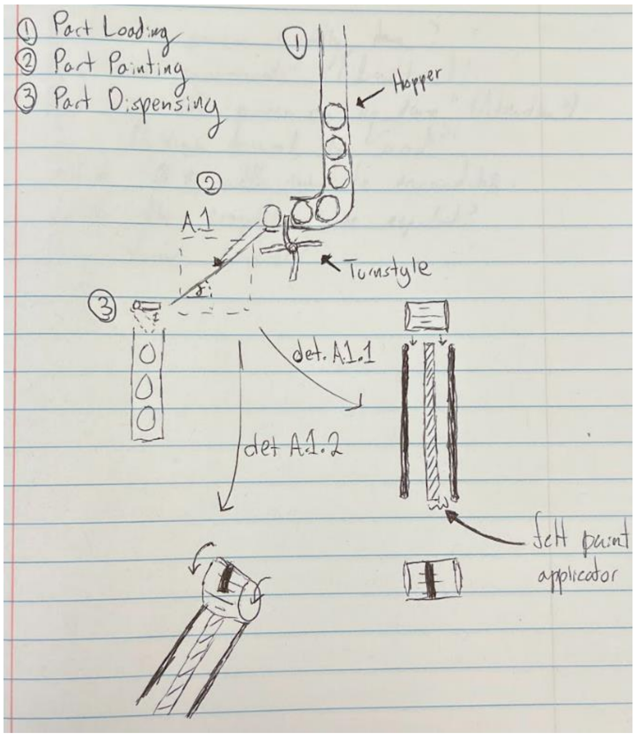
The third medium fidelity idea will be to create splines to fit inside of the bearings and an operator will manually load retainers onto splines to facilitate part intake. When a part makes it to the painting process the splines will be used to hold and rotate the bearing while the non-working surface is in contact with painting mechanism. The retainer will stay on spline for duration of drying and parts will be dispensed and stacked manually.

Concept 4



Our fourth medium fidelity concept includes a track that retainers would roll across sequentially, fed onto said track via a mechanism indicative of a gumball vending machine. A raised middle portion of the track would be lined with a multitude of small holes that Dykem would seep through, causing the rolling bearing retainer to roll across the layer of Dykem and pick up a thin layer on the non-working surface. The retainers would then be dispensed into a drying mechanism similar to a rotisserie oven, rotating about a convection chamber. Retainers could then be removed by stopping the rotation after the parts are dried and pulling the retainers off.

Concept 5



The final medium fidelity concept would utilize a hopper wherein the retainers are stacked, vertically so. The hopper would have a gate at the bottom that would control how retainers roll past onto the painting mechanism, a ramp with a strip of felt in the middle that contacts the lower bar of the retainers. This felt pad would wick Dykem out of a sealed pool of Dykem, much like an oil candle, and effectively stamp each bar that contacts it. From here, the retainers would roll into a ramp where they would slide out of the fume hood, into a collection bin.

1.6 Concept Selection

Introduction

The process of concept selection initiates by generating ideas about the design parameters that govern the overall functionality of the system. Various factors, such as production rate, processing accuracy, and the adaptability of the machine to different-sized bearings, can impact the simulator. These factors are evaluated based on their significance to the customer, and this assessment is then applied to the generated concepts. Through this approach, numerous possibilities are refined to prioritize higher fidelity options, ultimately leading to the identification of a preliminary concept for further development.

Binary Pairwise Comparison

With the help of the binary pairwise comparison tool, we are able to compare each customer's needs with one another, with the goal ranking each customer's needs in the order of their importance. The customer's needs in each row are compared to the needs in each column. In the chart an assigned '1' means that the row is a more important need than that of the need in the column. While a '0' means that the row is a less important need compared to the need in the column. From our binary pairwise comparison chart, it was found that painting the correct area on the bearing was the most significant customer need to meet.

Binary Pairwise Comparison Chart									
Customer Requirements	1	2	3	4	5	6	7	8	Total
1. Automated Process	-	1	0	0	0	1	0	1	3
2. Cycle Time	0	-	1	0	0	1	0	1	3
3. Paint Correct Area	1	0	-	1	1	1	1	1	6
4. Fit in Fume Hood	1	1	0	-	0	1	0	1	4
5. Process Range of Sizes	1	1	0	1	-	1	0	1	5
6. Quickly Configurable	0	0	0	0	0	-	0	1	1
7. Use Multiple Colors	1	1	0	1	1	1	-	0	5
8. Indicate Operation Status	0	0	0	0	0	0	1	-	1
Total	4	4	1	3	2	6	2	6	n - 1 = 7

House of Quality

The house of quality uses importance weight factors derived from the binary pairwise comparison to classify requirements. The design requirements are on the vertical column and the engineering characteristics are presented on the horizontal column. The numbers used to show the relativity between project requirements and engineering characteristics are 1, 3, and 9 where 1 represents no relativity, 3 represents minimal relativity, and 9 represents high relativity. In the chart our last three rows show the raw score that the engineering characteristic has accumulated, the relative weight percentage, and the rank of which engineering characteristics had the highest relative weight.

Engineering Characteristic									
Improvement Direction		↑	-	↑	↓	↑	↓	↓	-
Units		Part/min	mm^2	Diameter	Ft^2	Part/Load	%	%	Part/intvl
Customer Requirements	**Importance Weight Factor**	Production Rate	Processing Accuracy	Compatibility	Size	Part Intake Limit	Automatic Operation %	Reliability	Maintenance Interval
1. Automated Process	**3**	9		3	9	9	9		
2. Cycle Time	**3**	3	9	9		9	9	3	3
3. Paint Correct Area	**6**	1	9	9				1	1
4. Fit in Fume Hood	**4**			3	9	9			
5. Process Range of Sizes	**5**	1	9	9	9	3	9		
6. Quickly Configurable	**1**	3	3	9	3	9	3		
7. Use Multiple Colors	**5**	3	3		9	3	3	1	3
8. Indicate Operation Status	**1**	3		1		3	3	3	1
Raw Score (628)		68	144	157	156	132	120	23	31
Relative Weight %		10.83	22.93	25.00	24.8	21.02	19.11	3.66	4.94
Rank Order		6	3	1	2	4	5	8	7

The resulting rank order is as follows:

1. Compatibility
2. Size

3. Processing Accuracy
4. Part Intake Limit
5. Automatic Operation %
6. Production Rate
7. Reliability

This ranking system helps us decide which engineering characteristics are the most important for our specific project requirements. The characteristics that our House of Quality recognized as the most important were “Compatibility” and “Size” and the characteristics that were recognized for being the least important were “Reliability” and “Production Rate”.

Pugh Chart

From the Pugh chart all the fidelity concepts were inserted to figure out how each concept would perform relative engineering characteristics. The symbols used for comparison are listed in the table below.

Symbol	Representation
+	Better than
S	About the same
-	Poorer than

In the first table below, all the fidelity concepts were systematically analyzed by the engineering characteristics of the design’s compatibilities, size, limits on part intake, accuracy of processing and the ability to of automatic operations. From the results in the Pugh chart in table, it was found that our highest fidelity concepts were the inverted treadmill, double conveyor, the felt ramp, as well as the track using pores for the paint. Out of these high fidelities, a second Pugh chart from the second table below was used to compare the top designs. After comparing each high fidelity with the engineering characteristics, again it was concluded the inverted treadmill would satisfy the engineering characteristics the best.

		Concepts							
Engineering Characteristics	RANDBRIGHT RB 60	Linear Processor	Inverted Treadmill	Double Conveyor	Felt Ramp	Electromagnet	Spline	Pore Track	Gravity Ramp
Compatibility	**- DATUM -**	S	S	-	S	-	S	+	+
Size		S	+	S	+	S	S	-	-
Part Intake Limit		S	+	S	S	S	S	S	S
Processing Accuracy		S	S	S	-	-	S	S	-
Automatic Operation %		S	+	+	S	+	S	S	-
Total Pluses		0	3	1	1	1	0	1	1
Total Satisfactory		5	2	3	3	2	5	3	1
Total Minuses		0	0	1	1	2	0	1	3

Concepts					
Engineering Characteristics	Linear Process	Inverted Treadmill	Double Conveyor	Felt Ramp	Pore Track
Compatibility	- DATUM -	S	S	+	-
Size		+	S	-	-
Part Intake Limit		+	+	S	S
Processing Accuracy		+	+	-	-
Automatic Operation %		+	+	S	S
Total Pluses		4	3	1	0
Total Satisfactory		1	2	2	2
Total Minuses		0	0	2	3

AHP Chart

The Analytical Hierarchy Process (AHP) is used to statistically rank and assess different project requirements. In the AHP matrix, the horizontal and vertical axis are both represented by the customer needs. These customer needs are compared to each other to rank them by importance. From the results of the critical weight, it was found that the compatibility came at the highest, showing that the designs compatibility would be the most important engineering characteristic to focus on.

norm[C] Matrix							
	Analytical Hierarchy Process	A	A	A	A	A	
B	**Engineering Characteristic**	Compatibility	Size	Part Intake Limit	Processing Accuracy	Automatic Operation %	**Critical Weight {W}**
B	Compatibility	0.498	0.294	0.548	0.280	0.664	0.457
B	Size	0.166	0.098	0.061	0.200	0.044	0.114
B	Part Intake Limit	0.166	0.294	0.183	0.280	0.133	0.211
B	Processing Accuracy	0.071	0.020	0.026	0.040	0.027	0.037
B	Automatic Operation %	0.100	0.294	0.183	0.200	0.133	0.182
	Total	1.000	1.000	1.000	1.000	1.000	1.000

The customer need ranking is as follows:

1. Compatibility
2. Part Intake Limit
3. Automatic Operation %
4. Size
5. Processing Accuracy

From our AHP it was found that our most important customer needs were "Compatibility" and "Part Intake Limit", and the lowest ranked customer needs were "Processing Accuracy" and "Size".

Final Selection

Our final concept decision was the Inverted Treadmill, much akin to our first unofficial concepts like the Felt Ramp, albeit much more controlled due to the conveyor's influence. This allows the device to apply paint more consistently, where the ramp may have had half-painted parts due to the accumulated speed of the part as it rolled down. While the Inverted Treadmill and Double Conveyor use a similar function to roll the parts across the painting strip, the Inverted Treadmill's orientation would prevent the paint from dripping downwards onto parts of the retainer which we are trying to avoid getting any paint on.

1.8 Spring Project Plan

Chapter Two: EML 4552C

2.1 Spring Plan

Project Plan.

Build Plan.

Appendices

Appendix A: Code of Conduct

Mission Statement

This team will create a functional system which operates at the standards and expectations of the real-world engineering setting in which it will perform. Teammates will perform their assigned duties as agreed upon below. The goal of this project is to develop a device that will automate the painting of marking fluid (DYKEM) onto needle roller bearing retainers.

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Outside obligations

- Mason: 20 hours of work per week outside of classes, at the Innovation Hub. Schedule flexible, but high preference for outside of work hours. Unavailable on Sundays, most weekends save for online meetings between 12:00pm – 2:00pm.
-
- Andrew: Flexible schedule outside of school, SAE weekend obligations.
- Wesley: No outside obligations. Flexible schedule throughout the week.
- Maximilian: No outside obligations; flexible schedule during the week. Unavailable on Sundays, most weekends save for online meetings between 12:00pm – 2:00pm.
- Anthony: 25 Hours/Week working @ ASC Machine Shop, SAE weekend obligations.

Team Roles

Roles/Duties not detailed in this section will be split between all team members, based on current availability as well as strengths related to said duty. Such case-by-case role assignments must be done with full group consensus.

- Mason: Additive Design Engineer
  - Responsible for CAD models and prototypes related to the softer elements of the design, be they 3D-printed or other soft, non-machined materials.
- Andrew: Systems Integration Engineer
  - Responsible for interaction of sub-system components, ensuring sub-systems function correctly as one complete system.
- Wesley: Materials Engineer
  - Responsible for understanding the relation between the paint and machine parts used to paint bearing.
- Maximilian: Quality/Controls Engineer
  - Responsible for testing the quality of prototype and work produced. Also, responsible for coordinating efforts in robotic control and programming.
- Anthony: Machining Design/Controls Engineer
  - Responsible for CAD models and final machining of parts that make up the main structure of the device. Also responsible for coordinating efforts in robotic control and programming.

Communication

- All official communication will be done via Microsoft Teams general channel. Short term/coordination done via text and email.
- All meetings are mandatory unless a valid excuse is presented to the team. Meetings can only be called if there is an agenda, otherwise, they are non-mandatory.

Dress Code

- Meetings between team members can be conducted in any form of dress down to casual clothes. Meetings involving individuals outside of the base team will be conducted in business casual / formal attire depending on the meeting context. Virtual Design Reviews will be conducted in formal attire, I.e., suits.

Attendance Policy (when and what happens)

- All members in attendance for presentations and important meetings.
- Team members failing to notify the group of their absence 24 hours before the meeting will be given a strike. Upon gaining three strikes, the group will arrange a meeting with Dr. McConomy to discuss the course of action

How to notify group

- Official notifications should be brought up in the Microsoft Teams.
- General notifications should be brought up via text or email.

How to respond to people in professional meeting

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- Respectful and formal responses.
- No speaking over each other and cutting each other off.
- Responses that fulcrum around keeping JTEKT's best interest in mind.

Statement of Understanding

What do we do before Dr. McConomy or TAs (Teaching Assistant).

- Like the attendance policy, three strikes will be given. The rest of the group will vote if a strike should be given, 3/4 votes result in a strike.

At what point do we contact Dr. McConomy.

- Once three attempts at resolution (strikes) have been documented and failed.

What do you want Dr. McConomy to do when you come.

- Dr. McConomy's advice on how to proceed will be asked for during these meetings following his listening to each member's account of the details.

How to amend the Code of Conduct.

- A full 5/5 consensus on any amendment must be held to amend the code of conduct, or the amendment will be null.

Appendix B: Functional Decomposition

Appendix C: Target Catalog

Function	Target	Metric
Receive Part from User	Shall accommodate 7/8 to 2.5 inches outer diameter bearing retainers	Size
Secure Part	The device shall accommodate a load of 5.1 Newtons	Force
Move Part into Position	Move part into device within 2 seconds	Time
Receive User Input Parameters	The project shall have a setup time within 5 minutes	Time
Indicate Moving/Hazard	The project shall have a setup time within 5 minutes	Color
Indicate Moving/Hazard	Shall indicate Operation in progress with green	Color
Sense/ Indicate Part Presence	Part presence will be sensed in 0.1 sec	Time
Transmit Part Completion signal to dispensing	Dispensing system shall be notified of painting completion within 1 sec of painting completion	Time
Paint Part	The part shall have less than 1mm^2 of paint on the working surface	Size

Paint Part	The part shall have 360 degrees of paint coverage	Visual Inspection
Function	**Target**	**Metric**
Indicate Whole Process Completion	Shall indicate Operation completion with red & green	Color
Passively Dry Part	The parts shall be dried to the touch before being dispensed	Physical Inspection
Dispense Part	The device shall have a 3.5 second cycle time	Time
Receive Completion Signal	Machine shall begin dispensing within 1 second after painting	Time
Indicate Part Dispenses	The project shall increase part count by 1 per part completed	Quantity
*Customer Requirement	Any system exposing paint shall fit within the 2ft x 3ft x 3ft fume hood	Size
*Customer Requirement	Besides loading new parts, the process shall run for 30 minutes before user interaction is needed	Time
*Customer Requirement	Shall support 2 different colors of Dykem	Quantity

Appendix D: Idea Generation Table

Ideas

Painting Mechanism

Receiving

Dispensing

Processing

o.	Max	Drew	Mason	Anthony	Wesley
1.	*A ramp that paints the retainers as it rolls down*	A horizontal length of bearings on a treadmill that are pushed by a linear actuator and painted	Dykem run-out sensor that stops half-finished batches when empty	*Flat platform which bearings are rolled over by inverted treadmill*	Poles that hold several bearings moving forward on walking beams
2.	Mechanism that grabs the base of bearing from hopper and spins it accordingly to a paint brush or marker	Lazy Suzan mechanism with individual rotating tables around the outside, which hold 1 part each.	Take pictures of each bearing to allow at-a-glance quality check	*Pool of dykem enclosed by pneumatic walls which are depressed by weight of retainer*	Conveyor belt moving bearings away from paint section with a falling slide into holding area
3.	Mechanism that holds retainer still and in position while painting mechanism moves around it	6 bar linkage that constricts around the bearing to paint	Dykem in a stamp-like marking mechanism applied rapidly to bearing that spins in place	Geneva mechanism hopper to dispense 1 bearing at a time	Geneva bearing holder that also rotate individual bearing holders as paint from brush is applied

					https://www.youtube.com/watch?v=oemq3FDzPjs
4.	Small seat that the retainer goes in to spin retainer to be painted	Hopper that parts are vertically stacked in. 1 by 1 roll down a felt ramp of Dykem	Controlled rolling mechanism across Dykem paint surface	Gumball hopper to dispense 1 bearing at a time	Robotic arm picking up and rotating bearing on dykem brush.
5.	*Using a magnetic component to hold the bearings in place to be painted*	Parts stacked horizontally on rotating cylinder to be painted	Removable Dykem "cartridges" to allow for easy swapping of colors	Lazy Suzan beneath heat lamp for drying	Trap door that opens for bearing to fall once the painting segment is done
6.	Using the compressed air on hand to roll the bearings over a marker by blowing it	Painting mechanism that uses servo motor to pivot a marker on to a rotating bearing	The intake system counts incoming parts to double-check user input amount	Lazy Susan to passively dry	Conveyor belt pulling bearing into filter to individually receive one bearing at a time
7.	Using compressed air to actively dry retainer	Rather than rolling, pushing horizontally positioned parts along a track	Warmed intake system to help parts accept Dykem fluid better	Roll multiple bearings along paint strip at once via conveying thru rods	Rotating rods that hold and turn bearing as the painting pin meets bearing
8.	Using a spline to hold bearing retainers for painting process	Parts stacked on a rotating cylinder, painting mechanism only moves in Z axis	Helical rack silo for dispensed bearings	Vibrate painting mechanism to remove excess dykem	Conveyor belt that holds a strip contains a diagonal strip of dykem paint https://www.youtube.c

					om/watch?v=mrzC1eS79UM&t=129s
9.	Roll the bearings down a wall that has a painting mechanism attached at the right height	Cylindrical roller that rotates part, held upright by smaller rollers on the side	Convection-enabled chamber, like a large dehydrator to facilitate drying	Blow compressed air over painting mechanism to remove excess dykem	Flicking arm that slowly shoots bearing into holding area
10.	Spray the dykem on to the retainers	Separate tracks for each size bearing	Weight sensor to ensure correct number of bearings are dispensed, none lost	Invert painting mechanism to remove excess dykem	A robotic arm that drops bearings into holding area
11.	Use small cnc type arm to accurately paint around bearing	Stencil is attached to the part, Dykem is rolled over and the stencil is removed	Aid convective drying with heater and air movement	Store dykem in elevated reservoir to maintain hydraulic pressure	A painting pin that rotates around bearing
12.	Use a painting mechanism that "hugs" the part (nothing spins)	Finished bearings are stacked on a cylinder	Integration with light fence to prevent user injury	Use a master cylinder to pressurize dykem	System that identifies circular shape of bearings before grabbing
13.	Using a conveyer belt to feed part intake and part dispensing	A cylinder with a retractable spline that grabs on to the parts to rotate them	Identical Feeding/Dispensing "chambers" to allow for repeated batches, simplify process	Apply dykem with brush end effector	Rotating disks that grab and push standing up bearings
14.	A vibrating system to feed part intake from loading hopper	A Dykem soaked string that tightens around the parts	Visual count of completed parts in batch, likely next to progress indicator	Use gantry mechanism to sequentially paint bearings	Bucket elevator that takes in bearings from user
15.	A vibrating system to facilitate part	Bearing attaches directly to a	"Purge" functionality that allows a single	Suspend bearings on wire to facilitate convective drying	Bulk Bag equipment

	movement in dispensing	motor which spins and paints. Linear actuator removes finished bearings	retainer to be processed, testing the output or clearing single parts		connected to Hopper
16.	Arm extension with two seated ends that fits to the inside of retainers to grab them and manipulate them	Mechanical arm picks up bearings and puts them into place	Large 2/3 color light array on top of machine to allow for identification of progress across the factory	Suspend bearings in fluidized bed to encourage drying	Drum Box Container used with Hopper to take in large amounts of bearings
17.	Use dividers between each retainer to avoid paint disruption	Parts are transported up mechanical stairs into the fume hood and then painted	Current sensing on all moving parts to prevent excessive damage to device, stops when stall current is reached	Use stencil to avoid painting working areas of bearings	Having two brushes on either side of a rotating bearing, depending on color needed
18.	An arm that grabs and stacks retainers accordingly after dispensing	Parts are painted and then slide down ramp out of fume hood	Controls accessible from outside of Fume hood to keep hands away from device when in use	Use universal tracks with multiple selectable spacings for different sized bearings	System that times painting
19.	Manually loading onto splines for part intake	Bearings are stacked on a cylinder that inflates to spin the parts for painting	Pins that impede progress of rolling bearings to control procession	Use two painting end effectors to paint multiple parts at once	Bearing sitting in between two rolling conveyors that spin bearing around with painting brush in contact
20.	Movable finger that parts hit when being dispensed and add one to a counter	A carousel of horizontal cylinders, loaded with bearings that rotate to be painted	Hall Effect sensors to sense part presence	Use sensors to control timing of part ingress/egress via hopper mechanisms.	Funnel connected to vibrating Hopper that bearings fall into bearing

					segment of machine

Appendix E: Risk Assessment

INTRODUCTION

University laboratories are not without safety hazards. Those circumstances or conditions that might go wrong must be predicted and reasonable control methods must be determined to prevent incident and injury. The FAMU-FSU College of Engineering is committed to achieving and maintaining safety in all levels of work activities.

PROJECT HAZARD ASSESSMENT POLICY

Principal investigator (PI)/instructor are responsible and accountable for safety in the research and teaching laboratory. Prior to starting an experiment, laboratory workers must conduct a project hazard assessment (PHA) to identify health, environmental and property hazards and the proper control methods to eliminate, reduce or control those hazards. PI/instructor must review, approve, and sign the written PHA and provide the identified hazard control measures. PI/instructor continually monitor projects to ensure proper controls and safety measures are available, implemented, and followed. PI/instructor are required to reevaluate a project anytime there is a change in scope or scale of a project and at least annually after the initial review.

PROJECT HAZARD ASSESSMENT PROCEDURES

It is FAMU-FSU College of Engineering policy to implement followings:

1. Laboratory workers (i.e. graduate students, undergraduate students, postdoctoral, volunteers, etc.) performing a research in FAMU-FSU College of Engineering are required to conduct PHA prior to commencement of an experiment or any project change in order to identify existing or potential hazards and to determine proper measures to control those hazards.
2. PI/instructor must review, approve and sign the written PHA.
3. PI/instructor must ensure all the control methods identified in PHA are available and implemented in the laboratory.
4. In the event laboratory personnel are not following the safety precautions, PI/instructor must take firm actions (e.g. stop the work, set a meeting to discuss potential hazards and consequences, ask personnel to review the safety rules, etc.) to clarify the safety expectations.
5. PI/instructor must document all the incidents/accidents happened in the laboratory along with the PHA document to ensure that PHA is reviewed/modified to prevent reoccurrence. In the event of

PHA modification a revision number should be given to the PHA, so project members know the latest PHA revision they should follow.

6. PI/instructor must ensure that those findings in PHA are communicated with other students working in the same laboratory (affected users).
7. PI/instructor must ensure that approved methods and precautions are being followed by :

a. Performing periodic laboratory visits to prevent the development of unsafe practice.
b. Quick reviewing of the safety rules and precautions in the laboratory members meetings.
c. Assigning a safety representative to assist in implementing the expectations.
d. Etc.

8. A copy of this PHA must be kept in a binder inside the laboratory or PI/instructor's office (if experiment steps are confidential).

Project Hazard Assessment Worksheet				
PI/instructor: Shayne McConomy	Phone #:(850) 410-6624	Dept.: ME	Start Date:	Revision number: 0
Project: JTEKT Caterpillar Part Painter			Location(s): FAMU-FSU CoE, JTEKT Bearings USA; Cairo GA	
Team member(s): Anthony Wuerth Mason Gibson Max Jones Andrew McClung Wesley Jean-Pierre			Phone #: 305-283-3722 941-266-7330 954-994-5732 904-377-0393 561-574-9523	Email: amwuerth@fsu.edu mgibson5@fsu.edu mcj19a@fsu.edu acm20j@fsu.edu wj19b@fsu.edu

Experiment Steps	Location	Person assigned	Identify hazards or potential failure points	Control method	PPE	List proper method of hazardous waste disposal, if any.	Residual Risk	Specific rules based on the residual risk
Dykem Layout Fluid painting	ALL	Wesley Jean-Pierre	Spilling, physical chemical exposure from contact, inhalation of fumes	Placement of painting/drying device in fume hood	Dykem Paint remover, gloves, masks, and goggles.	Home Depot Lowes Leon County Hazardous Waste Center	HAZARD: 2 CONSEQ: Negligible Residual: Low Med	Wear protective equipment while testing
Painter treadmill	ALL	Mason Gibson	Entanglement	Light Fence hooked to automatic shutoff	N/A	N/A	HAZARD:1 CONSEQ: Moderate Residual: Low Med	Refrain from placing body parts into the device in motion.
Dykem Layout Fluid painting	ALL	Wesley Jean-Pierre	Fire hazard, strong solvent	Used in a premises with the presence of a fire extinguisher	Fire Extinguisher	Leon County Hazardous Waste Center	HAZARD: 3 CONSEQ: Moderate Residual: Medium	Have a fire extinguisher present during machine operations
Electrical Power wiring	ALL	Andrew McClung	Exposure to electrical current from outlet	Insulate wires in & out the machine. Don't connect to outlet without insulated wires	Rubber gloves on hand	Leon County Hazardous Waste Center	HAZARD: 4 CONSEQ: Severe Residual: High Residual:	When machine is plugged in use rubber while adjusting wires. Insulate all wires

Principal investigator(s)/ instructor PHA: I have reviewed and approved the PHA worksheet.

Name	Signature	Date	Name	Signature	Date

Team members: I certify that I have reviewed the PHA worksheet, am aware of the hazards, and will ensure the control measures are followed.

Name	Signature	Date	Name	Signature	Date
Wesley Jean-Pierre		11/24/2023	Anthony Wuerth		11/24/23
Mason Gibson		11/24/2023	Max Jones		11/24/23

DEFINITIONS:

Hazard: Any situation, object, or behavior that exists, or that can potentially cause ill health, injury, loss or property damage e.g. electricity, chemicals, biohazard materials, sharp objects, noise, wet floor, etc. OSHA defines hazards as "*any source of potential damage, harm or adverse health effects on something or someone".* A list of hazard types and examples are provided in appendix A.

Hazard control: Hazard control refers to workplace measures to eliminate/minimize adverse health effects, injury, loss, and property damage. Hazard control practices are often categorized into following three groups (priority as listed):

1. **Engineering control:** physical modifications to a process, equipment, or installation of a barrier into a system to minimize worker exposure to a hazard. Examples are ventilation (fume hood, biological safety cabinet), containment (glove box, sealed containers, barriers), substitution/elimination (consider less hazardous alternative materials), process controls (safety valves, gauges, temperature sensor, regulators, alarms, monitors, electrical grounding and bonding), etc.
2. **Administrative control:** changes in work procedures to reduce exposure and mitigate hazards. Examples are reducing scale of process (micro-scale experiments), reducing time of personal exposure to process, providing training on proper techniques, writing safety policies, supervision, requesting experts to perform the task, etc.
3. **Personal protective equipment (PPE):** equipment worn to minimize exposure to hazards. Examples are gloves, safety glasses, goggles, steel toe shoes, earplugs or muffs, hard hats, respirators, vests, full body suits, laboratory coats, etc.

Team member(s): Everyone who works on the project (i.e. grads, undergrads, postdocs, etc.). The primary contact must be listed first and provide phone number and email for contact.

Safety representative: Each laboratory is encouraged to have a safety representative, preferably a graduate student, in order to facilitate the implementation of the safety expectations in the laboratory. Duties include (but are not limited to):

- Act as a point of contact between the laboratory members and the college safety committee members.
- Ensure laboratory members are following the safety rules.
- Conduct periodic safety inspection of the laboratory.
- Schedule laboratory clean up dates with the laboratory members.
- Request for hazardous waste pick up.

Residual risk: Residual Risk Assessment Matrix are used to determine project's risk level. The hazard assessment matrix (table 1) and the residual risk assessment matrix (table2) are used to identify the residual risk category.

The instructions to use hazard assessment matrix (table 1) are listed below:

1. Define the workers familiarity level to perform the task and the complexity of the task.
2. Find the value associated with familiarity/complexity (1 – 5) and enter value next to: HAZARD on the PHA worksheet.

Table 1. Hazard assessment matrix.

		Complexity		
		Simple	Moderate	Difficult
Familiarity Level	Very Familiar	1	2	3
	Somewhat Familiar	2	3	4
	Unfamiliar	3	4	5

The instructions to use residual risk assessment matrix (table 2) are listed below:

1. Identify the row associated with the familiarity/complexity value (1 – 5).
2. Identify the consequences and enter value next to: CONSEQ on the PHA worksheet. Consequences are determined by defining what would happen in a worst case scenario if controls fail.

a. Negligible: minor injury resulting in basic first aid treatment that can be provided on site.
b. Minor: minor injury resulting in advanced first aid treatment administered by a physician.
c. Moderate: injuries that require treatment above first aid but do not require hospitalization.
d. Significant: severe injuries requiring hospitalization.
e. Severe: death or permanent disability.

3. Find the residual risk value associated with assessed hazard/consequences: Low –Low Med – Med– Med High – High.
4. Enter value next to: RESIDUAL on the PHA worksheet.

Table 2. Residual risk assessment matrix.

Assessed Hazard Level	**Consequences**				
	Negligible	Minor	Moderate	Significant	Severe

5	Low Med	Medium	Med High	High	High
4	Low	Low Med	Medium	Med High	High
3	Low	Low Med	Medium	Med High	Med High
2	Low	Low Med	Low Med	Medium	Medium
1	Low	Low	Low Med	Low Med	Medium

Specific rules for each category of the residual risk:

Low:

- Safety controls are planned by both the worker and supervisor.
- Proceed with supervisor authorization.

Low Med:

- Safety controls are planned by both the worker and supervisor.
- A second worker must be in place before work can proceed (buddy system).
- Proceed with supervisor authorization.

Med:

- After approval by the PI, a copy must be sent to the Safety Committee.
- A written Project Hazard Control is required and must be approved by the PI before proceeding. A copy must be sent to the Safety Committee.
- A second worker must be in place before work can proceed (buddy system).
- Limit the number of authorized workers in the hazard area.

Med High:

- After approval by the PI, the Safety Committee and/or EHS must review and approve the completed PHA.
- A written Project Hazard Control is required and must be approved by the PI and the Safety Committee before proceeding.
- Two qualified workers must be in place before work can proceed.
- Limit the number of authorized workers in the hazard area.

High:

- The activity will not be performed. The activity must be redesigned to fall in a lower hazard category.

Appendix A: APA Headings (delete)

Heading 1 is Centered, Boldface, Uppercase and Lowercase Heading

Heading 2 is Flush Left, Boldface, Uppercase and Lowercase Heading

Heading 3 is indented, boldface lowercase paragraph heading ending with a period.

Heading 4 is indented, boldface, italicized, lowercase paragraph heading ending with a period.

Heading 5 is indented, italicized, lowercase paragraph heading ending with a period.

See publication manual of the American Psychological Association page 62

Appendix B Figures and Tables (delete)

References

There are no sources in the current document.