Mech 4860: Engineering Design

Final Design Report

Project:	Paper Layup Machine
Company:	Botanical PaperWorks
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Executive Summary

Botanical PaperWorks, a leading producer of environmentally friendly seed paper products, makes biodegradable seed paper from post-consumer waste. The process to create these products is labour intensive. The process starts by creating a paper and seed slurry, where a mesh screen scoops up the slurry and forms it into a wet sheet. Pressure is applied on the sheets to reduce water weight, after which the paper goes to the drying station. Once the paper is dry, the paper is printed and packaged according to the orders.

The current paper thickness ranges from 0.223 mm to 0.273 mm, a 10% variation, across both a single sheet of paper and across multiple sheets, due to inaccuracies in the handmade process. The objective of this project was to develop a process that will reduce paper thickness variation to 3% between sheets and within a single piece of paper. As well, the process will decrease operator strain from a subjective strain scale of 5/10 to 3/10 and increase the current output to more than the current 96 sheets per hour, up to an ideal value of 192 sheets per hour.

The team generated 15 concepts that were compared against each other by using a screening matrix and a weighted scoring matrix. Eight concepts advanced to the testing and design phase. From these eight concepts, six concepts were designed and tested by rapid prototyping. The six that were tested were a slurry shaker, slicer, a scooter, a roller press, a piston, and a change in process layout. The remaining two, the modified hydraulic press and the thickness sensor, were not able to be tested due to a lack of testing equipment.

A unique element throughout this project is that the team has not been looking for the single best concept, but rather the ideal process. This means that although the best concepts were identified, they may not create the ideal process when combined. Through analysis of the test results, the following six concepts were optimized to create the ideal process: a slurry shaker to improve paper tolerances, a scooter to reduce operator strain, a roller press and piston that, if implemented properly, will improve tolerance and reduce production and drying time, and a process change layout that will improve the efficiency of the operators.

These six concepts were optimized and have become the final process design. There are also three opportunities for future changes, which would make the system more readily automatic. With all implemented changes, the total cost of the final design is between $32,050.44 and $32,395.44.

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1. Introduction

Botanical PaperWorks is a worldwide leading producer of environmentally friendly seed-paper products, with over 20 years of experience [1]. By making biodegradable seed-paper from post-consumer waste, Botanical PaperWorks has designed and produced a series of enviromentally friendly paper products including wedding invitations, wedding favors, event stationary, memorial pieces and corporate promotional products. Botanical PaperWorks caters to both businesses and indivuals that want to celebrate and promote events in an eco-friendly fashion. Figure 1 shows a process flow chart to help gain an understanding of how the entire process works.

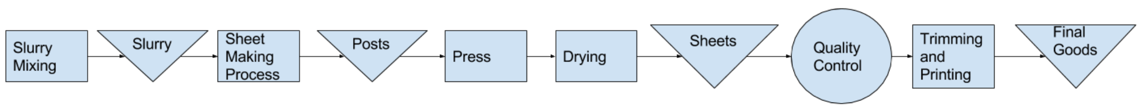


Figure 1: Process flow diagram for Botanical PaperWorks

The process flow chart in Figure 1 represents, in a general form, how the paper moves from raw materials to the final product. The boxes represent a task or process that the paper undergoes, the triangles represent an invetory of material or waiting queue, and the circle represents an inspection point. The process starts by adding seed to a paper slurry and mixing the slurry for consistancy. Once the slurry is ready, it travels to a station where an operator performs the sheet making process. The sheet making process can be seen in Figure 2.

Figure 2: Woman lifting copper screen from paper slurry to create a single sheet of paper [2]

During the the sheet making process an operator uses a mesh screen to scoop the slurry and form it into a wet sheet of paper. Figure 2 shows a woman forming a paper sheet by lifting a copper screen out of the paper slurry and waiting for the excess water to drain through the screen.

Once the paper is formed, the sheets are stacked between sheets of cotton in units of 20 sheets, or what is referred to as a post. The post is then taken to the hydraulic press, which can be seen in Figure 3.

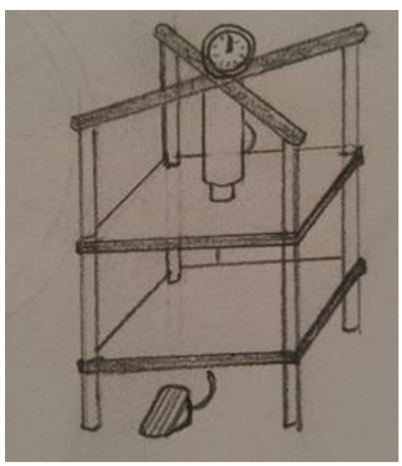


Figure 3: Hydraulic press used to squeeze water out of paper sheets

The purpose of the hydraulic press is to apply pressure to reduce the water content in the post and reduce drying time. Figure 3 shows a sketch of a paper press that would accomplish this task.

The paper is then sent to the drying station, where the paper is dried by controlling temperature and humidity through the use of fans, for up to two days. Once the paper is fully dried and contains no moisture, the paper is ready to be printed and packaged for the customers.

This report first describes the problem presented by Botanical PaperWorks with the expectations, customer needs, and limitations that the proposed solution must adhere to. Then, the methodology explains how the team generated the concepts, as well as the process of concept screening and concept scoring. Eight concepts advanced to the testing and design phase, where either a smaller scaled version was tested or more research was performed. Based on these results, six concepts were optimized to create the ideal process. Finally, some future recommendations have also been included in this report that Botanical PaperWorks can implement in the future with some more detailed design being performed.

1.1.Purpose and Problem

The objective of this project was to develop a mechanism to be used, either by hand or machine, to minimize variation between paper sheet thickness and to remain within tolerance for each individual sheet of paper. The project also addressed a need for a decrease in operator strain, and an increase the current output of the manufacturing process by December 6^{th}, 2017. Paper produced at Botanical PaperWorks has high variation in thickness between sheets of paper and within a single sheet due to their handmade process. This thickness variation ranges from 0.223 mm to 0.273 mm, which yields a 10% variation. Due to the frequency of this, printing on the paper is difficult as it causes paper jams in the printers which hinders production and eliminates the possibility to outsource printing. As well, the current process is labour intensive and strenuous on the operators, causing wrist and shoulder pain on a subjective scale of 5/10. With the process as it is currently stands, the plant has an output of approximately 2100 sheets of paper per day.

1.2. Expectation

There are three changes to the current process that would make the process ideal for Botanical PaperWorks.

The first change is to reduce the variation in paper thicknesses to a more acceptable level. Currently, the thickness varies by 10%. Botanical PaperWorks set the target tolerance at 3% variation. The ideal thickness is 0.248 mm, and has a thickness range from 0.241 mm to 0.255 mm, which would eliminate printing problems.

The second change is to determine if sheets of paper are outside of the new tolerance range before the paper goes to the drying station. This would allow the client to remove sheets of paper that could cause printing problems within the company, and for other printing companies.

Lastly, the third change is to improve paper throughput as Botanical PaperWorks would like to double their output, in order to reduce the storage needed for the busy months. This will be done by separating the paper making process into two sections: the operators forming the paper and the drying process. There are currently four workers who share the paper making process, alternating between three slurry stations each month. Each worker makes approximately 96 sheets of paper per hour, averaging over 2100 sheets of paper per day. The drying process currently takes one to two days to dry, which is dependent on the water weight contained in the paper. The weight of the water saturated sheet is 0.35g per 1 in^2. The weight of the dry sheet is 0.16g per 1 in^2. There is a reduction of 54% of weight.

1.3. Customer Needs

Five preliminary customer needs were identified and prioritized by the team, and after one modification to change the location of detecting the thickness to the second highest priority, Botanical PaperWorks agreed with the hierarchy produced.

The customer needs list is as follows.

1. The paper thickness is 0.248 ± 3% across the sheet, from 0.241 mm to 0.255 mm.
2. The paper thickness is detectable by the operator when the paper is outside the 3% variation (when the paper is outside of 0.241 mm to 0.255 mm) before the sheet goes through the drying process.
3. The paper making process is more productive.
    a. The paper throughput is faster per hour.
    b. The paper is pressed more quickly.
    c. The paper is pressed with an accurate weight.
    d. The paper is dried more quickly.
4. The paper making process is more ergonomic.
    a. The paper making process is less strenuous on operator's shoulders.
    b. The paper making process is less strenuous on operator's wrists.
    c. The paper making process is less strenuous on operator's lower back.
    d. The paper making process requires less physical exertion.
5. Increased output allows for a reduction in inventory levels and increased inventory turnover.

These needs are the reference for which the concepts have been prioritized during the concept scoring of this report.

1.4. Limitations

The specific limitations that have been imposed on this project are as follows:

- Any intended solution must remain under $300, 000 CAD. This is to include all testing expenses, purchased materials and machines, and labour to produce any of the concepts if needed.
- The paper must remain biodegradable, which is one of the key features that this company provides. Any solution that would inhibit the biodegradability of the produced paper would be a step backwards in the progress of the company.
- The seeds must be able to germinate after printing, which is another hallmark of the company that must remain with the implementation of any solution.
- The paper making process remains safe for the seeds. With the introduction of seeds into a paper making process, extra care must be taken through all steps of

production to ensure that the seeds are intact and able to produce. This limitation can be further specified as:

- The paper press is safe for the seeds. The press must not apply enough pressure on the seeds to cause them to crack. Another consideration when dealing with the press is that the heat from the increased pressure must also not destroy the seeds.
- The paper drying process is safe for the seeds. The drying process must not use excessive heat or humidity that would ruin the quality of the paper, or the seeds.

1.5. Technical Specifications

To determine if the proposed solution is successful, metrics were created to provide a value that could draw comparisons between not only the existing process, but also similar products from competitors: the benchmarks found in Appendix A . These metrics were ranked and given units, as well as marginal and ideal values that the proposed solution will achieve. With the metrics established, the specifications were combined into a house of quality which provides an overall depiction of the relationship between the customer needs, their corresponding metrics and how they all compare to benchmarked standards from competitors. This house of quality can be found in Appendix B .

1.6. Metrics with Marginal and Ideal Values

While the needs of the customer outline what our project will accomplish, the metrics assign a tangible value for measuring the success of meeting a specified need. Based on the needs that were provided, a list of metrics was created and is illustrated in TABLE I.

With the outlined metrics being used to define the project's success, the team decided on a reasonable range of values that will be attained after implementation. The ideal values for the project are determined by the needs and the team's definition of the project scope, and were validated by Botanical PaperWorks. These metrics along with their value ranges are shown in TABLE I. As seen below, the “<” and “<<” values are indications of reducing the values, without providing the exact values. Metric #7, the total production time per sheet, was determined at a site visit. Three runs were recorded, and the average time was used.

TABLE I: METRICS AND ASSOCIATED VALUES

Metric #	Need #	Metric	Imp	Units	Marginal Value	Ideal Value
1	1	Paper weight range	5	g	29.1-30.9	30
2	1	Thickness of paper	5	mm	0.241-0.255	0.248
3	2	Time to determine if paper is out of tolerance	4	seconds	10	5
4	3a	Force to lift copper tray	3	N	<	<<
5	3b	Force to hand press sheets	3	N	<	<<
6	3c	Force to lift buckets of paper slurry	3	N	89	0
7	4a,4b	Total production time per sheet, excluding drying	2	seconds	38	19
8	4a	Pre-dried sheet production	2	units/hr	144	192
9	4b	Time to press sheets on hydraulic press	2	seconds	60	30
10	4c	Force applied to bundle of sheets by press	2	subjective	5/10	3/10
11	5	Total inventory	2	units	<	<<
12	6,4a	Drying time after being pressed	1	hours	36	24

The most important metrics match the needs that the team prioritized earlier. Any proposed solution will be able to produce values for these metrics that fall within the given ideal or marginal value range.

2. Preliminary Concepts

Due to the nature of this project, Botanical PaperWorks is allowing for rapid proto-typing of various concepts. The team has taken into consideration the customer needs and limitations on the project. The team's methodology in creating the core concepts was to start by breaking down the processes that are currently used at Botanical PaperWorks. After generating different ideas, the team organized them in five categories: tolerances, ergonomics, drying, process, and sensors.

2.1.Methodology

In the concept description section, each of the 15 preliminary concepts are shown, identifying their name, a sketch of the concept and a short description.

Concept screening was then performed where each concept was grouped into categories that aimed to accomplish similar objectives. Each concept was screened using the following metrics: ease of implementation, cost, time, ergonomics, testability and ease of use.

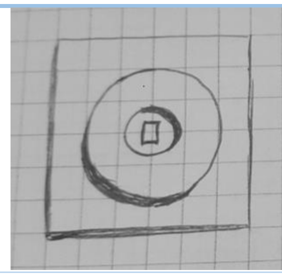
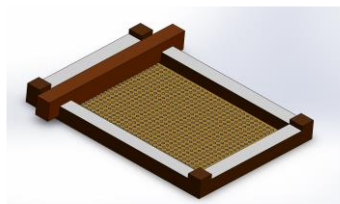
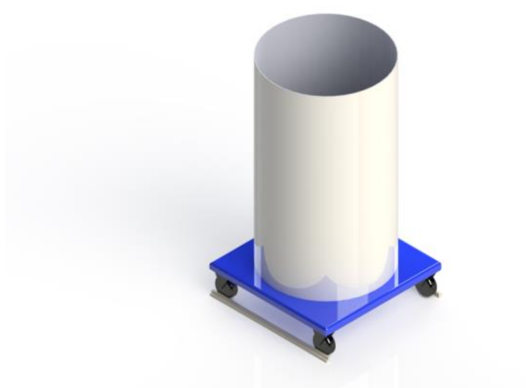
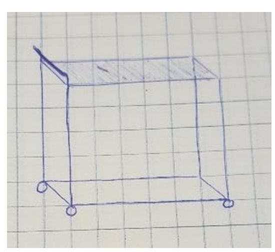
After concept screening, the concepts were scored against each other within their own category, using a weighted matrix to determine the top concepts for testing. The weights of these criteria were determined beforehand to provide a more thorough analysis of the concepts.

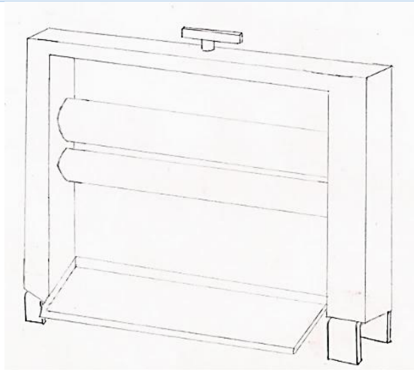
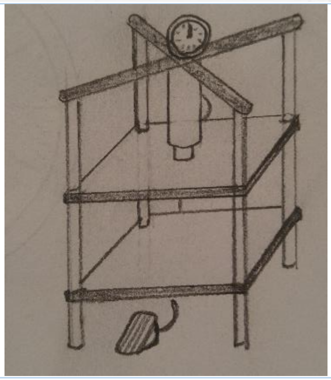
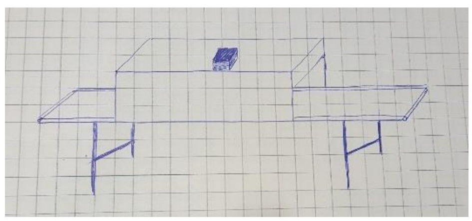
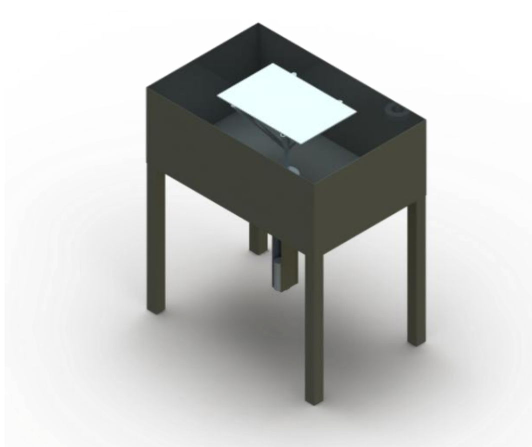
The concepts that scored higher, but not necessarily the highest, moved on to concept testing. The concept testing plan described how each concept was tested, as well as providing more details on the concepts, including an explanation on how the concept would be implemented.

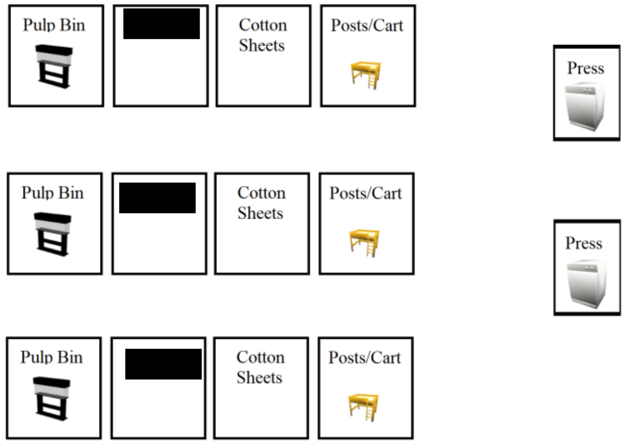
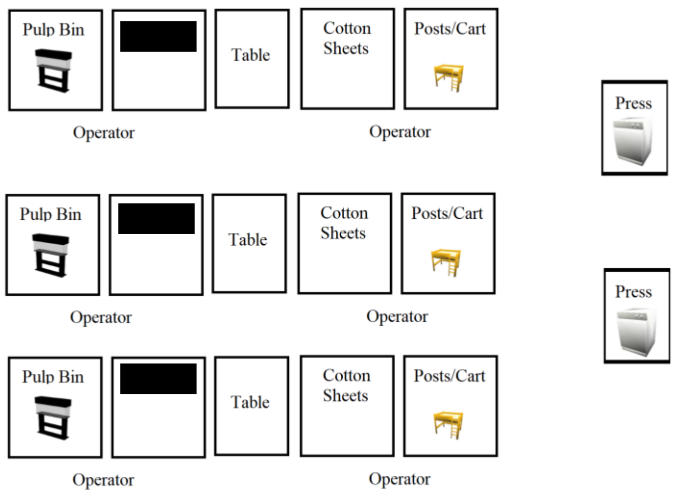
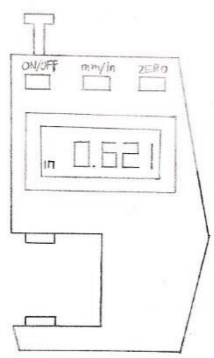
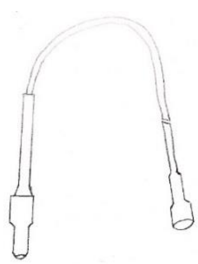
2.2.Concept Description

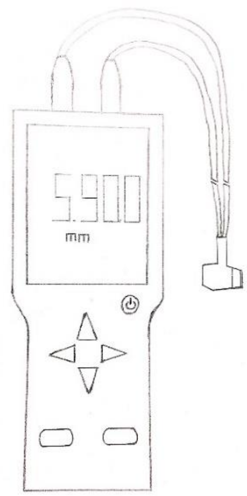
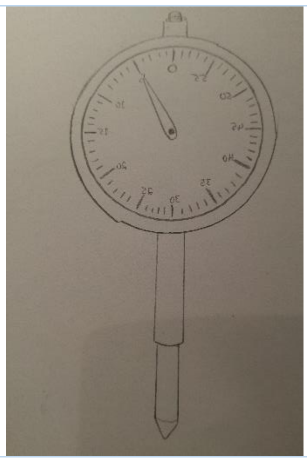
The 15 preliminary concepts that are evaluated are shown in TABLE II, identifying their name, a simple sketch of the concept, and a short description.

TABLE II: PRELIMINARY CONCEPTS

Concept Name	Sketch	Description
Slurry Tray Shaker	 (Bottom view)	A vibrating motor is attached to a board on top of a tire to vibrate and even out the wet sheets.
Slurry Tray Slicer		A straight edge is set at a desired height from the tray to create a uniform surface.
Scooter		Slurry buckets are placed on scooters to avoid lifting 40lbs buckets. Rubber pads and obstacle blocks are used to avoid rotating when slurry is being mixed.
Cart		A cart the same height as assembly tables and hydraulic press.
Leveling Tables	No sketch available	Make all tables in assembly line same height.

Roller Press		A clothes wringer is used to remove excess water from paper sheets as well as maintain a constant paper thickness.
Modified Hydraulic Press		Replace manual press with an automatic press that has a pressure gauge to more accurately press sheets.
T-Shirt Oven		A heated compartment that allows material to moves through, in order to dry the sheets and reduce the water weight.
Piston		A pneumatic piston is used to lower and lift the screen through the slurry mixture to reduce operator strain and maintain a level screen.

<table>
<tr><td>Change Process Flow</td><td>
</td><td>Change process layout so paper stacks end up close to the press.</td></tr>
<tr><td>Greenfield Paper Process</td><td>
</td><td>Change process layout to resemble Greenfield's layout. [3]</td></tr>
<tr><td>Digital Thickness Gauge</td><td>
</td><td>A digital thickness sensor directly detects the thickness in the same manner as a micrometre, but with a digital display.</td></tr>
<tr><td>Optical Sensor</td><td></td><td>A sensor component in a system that applies the principle of optics to detect the thickness.</td></tr>
</table>

Ultrasonic Sensor		A device that applies an ultrasonic wave to detect the thickness in papers, plastic and metal plates by placing the measuring head onto the object.
Feeler Gauge Dial		A gauge that measures small changes in height from a mounted reference point using a telescoping arm.

2.3. Concept Screening

Each concept was initially compared against a reference, which was the current process at Botanical PaperWorks. However, since there were five distinct categories of variables (tolerance, ergonomics, drying, process, and sensors), the results were inconclusive as all of the values were between one to three. The matrix can be seen in Appendix D .

The team then decided to compare each concept with the others in their category. Six screening criteria were used for this matrix: ease of implementation, cost, time, ergonomics, testability, and ease of use. The results can be seen in TABLE III.

TABLE III: CONCEPT SCREENING

Screening Criteria	Concept Variables														
	Tolerance		Ergonomics			Drying			Process			Sensors			
	Shaker	Slicer	Scooter	Cart	Leveling Tables	Press Roller	Modified Hydraulic Press	T-shirt Oven	Piston	Change Flow	Greenfield Paper Process	Digital sensor	Optical sensor	Ultrasonic sensor	"Feeler" gauge
Ease of Implementation	0	1	1	1	0	0	1	-1	-1	0	1	0	0	0	-1
Cost	0	1	1	0	-1	0	1	0	-1	0	0	1	0	-1	0
Time	0	0	1	1	0	0	1	0	1	0	-1	0	0	1	0
Ergonomics	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0
Testability	0	0	1	1	-1	-1	1	0	-1	0	0	0	0	0	0
Ease of Use	0	0	1	1	1	0	0	0	1	0	0	0	0	1	1
Sum	**0**	**2**	**6**	**5**	**0**	**0**	**5**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**0**
Rank	2	1	1	2	3	2	1	2	1	1	1	1	3	1	3

After compiling the results and the rankings, the concepts that were superior in their categories are the slicer, the scooter, the modified hydraulic press, the digital sensor and the ultrasonic sensor. In the process category, the scores were equal for every concept.

The team chose to move forward with a weighted matrix, to confirm the outcomes of the concept screening.

2.4. Concept Scoring

To score each concept, weights were assigned to each category that the concepts were compared against. Weighting for criteria was conducted using a criteria weighting matrix, which can be found along with the weights for each criterion in TABLE IV. TABLE IV shows that the most important criteria were the achievement of the ideal tolerance, the ability to detect the tolerance, and the time that each concept would take to complete the desired task once implemented.

TABLE IV: WEIGHTED MATRIX FOR CRITERIA COMPARISION

		Ease of Implemenation	Cost	Time	Ergonomics	Testability	Ease of Use	Dectecting Tolerance	Achieve Tolerance
	Criteria	A	B	C	D	E	F	G	H
A	Ease of Implemenation		B	C	D	A	F	G	H
B	Cost			C	B	B	B	G	H
C	Time				C	C	C	G	H
D	Ergonomics					D	D	G	H
E	Testability						E	G	H
F	Ease of Use							G	H
G	Dectecting Tolerance								H
H	Achieve Tolerance								
	Total Hits	1	4	5	3	1	1	6	7
	Weightings	0.1	0.4	0.5	0.3	0.1	0.1	0.6	0.7

With the weights assigned to each criterion, a scoring matrix for each concept was created to evaluate which concepts would move forward with development. This matrix is shown in TABLE V.

TABLE V: CONCEPT SCORING MATRIX

Scoring Criteria		Concept Variables															
		Tolerance		Ergonomics			Drying			Process			Sensors				
	Weight	Shaker	Slicer	Scooter	Cart	Leveling Tables	Press Roller	Modified Hydraulic Press	T-shirt Oven	Piston	Change Flow	Greenfield Paper Process	Digital sensor	Optical sensor	Ultrasonic sensor	"Feeler" gauge	
Ease of Implementation	0.1	0	0.1	0.1	0.1	0	0	0.1	-0.1	-0.1	0	0.1	0	0	0	-0.1	
Cost	0.4	0	0.4	0.4	0	-0.4	0	0.4	0	-0.4	0	0	0.4	0	-0.4	0	
Time	0.5	0	0	0.5	0.5	0	0	0.5	0	0.5	0	-0.5	0	0	0.5	0	
Ergonomics	0.3	0	0	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0	0	0	0	0	0	
Testability	0.1	0	0	0.1	0.1	-0.1	-0.1	0.1	0	-0.1	0	0	0	0	0	0	
Ease of Use	0.1	0	0	0.1	0.1	0.1	0	0	0	0.1	0	0	0	0	0.1	0.1	
Detecting Tolerance	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0.6	0.6	
Achieving Tolerance	0.7	0.7	0.7	0	0	0	0.7	0.7	0	0.7	0	0	0	0	0	0	
Sum		0.7	1.2	1.5	1.1	-0.1	0.9	2.1	0.2	1	0	-0.4	0.4	0	0.8	0.6	
Rank		2	1	1	2	3	2	1	3	1	2	3	3	4	1	2	

The concept scoring matrix in TABLE V shows that the concepts that should further be developed are the slicer, scooter, modified hydraulic press, and ultrasonic sensor.

However, since both the team and Botanical PaperWorks are looking for the ideal process and not a single ideal concept, multiple concepts were considered, as the best concepts may not produce the ideal process when implemented together. For example, even though the modified hydraulic press ranked number one in its category, it would not be suited to create a higher level of automation in the process, which is ideal.

3. Testing Plans and Detailed Concept Descriptions

The concept testing plan consists of how the concepts were tested at Botanical PaperWorks to ensure that they will produce the desired outcome. A planned execution vs. results matrix will be used for each test, to define if the results are conclusive. An example is shown in TABLE VI, where the outcome of each box is described below.

TABLE VI: PLANNED EXECUTION VS. RESULTS MATRIX

	Planned Execution		
Results		Yes	No
	Yes	i	ii
	No	iii	iv

This matrix is useful to show if the testing gives valid information.

i. If the testing was executed as planned and the results are what is expected, the testing is valid.
ii. If the testing was not executed as planned and the results are what is expected, the testing was lucky.
iii. If the testing was executed as planned and the results are not what is expected, the testing needs revision.
iv. If the testing was not executed as planned and the results are not what is expected, this isn't useful for the report.

The concepts that will be expanded upon are as follows: the shaker, the slicer, the scooter, the roller press, and the piston.

Although the modified hydraulic press is one of the top scoring concepts, the team was not able to find a way to test this concept without buying a hydraulic press. As a result, a testing plan was created for the roller press as an alternative. It is believed that this option could work better in conjunction with other concepts to create the ideal process for Botanical PaperWorks.

3.1. Slurry Tray Shaker

The slurry tray shaker is designed to eliminate the thickness variation among both a single sheet of paper as well as among multiple sheets. This concept is adapted from a simple concrete vibrating table which is used to settle concrete without any air pockets.

Figure 4 shows a sketch of the bottom of the shaker. A vibrating motor is attached to a piece of wood, which is connected on top of a tire.

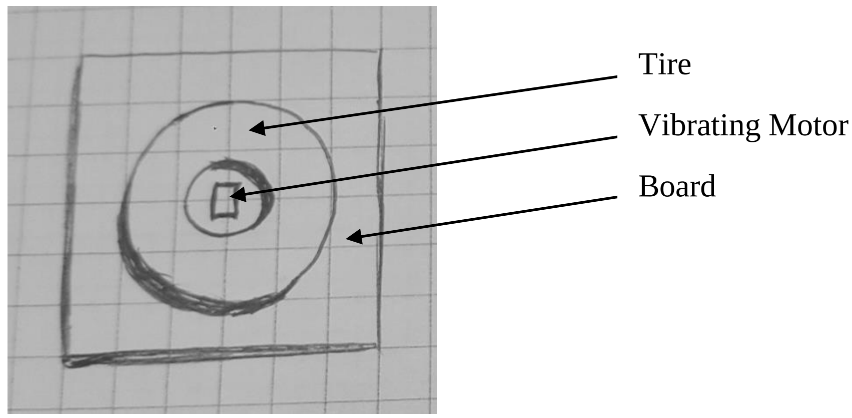


Figure 4: Sketch of the bottom of the shaker

Figure 5 shows a sketch of the shaker in use, with a tray on top.

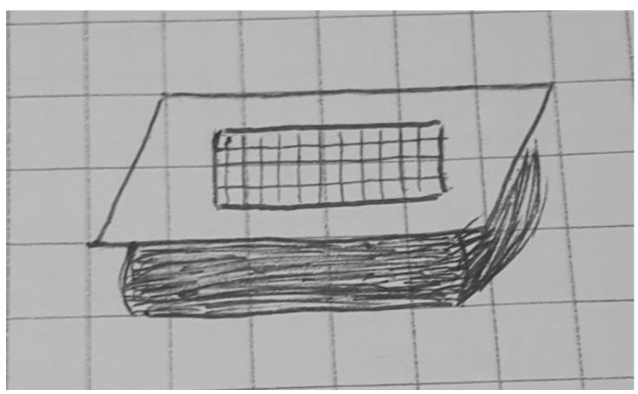


Figure 5: Sketch of the shaker in use with a tray on top

The concept elements are described in detail in the bill of materials,

TABLE *VII*.

TABLE VII: BILL OF MATERIALS FOR SHAKER

Description	Quantity	Unit	Unit Cost (CAD $)	Supplier
Vibrating Motor [4]	1	EA	$222.00	History Stones
Tire [5]	1	EA	$10.00	Thomas Auto & Tire
Plywood, at least 2 feet x 2 feet [6]	1	EA	$7.85	Home Depot
Total			$239.85	

3.2.Slurry Tray Slicer

The slurry tray slicer is designed to correct thickness variation by skimming a straight edge along the surface of the slurry mixture. This concept can be tested without altering the current setup at Botanical PaperWorks, with the introduction of a few components onto the trays that are already in use. This includes three 2 inch by 2 inch boards for construction, a straight razor edge to level the slurry mixture, as well as two lengths of ABS plastic to slide the slicer along. Figure 6 shows a sketch of what the slicer will look like for testing.

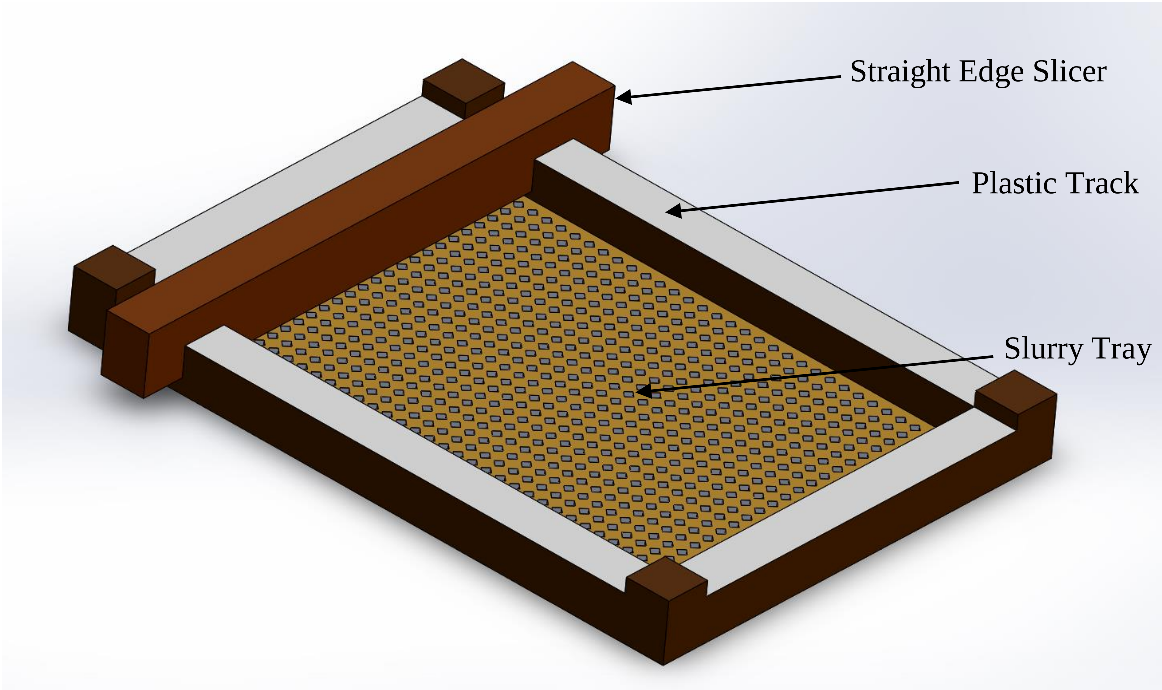


Figure 6: Slurry slicer sketch

A bill of materials list that will be used to build and test this concept can be seen in TABLE VIII.

TABLE VIII: BILL OF MATERIALS FOR SLICER

Description	Quantity	Unit	Unit Cost (CAD $)	Supplier
2"x 2" Board [7]	3	EA	$5.67	Home Depot
1 ½" x 18" ABS Plastic [8]	1	EA	$5.98	Home Depot
4" Razor Scraper Blades [9]	6	EA	$2.97	Home Depot
Total			$40.81	

3.3. Scooter

The scooter concept is designed to address the issue of heavy lifting for the paper making operators, which involves lifting 40 lbs buckets and carrying them up to 20 feet. Currently, the operator needs to lift the bucket that contains the paper slurry and move it from the mixer to the water sink. Our concept involves utilizing a scooter and placing the bucket onto it so the operators can move it easier. A three dimensional model of the scooter is shown in Figure 7.

Figure 7: Scooter concept model

Botanical PaperWorks mixes their own paper slurry in the buckets that are used for transporting to the slurry vats. Therefore, using just a scooter to help alleviate operator strain does not take in to consideration how they would manage to mix the slurry within the bucket, as a scooter would tend to spin and hinder their mixing process. Figure 8 shows a solution to this problem.

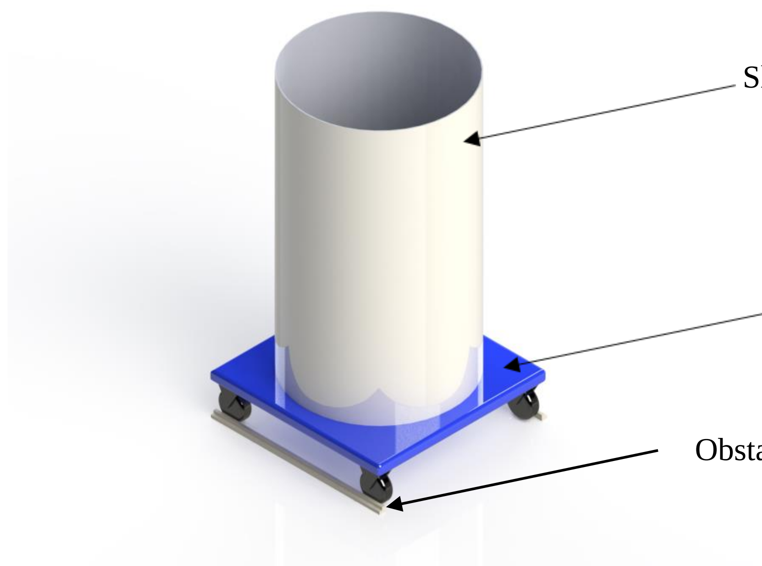


Figure 8: Model of scooter with added design considerations

To make the scooter a more viable concept for Botanical PaperWorks, some tracks were added to the testing of this design to stop any rotation during mixing. While the scooter itself will not rotate, our solution is to stick a rubber pad on the surface of the scooter, so that when the paper slurry is mixing, the rubber pad can use friction to prevent rotation of the bucket. The obstacle blocks were added in close proximity to the wall in order to limit tripping hazards. The bill of materials for the scooter is shown in TABLE IX.

TABLE IX: BILL OF MATERIALS FOR SCOOTER

Description	Quantity	Unit	Unit Cost (CAD $)	Supplier
Gym Scooter [10]	1	EA	$19.99	Amazon
Rubber Pad [11]	2	EA	$2.34	eBay
Obstacle Blocks [12]	2	EA	$12.39	eBay
Total			$49.45	

3.4. Roller Press

The roller press concept is based on a clothes wringer, which wrings the water out of clothes to speed up drying time. Ideally, this design will not only speed up the drying process by wringing water out of the paper sheets more efficiently than the current process, but the parallel rollers would also press each sheet evenly to achieve the ideal tolerance at the thickness 0.248 mm.

Figure 9 shows a sketch of a clothes wringer based on of a model by Calliger.

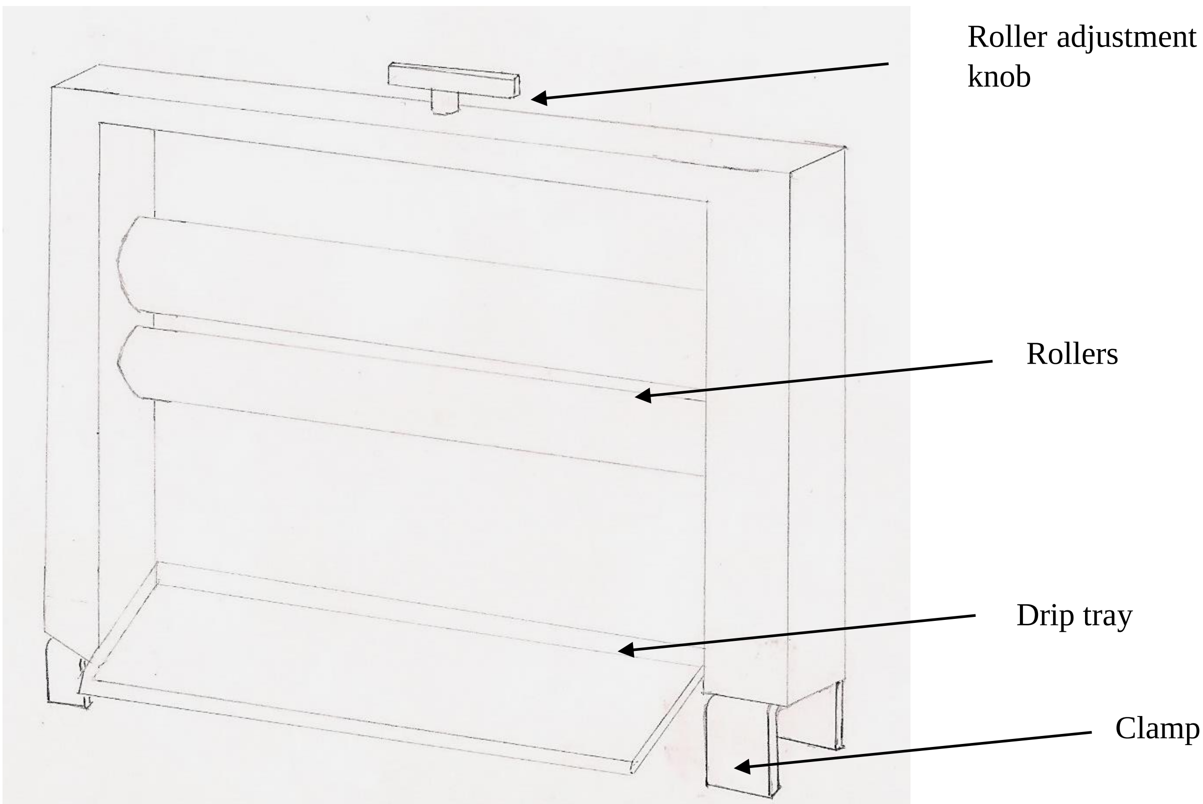


Figure 9: Sketch of clothes wringer

The roller press in Figure 9 consists of two parallel and adjustable rollers with a dripping tray and clamps to secure the mechanism to either a table or the side of a bucket.

To test this process on a small scale, a pasta maker could be used as a prototype to limit prototyping costs. A bill of materials can be found in TABLE X.

TABLE X: BILL OF MATERIALS FOR ROLLER PRESS

Description	Quantity	Unit	Unit Cost (CAD $)	Supplier
Clothes wringer [13]	1	EA	$195.00	Amazon
Pasta maker [14]	1	EA	$56.97	Walmart
Total			$251.97	

3.5.Piston

The piston concept is a design that would minimize the lifting load on the operator to almost none by pulling the screen through the slurry mixture and lifting the screen out of the pulp slurry. This concept could also help achieve the ideal tolerance of 3% by maintaining a more level screen surface as it rises out of the slurry.

Figure 10 shows a sketch of how this concept would be implemented into the slurry bucket.

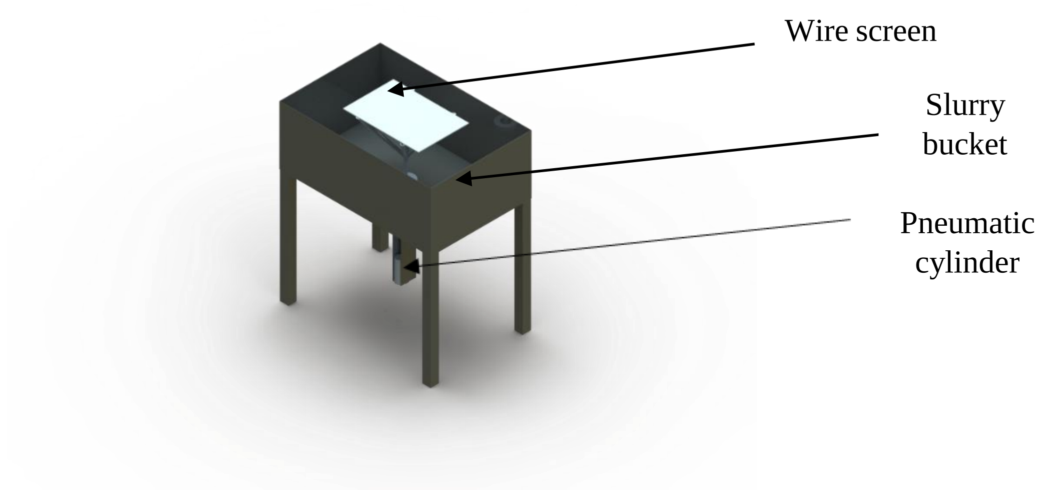


Figure 10: Sketch of piston concept design

Figure 10 shows a pneumatic piston attached to wire supports to hold the screen as it lowers and raises the screen through the slurry. Industrial magnets would be used to fix the screen onto the wire supports. A pneumatic cylinder is the ideal cylinder type to be used because this application has minimal loads, and pneumatic cylinders cost less than hydraulic ones.

Ideally, the cylinder would be controlled by a single push button so that the operator could work on other tasks as the screen moves through the slurry. Computational fluid dynamics was used in place of prototyping to reduce prototyping costs, and a pneumatic piston will be chosen after accurate results are found. A bill of materials can be found in TABLE XI.

TABLE XI: BILL OF MATERIALS FOR PISTON

Description	Quantity	Unit	Unit Cost (CAD $)	Supplier
Pneumatic cylinder	1	EA	Not yet established	Not yet established
Wire supports	4	EA	$7.56	Metal Supermarkets
Industrial magnets	4	EA	$6.99	Princess Auto
Seal	1	EA	$5 - $10	Seal Direct
Total			$63.50 – $68.20 (plus the pneumatic cylinder)	

3.6. Change Process Layout

The current process at Botanical PaperWorks is shown in Figure 11.

Figure 11: Current process

The current process does not follow a linear flow path, which takes extra time and energy for the operators. By changing the process to Figure 12, it will save the operators the extra movement and make the flow path linear.

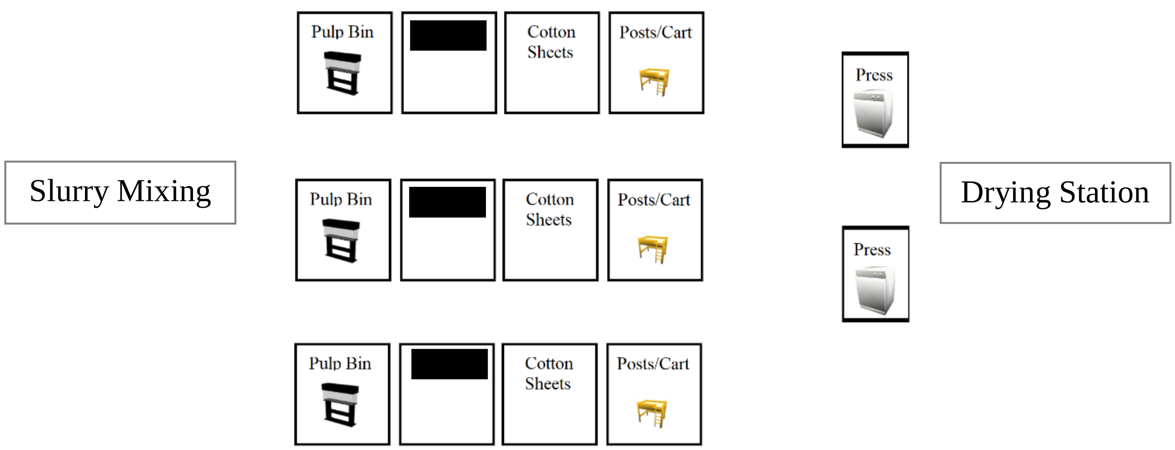


Figure 12: Change process flow

This change is not costly since the operators will simply switch the location of the equipment and this can be done on days that the operators are not making paper.

3.7.Ultrasonic Sensor

After the handmade paper is made and dried, an inspection procedure is applied to detect if the variation of paper thickness is allowable or not. After the concept scoring section, the ultrasonic sensor is considered to be the best concept to detect the paper thickness because of the advantages of ease of use, accuracy and detection speed. An example of an ultrasonic sensor is shown in Figure 13. The measuring range of this sensor is between 1 – 300 mm with a resolution of 0.01 mm, and an accuracy of ±0.1 mm.

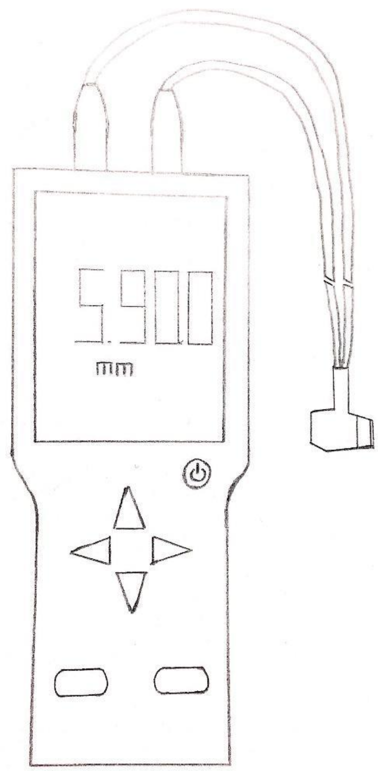


Figure 13: Ultrasonic Thickness Sensor

A bill of materials for the ultrasonic sensor can be found in TABLE XII.

TABLE XII: BILL OF MATERIALS FOR ULTRASONIC SENSOR

Description	Quantity	Unit	Unit Cost (CAD $)	Supplier
Ultrasonic Sensor	1	EA	Not yet established	Not yet established
Total			Not yet established	

4. Testing Results

The testing of the concepts was performed by Botanical PaperWorks, with various materials. For testing purposes, the product that would be used to test the concept is not always the same as the final product. For example, the roller press was tested by using a pasta maker, where the actual roller press is much larger and more expensive. This process was followed where possible, to save both time and money as most materials could be bought at a hardware store immediately, instead of waiting weeks to receive a more expensive product from overseas. The team believes that by using this assumption, the testing results will be accurate enough to determine if it is worth moving forward with the design.

4.1. Slurry Tray Shaker

Testing the shaker concept would be implemented by using a palm sander attached to the side of the [redacted] table to determine if the shaking of this motor is sufficient enough to control the thickness variation of the sheets. Since a palm sander would be used instead of vibrating motor for testing, a revised bill of materials for the shaker is shown in TABLE XIII, with the required materials for testing.

TABLE XIII: BILL OF MATERIALS FOR TESTING SHAKER

Description	Quantity	Unit	Unit Cost (CAD $)	Supplier
Palm Sander [15]	1	EA	$25.00	Resale site
Total			$25.00	

Due to time constraints, the testing for the shaker concept was not executed. However, the team still decided to move forward with this concept into detailed design, as it is believed that it will succeed in reducing paper thickness variation.

4.2. Slurry Tray Slicer

The testing of the slicer concept was carried out by Botanical PaperWorks as per the team's instructions. This involved mounting the slicer on the slurry trays being used in production. A series of tests were performed on sheets of seed paper after being initially formed while still wet to try and take down the high spots that account for the paper thickness variation. The setup can be seen in Figure 14 below.

Figure 14: Slurry slicer testing setup

The tests quickly displayed a problem with this design. The paper at this stage of formation would adhere to itself and would catch on the slicer edge. This caused the paper to be dragged and torn as shown in Figure 15 below.

Figure 15: Slurry slicer testing results

As can be seen from the figure above, the tearing of the paper occurred only on the sides. The source of this problem is a combination of tray material deformation, and inaccuracies in the concept test build. Figure 16 and Figure 17 below demonstrate these problems.

Figure 16: Image of inaccuracy with testing build

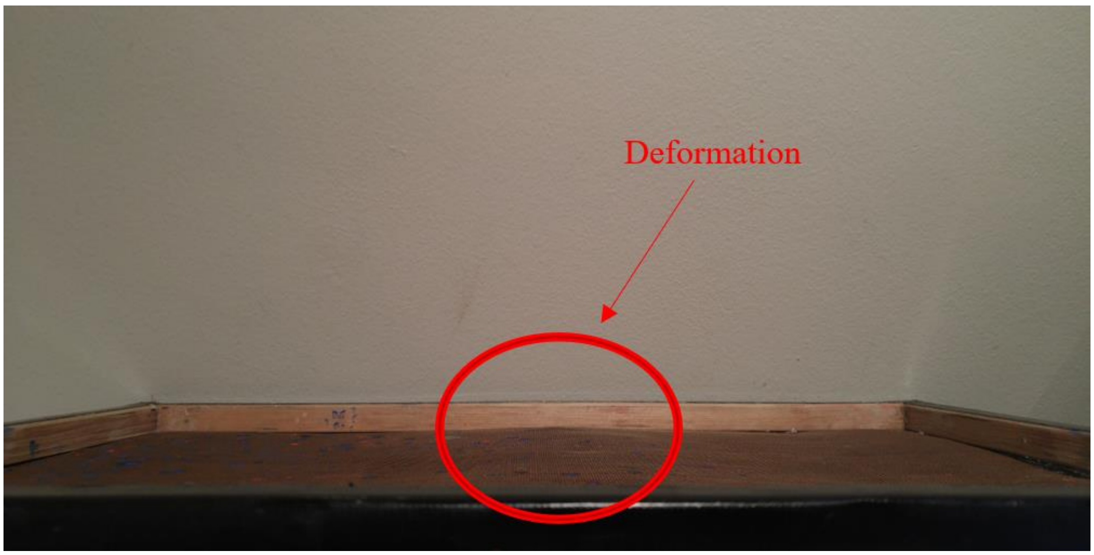


Figure 17: Deformation of slurry tray

To correct these problems, the slurry tray material would have to be monitored and replaced often to ensure it does not deform too much and create a non-uniform surface for the slicer to run over.

The results from testing the slicer are seen in TABLE XIV and support the decision to not move the slicer into detailed design.

TABLE XIV: PLANNED EXECUTION VS RESULTS FOR SLICER

	Planned Execution		
Results		Yes	No

	Yes		
	No		x

The slicer testing was not executed as planned since there were slight inaccuracies with the construction of the testing equipment and the results are not what was expected. It was determined though, that for this concept to work, high levels of precision and maintenance would be needed. Therefore, the slicer will not advance to the final design phase.

4.3.Scooter

The testing of the scooter was implemented by Botanical PaperWorks. This involved setting the slurry bucket on a scooter, to limit lifting. This improved the ergonomics for the operators as they do not need to lift and carry the buckets up to 20 feet anymore.

The results from testing the scooter are seen in TABLE XV and support the decision to move into detailed design.

TABLE XV: PLANNED EXECUTION VS RESULTS FOR SCOOTER

	Planned Execution		
		Yes	No
Results	Yes	x	
	No		

The scooter testing was executed as planned and the results are what were expected, therefore the scooter will advance.

4.4.Roller Press

One test of the roller press was carried out by Botanical PaperWorks, and three were carried out by the team. The test was done using a pasta maker instead of a clothes wringer to save on prototyping cost. A set up of the test can be seen in Figure 18.

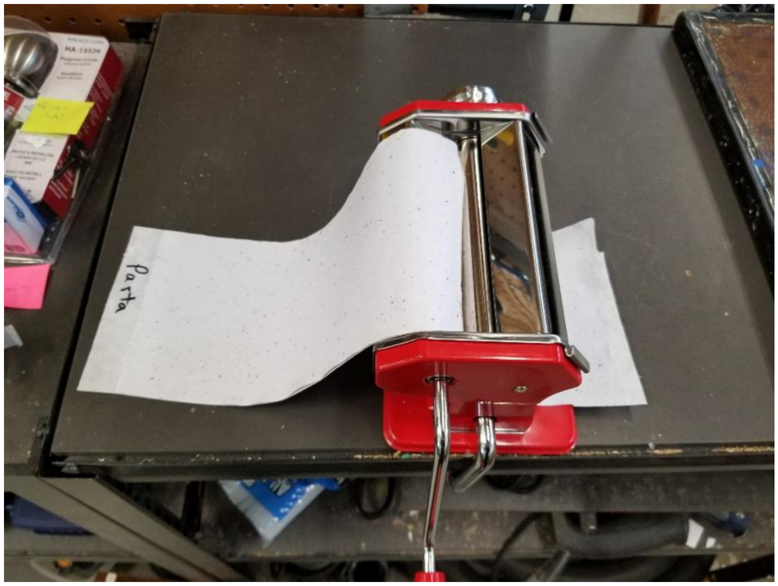


Figure 18: Set up of roller press test

In the first test, almost every basil seed was crushed when it passed through the rollers. Figure 19 shows an image of a control basil seed (A) compared to the crushed seed (B) that went through the rollers.

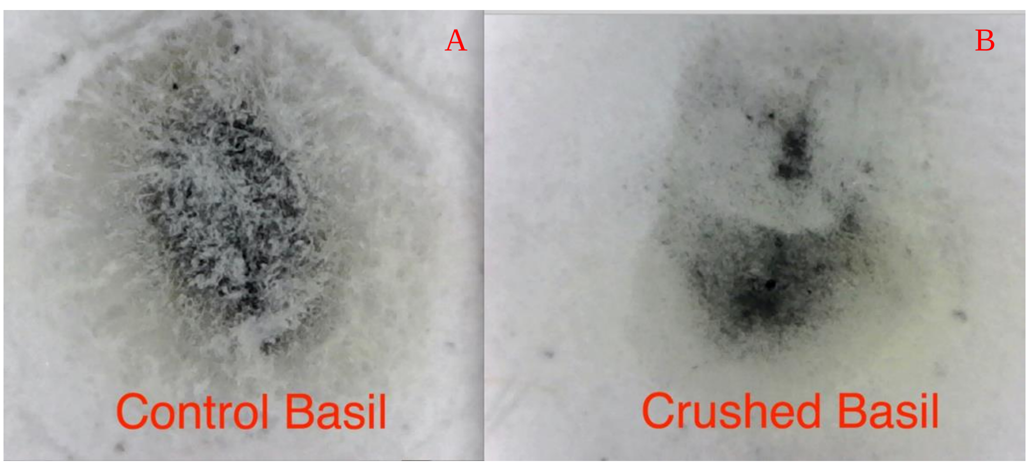


Figure 19: Control basil seed (A) vs crushed basil seed (B)

From the testing performed, the team concluded that the basil seeds were crushed by the intense point load created by the steel rollers. Ideally, the rollers would be made from nitrile rubber as opposed to steel, in order to avoid destroying the seeds. Additional testing would need to be performed to determine if lowering the contact pressure on the basil seeds corrected this issue. As well as crushing the basil seeds, the roller press significantly wrinkled the seed paper on the first test. Figure 20 shows seed paper wrinkled by the roller press compared to a control seed paper.

Figure 20: Seed paper wrinkled by the roller press (left) vs a control seed paper (right)

When comparing the wrinkled paper to the control paper, additional testing is needed to confirm if the pressure imposed by the steel rollers is at fault, or if the paper is wrinkling due to hitting the side of the pasta maker. Since the pasta maker has no pressure gauge, the exact pressure exerted is unknown.

To simulate the ductility of rubber and lower the contact pressure on the seed paper, the team layered sheets of cotton towel between the seed paper until the basil seeds were no longer being crushed. Figure 21 shows basil seed paper with various layers of cotton towel being compared to a control basil seed paper.

Figure 21: Basil seed paper after being compressed by the roller press with varying layers of cotton sheets compared to the control basil seed paper

Figure 21 shows that sandwiching layers of cotton sheets around the seed paper prevented the basil seeds from being crushed. This indicated that rubber rollers would reduce the contact stress on the basil seeds and prevent them from being crushed. The germination rates still have to be tested to ensure that the seeds are not being damaged, but results will not come in time for the duration of this project. The wrinkling in the seed paper was also found to completely reduce, with the addition of the cotton sheets, unless the cotton sheet had a wrinkle prior to going through the rollers. Figure 22 shows a comparison between the wrinkles produced when the seed paper was fed through the rollers without any cotton sheets, and with one cotton sheet.

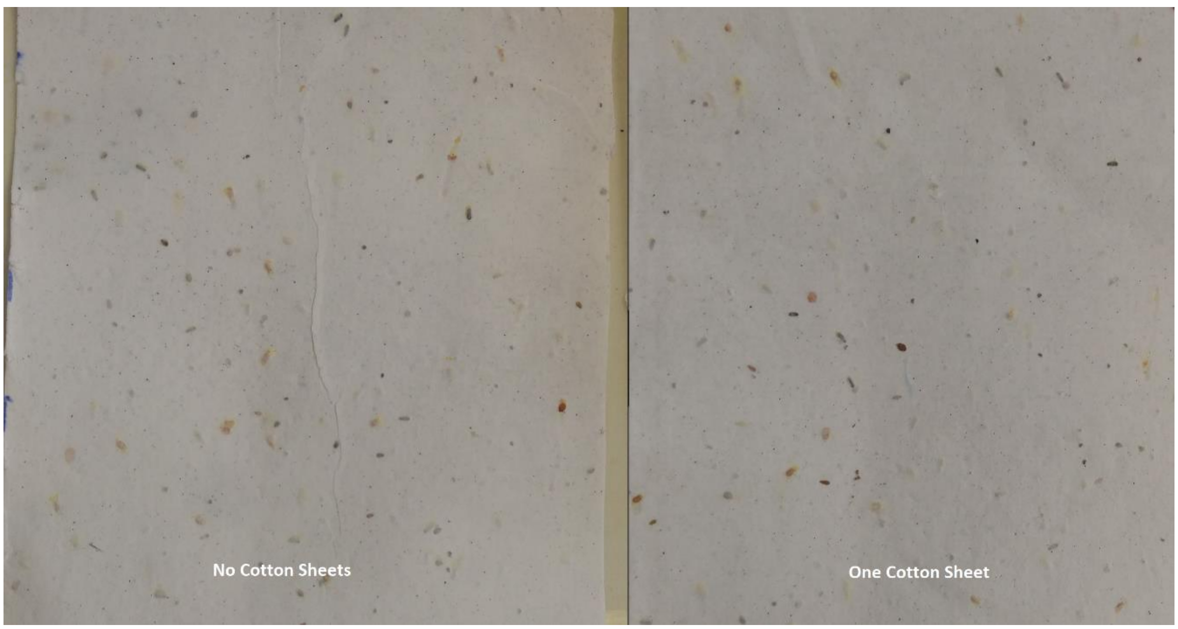


Figure 22: Comparison of wrinkles produced between no cotton sheets (left) and one cotton sheet (right)

Figure 22 shows that the wrinkling produced by the rollers was most likely due to excessive contact pressure caused by the steel rollers. Nitrile rollers should eliminate this issue. TABLE XVI shows a summary of the quantitative results of these tests.

TABLE XVI: SUMMARY OF ROLLER PRESS TESTING RESULTS

[redacted]

	0.42	0.41	2%	2%	2%	
	0.39	0.36	8%	9%	10%	
Test 2	0.47	0.44	6%	12%	16%	12%
	0.52	0.53	-2%	3%	2%	
	0.55	0.54	2%	3%	3%	
	0.57	0.55	4%	7%	5%	
	0.56	0.55	2%	5%	5%	
Test 3	0.71	0.69	3%	28%	25%	5%
	0.54	0.53	2%	3%	4%	
	0.54	0.54	0%	3%	2%	
	0.51	0.51	0%	8%	7%	
	0.48	0.48	0%	14%	13%	
Test 4	0.56	0.57	-2%	4%	0%	5%
	0.56	0.55	2%	4%	4%	
	0.62	0.61	2%	6%	7%	
	0.61	0.58	5%	4%	2%	
	0.57	0.54	5%	2%	5%	

TABLE XVI shows that the rollers reduced the water weight in the seed paper significantly which will increase drying time and improve the overall tolerance in the paper.

The results from testing the pasta maker are seen in TABLE XVII.

TABLE XVII: PLANNED EXECUTION VS RESULTS FOR ROLLER PRESS

	Planned Execution		
Results		Yes	No
	Yes		
	No	x	

The roller press testing was executed as planned and the results are not what were expected, therefore the testing needs revision, such as using rubber rollers.

4.5. Piston

After consultation with Dr. Ormiston [16], performing computational fluid dynamics would be out of the scope of this project and take too long due to the complexity of this simulation.

A few simplified versions of the problem were done, but they were found to not be accurate and to not reflect the actual flow pattern.

Instead of using CFD to test this concept, a screen was pulled through a settled pulp bucket to see if it would adequately mix the slurry. The screen was only moved in a linear motion to the bottom of the pulp bin leaving a bit of a gap for the head of the linear actuator, and back out of the slurry mixture. Figure 23 shows a before and after picture of the slurry in this experiment.

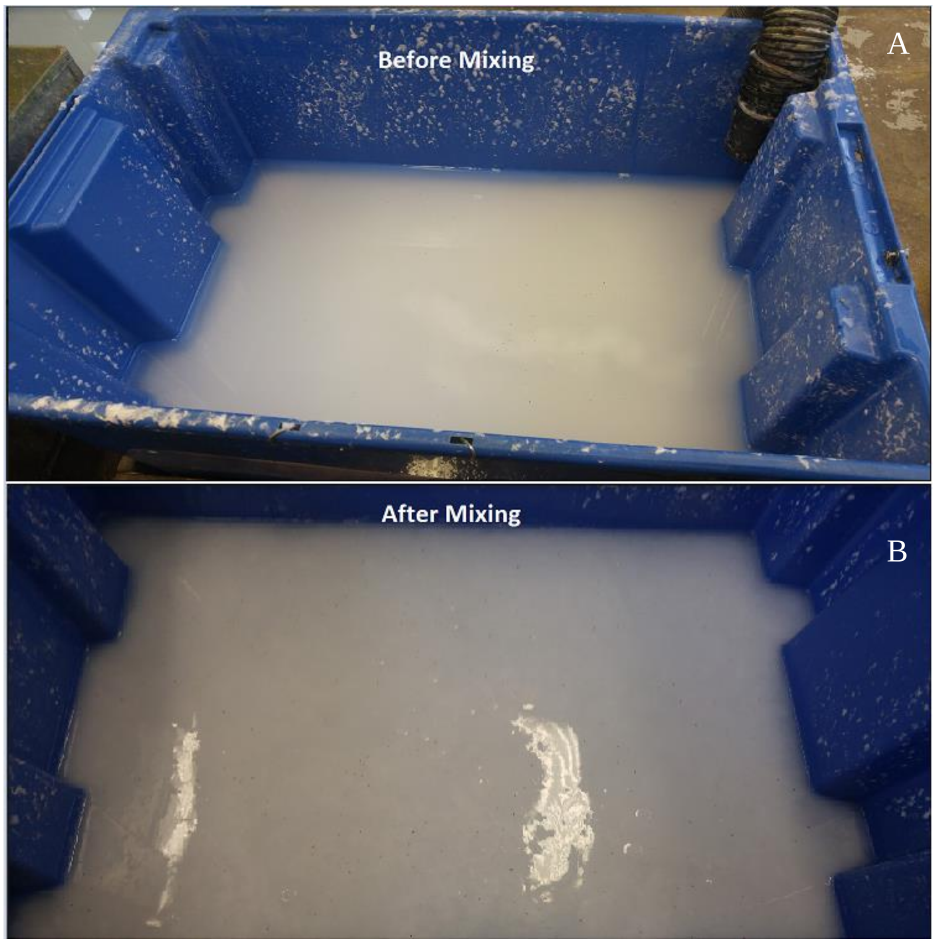


Figure 23: Pulp bucket comparison before (A) and after (B) mixing

The slurry was well mixed after pulling the screen through the mixture and the operator would have to perform little to no mixing of slurry in the execution of this concept.

As the entire piston could not be tested, TABLE XVIII shows the results from the testing that was performed, which involved mixing the pulp vertically. These results support the decision to move into detailed design.

TABLE XVIII: PLANNED EXECUTION VS RESULTS FOR VERTICAL MIXING

	Planned Execution		
Results		Yes	No
	Yes	x	
	No		

The testing was executed as planned and the results are what was expected, therefore the vertical mixing and piston concepts will advance.

5. Optimization

Each concept that moved forward after concept scoring and testing has been optimized in the following section. This includes the implementation and the cost of the components.

5.1. Slurry Shaker Tray

In order to properly implement a shaker concept in with the current process, a few considerations should be made. The first consideration is how to implement this concept in the most efficient way possible with the setup already being used at Botanical PaperWorks.

It was decided that implementation of the shaker with the [redacted] table would provide the best results as it can be easily adapted for both purposes. This would involve mounting an eccentric weight motor to the frame of the [redacted] table that will shake the slurry mixture before drying to even out the variation in thickness. This would also involve some integration of wiring with the [redacted] table control for ease of use by the operator. An image of this can be seen in Figure 24.

[redacted]

Figure 24: [redacted] table with vibrating motor attached to side and rubber feet

Another consideration that was made is to attach rubber feet to the bottom of the [redacted] table, so as to eliminate any vibration that would cause movement of the [redacted] table.

A cost breakdown of this detailed design is displayed in TABLE XIX.

TABLE XIX: COST BREAKDOWN FOR SHAKER DESIGN

Item	Cost (CAD $)
Vibrating Motor **[4]**	$222.00
Rubber pads (6) **[11]**	$14.04
Total	$236.04

5.2.Scooter

The scooter concept improves ergonomics for the operators, by limiting the heavy lifting of the slurry buckets. The gym scooter is made from plastic with the maximum loading of 100 lbs, which is more than sufficient for the 40 lbs slurry buckets.

To optimize the scooter performance, a handle should be installed, making the scooter more user friendly and avoiding the need to bend down and pick up the handle.

5.3. Roller Press

From the testing results, we can conclude that the roller press does in fact improve paper tolerances. As well, the hydraulic press may be detrimental to improving tolerances when put in such large posts, at such high pressures. To outweigh the benefits of using a modified hydraulic press, the roller press must be able to work efficiently enough to not cause time delays in paper production.

The roller press concept works towards full automation of the paper making process for Botanical PaperWorks. However, if the roller press is implemented alone, the production time of each sheet of seed paper will increase as it requires each sheet to be individually pressed, rather than in the current 20 sheet posts on the hydraulic press.

To achieve the required effieciency, an automatic and continuous system for paper production would need to be implemented. An illustration of this can be seen below in Figure 25.

Figure 25: Roller press and table with cotton feed

In the system shown, a plant layout change would have to occur, as well as the introduction of a continuously fed belt of cotton for the paper to travel on as it is moved through the roller press. This continuous system would feed through the press in batch sizes of three, which is the maximum post size that Botanical PaperWorks uses when drying their paper.

This system would eliminate the need for stacking the paper into the 20 sheet posts, and then seperating into three stack posts which is cumbersome and time consuming. This system could also automatically feed the paper through the press at a desired speed and set pressure to ensure consistent pressure is applied to each indiviual sheet. Based on testing, this was shown to improve the tolerance, and with individual pressing, it is believed that the drying time will be reduced as well.

TABLE XX shows the cost breakdown for the roller press design.

TABLE XX: COST BREAKDOWN FOR ROLLER PRESS DESIGN

Item	Cost (CAD $)
Roller Press **[17]**	$6250
Roller Table **[18]**	$194
Roller Table Legs (2) **[19]**	$170
Total	$6614

5.4. Piston

The idea of this design is to use a pneumatic cylinder or linear actuator to raise and lower the copper screen through the slurry to eliminate operator strain. Figure 26 shows how this design would be implemented in Botanical PaperWorks.

Figure 26: Piston design implemented under stainless steel sink

The piston design would be fixed to the bottom of a stainless steel sink with a stainless steel housing and a piston seal to prevent water from leaking onto the shop floor. The screen would be held up with stainless steel rod supports and fastened to the supports using strong industrial magnets.

Initially, a pneumatic cylinder was to be used for this design, but compressed air would increase the noise pollution on the manufacturing floor and a pneumatic cylinder would require a sophisticated control system to allow the cylinder to operate at a push of a button. For these reasons, a water proof linear actuator is recommended instead.

Linear actuators are better suited to applications with little load and longer strokes, as needed in this design. They also have the ability to have more sophisticated control systems easily implemented, such as an Arduino controller. Four linear actuators were considered from four different suppliers: Princess Auto, Figrelli Automations, Ge Ming, and Tolomatic. TABLE XXI shows a summary of what information was found.

TABLE XXI: SUMMARY OF LINEAR ACTUATOR RESEARCH

	Price (CAD $)	Stroke	Duty Cycle	IP Rating	Controller Compatibility
Princess Auto Hydroworks SKU: 8507840 [20]	$84.89	12 in	25%	IP65	Hydroworks Controllers
Figerlli Automations Classic Rod Linear Actuators [ref] [21]	$132.00	12 in	20%	IP54	Arduino
Ge Ming HTA2500 Linear Actuator [22]	$35.00	Adjustable up to 300 mm (11.8 in)	25%	IP54 with IP65 option	Unknown
Tolomatic ERD015 [23]	N/A	12 in	100%	IP67	Arduino

The stroke length refers to the fully extended length of a linear actuator. A stroke length of 12 inches or above is necessary for this application . Therefore, research was focused on linear actuators with a stroke length of 12 inches to limit costs.

The duty cycle refers to the ratio of active to inactive time of the linear actuator [24]. The duty cycle referenced in TABLE XXI states the duty cycle when the linear actuator experiences a maximum loading condition. The duty cycle will be much higher in reality as the copper screen and pulp mixture do not even account for 25% of the maximum load for any of these actuators.

The Ingress Protection, IP, rating denotes the environmental protection of the linear actuators [25]. An IP rating of at least IP65 is needed for this application, but IP67 or higher would be ideal. IP65 means that the actuator is totally protected against solids and dust, and water resistant to low velocity water jets. IP67 means that the part is dust proof as well as water proof for short periods of time. There is one higher IP rating, IP69, which means that the actuator will be protected for close range high pressure jet sprays in high temperatures as well as long emersions in water.

The controller compatibility column states the controllers that are compatible with the linear actuator. If no controller is used, each actuator operates by holding a button until the actuator hits its limit switch, where it automatically stops until the button is pressed again. This would be a time-consuming process, but would not produce any ergonomic strain on the operator.

When compared, the linear actuator best suited for this purpose with the best price is the Ge Ming HTA2500 linear actuator. This is due to its IP rating of 65 and maximum speed of three centimeters per second, which should be suitable for this purpose. The duty cycle is only 25%, but that is taken under the maximum loading conditions of 800 N. Our application does not approach forces at that level, and would therefore increase the possible duty cycle that can be achieved.

A stainless-steel sink, like those that are used in restaurants, would be ideal for the implementation of this design to make mounting and sealing easier. The linear actuator should be firmly mounted onto the bottom of the slurry bin with a stainless-steel housing as seen in Figure 27.

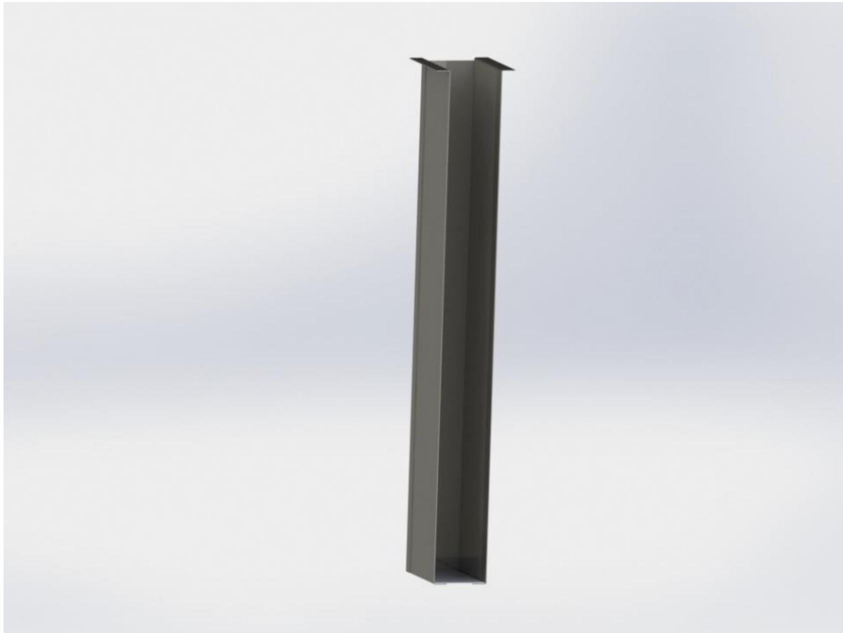


Figure 27: Linear actuator housing

The housing can either be mounted using standard fasteners and sealed with silicone caulking or welded directly onto the bottom of the sink. Welding is recommended to prevent leaks forming from the pulp bin. The housing is made of four simple panels spot welded together. The bottom panel should be left free until it is ensured that the linear actuator fits properly into the housing. Drawings for the linear actuator housing can be found in Appendix E .

A piston seal is required to seal the linear actuator rod to prevent the slurry mixture from leaking onto the facility's floor. A piston seal housing would need to be manufactured or sourced to weld onto the bottom of the pulp bin to maintain a proper seal around the linear actuator rod. Drawings for a piston seal housing were not created as the linear actuator rod diameter could not be obtained from the information provided by the manufacturer.

The wire supports would be made out of stainless steel to avoid corrosion in the water. After calculations, using a height of four inches and an incline of 20 degrees, each support would need to be 11.5 inches long, requiring four feet of material required.

A cost breakdown summary of the piston design is shown in TABLE XXII.

TABLE XXII: COST BREAKDOWN OF PISTON DESIGN

Item	Cost (CAD $)
Liner Actuator **[22]**	$35.00
Linear Actuator Housing **[26]**	$70 - $140
Stainless Steel Sink **[27]**	$269.99
Piston Seal **[28]**	$5 - $10
Piston Seal Housing **[29]**	$40 - $80
Wire Supports (0.125 in diameter) **[30]**	$7.56
Industrial Magnets **[31]**	$6.99
Total	$434.48 - $549.54

TABLE XXII shows the total design would cost between $435 and $550. A controller is still needed for the final implementation of this design. An Arduino controller is compatible with the vast majority of linear actuators, but it is uncertain if an Arduino is compatible with the Ge Ming linear actuator due to ambiguous technical specifications. An Arduino controller is desirable for this design because of the large amount of opensource code available to aid in creating the software to control the linear actuator.

5.5. Thickness Measurement Sensor

The thickness measurement sensor is important to the success of this project, as it provides a quick way of determining if the paper is within the acceptable variation range. The team originally decided to use the ultrasonic sensor, but after more research was conducted, it was found that this type of sensor would provide inaccurate results when measuring paper thickness. Therefore, a laser thickness sensor was found and decided on as our final design.

The multi-function analog laser sensor from Keyence [32] provides a high degree of accuracy in the measurement of thickness variation and is flexible in height control. This laser sensor is capable of high resolutions, from 1- 50 μm, based on different measurement ranges of sensor series. It also satisfies IP67 water proofing standard to work in a wet environment.

To apply the laser sensor into our paper making process, two IL-065 laser sensors are placed 20 cm apart above the [redacted] table, mounted on a swinging cantilever beam. The measurement range for the IL-065 sensor is 55 – 105 mm with the display resolution of 2 μm. When the worker is operating the [redacted] table, the cantilever mount is available to rotate at different angles to keep the work space clear. When the process is finished, the worker can rotate the sensor mounting and place the sensors above the paper to detect the thickness variance.

After the sensors are mounted, the LK-G3001(P)V integrated controller or LK-G3001(P) direct controller is able to set parameters for these sensors by connecting them to it. Then the peripheral equipment such as PC, data logger and PLC can detect the thickness variation and record the data. A schematic diagram of the entire thickness measurement setup is shown in Figure 28.

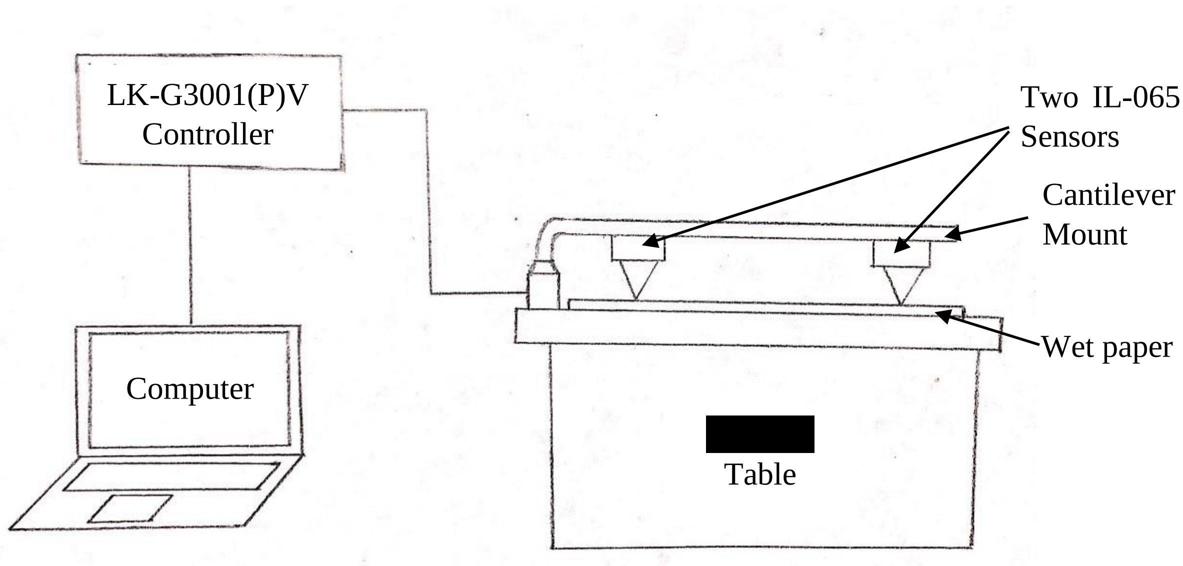


Figure 28: Paper thickness measurement processing

A cost breakdown for this sensor and controller package is listed in TABLE XXIII.

TABLE XXIII: COST BREAKDOWN FOR LASER SENSOR

Item	Cost (CAD)
Laser Thickness Sensor and Controller **[32]**	$1700
Total	$1700

6. Final Design

The concepts included in the final design are: the scooter, the shaker, the roller press, the piston, and the laser sensor. A new process would be required to properly implement all the designs. Figure 29 shows a flow chart of the manufacturing process required to implement all the concepts.

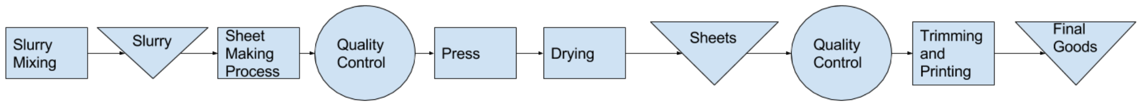


Figure 29: Recommended process flow diagram

The changes made in the flow chart was to add an inspection point immediately after the sheet making process and to eliminate the inventory before the press. The additional inspection point will eliminate rework caused by grossly delayed feedback for acceptable paper sheet thicknesses. Eliminating the need for rework will increase production by decreasing the waste found in the manufacturing process. Reducing the inventory levels in the process reduces production waste and is ideal.

A three dimensional model of the final design can be seen in Figure 30.

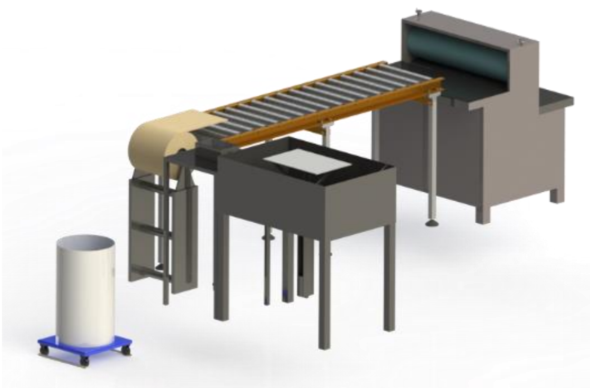


Figure 30: Final process

The process will start with mixing the slurry as in the current process, but will use a scooter to maneuver the slurry buckets through the manufacturing plant to reduce operator strain. The slurry will be transported into the stainless steel bin where the linear actuator will form a wet paper sheet by dipping the copper screen vertically into the slurry. The operator will then take the copper screen and transfer the paper onto a cotton sheet for transport to the roller press. After the sheets are pressed an operator will assemble the sheets into stacks for drying and the process will continue the same as before. The final design should be implemented so that the flow of the paper sheets travels in one direction at all times to limit the total travel distance and time of the final product.

6.1. Recommendations

The team recommends for Botanical PaperWorks to proceed with the following concepts: the scooter, the shaker, the piston, the roller press, the process layout change, and the laser displacement sensor. The following concepts were selected as they are effective, performed well in testing and have a valid cost breakdown.

The scooter is an effective way to move the slurry buckets around the plant, without needing to lift the heavy buckets long distances.

The piston and the roller press are both faster and more ergonomic for the operators, while also allowing for future improvements to be made seamlessly.

The process layout change is an easy and logical change that will ensure a smoother transition into a more automatic process flow.

While the following two concepts were not tested, the team believes that they will meet the targeted expectations.

When used in concrete applications, shakers are able to settle particulates well. The team believes this principle can be applied to a paper slurry mixture to reduce the paper thickness.

The laser displacement sensor is accurate and easy to use, with the ability to place these sensors at every station.

7. Future Considerations

Due to the limited scope of this project, and time constraints, some concepts were generated that could be implemented by Botanical PaperWorks in the future, but were not included in detailed design. Some of these concepts address the customer needs in more detail.

7.1. Hydraulic Lifting Table

If the strain on operators is a persistent problem at Botanical PaperWorks, then a modified scooter concept is suggested. The following lifting table would use either a hydraulic or scissor jack to alleviate the lifting strain when transferring the paper slurry from the buckets to the slurry vats. A diagram for this concept can be seen in Figure 31.

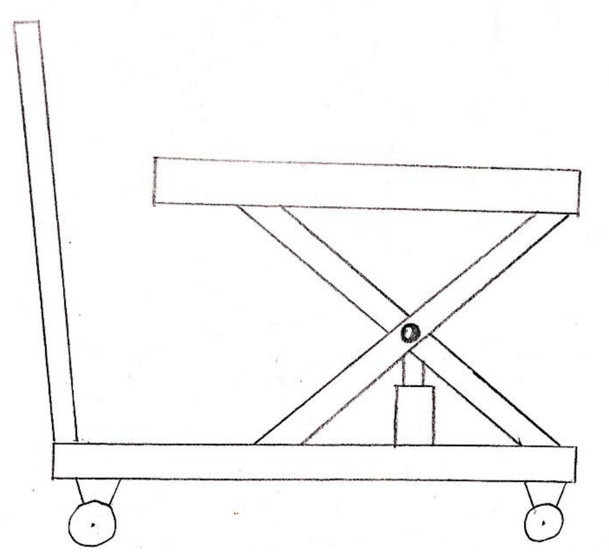


Figure 31: Drawing for hydraulic lifting table

The lifting table usually has the lifting capacity of 300 – 500 lb with 4 rotation wheels, and it can rise to a maximum height of about 30 inches above the ground. The schematic diagram for a hydraulic lifting table is shown in Figure 31, and two examples are shown in TABLE XXIV.

TABLE XXIV: EXAMPLES OF HYDRAULIC LIFTING TABLE

Item	Lifting Capacity (lb)	Material	Price (CAD $)	Supplier
Hydraulic Motorcycle Lift Table [33]	300	Metal	$149.95	Extreme Max
Hydraulic Scissor Lift Table Cart [34]	500	Metal	$169.99	Goplus

7.2. Slurry Trough

A consideration that Botanical PaperWorks could act on in the future is the idea of changing their current slurry mixing and transport process to a more contained trough system. Figure 32 depicts a preliminary render of how this system might work.

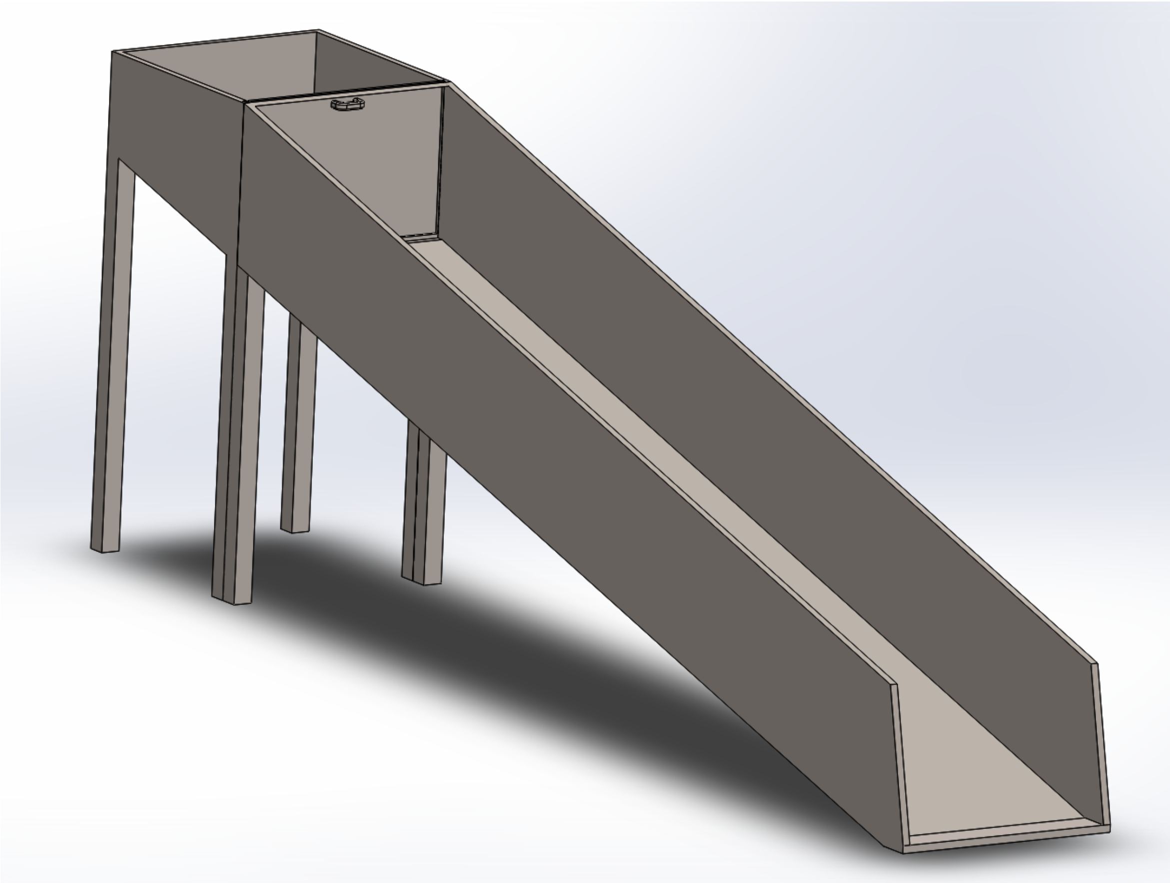


Figure 32: Slurry trough 3D model

This system would eliminate the need for moving the five-gallon pails of slurry to the vats, and therefore, eliminate operator strain altogether. To fully implement this system though would take considerable planning for how to set up the plant layout, as well as modification to their mixing stations.

7.3. Printing

To eliminate printer jams screen printing could be used. A four colour CMKY screen printing method would be necessary to achieve the detail required in most printing applications. CMKY screen printing is complex and would need to be outsourced to a skilled third party to achieve the quality necessary.

8. Cost Breakdown

Before testing the concepts, a cost breakdown was created for the testing plan and final design. TABLE XXV shows the cost breakdown of the testing plans.

TABLE XXV: COST BREAKDOWN FOR TESTING

Design	Description	Quantity	Unit Cost (CAD $)
Shaker	Palm Sander [15]	1	$25.00
Slicer	2"x 2" Board [7]	3	$5.67
Slicer	1 ½" x 18" ABS Plastic [8]	1	$5.98
Slicer	4" Razor Scraper Blades [9]	6	$2.97
Scooter	Gym Scooter [10]	1	$19.99
Roller Press	Pasta maker [14]	1	$56.97
Total			$142.77

Since the shaker, scooter and roller press concepts had additional parts added after the testing phase, TABLE XXVI shows the cost breakdown of final design. Since some of the concepts have various prices, the total is given as a range.

TABLE XXVI: COST BREAKDOWN FOR FINAL DESIGN

Design	Description	Quantity	Unit Cost (CAD $)
Shaker	Vibrating Motor [4]	3	$222.00
Scooter	Rubber Pad [11]	6	$2.34
Scooter	Obstacle Blocks [12]	2	$12.39
Roller Press	Roller Press [17]	3	$6250.00
Roller Press	Roller Table [18]	3	$194.00
Roller Press	Roller Table Legs [19]	6	$85.00
Piston	Liner Actuator [22]	3	$35.00
Piston	Linear Actuator Housing [26]	3	$70 - $140
Piston	Stainless Steel Sink [27]	3	$269.99
Piston	Piston Seal [28]	3	$5 - $10
Piston	Piston Seal Housing [29]	3	$40 - $80
Piston	Wire Supports (0.125 in diameter) [30]	3	$7.56
Piston	Industrial Magnets [31]	3	$6.99
Sensor	Laser Thickness Sensor and Controller [32]	6	$1700.00
Total			$32,050.44 - $32,395.44

Since there are concepts that the team was not able to analyze, TABLE XXVII shows the cost breakdown of the future considerations. Since not all of these concepts will be implemented, the total is given as a range.

TABLE XXVII: COST BREAKDOWN FOR FUTURE CONSIDERATIONS

Design	Description	Quantity	Unit Cost (CAD $)
Lifting Table	Hydraulic Motorcycle Lift Table [33]	1	$149.95
Lifting Table	Hydraulic Scissor Lift Table Cart [34]	1	$169.99
Total			$149.95 - $169.99

The total cost of the testing is $142.77, the total cost of the final design is between $32,050.44 and $32,395.44, and the total cost of the future considerations is between $149.95 and $169.99.

9. Summary

The objectives of this project are to develop a process to be used, either by hand or machine, to improve tolerances to within 3% variation from the current 10% variation, decrease operator strain, and increase the current output of 96 sheets per hour.

This process and its components must ensure that the paper produced agrees with the customer needs and abides by all project limitations. It will solve the printing problems currently encountered, and make it physically easier on the operators while increasing the total throughput.

The concepts that were decided upon to be a part of the final design process were: The scooter, the shaker, the piston, the roller press with roller table and the laser sensor. These concepts were decided upon because they provided the most benefits when used in conjunction with one another. When implemented, this process is expected to meet all marginal values for the desired metrics.

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Appendices

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Appendix A Benchmarking

Research on competitors establishes a target for the final design. The companies researched were, Green Field Paper Company, Plantable Seed Papers, and Blooim. Six different categories were used to compare Botanical PaperWorks against their competitors. These categories are, approximate tolerances, approximate germination rates, handmade or machine-made paper, production rate, size of sheets, thickness of paper and prices. However, some of this information was not available for certain companies due to a lack of response. As information becomes available, the ideal metrics for this project may change. TABLE XXVIII shows a summary of the benchmarking information found.

TABLE XXVIII: BENCHMARKING RESEACH INFORMATION

	Botanical PaperWorks	Green Field Paper Company	Plantable Seed Papers	Bloomin
Approximate Germination Rates	*information not available	*information not available	*information not available	1% for the ECOnomy paper [35]
Handmade or Machine Made	Handmade [1]	Both [36]	Handmade [37]	Handmade [35]
Size of Sheets	12"x18" [1]	23"x35" [36]	14"x25" [37]	23'x35" [35]
Thickness of Paper	9.75 pt. [1] [38]	22 pt. [36]	*information not available	12 pt. or 150-220 gsm [35]
***Prices**	$1.85/ 8.5"x11" sheet [1]	$19.95/5 sheets of 13"x19" [36]	$6.00/sheet for small orders [37]	$1.35/ 8.5"x11" sheet [35]

*further detail of pricing can be found in Appendix C

While much of the criteria in TABLE XXVIII is self-explanatory, a more in-depth explanation is need for a few categories to gain insight about why they were chosen to compare the companies against and their meaning. These categories are the size of sheets, the thickness of the paper, and the prices.

The size of sheet recorded for each company corresponds with the size of screen used to make the raw sheets of paper from the pulp slurry. The size of sheets was recorded to discover any advantages to using larger screens on either throughput rate or operator ergonomics.

The thickness of the paper was measured from the least expensive seeded paper produced by each company. Thickness was measured again to see if there are any advantages to a certain paper thickness in production.

Prices of the paper for each company corresponded to the cheapest stock paper produced by each company in their cheapest stock size. Typically, the lower end paper was usually undyed paper sheets with lower germination rates. Only prices for the smallest order are shown in the table and more information is available for a range in order sizes in Appendix C.

Appendix B House of Quality

A house of quality is a tool that relates the limitations to the metrics of a project. The house of quality created for this project can be seen on the next page in Figure 33. The customer needs can be seen in the vertical column, customer requirements, and the metrics are shown in the horizontal column, technical requirements.

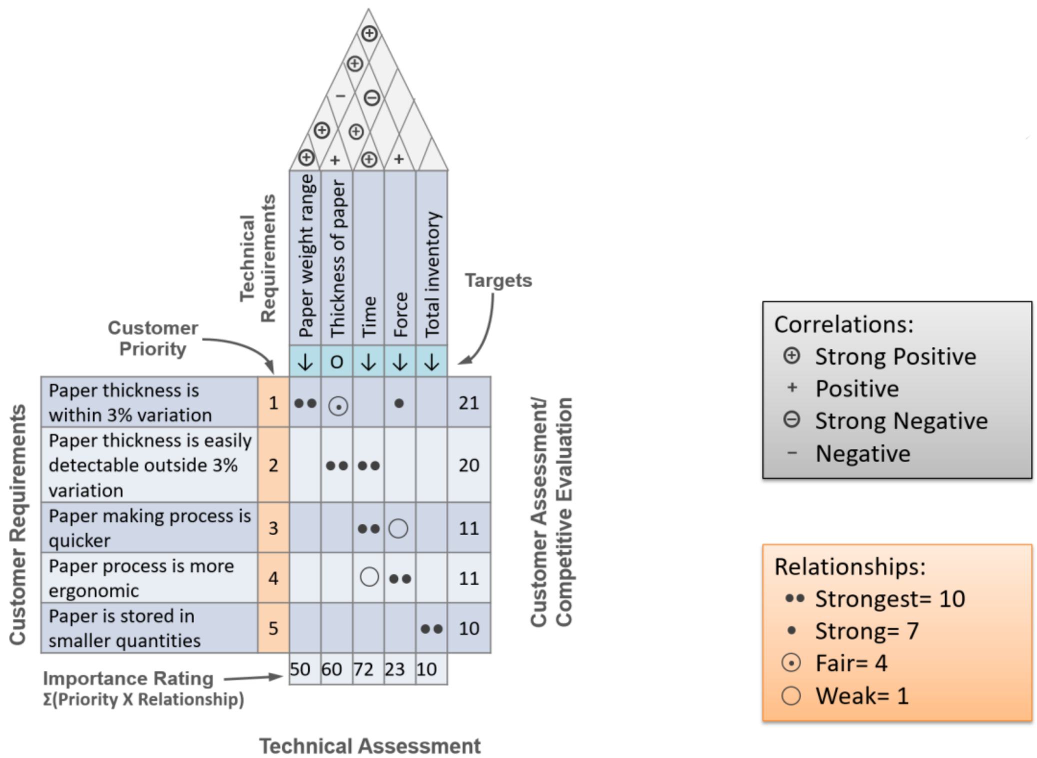


Figure 33: House of quality [11]

Figure 33 shows in order, that most important metrics are the time, thickness of paper, and paper weight range in weighted rank. Figure 33 also shows that the most important customer needs, in order, are paper thickness is within 3% variation, paper thickness is easily detectable outside 3% variation, and paper making process is quicker in weighted rank. This information is important to help focus the resources available in this project to more important customer needs.

Appendix C Prices of Orders for Seed Paper Companies

Prices for paper orders widely differed depending on the size of order placed for mostly paper companies, below are tables for pricing for various order sizes for Botanical PaperWorks, Greenfield Paper Company, and Plantable Seed Papers. Bloomin does not price their ECOnomy seed paper differently by order size.

TABLE XXIX: PRICING FOR BOTANICAL PAPERWORKS NATURAL WHITE WILDFLOWER SEED PAPER

	Botanical PaperWorks
0-99	$1.85 [1]
99 or above	$1.55 [1]

The paper that the Botanical PaperWorks prices are taken from is their natural white wildflower seed paper. The next prices shown are from Green Field Paper Company.

TABLE XXX: PRICING FOR GREEN FIELD PAPER COMPANY GROW-A-NOTE SHEET IN NATURAL WHITE

	Green Field Paper Company
5 [13"x19"]	$19.95 [3]
25 [13"x19"]	$90.00 [3]
50 [13"x19"]	$175.00 [3]
10 [8.5"x11"]	$21.95 [3]
25 [8.5"x11"]	$50.00 [3]
50 [8.5"x11"]	$90.00 [3]

The Green Field Paper Company paper that prices are shown above is the Grow-A-Note sheet in natural white. This paper closely resembles the Botanical PaperWorks paper used, which is why it was chosen. The last company that detailed pricing was taken from Plantable Seed Papers and can be seen in TABLE XIV.

TABLE XXXI: PRICING FOR PLANTABLE SEED PAPERS STANDARD PAPER

	Plantable Seed Papers
0-40	$6.00 [4]
41-120	$5.75 [4]
121-240	$5.50 [4]
241-480	$5.25 [4]
481-960	$5.00 [4]
961-1920	$4.75 [4]
1921-3840	$4.50 [4]
3891 and above	$4.25 [4]

The prices from Plantable Seed Papers was taken from their standard paper pricing chart. Their standard paper comes in 19”x25” size sheets and are untrimmed.

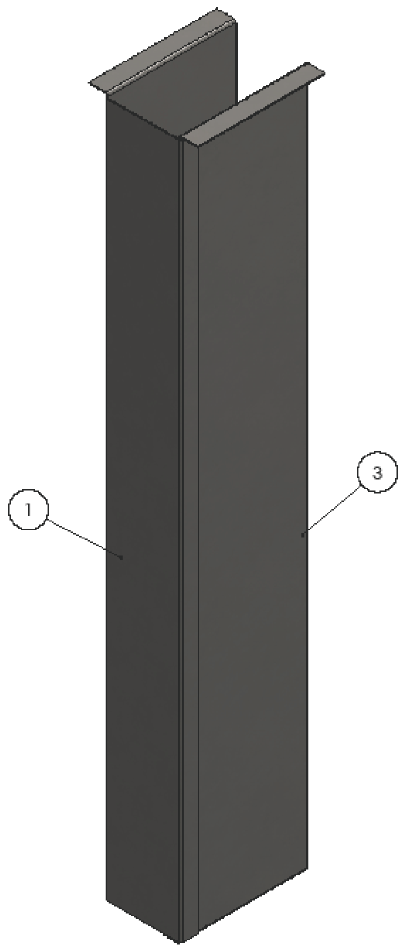
Appendix D Concept Comparison Table

For selecting those concepts that we came up to improve paper making processes, a concept comparison table is applied to compare the relevancy of concepts with some selection criteria, such as ease of implementation, cost and time. We compare each concept with the current process, and score each concept from -1 to +1, for example, +1 means the concept has an improvement comparing with the current for a certain criterion. All the details are shown in TABLE XV.

TABLE XV: CONCEPT COMPARISON TABLE

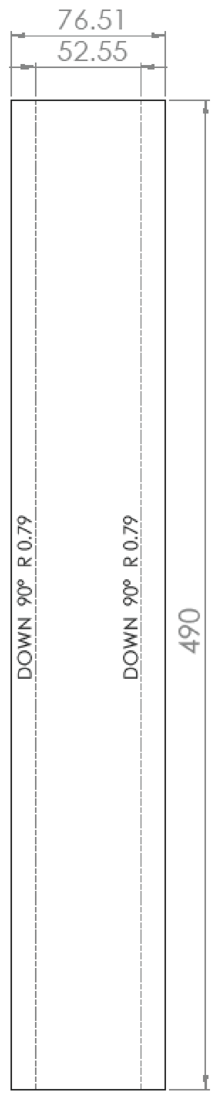
Selection Criteria	Concept Variables															
	Shaker	Slicer	Scooter	Cart	Leveling Tables	Press Roller	Modified Hydraulic Press	T-shirt Oven	Piston	Change Flow	Greenfield Paper Process	Digital sensor	Optical sensor	Ultrasonic sensor	"Feeler" gauge	Reference
Ease of Implementation	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0
Cost	1	1	-1	-1	-1	-1	1	-1	1	1	0	1	1	1	1	0
Time	-1	-1	1	1	0	-1	1	-1	1	1	0	1	1	1	1	0
Ergomics	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Testablity	1	1	1	1	-1	-1	0	-1	-1	1	1	-1	-1	-1	-1	0
Ease of Use	1	1	1	1	1	0	1	-1	1	0	0	0	0	1	0	0
Sum	**1**	**1**	**2**	**2**	**-1**	**-3**	**3**	**-4**	**2**	**2**	**0**	**0**	**0**	**1**	**0**	**0**
Rank	**6**	**6**	**2**	**2**	**14**	**15**	**1**	**16**	**2**	**2**	**9**	**9**	**9**	**6**	**9**	**9**

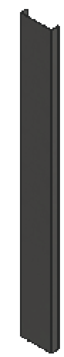
Appendix E Drawings



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Linear Actuator Housing Back Plate		1
2	Linear Actuator Housing Bottom Plate		1
3	Linear Actuator Housing Side Plate		2

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
	NAME	SIGNATURE	DATE		TITLE:		
DRAWN	AT		11/29/2017		Linear Actuator Housing		
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: Stainless Steel Gauge 20	DWG NO.		A3
				WEIGHT:	SCALE 1:2	SHEET 1 OF 4	





UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	AT		11/29/2017
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Linear Actuator Housing Back Plate

MATERIAL: Stainless Steel Gauge 20

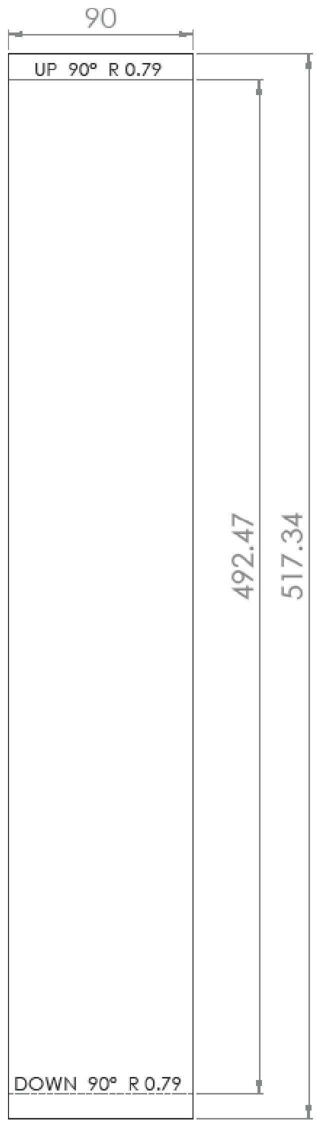
DWG NO.

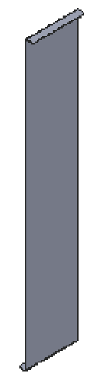
A3

WEIGHT:

SCALE 1:2

SHEET 2 OF 4





UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING / REVISION

	NAME	SIGNATURE	DATE
DRAWN	AT		11/29/2017
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Linear Actuator Housing Side Plate

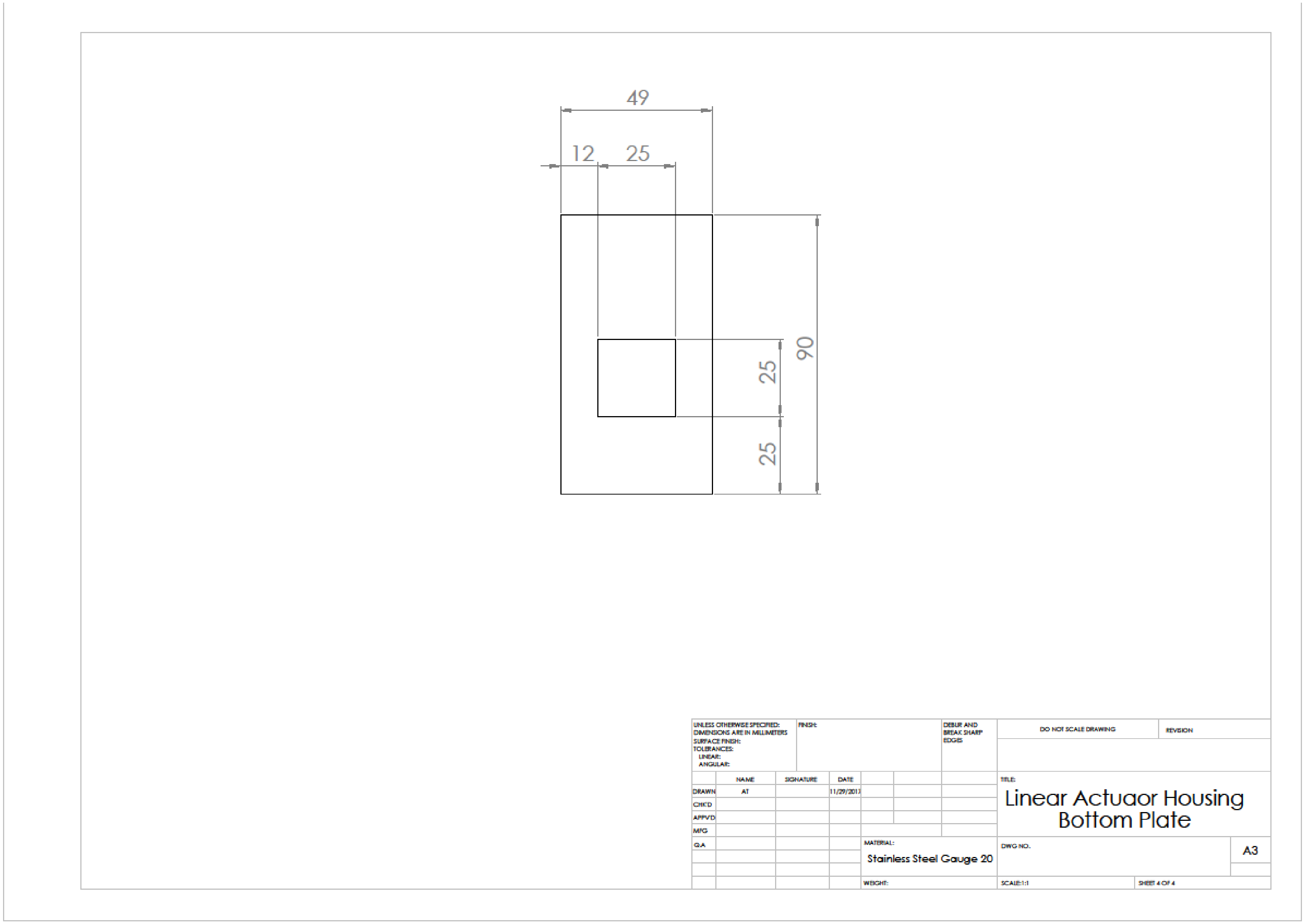
MATERIAL: Stainless Steel Gauge 20

DWG NO. A3

WEIGHT:

SCALE: 1:2

SHEET 3 OF 4


49
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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
AT
11/29/2017
CHK'D
APPV'D
MFG
Q.A
TITLE:
Linear Actuaor Housing Bottom Plate
MATERIAL:
Stainless Steel Gauge 20
DWG NO.
A3
WEIGHT:
SCALE:1:1
SHEET 4 OF 4

Appendix F Project Schedule

This section contains information on the project schedule through the use of a Gantt Chart and the progression of the project with a WBS.

In order to achieve a more efficient execution of the whole project, there are two scheduling tools that are applied during this project: the Gantt Chart and the Work Breakdown Structure (WBS). The Gantt Chart is used to track the project tasks with start dates and deadlines to evaluate the project progress and can be found in Appendix G . The Work Breakdown Structure is used to split project plans into small tasks to help manage the teams schedule. A figure depicting the WBS can been seen in Appendix H .

A weekly schedule is help us to split the final objective into small tasks and focus on what we achieved for each week. It is more flexible to adjust than the Gantt Chart to manage the project process of the group.

The weekly schedule from Oct. 29 till up to Dec. 7 for our group is shown in Table XXXI.

Table XXXII: WEEKLY SCHEDULE FOR OCT. 29 TO DEC. 7

Period	Tasks
Oct.29 – Nov. 4	• Phase 3 headings & Introduction added • Visited to Botanical PaperWorks
Nov. 5 – Nov. 11	• Visited to Botanical PaperWorks • Concepts tested
Nov. 12 – Nov. 18	• Focused on Report Writing
Nov. 19 – Nov. 25	• Finished report initial draft on Nov. 22nd
Nov. 26 – Dec. 2	• Finished report draft on Nov. 27th
Dec. 3 – Dec. 7	• Finished poster on Dec. 4th • Practiced oral presentation • Finished final project report on Dec. 6th

Appendix G Gantt Chart

The following figures show the Gantt Chart of this engineering design project starting from phase 1 to phase 3. Each of the tasks are labeled with the start date and the finish date, as well as the corresponding expected duration of each task.

WBS	Task Mode	Task Name	Duration	Start	Finish
1		Phase I	11 days	Mon 17-09-18 8:00 AM	Mon 17-10-02 5:00 PM
1.1		Preliminary Meetings	1 day	Mon 17-09-18 8:00 AM	Mon 17-09-18 5:00 PM
1.1.1		Warm-up Meeting	0 days	Mon 17-09-18 8:00 AM	Mon 17-09-18 8:00 AM
1.1.2		Client Introduction	0 days	Tue 17-09-19 8:00 AM	Tue 17-09-19 8:00 AM
1.1.3		Project Overview	0 days	Tue 17-09-19 8:00 AM	Tue 17-09-19 8:00 AM
1.2		Preliminary Research	3 days	Tue 17-09-19 8:00 AM	Thu 17-09-21 5:00 PM
1.2.1		Background of Botanical PaperWorks	1 day	Tue 17-09-19 8:00 AM	Tue 17-09-19 5:00 PM
1.2.2		Current Working Progress	2 days	Tue 17-09-19 8:00 AM	Wed 17-09-20 5:00 PM
1.2.3		Specifications of	3 days	Tue 17-09-19 8:00 AM	Thu 17-09-21 5:00 PM
1.3		Identify Problem Research	2 days	Tue 17-09-19 5:00 PM	Thu 17-09-21 5:00 PM
1.3.1		Identify Probelm and	1 day	Tue 17-09-19 8:00 AM	Tue 17-09-19 5:00 PM
1.3.2		Identify Expectations	1 day	Wed 17-09-20 8:00 AM	Wed 17-09-20 5:00 PM
1.3.3		Identify Customer Needs	1 day	Thu 17-09-21 8:00 AM	Thu 17-09-21 5:00 PM
1.3.4		Identify Limitations	0 days	Fri 17-09-22 8:00 AM	Fri 17-09-22 8:00 AM
1.3.5		Identify Technical	0 days	Sat 17-09-23 8:00 AM	Sat 17-09-23 8:00 AM
1.3.5.1		Metrics with Marginal and Ideal Values	0 days	Sat 17-09-23 8:00 AM	Sat 17-09-23 8:00 AM
1.3.5.2		House of Quality	0 days	Sat 17-09-23 8:00 AM	Sat 17-09-23 8:00 AM
1.4		Project Management	7 days	Wed 17-09-20 8:00 AM	Thu 17-09-28 5:00 PM
1.4.1		Create Gantt Chart	3 days	Wed 17-09-20 8:00 AM	Fri 17-09-22 5:00 PM
1.4.2		Create WBS	4 days	Mon 17-09-25 8:00 AM	Thu 17-09-28 5:00 PM
1.5		Phase I Report	5 days	Sat 17-09-23 8:00 AM	Sat 17-09-30 8:00 AM
1.5.1		Phase I Report Draft	3 days	Sat 17-09-23 8:00 AM	Wed 17-09-27 5:00 PM
1.5.2		Report Draft Reviews	1 day	Thu 17-09-28 8:00 AM	Fri 17-09-29 8:00 AM
1.5.3		Report Correction	1 day	Fri 17-09-29 8:00 AM	Sat 17-09-30 8:00 AM
1.6		Phase I Presentation	0 days	Sun 17-10-01 8:00 AM	Sun 17-10-01 8:00 AM
1.6.1		Create PPT Slides	1 day	Sun 17-10-01 8:00 AM	Mon 17-10-02 5:00 PM
1.6.2		Presentation Practice	2 days	Mon 17-10-02 8:00 AM	Tue 17-10-03 5:00 PM
1.7		Phase I Report Due	0 days	Mon 17-10-02 8:00 AM	Mon 17-10-02 8:00 AM
1.8		Phase I Presentation Due	1 day	Tue 17-10-03 8:00 AM	Tue 17-10-03 5:00 PM
1.9		Phase I Peer Evaluation Due	0 days	Tue 17-10-03 8:00 AM	Tue 17-10-03 8:00 AM
1.10		Meeting Minutes & Gantt Chart Due	0 days	Wed 17-10-11 8:00 AM	Wed 17-10-11 8:00 AM

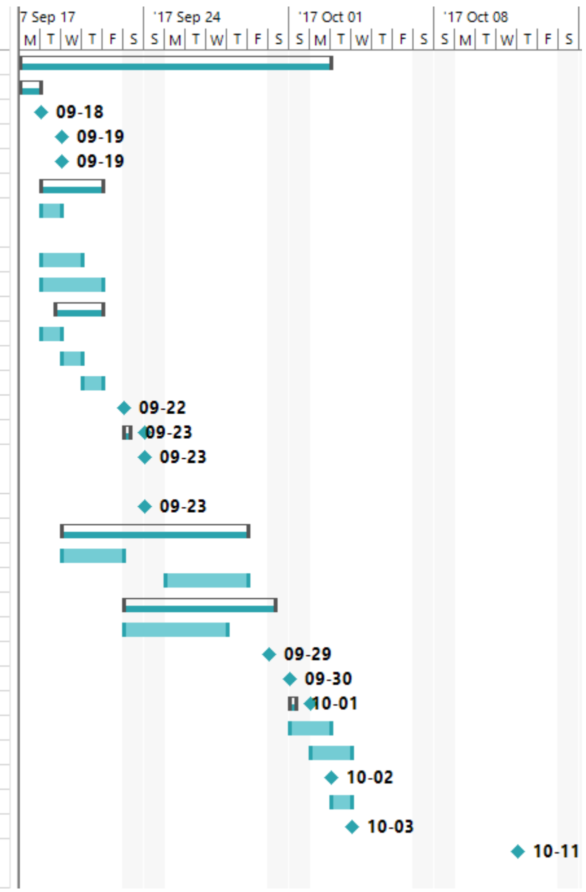

Figure 34: Gantt chart in phase I [39]

Figure 34 shows the schedule created for phase I of the project. Milestones can be seen as diamonds on the Gantt chart and tasks as bars spanning the task's duration. Phase II can be seen in Figure 35.

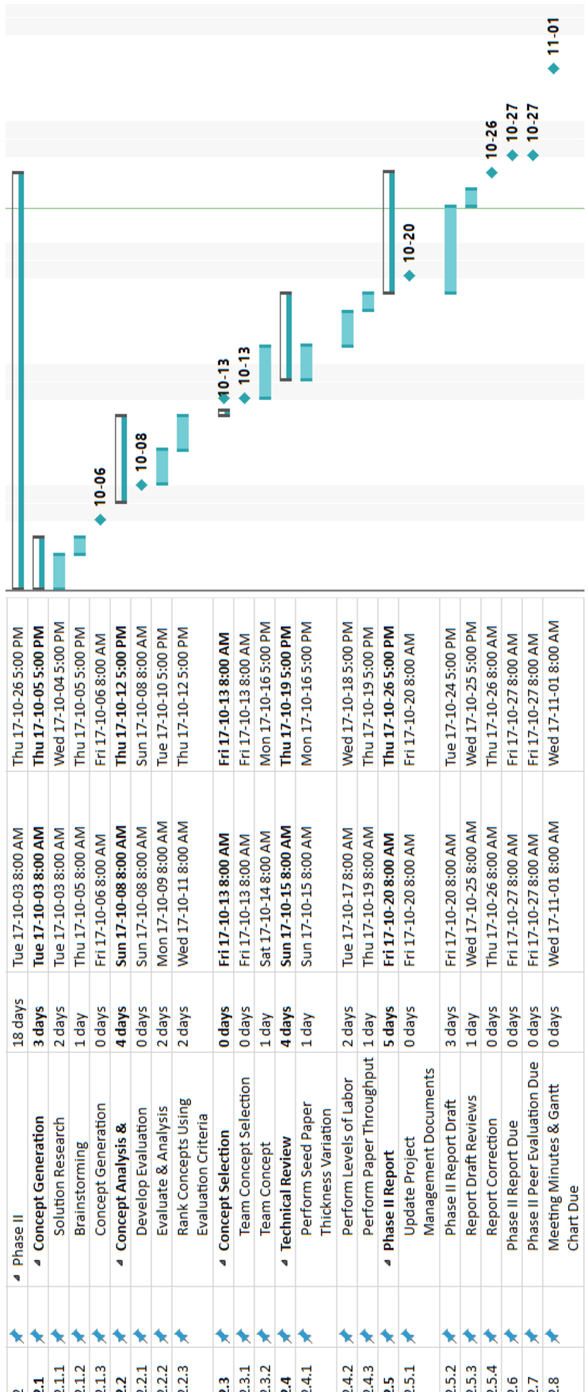

Figure 35: Gantt chart in phase II [39]

Figure 35 is the schedule created for phase II in Gantt chart format. Important tasks for phase II are concept design and concept selection. The phase II report deadline is November 17th. Phase III can be seen below in Figure 36.

3	Phase III	29 days	Fri 17-10-27 8:00 AM	Wed 17-12-06 5:00 PM
3.1	Detailed Design Analysis	15 days	Fri 17-10-27 8:00 AM	Thu 17-11-16 5:00 PM
3.1.1	Finalize Technical Design	2 days	Fri 17-10-27 8:00 AM	Mon 17-10-30 5:00 PM
3.1.2	Cost Analysis	3 days	Tue 17-10-31 8:00 AM	Thu 17-11-02 5:00 PM
3.1.3	Selection of Products	0 days	Sat 17-11-04 8:00 AM	Sat 17-11-04 8:00 AM
3.1.4	Generate Technical	9 days	Mon 17-11-06 8:00 AM	Thu 17-11-16 5:00 PM
3.1.5	Create BOM	9 days	Mon 17-11-06 8:00 AM	Thu 17-11-16 5:00 PM
3.2	Final Reporting	14 days	Fri 17-11-17 8:00 AM	Wed 17-12-06 5:00 PM
3.2.1	Phase III Report	10 days	Fri 17-11-17 8:00 AM	Thu 17-11-30 5:00 PM
3.2.1.1	Require Permissions of	5 days	Fri 17-11-17 8:00 AM	Thu 17-11-23 5:00 PM
3.2.1.2	Update Project Management	0 days	Fri 17-11-17 8:00 AM	Fri 17-11-17 8:00 AM
3.2.1.3	Phase III Report Draft	7 days	Fri 17-11-17 8:00 AM	Mon 17-11-27 5:00 PM
3.2.1.4	Report Draft Reviews	1 day	Tue 17-11-28 8:00 AM	Tue 17-11-28 5:00 PM
3.2.1.5	Report Correction	2 days	Wed 17-11-29 8:00 AM	Thu 17-11-30 5:00 PM
3.2.2	Final Presentation	4 days	Fri 17-12-01 8:00 AM	Wed 17-12-06 5:00 PM
3.2.2.1	Oral Presentation	0 days	Fri 17-12-01 8:00 AM	Fri 17-12-01 8:00 AM
3.2.2.1.	Create PPT Slides	0 days	Fri 17-12-01 8:00 AM	Fri 17-12-01 8:00 AM
3.2.2.1.	Presentation Practice	1 day	Sat 17-12-02 8:00 AM	Mon 17-12-04 5:00 PM
3.2.2.2	Poster Presentation	3 days	Sun 17-12-03 8:00 AM	Wed 17-12-06 5:00 PM
3.2.2.2.	Prepare Poster	1 day	Sun 17-12-03 8:00 AM	Mon 17-12-04 5:00 PM
3.2.2.2.	Presentation Practice	2 days	Tue 17-12-05 8:00 AM	Wed 17-12-06 5:00 PM
3.3	Draft Report Due	0 days	Fri 17-12-01 8:00 AM	Fri 17-12-01 8:00 AM
3.4	Final Report Due	0 days	Wed 17-12-06 8:00 AM	Wed 17-12-06 8:00 AM
3.5	Poster & Oral Presentation	0 days	Thu 17-12-07 8:00 AM	Thu 17-12-07 8:00 AM
3.6	Invite Client to Final	0 days	Wed 17-12-06 8:00 AM	Wed 17-12-06 8:00 AM
3.7	Peer Evaluation Due	0 days	Thu 17-12-07 8:00 AM	Thu 17-12-07 8:00 AM
3.8	Meeting Minutes & Gantt Chart Due	0 days	Wed 17-11-29 8:00 AM	Wed 17-11-29 8:00 AM
3.9	Copyright Agreement Form	0 days	Thu 17-12-07 8:00 AM	Thu 17-12-07 8:00 AM

Figure 36: Gantt chart in phase III [39]

Figure 36 is the schedule created for phase III in Gantt chart format. The most important phase III deliverable is a detailed analysis of the final design. The phase III report deadline is December 6th.

Appendix H Work Breakdown Structure

The Work Breakdown Structure (WBS) is used to visualize tasks of the whole project. The entire project is divided into three phases, and tasks in each phase are displayed in Figure 37.

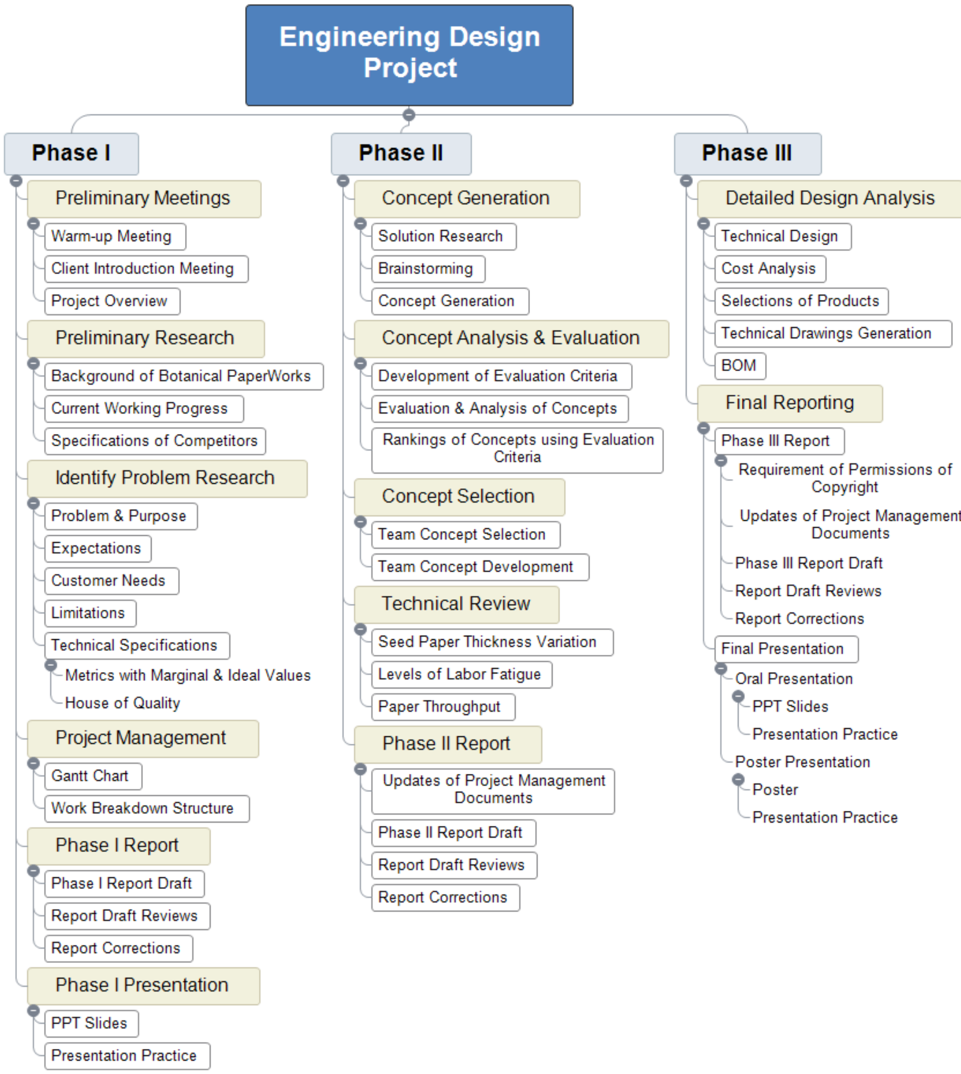

Figure 37: Work breakdown structure