## Concept Selection

Concept generation first helped in the creation of hundreds of possible solutions to our project. Then, those options were compared to each other and further reduced to eight final options. After, concept selection was used to compare the eight options from concept generation to further narrow the options and pick the final winner.

After our team decided on the top eight designs from concept generation, the next step was to perform multiple comparison methods for these designs to achieve an overall concept winner. The methods used for this selection step were a house of quality, Pugh charts, and an analytical hierarchy process. Through these methods, we were able to apply engineering characteristics to each design. We were then able to rank each design based off the importance of each engineering characteristic. Finally, the designs were compared to each other and concepts were eliminated until a final idea was left. One more check was performed to make sure everything done in the selection process was consistent.

House of Quality (HoQ) is a method of ranking engineering qualities versus customer requirements. This method is deployed in order to properly organize design qualities and prioritize aspects of the project. Below, you can see our completed HoQ table.

Table 4: *House of Quality*

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |   |   |   |   |   |   |   |   |   |
|   |   | Engineering Characteristics  |
|    | Units  | Watts  | Amps  | Volts  | N/A  | cm^3  | N  | kg  | $  |
| Customer Requirements  | Importance Weight Factor  | Power  | Current  | Voltage  | Material   | Dimensions   | Impact Force  | Weight  | Cost |
| Weatherproof  | 2  |    |    |    | 9  | 3  | 3  | 3  | 3  |
| Temperature Control  | 5  | 3  | 9  | 3  | 3  | 3  | 1  | 1  | 3  |
| Program  | 6  | 9  | 9  | 9  |    | 3  |    |    |    |
| Environmentally Sustainable  | 1  |    |    |    | 3  | 1  | 1  | 1  | 3  |
| Impact Resistance  | 4  |    |    |    | 9  | 3  | 9  | 3  | 3  |
| Adhere to SAE Guidelines  | 7  | 3  | 1  | 9  | 3  | 3  | 9  | 3  | 1  |
| Monitor Current, Voltage, and Charge  | 8  |    | 9  | 9  |    |    |    |    | 1  |
| Monitor Power Input and Output  | 2  | 9  | 3  | 3  |    |    |    |    | 1  |
| Weight  | 1  | 1  |    | 1  | 3  | 9  | 3  | 9  | 3  |
| Raw Score (906)  | 109  | 184  | 211  | 96  | 82  | 114  | 54  | 56  |
| Relative Weight (%)  | 0.1203  | 0.2031  | 0.2329  | 0.1060  | 0.0905  | 0.1258  | 0.0596  | 0.0618  |
| Rank Order  | 4  | 2  | 1  | 5  | 6  | 3  | 8  | 7  |

As seen in the HoQ above, the “importance weight factors” for the customer requirements were needed in order to fill out the table. These weight factors were found by completing a piecewise comparison chart for the customer requirements. This chart can be seen in Appendix E. After finding the weight factors and adding them to the HoQ, each engineering characteristic was compared to the customer requirements in terms of how relatable the two were to each other. After filling out all the values, they were summed together, and we got ranking orders of the engineering characteristics. According to the chart, monitoring for the voltage and the current for the battery management system were among the top characteristics. The cost and weight of the system is not as important for our designs.

Pugh charts are a method into introducing and specifying design idea concepts that are more beneficial than other alternatives. These charts will compare these concepts to a datum in which each criterion will show the benefits or consequences compared to others. Our first Pugh chart can be seen below.

Table 6: *Pugh chart 1*

|  |  |  |
| --- | --- | --- |
|   |   | Design Concepts   |
| Selection Criteria   | Current SAE Formula Vehicle  | Design 1   | Design 2   | Design 3   | Design 4  | Design 5  | Design 6  | Design 7  | Design 8  |
| Power   | Datum  | -  | -  | -  | -  | -  | -  | -  | -  |
| Current  | +  | +  | +  | +  | +  | +  | +  | +  |
| Voltage  | +  | +  | +  | +  | +  | +  | +  | +  |
| Material  | S  | S  | S  | S  | S  | S  | S  | S  |
| Dimensions  | +  | +  | +  | -  | S  | +  | +  | +  |
| Impact Force  | +  | +  | -  | +  | S  | +  | +  | +  |
| Weight  | +  | +  | +  | +  | +  | +  | +  | +  |
| Cost  | -  | -  | -  | -  | -  | -  | -  | -  |
| # of Pluses  | 5  | 5  | 4  | 4  | 3  | 5  | 5  | 5  |
| # of Minuses  | 2  | 2  | 3  | 3  | 2  | 2  | 2  | 2  |

As seen in the chart above, the top eight of our designs from concept generation can be seen along with a datum. The datum we chose for the chart was the current SAE formula vehicle. Each design concept was then compared to this datum based off the engineering characteristics from the HoQ. Each design was given either a plus, minus, or a satisfactory for each selection criteria when compared to the data. Usually for a Pugh chart, the lowest ranking engineering characteristics can be discarded before filling out the chart. In our case, it was necessary to keep all of the characteristics in order to have more diversity to compare against. After going through each design and observing the positives and negatives of each idea, the total number of each were recorded. After observing the total numbers of pluses and minuses, designs 3, 4, and 5 all had less pluses and more minuses than the other ideas. Therefore, these three concepts were eliminated, and the remaining designs were placed into another Pugh chart with a different datum. This chart can be seen below.

Table 7: *Pugh chart 2*

|  |  |  |
| --- | --- | --- |
|   |   | Design Concepts   |
| Selection Criteria   | Design 1  | Design 2   | Design 6  | Design 7  | Design 8  |
| Power   | Datum  | S  | S  | S  | S  |
| Current  | S  | S  | +  | +  |
| Voltage  | S  | S  | S  | S  |
| Material  | -  | -  | S  | S  |
| Dimensions  | -  | S  | S  | S  |
| Impact Force  | S  | S  | S  | S  |
| Weight  | +  | -  | -  | -  |
| Cost  | S  | S  | -  | -  |
| # of Pluses  | 1  | 0  | 1  | 1  |
| # of Minuses  | 2  | 2  | 2  | 2  |

As seen in the second Pugh chart above, the new datum that was selected was design 1. This was because all the remaining designs had the same number of pluses and minuses so any of them would have been sufficient as the new datum. The same process for the first Pugh chart was then used for the second one. After observing the total number of pluses and minuses of the chart, compared to design 1, the other four designs had more minuses than pluses. This led us to believe that design 1 was the best concept for our project. Designs 7 and 8 were also close because of which criteria they were better in compared to design 1.

Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) is used to make specific calculations to match the consistency of the decisions and weights across all charts. The first chart that was created for the AHP can be seen below.

Table 8: *Analytical Hierarchy Process chart 1*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|   | Power  | Current  | Voltage  | Material   | Dimensions   | Impact Force  | Weight  | Cost  |
| Power   | 1.00  | 3.00  | 5.00  | 0.33  | 0.14  | 0.33  | 0.14  | 0.14  |
| Current  | 0.33  | 1.00  | 1.00  | 0.20  | 0.14  | 0.33  | 0.14  | 0.14  |
| Voltage  | 0.20  | 1.00  | 1.00  | 0.14  | 0.14  | 0.33  | 0.14  | 0.14  |
| Material  | 3.00  | 5.00  | 7.00  | 1.00  | 0.20  | 7.00  | 0.33  | 0.14  |
| Dimensions  | 7.00  | 7.00  | 7.00  | 5.00  | 1.00  | 7.00  | 3.00  | 0.33  |
| Impact Force  | 3.00  | 3.00  | 3.00  | 0.14  | 0.14  | 1.00  | 0.14  | 0.14  |
| Weight  | 7.00  | 7.00  | 7.00  | 3.00  | 0.33  | 7.00  | 1.00  | 0.33  |
| Cost  | 7.00  | 7.00  | 7.00  | 7.00  | 3.00  | 7.00  | 3.00  | 1.00  |
| Sum  | 28.53  | 34.00  | 38.00  | 16.82  | 5.10  | 30.00  | 7.90  | 2.38  |

The chart seen above is a pairwise matrix comparing the engineering characteristics to each other. The characteristics were rated by determining which characteristic was more important than another in a direct comparison (as decided by the team). This was done by placing a value of either 1, 3, 5, 7, or 9 on the more important characteristic and the inverse of whichever number chosen on the other characteristic. After filling out the entire table, the totals were gathered and recorded. The next step in the AHP was to normalize the comparison matrix above. This normalized table can be seen below.

Table 9: *Normalized AHP chart*

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|   | Power  | Current  | Voltage  | Material   | Dimensions   | Impact Force  | Weight  | Cost  | Criteria Weights  |
| Power   | 0.04  | 0.09  | 0.13  | 0.02  | 0.03  | 0.01  | 0.02  | 0.06  | 0.05  |
| Current  | 0.01  | 0.03  | 0.03  | 0.01  | 0.03  | 0.01  | 0.02  | 0.06  | 0.02  |
| Voltage  | 0.01  | 0.03  | 0.03  | 0.01  | 0.03  | 0.01  | 0.02  | 0.06  | 0.02  |
| Material  | 0.11  | 0.15  | 0.18  | 0.06  | 0.04  | 0.23  | 0.04  | 0.06  | 0.11  |
| Dimensions  | 0.25  | 0.21  | 0.18  | 0.30  | 0.20  | 0.23  | 0.38  | 0.14  | 0.24  |
| Impact Force  | 0.11  | 0.09  | 0.08  | 0.01  | 0.03  | 0.03  | 0.02  | 0.06  | 0.05  |
| Weight  | 0.25  | 0.21  | 0.18  | 0.18  | 0.07  | 0.23  | 0.13  | 0.14  | 0.17  |
| Cost  | 0.25  | 0.21  | 0.18  | 0.42  | 0.59  | 0.23  | 0.38  | 0.42  | 0.33  |
| Sum  | 1.00  | 1.00  | 1.00  | 1.00  | 1.00  | 1.00  | 1.00  | 1.00  | 1.00  |

The table above was normalized by going through each element and dividing it by the total sum of the column. This was done for each column and row until the table was filled out. Criteria weights were then calculated by taking the sum of each row. These weights can be seen in the rightmost column. To check that the normalization was correct, all columns were summed to make sure that each sum was equal to one.

The next step was to check for consistency to make sure all the values were accurate, and we weren't being biased in our decisions. To do this, the first thing that was found was a weighted sum vector. This was calculated by taking all the values from table 8 aside from the sums and multiplying it by the criteria weights vector in table 9. This output vector was then multiplied by the criteria weights vector to get a consistency vector. The average of all the values in the consistency vector was then calculated and found to be 9.2754. A random index value, RI, was then found from a table depending on the number of criteria we had. In our case, we had eight criteria which correlated to an RI value of 1.4. A consistency index was solved for by using the average of the consistency vector. This consistency index, CI, was found to be 0.1822. Finally, the consistency ratio, CR, was solved for by dividing the CI by the RI. The CR was found to be 0.1301. This CR was then checked to see if it was less than 0.1 to check for comparison consistency. Our calculated CR was not less than the standard of 0.1, but we decided that it was close enough to move forward because the small bias we had was toward the engineering characteristics of monitoring the power, voltage, and current within the battery management system. These values are crucial to monitor, not only for the purpose of the project, but also for the safety of the driver of the vehicle that this battery system will be incorporated into.

The AHP method was also used to validate each design against each engineering characteristic. This was done by completing a pairwise matrix comparison for each engineering characteristic for final designs 1, 7, and 8. These matrices can be found in appendix E. The same numbering system from before was used in this process for every pairwise matrix. After filling out each matrix, they were normalized the same as before. The criteria weights were calculated and all the same vectors that were found in our first AHP were also found for these matrices. The CR’s were then all calculated for and checked against the standard value of 0.1. Every CR that we found for each matrix was less than that standard value.

The next step in this process was to construct the final rating matrix. This was done by taking all the engineering characteristics with their corresponding criteria weight vectors and placing them all into a matrix against the three designs, 1, 7, and 8. This completed matrix can also be found in appendix E. The alternative values for each design were then calculated by taking the transpose of the final rating matrix and multiplying it by the original criteria weight vectors that were found in the first AHP. This gave a vector of the alternative values which can be seen in appendix E. From this vector, it shows that the highest value belongs to design 1, which gives us more reason to believe that this design is superior to the others.

Through this overarching process we were able to start with all design ideas, list all engineering characteristics, and assign weights and importance to each step. Through creating the Pugh, we were able to list the positives and consequences through each decision-making process. Narrowing down the design options we were able to have a more specific comparison among the top design ideas and further analyzed the benefits and consequences of each one. After AHP charts were then used to confirm the consistency of our data to make sure there was no major bias in our design making process. After carefully taking notes on each of the charts and comparing each of the top design ideas we have concluded that design one is superior when compared with the other designs.