Design for Manufacturing, Reliability, and Economics

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Design for Manufacturing

The first step in the manufacturing process of the coating machine for SLMP is to construct the frame and funnel. The frame and funnel were designed using Creo Parametric 2.0. The construction of the frame and funnel were outsourced to Metal Fabrication and sales of Tallahassee. Mechanical drawings from Creo were used to ensure exact dimensioning when machining the frame and funnel. It took Metal Fabrication and sales of Tallahassee a total of 5 business days to finish both components. This manufacturing decision was made due to the time constraints of the project timelines.

Once the frame and funnel were completed the next step of manufacturing was the purchase and mounting of appropriate vibration motors. The actuators, or DC motors with offset weights, purchased have varying amplitudes and voltages to produce significant vibrations within the funnel and meshes. The actuators were attached to the two long sides of the funnel with motor brackets and JB weld epoxy glue. This was done to ensure that the integrity of the funnel, which houses the loaded SLMP. The SLMP must not be obstructed as our goal to produced a uniform and constant flow rate onto the anode. The JB weld was a quick and inexpensive method in which to fasten the vibrators.

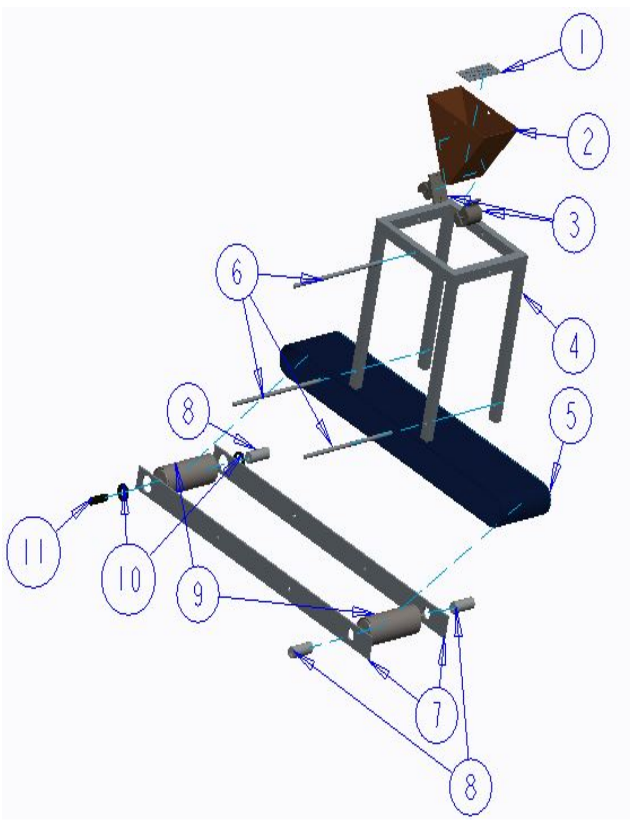
Two flat steel bars were bolted along the bottom of frame's legs on each side. The bolts go into predrilled holes in the frame. To construct the conveyor belt, two rollers were fixed onto the two flat steel bars. One of the rollers is the driver and the other is idle rolling. The driver roller was fitted with radial double shielded bearings to safeguard frictionless and continuous movement. The bed of the conveyor belt was made from a PVC belt that is glued together with epoxy. The PVC belt is in tension with the two rollers. Brackets were used to make the conveyor level. This frame was necessary to guarantee that the conveyor belt would be set at a fixed distance, the belting material would be constantly help in sufficient tension, and to facilitate the movement of the prototype. A hexagonal female to male round adapter was 3-D printed in the machine shop at FAMU-FSU College of Engineering, with the help of Professor Keith Larson. This adapter was essential to the assembly of the prototype to couple the hexagonal shaft of the roller and the shaft of the stepper motor. The stepper motor was fixed onto the shaft of the driver roller via the hex to round adapter and steel flat bar.

The meshes purchased were selected in 3 differing opening diameters in a steel wire cloth material. This material was selected for its durability and rigidity. These meshes will be able to be fastened in tension to increase particle dispersion and have secure fit along the walls of the funnel fold. Epoxy is used on the side of the meshes to further secure them to the sides of the funnel. This was done to shorten the assembly time to be cost efficient. To enclose the frame and components, plexiglass was glued onto the sides of the frame. The plexiglass on the top of the frame was not glued, but hinged so as to allow an opening to add more SLMP into the funnel. The plexiglass is used as a protective barrier for the user, to guarantee that they do not unknowingly come into contact with SLMP. Holes were drilled through the plexiglass to feed wires from the Arduino to the two motors on the funnel. The stepper motor was also connected to the Arduino.

The assembly process took longer than the project team had initially estimated. Due to procurement issues, such as purchasing order delays, items under back-order, and long shipping periods, manufacturing and assembly time was automatically increased and prolonged. The process step that changed the project timeline most drastically was the purchasing process. A note for future teams attempting this type of the prototype would be place procurement orders as soon as possible, preferable before the 2^{nd} period of the project time line. Procurement had to be completed by individual members of the team to shorten the shipping time and product pick up. The assembly process was allocated a month of labor to complete, the process has now been re-evaluated to require a month and half for full completion. Additional days must be added into the time period due to the 24 hour curing time of the epoxy and JB weld used to attach specific parts. The other days added were due to trouble shoot the prototype design. The troubleshooting included how to securely attach the actuators, meshes, and fasteners to the frame and funnel. The total time of the assembly took 14 days, or 75 real time hours. This approximation does not include the curing time of any epoxy or JB weld. One particular step that took longer than expected was attaching the conveyor belt in tension.

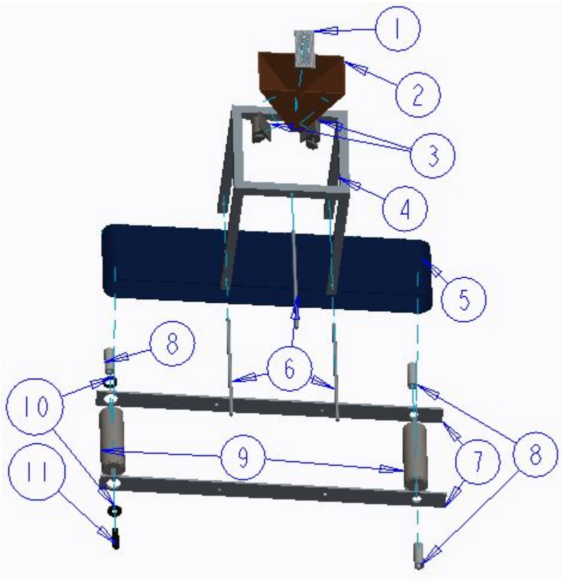
The varying number of components used to assemble the final design prototype are noted to include essential parts that are necessary to produce a high level of quality. This final design was produced with the appropriate quantity of components to ensure that the prototype would have high functionality in the coating process. Some assembly portions did require less invasive structuring than others, for example the vibration actuators were attached to the funnel using metal straps rather than building a encasing to attach to funnel wall. This was done to simplify the design and to create better contact between the funnel wall and the vibration actuators. Other aspects of the final design required more components; this was required in the conveyor system, as it was more complex. The conveyor system needed a high number of components for the structure to work and produce reliable results. Some of the more important parts included; hexagonal socket, bearing, frame flat bars, rollers, conveyor belt and an original adapter to connect the roller to the motor.

Exploded View



Bill of Materials		
No.	Part	Quantity
1	Mesh	1
2	Funnel	1
3	Vibrating Motor	2
4	Frame	1
5	Conveyor Belt	1
6	Shaft	3
7	Flat Bar	2
8	Socket	3
9	Roller	2
10	Bearing	2
11	Hex to Round Adapter	1

Figure 1. Shows a detailed exploded of the assembled design in Creo. It is featured along side the bill of materials.



Bill of Materials		
No.	Part	Quantity
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4	Frame	1
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6	Shaft	3
7	Flat Bar	2
8	Socket	3
9	Roller	2
10	Bearing	2
11	Hex to Round Adapter	1

Figure 2. Exploded view of assembled prototype in Creo, front angle with bill of materials on the side.

Design for Reliability

Reliability is a huge aspect of design. Often times, as is the case with this project, time and resources are limited and consequently reliability suffers. The prototype machine is not as reliable as the design group would hope but with the resources allotted, it is reasonably reliable. With that being said, the prototype machine is subject to various modes of failure. In this section all modes of failure will be assessed and discussed, including the design choices made and advice for future work on the design.

The prototype machine performs the task of coating without much strain on the machine. However, with repeated use many of the components fatigue and eventually fail. The component most likely to break is our 3D printed adapter, which was printed with a relatively weak plastic. As shown in the FMEA table found in the appendix in section II, the adapter has the highest risk priority number (RPN) of 240. This part will likely fail within 50 uses of the machine as it has already broken during our troubleshooting of the machine. The failure of this part would mean a cease of operations, as the conveyor system would fail. The hex adapter has since been redesigned as thicker and hopefully more durable. With more resources, this part should be refabricated with a more durable material and through a different fabrication process, such as die-casting.

The second component most likely to fail has been estimated to be the conveyor belt. The belt is held together with an epoxy and is held under tension. As shown in the FMEA table found in the appendix section II, the belt has the second highest RPN of 168. This part will likely fail within 100 uses. The failure of this part would result in a failure of the conveyor system. The belt has been adhered together using a strong epoxy that has an estimated strength of 3,200 psi. In future works, it is recommended that the belt be secured with stronger adhesive or perhaps manufactured as continuous.

The component third most likely to fail is estimated to be the vibrational actuators. Through the coating process these motors are vibrating against the face of the steel funnel and endure considerable strain through repeated use. As shown in the FMEA table found in the appendix in section II, the vibration actuators have the third highest RPN of 144. These eccentric rotating masses are estimated to fail within 125 uses. To reduce the wear on the actuators, electrical tape has been applied to the actuators and it serves to insulate them from the surface of the funnel during use. In future works, it is recommended that the actuators be encased in a protective shell.

Other notable parts likely to fail are the vibration actuator mounts and conveyor belt motor. The motor mounts on the funnel were adhered using J.B. weld. They were secured in this manner due to limited time and resources. This part is likely to fail within 100 uses. As shown in the FMEA table, found in the appendix in section II, the motor mounts have a RPN of 54. The failure of this part would cause a failure of the vibration induction. In future works, it is recommended that the actuators are mounted in a more permanent manner. The conveyor belt motor is a risk as the conveyor system is relatively heavy. Repeated times driving the system, the motor will fatigue and fail. It is likely that this part will fail after 200 uses. Failure of this part would mean a failure of the conveyor system. To combat this risk a high torque motor has been secured to minimize wear on the motor during use. All other risks and potential failures considered are depicted in the FMEA table in section II of the appendix.

FEM analysis was performed using ProE on our preliminary design for our frame with a distributed load to simulate the weight of a loaded funnel. The simulation, depicted in Figure 3 and Figure 4 below, showed that even with loads scaled 2,500 times, the stresses in the structure remained in the negligible region. The results of this simulation are what drove the design team to choose steel for the structure.

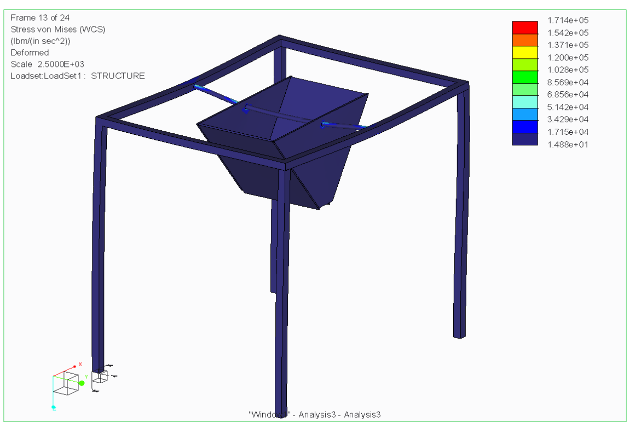


Figure 3. Image of maximum stress state of the FEM simulation in ProE.

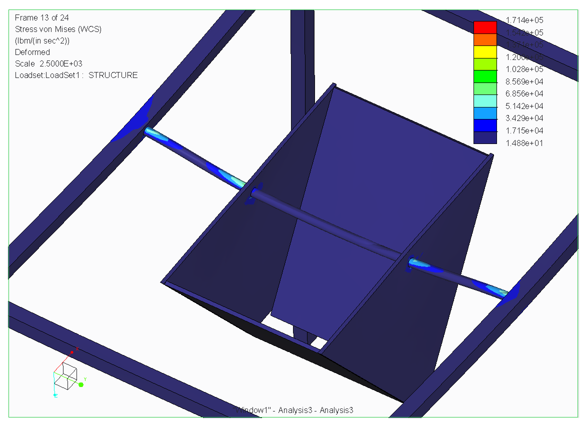


Figure 4. Close up of maximum stress state of FEM simulation.

With regular maintenance it's estimated that this machine will last the life of the bearings. The method in which the bearings were secured to the frame, it would deem their replacement difficult. Consequently the life of the prototype is estimated to be equivalent to the life of the bearings. The bearing life was estimated to be 250 million revolutions using Matlab, the script for which can be found in the appendix. The .m script utilized Equation 1 shown below, which yields the life of the bearing in millions of revolutions.

$$L_{10} = t * rpm * \frac{60min}{hour}$$

Equation 1

Design for Economics

The goal of this project is to create a prototype machine that can coat a pre-existing anode with a uniform layer of Stabilized Lithium Metal Powder. From the initial conceptualization, the team's main focus has been on manufacturing a viable and cost-effective prototype machine that will meet our sponsor's needs. Throughout the several design models generated over the course of the project, cost efficiency has continually been one of the major factors in the selection process, along with safety and reliability.

The current technology available for coating SLMP has been recently developed within the last 6 months. This is due to the novelty of Stabilized Lithium Metal Powder as a product as well as being commercially obtainable. Two companies have invested in fabricating prototype machines for coating SLMP: FMC Lithium Corporation and Tokyo Electron Limited.

FMC Lithium Corporation has created a slurry application system, which is estimated to cost around 2 million dollars. It encompasses a conveyor belt system with several rollers that move an anode sheet used as a belt. This belt is sprayed with a mixture of a solvent and SLMP and then heated until the solvent is melted off, leaving on a uniform layer of SLMP on the anode.

Tokyo Electron Limited has invested a significant amount of capital in researching a complex method of application. The basis of the technique is a slurry application, but it employs the use of harmful gases to seal and bond the SLMP to a pre-existing anode. Essentially an anode is placed within a chamber in which it is sprayed with a slurry mixture, and then by utilization of argon gas, the solvent is melted to leave only the SLMP remaining upon the anode surface. The chamber used during the SLMP spraying is a vacuum/depressurized chamber and the nozzle system implemented is very extensive and precise. This prototype machine has been estimated to cost $6 million dollars to manufacture and has a 6-month construction period.

The senior design team was given an allotted budget of $2,000 US dollars for the construction of a prototype machine. The selected method of approach, dry powder dispersion, was chosen due to the time constraints of the project, its feasibility, and the elimination of harmful gases and solvents used in the application procedure. The current expenditure of the project has totaled to $1,489.44. The detailed breakdown of the budget can be found in the Appendix, Section III.

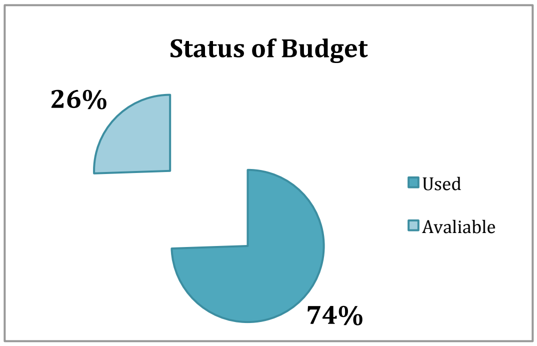


Figure 5. Pie Chart depicting the status of the budget breakdown.

Of the $2,000 US dollars, 74% of the budget has been spent, as depicted in Figure 5. The budget apportionment, as seen in Figure 6, was divided into 4 sections: machining, parts for assembly, electrical components, and raw materials. The machining cost accounted for 36% of the spent budget. Although this percentage seems high, it accounts for construction and welding of the part within a 2-day period at a rate of $150 dollars per hour for labor. To reduce the cost of overall prototype, it is recommended to have in-house machining if time permits. The materials for assembly summed to a total of 28% of the budget, $416. 67. The accumulation of electrical components was 33% of the budget depleted, which accounts for $496.72. The remaining 3% of the spent budget was used to purchase raw materials for the construction process.

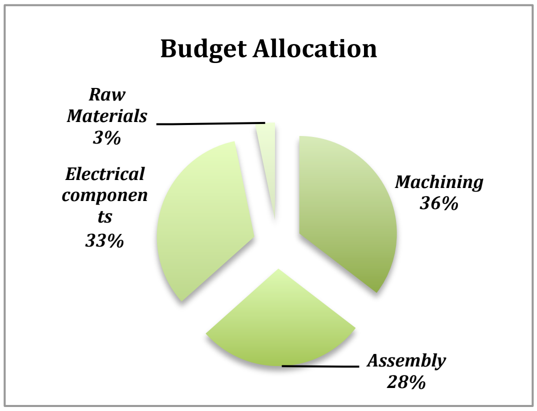


Figure 6. Pie chart the illustrates the budget allocation in 4 sections: machining, parts for assembly, electrical components, and raw materials.

Thru the course of the project, numerous design choices were made in order to consolidate time or budgetary limitations. The frame and funnel of the prototype was originally elected to be fabricated in-house at the college of engineering machine shop, however due to the large volume of senior design projects being built, the average wait time for individual part construction was estimated at 2 weeks. The team chose an alternate route in order to speed-up this wait time and commissioned metal fabrication and sales of Tallahassee to construct the frame and funnel. The materials under consideration for this production were A36 Steel and Aluminum. The locale did not have sufficient amounts of the correctly dimensioned Aluminum and the material was under back-order, thus it was decided to create the frame and funnel out of A36 steel. The conveyor belt system was built using individual parts rather than purchasing a cohesive single system due to the cost difference, equating to $5,000 US dollars, which outweighed the calculated labor time the team would be required to perform. In constructing the conveyor belt, the team was able to stay well with-in the designated budget and still progress the overall status of the prototype. The belting and rollers were procured from suppliers that provide replacement parts to pre-existing conveyor systems, thus the shipping time was accelerated. The distribution of the budget used in the construction of each major component or subsystem can be found in Figure 7.

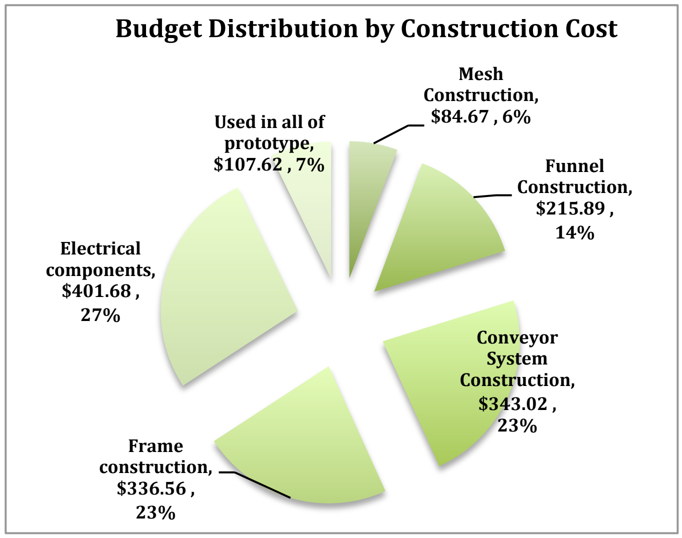


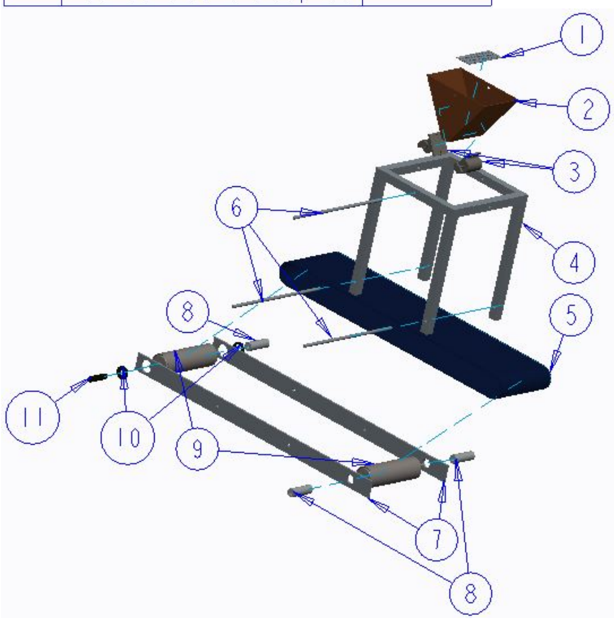
Figure 7. Pie chart that shows the budget distributions by component construction costs.

The current technology commercially available for coating Stabilized Lithium Metal Powder is extremely expensive ranging in the millions of dollars to purchase and produce. The senior design team’s competitive design is valued at $ 1,489.44 US Dollars, which is well below price of any other application system. It has been devised in such a manner that it is cost-efficient, safe, and reliable, considering the time constraints under which it was fabricated.

Appendix

Section I: Design of Manufacturing

Bill of Materials		
No.	Part	Quantity
1	Mesh	1
2	Funnel	1
3	Vibrating Motor	2
4	Frame	1
5	Conveyor Belt	1
6	Shaft	3
7	Flat Bar	2
8	Socket	3
9	Roller	2
10	Bearing	2
11	Hex to Round Adapter	1



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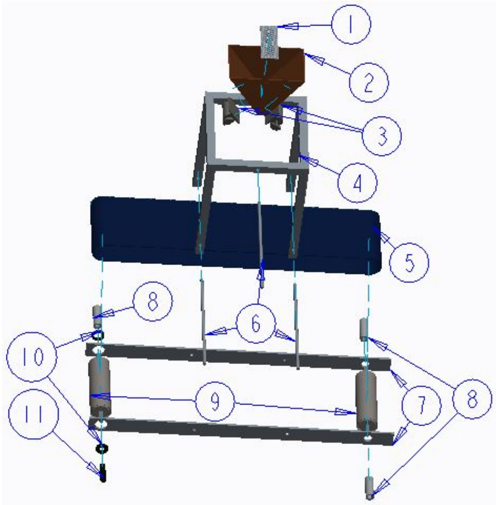
10	Bearing	2
11	Hex to Round Adapter	1



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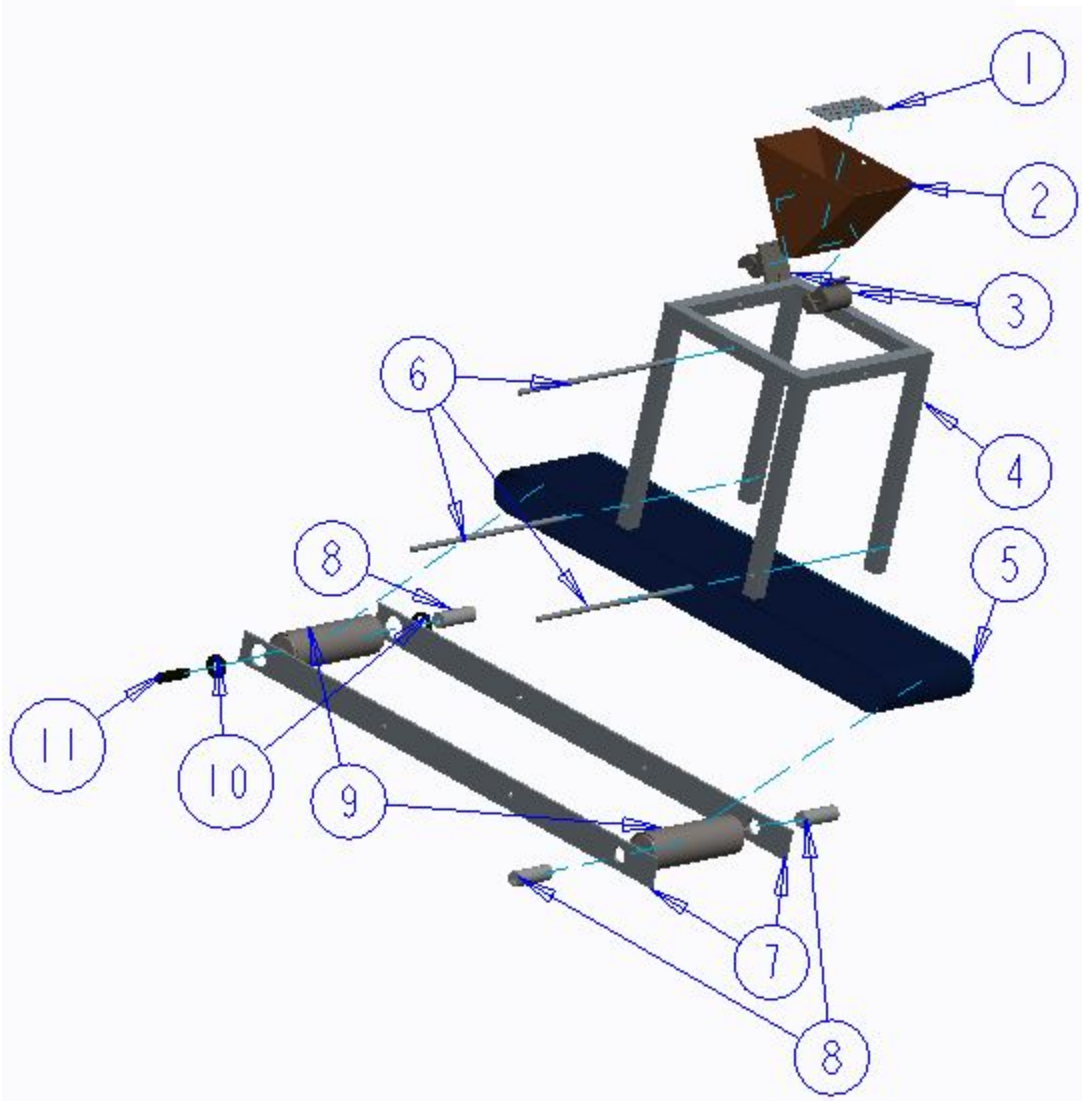


Failure Modes Effects Analysis

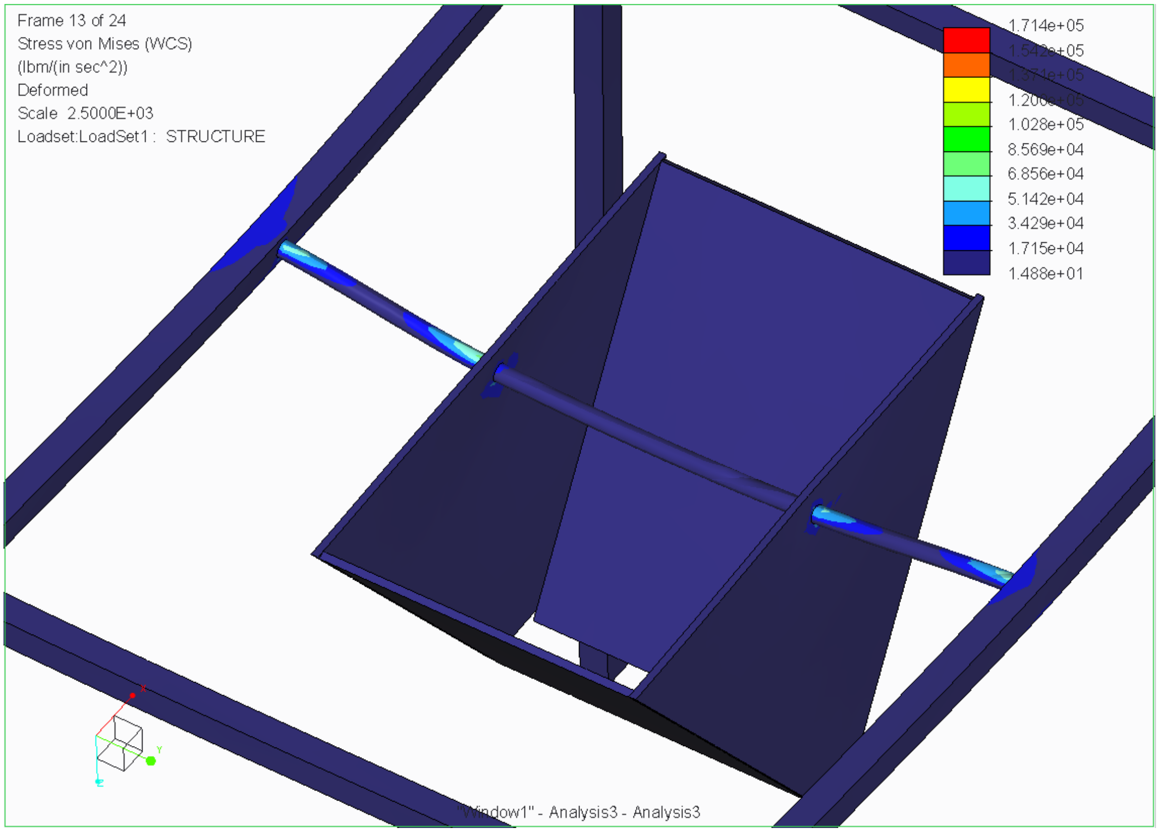
Team #:	16
Project Title	Prototype Coating Maching for SLMP

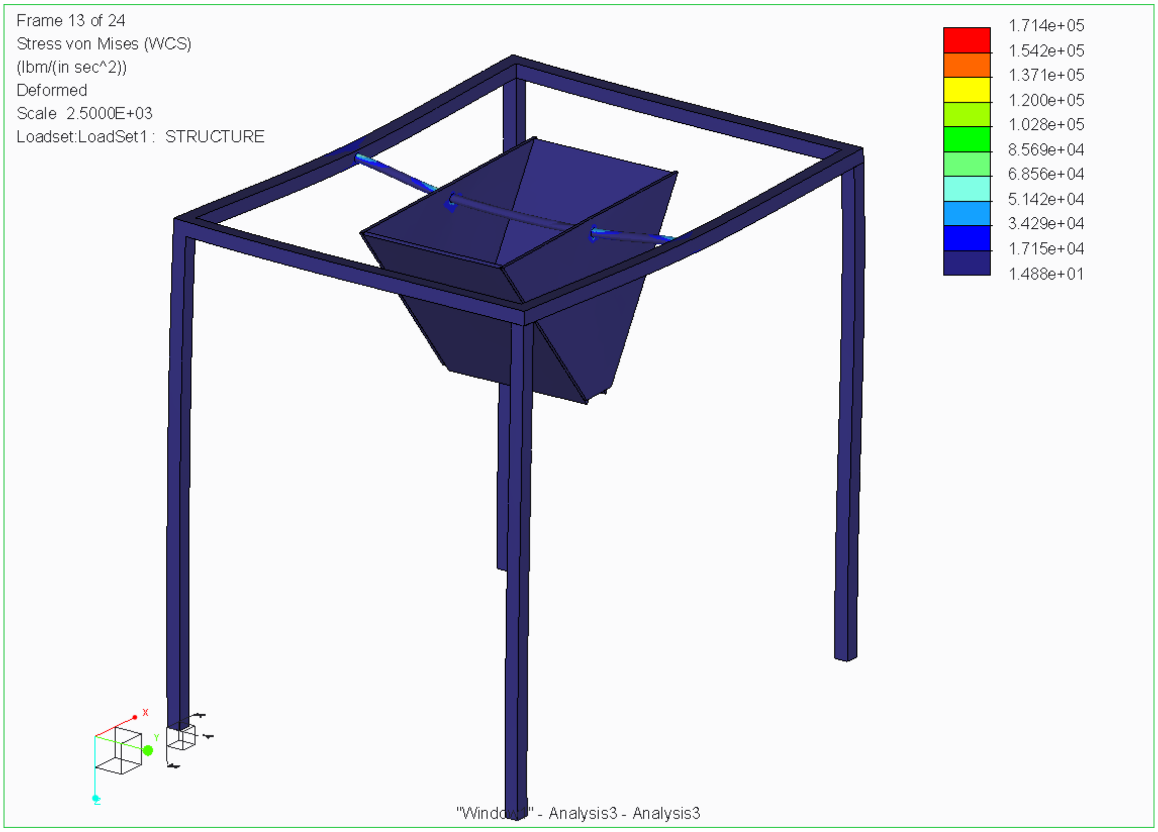
Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken	SEV	OCC	DET	RPN
What is the Process Step or Input?	In what ways can the Process Step or Input fail?	What is the impact on the Key Output Variables once it fails (customer or internal requirements)?	How **Severe** is the effect to the customer?	What causes the Key Input to go wrong?	How **often** does cause or FM **occur**?	What are the existing **controls** and procedures that prevent either the Cause or the Failure Mode?	How well can you **detect** the Cause or the Failure Mode?		What are the actions for reducing the occurrence of the cause, or improving detection?	Who is Responsible for the recommended action?	Note the actions taken. Include dates of completion.				
Hex Adapter for driving roller	Deformation of the adapter	Ceases operations until part is replaced	4	Weak material. Excessive force easily causes failure	6	Ensure motor is grounded and not hanging on adapter. Visual Inspection.	10	240	Refrabricate part with stronger material		Redesign for thickness and durability	4	6	10	240
Motor mounts on funnel face	Deformation of bolt adhesion	Causes failure to induce vibration	3	Excessive torque applied to bolt; wear from vibration.	2	Hand tighten nuts to secure motor mount.	9	54	Secure bolts in a more permanent manner; bore hole through funnel and run bolt through.		Secured with J.B. weld	3	2	9	54
Conveyor belt motor	Insufficient torque to drive system	Failure of conveyor system	6	Heavy belt, ficition with frame, low voltage applied to motor	2	Avoid belt contact with frame; minimize weight of belt.	9	108	Trim belt to minize friction; use lighter belt; use high torque motor	Design group	Belt trimmed. Motor with high torque ordered.	6	2	9	108
Conveyor belt	Deformation of belt adhesion	Failure of conveyor system	7	Excessive tension applied to belt.	3	Avoid high tension; secure belt with epoxy.	8	168	Refashion belt; use stronger adhesion.	Design group	Epoxy applied to reinforce joint; searched for alternative lighter belts	7	3	8	168
Funnel Suspension	Funnel movement	Inconsistent flow onto anode	3	External forces acting upon structure	1	Keep structure in controlled environmnet; avoid external forces	4	12	Still funnel before activating the machine	User	Funnel secured with nuts	3	1	4	12
Electrical System	Electrical component failure	Failure of input system, vibration system, and conveyor system	9	Excessive voltage applied to component	1	Ensure proper voltage is applied across all electrical components	6	54	Moderate voltages and inspect system often.	Design group	Redesign of circuitry to ensure proper voltages are applied	9	1	6	54
Internal Mesh	Displaced mesh	Failure to moderate flow	1	Mesh moved such that exit orifice is not completely covered	2	Check internal mesh before loading the funnel	3	6	Develop a way to fix a mesh to walls of funnel	Design group	Fit large opening mesh to funnel	1	2	3	6
Roller Bearings	Deformation of bearing	Failure of conveyor system	5	Fatigue after hundreds of uses	1	Visual inspection	6	30	Keep bearings lubricated. Replace when part exceeds bearing life	User		5	1	6	30
Vibration Actuators	Failure of actuation	Failure of vibration system	6	Fatigue after hundreds of uses	3	Visual inspection	8	144	Secure vibrating motors tight against funnel	User	Secured vibrating motors	6	3	8	144

```
>> t = 1/6;%duration of coating process in hours
rpm = 25;%rev/min
L_bearing = t*rpm*60%life calculation in millons of revolutions

L_bearing =

  250.0000
```




Frame 13 of 24
Stress von Mises (WCS)
(lbm/(in sec^2))
Deformed
Scale 2.5000E+03
Loadset:LoadSet1 : STRUCTURE
1.714e+05
1.542e+05
1.371e+05
1.200e+05
1.028e+05
8.569e+04
6.856e+04
5.142e+04
3.429e+04
1.715e+04
1.488e+01
- Analysis3 - Analysis3

Section III : Design for Economics

Component	Distributor/Manufacturer	Price per Unit	Quantity	Total
Meshes	Grainger Industrial Supplier	$21.79	3	$65.38
Frame & Funnel	Metal Fabrication and Sales of Tallahassee	$360.80	1	$360.80
Rollers	Grainger Industrial Supplier	$24.30	2	$48.60
Conveyor belt	Grainger Industrial Supplier	$5.78	9	$52.00
DC Vibration motors	Amazon	$6.05	2	$12.09
Plexiglas	Home Depot	$7.99	2	$15.98
Microprocessor	Arduino	$44.99	1	$44.99
Stepper motor	Adafruit	$14.00	1	$14.00
DC motor	Phigidt	$107.49	1	$107.49
LCD display	Sparkfun	$4.99	1	$4.99
Keypad	Sparkfun	$8.99	1	$8.99
On/off switch	Sparkfun	$1.99	1	$1.99
Power supply	Adafruit	$24.95	1	$24.95
Hinges	Home Depot	$3.39	1	$3.39
Motor shield	Amazon	$34.95	1	$34.95
Frame for conveyor	Metal Fabrication and Sales of Tallahassee	$166.82	1	$166.82
Clamps	Home Depot	$0.97	4	$3.88
Miscellaneous Electrical Components	Adafruit/Radioshack	$130.99	1	$130.99
Miscellaneous Hardware	Home Depot	$35.00	1	$35.00
Hex nut- 5/16	Home Depot	$0.35	6	$2.10
Hex nut- 5/8	Home Depot	$0.11	8	$0.88
Lock nuts- 5/16	Home Depot	$1.97	1	$1.97
Lock nuts-3/8	Home Depot	$1.70	1	$1.70
Female DC Power	Adafruit	$2.00	1	$2.00

Adapter				
2-Way 2.1 mm Barrel Jack Splitter	Adafruit	$2.95	1	$2.95
Jumper Wires	Adafruit	$3.95	1	$3.95
Stepper Motor Mount	Adafruit	$2.24	4	$8.95
Adafruit Shipping	Adafruit	$11.51	1	$11.51
Radial Bearings	Grainger Industrial Supplier	$14.66	2	$29.32
Plastic line level	Home Depot	$2.97	1	$2.97
Plexiglass	Home Depot	$9.78	2	$19.56
Epoxy-Loctite	Home Depot	$4.97	1	$4.97
Epoxy- Gorilla	Home Depot	$5.47	4	$21.88
JB Weld	Home Depot	$5.67	4	$22.68
Contour 600-Watt Single-Pole Preset Dimmer - White	Home Depot	$17.97	1	$17.97
Plastic corner guard 3/4" x 3/4" x 4'	Home Depot	$2.48	2	$4.96
Electrical tape	Home Depot	$0.79	1	$0.79
8" Zinc mending plate	Home Depot	$2.28	2	$4.56
1/4" drive 7/16" 6pt deep	Home Depot	$1.98	4	$7.92
48"-1/2"x 1/4" Steel plain flat bar	Home Depot	$11.68	1	$11.68
1'x1' plain aluminum sheet	Home Depot	$7.47	1	$7.47
Sheet metal aluminum Gauge 21 6x8	Home Depot	$8.97	1	$8.97
7" wire stripper	Home Depot	$7.93	1	$7.93
Threaded Rod	Home Depot	$1.76	1	$1.76

Zinc 5/16x 24"				
GE ergonic plastic sheet cutter	Home Depot	$4.97	1	$4.97
Plastic drop cloth	Home Depot	$1.98	1	$1.98
Steel plain flat bar	Home Depot	$13.99	1	$13.99
Tread mill belting	Amazon	$48.60	1	$48.60
Microprocessor	Arduino	$25.60	1	$25.60
Microprocessor	Arduino	$41.73	1	$41.73
Silicon glue	Home Depot	$3.89	1	$3.89
			Total	$1489.44

Breakdown by Major Components	Total Cost
Mesh Construction	$84.67
Funnel Construction	$215.89
Conveyor System Construction	$343.02
Frame construction	$336.56
Electrical components	$401.68
Used in all of prototype	$107.62

Budget Allocation

Process	Cost
Machining	$527.62
Assembly	$416.67
Electrical	$496.72
Raw materials	$48.43
Total	$1,489.44

Budget	$2000
Used	$1489.44
Available	$510.56