Team 501 Concept Selection

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Concept Selection

Concept selection is a vital part of the engineering design process. This is where the design team takes the generated concepts and compares them to one another in a systematic way. Concept selection tools help to remove bias in the selection process. The first step is to use a streamlined "House of Quality" (HOQ) to infuse the voice of the customer into the engineering characteristics. Then, "Pugh Charts" are used to simply compare concepts to a datum and each other. Finally, "Analytical Hierarchy Process" (AHP) is used to select a concept in a very controlled manner. These processes will be discussed and implemented. A concept will be selected after all processed have been completed.

House of Quality (HOQ)

The HOQ is used to infuse the voice of the customer into the design process. This is done by comparing the correlation of engineering characteristics to customer requirements. The correlations and requirements are both ranked in a systematic way, and this results in weighted engineering characteristics. This tells designers which engineering characteristics are a priority over others.

		Engineering Characteristics						
Improvement Direction		↑	↑	↑	↑	↑	↓	↓
Units		Gram	Gram	Newton	Cubic Meter	OSHA	Percent Relative Moisture	Seconds
Customer Requirements	**Importance Weight Factor**	**Amount of Separated Powder**	**Amount of Contained Powder**	**Supportable Load**	**Operable Volume**	**Met Safety Standards**	**Contamination**	**Added Time to Overall Process**
Separate More Powder From the Part	4	9	3		1			1
Recover the Separated Powder	3	3	9		1			
Prevent Powder Contamination	5	1	1				9	
Hold the Part During Process	1	3		9	9			
Ensure Operator Safety	5			3		9		
Integrate With Current System	2							9
Raw Score	249	53	44	24	16	45	45	22
Relative Weight %		21.29	17.67	9.64	6.43	18.07	18.07	8.84
Rank Order		1	4	5	7	2	2	6

Figure 1. House of Quality Analysis

The HOQ clearly shows which engineering characteristics are the most important. The most important is the amount of separated powder. Close behind are safety standards and the contamination of the powder. These results were expected since they align with two of the key goals of the project (recycling powder and safety). The ranking of the customer requirements was determined using pairwise comparison. This can be seen in Figure 2. The found comparison values were interpreted into an importance weight factor between one and five. The results of the HOQ will help to focus on the more important engineering characteristics.

	Separate More Powder From the Part	Recover the Separated Powder	Prevent Powder Contamination	Hold the Part During Process	Ensure Operator Safety	Integrate With Current System	Sum	Rank (1-5)
Separate More Powder From the Part	~	1	0	1	0	1	**3**	**3**
Recover the Separated Powder	0	~	0	1	0	1	**2**	**2**
Prevent Powder Contamination	1	1	~	1	0	1	**4**	**5**
Hold the Part During Process	0	0	0	~	0	0	**0**	**1**
Ensure Operator Safety	1	1	1	1	~	1	**5**	**5**
Integrate With Current System	0	0	0	1	0	~	**1**	**1**
Sum	**2**	**3**	**1**	**5**	**0**	**4**		

Figure 2. Pairwise Comparison for Customer Requirement Ranking

Pugh Chart

Pugh charts are a simple way to select concepts based on engineering characteristics. This is done by comparing a single engineering characteristic of each individual design to that of a datum. The datum used for this project was the current powder recovery process. Eight concepts were compared to this datum (the five medium-fidelity and three high-fidelity concepts). This comparison can be seen in Figure 3.

Engineering Characteristics	Current Recovery Process	Tiny Tube Blower	Encased Low to High Frequency Vibration	Hanging Faucet Electromagnet	Electrostatic Brush	CNC Axis Part Mover	Spinning Sifter	Vibration Through all Stages	Multi-Directional Vibration
		Concepts							
Amount of Separated Powder	DATUM	+	+	+	+	+	+	+	+
Amount of Contained Powder		+	+	+	+	+	+	+	+
Supportable Load		S	S	S	S	-	-	-	-
Operable Volume		S	S	S	S	S	S	S	S
Met Safety Standards		S	S	S	S	S	S	S	S
Contamination		S	+	S	S	S	+	S	S
Added Time to Overall Process		-	-	-	S	S	-	-	-
	Total +	2	2	2	2	2	2	2	2
	Total -	1	1	1	0	1	2	2	2

Figure 3. First iteration of the Pugh Chart method with the current system as the datum.

The first iteration of the Pugh method showed three concepts that had two negatives in the analysis. These concepts were eliminated as options, and the electrostatic brush was decided to be the next datum. This is because it had no negatives and was not the overall best. If the overall best was selected as the datum, the analysis may be indeterminant. The second iteration can be seen in Figure 4.

Engineering Characteristics	Electrostatic Brush	Tiny Tube Blower	Encased Low to High Frequency Vibration	Hanging Faucet Electromagnet	CNC Axis Part Mover
		Concepts			
Amount of Separated Powder	DATUM	S	+	-	S
Amount of Contained Powder		+	+	-	S
Supportable Load		S	S	S	-
Operable Volume		S	S	S	S
Met Safety Standards		S	S	S	S
Contamination		+	+	S	+
Added Time to Overall Process		S	-	S	S
	Total +	2	3	0	1
	Total -	0	1	2	1

Figure 4. The second iteration of the Pugh method with the electrostatic brush as the datum.

The second iteration of the Pugh method showed that only one concept received no negatives, but this also did not have the most positives. The tiny tube blower had two positives and no negatives, whereas the encased low to high frequency vibration concept had three positives and one negative. The encased low to high frequency vibration is the best concept because it had the most positives, and its only negative is a low priority engineering characteristic. The added time engineering characteristic ranked to be the 6th most important out of 7. The positives of more important categories negate the single negative of having to run longer.

Analytical Hierarchy Process (AHP)

The analytical hierarchy process (AHP) is a matrix-based method to select the best concept. The method initially has the designer rank evaluation criteria against each other, and then check the validity of this step. Then, top concepts are compared based on a specific evaluation criterion. The first needed comparison is the "criteria comparison matrix." This can be seen in Figure 5.

	Criteria Comparison Matrix [C]					
	Ensure Operator Safety	Prevent Powder Contamination	Separate More Powder From the Part	Recover the Separated Powder	Integrate With Current System	Hold the Part During Process
Ensure Operator Safety	1.00	1.00	0.33	0.33	0.33	3.00
Prevent Powder Contamination	1.00	1.00	0.33	0.33	0.33	3.00
Separate More Powder From the Part	3.00	3.00	1.00	1.00	0.33	3.00
Recover the Separated Powder	3.00	3.00	1.00	1.00	3.00	3.00
Integrate With Current System	3.00	3.00	3.00	0.33	1.00	3.00
Hold the Part During Process	0.33	0.33	0.33	0.33	0.33	1.00
Sum	**11.33**	**11.33**	**6.00**	**3.33**	**5.33**	**16.00**

Figure 5. AHP – Criteria Comparison Matrix.

The criteria comparison matrix is used to compare the evaluation criteria. The ranking is an odd number exaggerated scale. This presents the importance of each more clearly. The inverse of the ranking can be found across the diagonal. This matrix is normalized based off the column sums to show the consistency of the matrix. This normalization can be seen in Figure 6.

	Normalized Criteria Comparison Matrix [NormC]						
	Ensure Operator Safety	Prevent Powder Contamination	Separate More Powder From the Part	Recover the Separated Powder	Integrate With Current System	Hold the Part During Process	Criteria Weight {W}
Ensure Operator Safety	0.09	0.09	0.06	0.10	0.06	0.19	0.10
Prevent Powder Contamination	0.09	0.09	0.06	0.10	0.06	0.19	0.10
Separate More Powder From the Part	0.26	0.26	0.17	0.30	0.06	0.19	0.21
Recover the Separated Powder	0.26	0.26	0.17	0.30	0.56	0.19	0.29
Integrate With Current System	0.26	0.26	0.50	0.10	0.19	0.19	0.25
Hold the Part During Process	0.03	0.03	0.06	0.10	0.06	0.06	0.06
Sum	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Figure 6. AHP – Normalized Criteria Comparison Matrix.

The sum of the normalized matrix columns should add up to one, and they do. The "criteria weight" is then found by averaging the rows. This shows the relative weights of each criteria. A consistency check must be done, and this can be seen in Figure 7.

{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weight	Cons={Ws}./{W} Consistency Vector
0.61	0.10	6.32
0.61	0.10	6.32
1.33	0.21	6.42
2.00	0.29	6.88
1.72	0.25	6.87
0.37	0.06	6.56
		λ = 6.5639

Figure 7. AHP – Consistency Check Matrix.

The calculated consistency vector is averaged and called lambda. This lambda is used with random index values (RI) to check the overall consistency. The calculations to do so are shown below.

$$Consistency\ Index = CI = \frac{\lambda - n}{n - 1} = \frac{6.5639 - 6}{6 - 1} = 0.11278$$

$$Consistency\ Ratio = CR = \frac{CI}{RI} = \frac{0.11278}{1.25} = 0.090$$

$$CR < 0.10$$

The consistency ratio is below one tenth, so the criteria comparison matrix is valid.

The next step is to compare the three high-fidelity concepts to one another based on a specific criterion. The chosen criterion to show is the amount of separated powder. This starts with a comparison matrix. This can be seen in Figure 8.

	Recovered Powder Comparison Matrix [C]		
	Encased Low to High Frequency Vibration	**Tiny Tube Blower**	**Hanging Faucet Electromagnet**
Encased Low to High Frequency Vibration	1.00	3.00	3.00
Tiny Tube Blower	0.33	1.00	1.00
Hanging Faucet Electromagnet	0.33	1.00	1.00
Sum	**1.67**	**5.00**	**5.00**

Figure 8. AHP – Recovered Powder Comparison Matrix.

The basic process for the recovered powder criterion is like the comparison done in Figure 5. The inverse of the ranking can be found across the diagonal and needs to be normalized. This can be seen in Figure 9.

Recovered Powder Normalized Comparison Matrix [NormC]	Encased Low to High Frequency Vibration	Tiny Tube Blower	Hanging Faucet Electromagnet	Design Alternative Priorities {PI}
Encased Low to High Frequency	0.60	0.60	0.60	0.60
Tiny Tube Blower	0.20	0.20	0.20	0.20
Hanging Faucet Electromagnet	0.20	0.20	0.20	0.20
Sum	**1.00**	**1.00**	**1.00**	**1.00**

Figure 9. AHP – Normalized Recovered Powder Comparison Matrix.

The matrix was normalized and summed across the rows to find the "PI" alternative values. The sums of each column should be equal to one, and they are. Now a consistency check must be done. This is done in Figure 10.

{Ws}=[C]{PI} Weighted Sum Vector	{PI} Criteria Weight	Cons={Ws}./{PI} Consistency Vector
1.80	0.60	3.00
0.60	0.20	3.00
0.60	0.20	3.00
		λ = 3.000

Figure 10. AHP – Recovered Powder Consistency Check.

The calculated consistency vector must be used as before to check the validity of this exercise. This can be seen below.

$$Consistency\ Index = CI = \frac{\lambda - n}{n - 1} = \frac{3 - 3}{3 - 1} = 0$$

$$Consistency\ Ratio = CR = \frac{CI}{RI} = \frac{0}{0.54} = 0$$

$$CR < 0.10$$

The consistency ratio is below one tenth, so the comparison is valid.

The next step is to do this for all criteria. The work for each will not be shown, but it is the same as for the recovered powder example. The resulting PIs are tabulated in Figure 11.

Selection Criteria	Encased Low to High Frequency Vibration	Tiny Tube Blower	Hanging Faucet Electromagnet
Ensure Operator Safety	0.33	0.33	0.33
Prevent Powder Contamination	0.43	0.43	0.14
Separate More Powder From the Part	0.60	0.20	0.20
Recover the Separated Powder	0.43	0.43	0.14
Integrate With Current System	0.33	0.33	0.33
Hold the Part During Process	0.60	0.20	0.20

Figure 11. AHP – Resulting PIs for all criteria.

This matrix of values is then transposed and multiplied by the criteria weights vector {W} from Figure 6. This results in the final ranking of the three high-fidelity concepts, which can be seen in Figure 12.

Concept	Alternative Value
Encased Low to High Frequency Vibration	0.440
Tiny Tube Blower	0.334
Hanging Faucet Electromagnet	0.222

Figure 12. AHP – Final Ranking of High-Fidelity Concepts.

The encased high to low frequency vibration ranked the highest from the AHP. This makes sense because it is believed to recycle more powder than the others, while also preventing contamination due to contact to an electromagnet or the tiny tube. This lines up with the results of the Pugh chart method and will be the chosen design.

Final Selection

The selected design for this project is the encased low to high frequency vibration. The general idea of this concept is relatively simple, and it can be seen in Figure 13. The part will be flipped and mounted upside down. A vibration mechanism with then vibrate at different frequencies. The original concept was to vibrate from low to high frequencies alone. Research showed that the frequency and force both can change dramatically. There is also the concept of ultrasonic cleaners moving at an insensible frequency. The best vibration technique must be explored and selected.

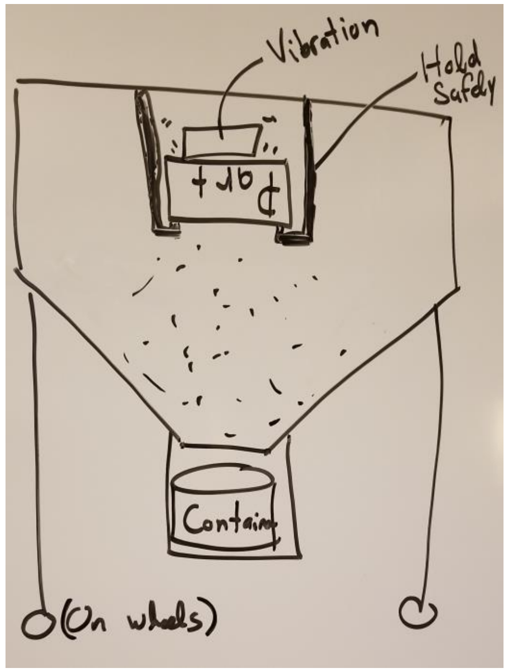

Figure 13. The Selected Design Vibrating an Upside-Down Part in an Enclosure.

Another key aspect of this concept is that the system must be enclosed. The act of vibrating powder off the part would release powder into the nearby atmosphere. This powder must be contained, and restricted from the operator's atmosphere, as a safety precaution. The enclosure also would act as a contamination free zone. Many enclosures, such as sandblasters, have other particles throughout. The enclosure for this concept would only be used for this metal powder recovery, keeping it clean and contaminate free.

The final key aspect of this concept is a recovered powder guidance and storage system. A funnel type of guidance system is planned to be used, and this could even be part integrated enclosure's geometry. The powder would then drop into the containers currently used by the operators. This funnel system would use gravity as its driving force in the capture of the metal powder.

While the key objectives of this concept are the vibration mechanism and enclosure, other aspects may be introduced as well. For example, it would be very easy and inexpensive to implement compressed air in the enclosure. Very thin, long, tools could be used with the vibration mechanism to remove more powder. Various aspects from other concepts will not be forgotten, as they could work well as a supplementary system. The priority of the project will be on the vibration and enclosure design, but other components may be added as well.