10/25/2019

EML4551-2

Team 510: Climatic Camera

Concept Selection

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House of Quality

The purpose of the House of Quality (HoQ) is to translate the customer requirements into quantifiable design variables. This is done by relating the said requirements to engineering characteristics. The customer requirements were selected from a summary of the customer needs done earlier in the project. To determine the important weight factor of each customer requirement, a binary comparison chart was made. The requirements were compared to one another by asking the question “Is the row better than the column?”. If this was true a 1 was put in that place, but if false a 0 was placed. The numbers were then mirrored over the diagonal and the sums of each row and column was calculated. To confirm this was done properly, the following equation was used on each row and column pair:

Equation 1: $$T_1 + T_2 = n - 1$$

where n is the number of customer requirements, T_1 is the total of the row, and T_2 is the total of the column. The binary comparison chart performed on this project is shown below.

Table 1: Binary Comparison Chart

Customer Requirements	1	2	3	4	5	6	7	8	9	10	11	12	13	Total 1
1. Remote Accessibility	-	0	0	0	1	0	0	0	1	0	0	1	1	4
2. Continuous Monitoring	1	-	1	1	1	1	0	0	1	0	1	1	1	9
3. Computer Connection	1	0	-	0	1	0	0	0	1	0	0	0	0	3
4. Mobility When Required	1	0	1	-	1	1	0	0	1	0	1	1	1	8
5. Versatile Power Source	0	0	0	0	-	0	0	0	0	0	0	0	1	1
6. Compact	1	0	1	0	1	-	0	0	1	0	1	1	1	7
7. Functionality During Testing	1	1	1	1	1	1	-	1	1	1	1	1	1	12
8. Doesn't Affect Integrity of Chamber	1	1	1	1	1	1	0	-	1	0	1	1	1	10
9. Temp and Time Recording	0	0	0	0	1	0	0	0	-	0	0	0	0	1
10. Clear Visibility	1	1	1	1	1	1	0	1	1	-	1	1	1	11
11. System Connections fit Through Porthole	1	0	1	0	1	0	0	0	1	0	-	1	1	6
12. Inexpensive	0	0	1	0	1	0	0	0	1	0	0	-	0	3
13. Safe	0	0	1	0	0	0	0	0	1	0	0	1	-	3
Total 2	8	3	9	4	11	5	0	2	11	1	6	9	9	12

The Total 1 column of the binary comparison chart was extracted and used as the importance weight factor in the HoQ. The engineering characteristics were selected as those which encompassed the entirety of the targets and metrics. Once put into place, each characteristic was rated on a 1,3,9 scale for its importance in the customer requirement. The sum of the product of each column was found (importance weight factor x characteristic rate summed across the column), then ranked for its weight compared to the total raw score. The resulting HoQ is shown below.

Table 1: House of Quality

		Engineering Characteristics										
Improvement Direction		↓	↓	↓	↑		↑		↑	↓	↓	
Units		m/s^2	m	Δ Degrees	frame/s	n/a	GB	n/a	hh:mm:ss	°C	%	n/a
Customer Requirements	Importance Weight factor	Provide Stability	Secure Position	Secure Rotational Angle	Capture Visuals	Transmit Visuals	Store Visuals	Replay Visuals	Record Time	Control Temp.	Control Humidity	Supply Power
1. Remote Accessibility	4					9	3	9	3			
2. Continuous Monitoring	9				9	3			1			3
3. Computer Connection	3				3	9	9	9				
4. Mobility When Required	8	3	3	3						1		3
5. Versatile Power Source	1									3	3	9
6. Compact	7	1	1	1		1				3	1	3
7. Functionality During Testing	12				9	9			1	9	9	3
8. Doesn't Affect Integrity of Chamber	10		3							9	3	
9. Temp and Time Recording	1				1	3	3		9	1		
10. Clear Visibility	11	3	1	1	9	3		9		9	9	3
11. Aux System fits Through Porthole	6					9				3	1	1
12. Inexpensive	3	1	1	1		1	3			1		
13. Safe	3					3				9	3	9
Raw Score (1870)		67	75	45	298	307	51	162	42	378	262	183
Relative Weight %		3.58	4.01	2.41	15.94	16.42	2.73	8.66	2.25	20.21	14.01	9.79
Rank Order		8	7	10	3	2	9	6	11	1	4	5

The information gained from the House of Quality determined the ranked importance of each engineering characteristic. The most important (1) was found to be "Control Temperature," while the least important (11) was "Record Time". The rankings were then used in Pugh Charts to determine the best design of the selected concepts.

Pugh Chart

The Pugh Chart was utilized to identify the best concepts. With the aid of the House of Quality chart above, we were able to generate the most important evaluation criteria (engineering characteristics). These engineering characteristics can be seen on the far-left column of the Pugh

Chart. Next, we chose nine of the most promising concepts from the 100 generated concepts. These nine concepts can be seen on the top row on the Pugh Chart.

The concepts were compared to an existing product (Datum). The “ChamberCam,” Dynamic Intelligent Solution (DIS) product, was chosen as the datum for comparison. Each of the nine concepts were then compared to the datum for their capabilities in the engineering characteristics. If the engineering characteristic of the concept is better than the datum that block gets a “+”, worse gets a “-”, and equal gets an “S”. After evaluating all concepts, the positives and negatives were totaled at the bottom of the chart. The first Pugh Chart, which compares the nine chosen concepts to the datum, is shown below.

Table 2: First Pugh Chart (8 Concepts)

		Concepts								
Engineering Characteristics	ChamberCam	Comp. Air Clamped Borescope	Vacuum Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera	Infrared Camera, Vacuum	FireCam w/ Vortex Tubes	Borescope, Resistive Heater	Compressed Air Cooled GoPro	Water Cooled Borescope	Slider Linkage, Comp Air HD Camera
Control Temperature	Datum	S	-	S	-	S	-	S	S	S
Transmit Visuals		S	S	S	S	S	S	S	S	S
Capture Visuals		-	-	S	+	-	-	-	-	-
Control Humidity		S	-	S	S	S	-	S	S	S
Supply Power		S	S	S	S	-	S	-	S	S
Replay Visuals		-	-	-	S	-	-	-	-	-
Secure Position		+	+	+	-	S	S	S	S	+
Provide Stability		S	S	S	S	S	S	S	S	+
Store Visuals		-	-	-	-	-	-	-	-	-
Secure Rotational Angle		+	+	+	S	S	S	S	S	+
Record Time		S	S	S	S	S	S	S	S	S
# of Pluses		2	2	2	1					3
# of Minuses		3	5	2	3	4	5	4	3	3

After completing the first Pugh Chart, the concepts were narrowed down to perform a second iteration. The concepts with the most minuses and least number of pluses were eliminated (See concepts highlighted in yellow). These included the FireCam with Vortex Tubes, Borescope with Resistive Heater, Compressed Air-Cooled GoPro, and the Water-Cooled Borescope. A new datum was then picked from the remaining concepts based off the most satisfactory distribution. Slider linkage with Compressed Air HD Camera (highlighted in green) was chosen because it has even number of pluses and minuses and overall highest number of pluses in comparison to the other concepts. The second Pugh Chart was completed with the four remaining concepts.

Table 3: Second Pugh Chart (4 Concepts)

		Concepts			
Engineering Characteristics	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum, Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera	Infrared Camera, Vacuum
Control Temperature	New Datum	**S**	-	**S**	-
Transmit Visuals		**S**	**S**	**S**	**S**
Capture Visuals		-	-	**S**	+
Control Humidity		**S**	-	**S**	-
Supply Power		**S**	**S**	**S**	**S**
Replay Visuals		-	-	**S**	**S**
Secure Position		**S**	**S**	**S**	-
Provide Stability		**S**	**S**	**S**	**S**
Store Visuals		**S**	**S**	**S**	**S**
Secure Angle		**S**	**S**	**S**	-
Record Time		**S**	**S**	**S**	**S**
# of Pluses					1
# of Minuses		2	4		4

Following the completion of the second Pugh Chart, the best three designs were chosen to move forward to the Analytical Hierarchy Process (AHP). The concepts selected (highlighted in green) were the Compressed Air, Clamped Borescope, Vacuum + Compressed Air, Suction Cup Attached HD Camera, and the previously selected datum the Slider Linkage with Compressed Air HD Camera. Each of these concepts has a high value to solve the design challenges. They were further analyzed to determine which one was best for our product.

Analytical Hierarchy Process

Following the House of Quality, the Analytical Hierarchy Process (AHP) was done to guarantee there was no bias in the concept selection process and to determine the best overall product. The first step in the AHP was to do determine the weight of the engineering characteristics through pairwise comparison. Similar to the binary comparison done earlier, the pairwise uses reciprocals rather than ones and zeroes. The pairwise comparison was performed and is shown below.

Table 4: Criteria Comparison Matrix

Development of Candidate Set of Criteria Weights {W}												
Criteria Comparison Matrix [C]												
	Provide Stability	Secure Position	Secure Angle	Capture Visuals	Transmit Visuals	Store Visuals	Replay Visuals	Record Time	Control Temp	Control Humidity	Supply Power	Sum
Provide Stability	1	1	1	5	0.33	0.33	0.33	0.14	9	7	1	26.13
Secure Position	1	1	1	5	0.2	0.2	0.33	0.14	9	7	1	25.87
Secure Angle	1	1	1	3	0.33	0.14	0.14	0.11	7	5	0.33	19.05
Capture Visuals	0.2	0.2	0.33	1	0.2	0.14	0.2	0.11	0.33	0.33	1	4.04
Transmit Visuals	3	5	3	5	1	0.2	0.33	0.2	5	7	5	34.73
Store Visuals	3	5	7	7	5	1	3	1	9	9	3	53
Replay Visuals	3	3	7	5	3	0.33	1	0.2	7	5	3	37.53
Record Time	7	7	9	9	5	1	5	1	9	9	5	67
Control Temp	0.11	0.11	0.14	3	0.2	0.11	0.14	0.11	1	0.33	0.2	5.45
Control Humidity	0.14	0.14	0.2	3	0.14	0.11	0.2	0.11	3	1	0.33	8.37
Supply Power	1	1	3	1	0.2	0.33	0.33	0.2	5	3	1	16.06

Once complete, the sum of each column was found and used to create the normalized matrix shown below. This was done by dividing each element in the column by the column's sum.

Table 5: Normalized Criteria Comparison Matrix

Development of Candidate Set of Criteria Weights {W}												
Normalized Criteria Comparison Matrix [Norm C]												
	Provide Stability	Secure Position	Secure Angle	Capture Visuals	Transmit Visuals	Store Visuals	Replay Visuals	Record Time	Control Temp.	Control Humidity	Supply Power	Sum
Provide Stability	0.038	0.038	0.038	0.191	0.013	0.013	0.013	0.005	0.344	0.268	0.038	1.000
Secure Position	0.039	0.039	0.039	0.193	0.008	0.008	0.013	0.005	0.348	0.271	0.039	1.000
Secure Angle	0.052	0.052	0.052	0.157	0.017	0.007	0.007	0.006	0.367	0.262	0.017	1.000
Capture Visuals	0.050	0.050	0.082	0.248	0.050	0.035	0.050	0.027	0.082	0.082	0.248	1.000
Transmit Visuals	0.086	0.144	0.086	0.144	0.029	0.006	0.010	0.006	0.144	0.202	0.144	1.000
Store Visuals	0.057	0.094	0.132	0.132	0.094	0.019	0.057	0.019	0.170	0.170	0.057	1.000
Replay Visuals	0.080	0.080	0.187	0.133	0.080	0.009	0.027	0.005	0.187	0.133	0.080	1.000
Record Time	0.104	0.104	0.134	0.134	0.075	0.015	0.075	0.015	0.134	0.134	0.075	1.000
Control Temp	0.020	0.020	0.026	0.550	0.037	0.020	0.026	0.020	0.183	0.061	0.037	1.000
Control Humidity	0.017	0.017	0.024	0.358	0.017	0.013	0.024	0.013	0.358	0.119	0.039	1.000
Supply Power	0.062	0.062	0.187	0.062	0.012	0.021	0.021	0.012	0.311	0.187	0.062	1.000
Criteria Weight	0.055	0.064	0.090	0.209	0.039	0.015	0.029	0.012	0.239	0.172	0.076	

After normalizing the comparison table, the columns were averaged to produce the row on the bottom of the table. This is the critical weight vector, which will be used to determine the best concept. To determine if the critical weight vector is void of bias, a consistency check must be done. The equations used to find the necessary values include:

Equation 2: $\{W_s\} = [C].* \{W\}$

Equation 3: $\{Cons\} = \{W_s\}./\{W\}$

Equation 4: $CI = \frac{\lambda - n}{n-1}$

Equation 5: $CR = \frac{CI}{RI}$

where {W_s} is the weighted sum vector, [C] is the criteria comparison matrix, {W} is the criteria weight vector, {Cons} is the consistency factor vector, CI is the consistency index, λ is the average consistency factor, n is the number of criteria, CR is the consistency ratio, and RI is random index value. Matrix operations were performed where they apply, and RI was retrieved from an index table. The following table shows the consistency check for the engineering characteristics critical weight vector, {W}.

Table 6: Consistency Check

Consistency Check (n = 11)		
Weighted Sum {Ws}	Criteria Weight {W}	Consistency Factor (Cons.)
0.71	0.055	12.94
0.80	0.064	12.50
1.09	0.090	12.11
2.73	0.209	13.06
0.43	0.039	11.03
0.19	0.015	12.51
0.33	0.029	11.53
0.15	0.012	12.56
3.21	0.239	13.43
2.30	0.172	13.37
0.89	0.076	11.71
Average Consistency Vector (λ)		12.43
Consistency Index (CI)		0.143
RI Value (11 Criteria)		1.51
Consistency Ratio (CR)		0.09

Since the consistency ratio was less than 0.1, the critical weight vector was deemed valid and could therefore be used to calculate for the best concept. Before this could be done, the final rating matrix had to be determined. This was done by repeating the AHP with the three selected concepts for each of the engineering characteristics, a total of eleven times. Once completed, each design alternative priority vector {Pi} was placed into the final rating matrix. The matrix was then transposed and is shown in the following table.

Table 7: Final Rating Matrix (Transposed)

Final Rating Matrix (Transposed)											
Selection Criteria											
	Provide Stability	Secure Position	Secure Angle	Capture Visuals	Transmit Visuals	Store Visuals	Replay Visuals	Record Time	Control Temp	Control Humidity	Supply Power
Slider Linkage, Comp Air HD Camera	0.63	0.33	0.33	0.45	0.33	0.33	0.45	0.33	0.14	0.2	0.33
Comp. Air Clamped Borescope	0.26	0.33	0.33	0.09	0.33	0.33	0.09	0.33	0.14	0.2	0.33
Vacuum + Comp. Air, Suction Cup, HD Camera	0.11	0.33	0.33	0.45	0.33	0.33	0.45	0.33	0.71	0.6	0.33

With the final rating matrix, one last equation was done to calculate the alternative value using matrix multiplication.

Equation 6: $$Alternative\ Value = [Final\ Rating\ Matrix]^{T}.*\ \{W\}$$

In this equation, the transposed final rating matrix is matrix multiplied with the critical weight vector, {W} from the AHP of the engineering characteristics. The results were formed in the following table.

Table 8: Final Alternative Values

Final Alternative Value	
Concept	Alternative Value
Slider Linkage, Comp Air HD Camera	0.31
Comp. Air Clamped Borescope	0.20
Vacuum + Comp. Air, Suction Cup, HD Camera	0.48

From this table it was determined that the Vacuum shell with compressed air, suction cup attached HD camera was the best concept that met the design criteria.

Final Concept

All three of the final concepts that were analyzed have the potential to meet the design challenge we are facing. Due to the inexistent products, we had to speculate on their performance. Further analyzing the "best concept," (the Vacuum shell with compressed air, suction cup attached HD camera) we were able to see some potential flaws. For one, suction cups may not remain attached to the chamber walls, or stay in place, as humidity, temperature, and pressure change. We considered having a lever suction cup, but with increasing temperatures, the air inside the suction cup may expand and the device could fall. We considered the other two concepts attachment mechanisms (Slider linkage and Clamps). The vacuum part of the design relies on ideal conditions on construction of the device, however in practice manufacturing a perfect vacuum is difficult considering the circumstances. A slightly positive pressure could be used inside the camera chamber to keep moisture out of the enclosure in case of any leaks, this avoids potential risk of damaging the electronics. Through prototyping and testing we will be able to see which mechanism can work best for our design. Also, the compressed air line would need a filter to have dry air (preventing moisture inside the camera chamber) at room temperature to circulate inside the enclosure. All the final comparison designs have the mobility qualities that a borescope camera would have, but contain variations in mounting and high definition cameras. Using all the methods for process selection, the final design to move forward with is a combination of the elements in the top three concepts analyzed. Again, through prototyping, testing, and consulting engineering professionals, the team will determine which design will be most effective for our project.

Appendix A: Concept AHP

Criteria Comparison Matrices

Table 9: Provide Stability Criteria Comparison Matrix

Provide Stability Comparison [C]			
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera
Slider Linkage, Comp Air HD Camera	1	3	5
Comp. Air Clamped Borescope	0.33	1	3
Vacuum + Comp. Air, Suction Cup, HD Camera	0.2	0.33	1
Sum	1.53	4.33	9

Table 10: Secure Position Criteria Comparison Matrix

Secure Position Comparison [C]			
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera
Slider Linkage, Comp Air HD Camera	1	1	1
Comp. Air Clamped Borescope	1	1	1
Vacuum + Comp. Air, Suction Cup, HD Camera	1	1	1
Sum	3	3	3

Table 11: Secure Angle Criteria Comparison Matrix

Secure Angle Comparison [C]			
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera
Slider Linkage, Comp Air HD Camera	1	1	1
Comp. Air Clamped Borescope	1	1	1
Vacuum + Comp. Air, Suction Cup, HD Camera	1	1	1
Sum	3	3	3

Table 12: Capture Visuals Comparison Matrix

Capture Visuals Comparison [C]			
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera
Slider Linkage, Comp Air HD Camera	1	5	1
Comp. Air Clamped Borescope	0.2	1	0.2
Vacuum + Comp. Air, Suction Cup, HD Camera	1	5	1
Sum	2.2	11	2.2

Table 13: Transmit Visuals Comparison Matrix

Transmit Visuals Comparison [C]

	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera
Slider Linkage, Comp Air HD Camera	1	1	1
Comp. Air Clamped Borescope	1	1	1
Vacuum + Comp. Air, Suction Cup, HD Camera	1	1	1
Sum	3	3	3

Table 14: Store Visuals Comparison Matrix

Store Visuals Comparison [C]			
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera
Slider Linkage, Comp Air HD Camera	1	1	1
Comp. Air Clamped Borescope	1	1	1
Vacuum + Comp. Air, Suction Cup, HD Camera	1	1	1
Sum	3	3	3

Table 15: Replay Visuals Comparison Matrix

Replay Visuals Comparison [C]			
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air,

			Suction Cup, HD Camera
Slider Linkage, Comp Air HD Camera	1	5	1
Comp. Air Clamped Borescope	0.2	1	0.2
Vacuum + Comp. Air, Suction Cup, HD Camera	1	5	1
Sum	2.2	11	2.2

Table 16: Record Time Comparison Matrix

Record Time Comparison [C]			
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera
Slider Linkage, Comp Air HD Camera	1	1	1
Comp. Air Clamped Borescope	1	1	1
Vacuum + Comp. Air, Suction Cup, HD Camera	1	1	1
Sum	3	3	3

Table 17: Control Temperature Comparison Matrix

Control Temperature Comparison [C]			
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera

Slider Linkage, Comp Air HD Camera	1	1	0.2
Comp. Air Clamped Borescope	1	1	0.2
Vacuum + Comp. Air, Suction Cup, HD Camera	5	5	1
Sum	7	7	1.4

Table 23: Control Humidity Comparison Matrix

Control Humidity Comparison [C]			
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera
Slider Linkage, Comp Air HD Camera	1	1	0.33
Comp. Air Clamped Borescope	1	1	0.33
Vacuum + Comp. Air, Suction Cup, HD Camera	3	3	1
Sum	5	5	1.66

Table 23: Supply Power Comparison Matrix

Supply Power Comparison [C]			
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera
Slider Linkage, Comp Air HD Camera	1	1	1

Comp. Air Clamped Borescope	1	1	1
Vacuum + Comp. Air, Suction Cup, HD Camera	1	1	1
Sum	3	3	3

Normalized Criteria Comparison Matrices

Table 18: Provide Stability Normalized Criteria Comparison Matrix

Normalized Provide Stability Comparison [NormC]				
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera	Design Alt. Priorities {Pi}
Slider Linkage, Comp Air HD Camera	0.65	0.69	0.56	0.63
Comp. Air Clamped Borescope	0.22	0.23	0.33	0.26
Vacuum + Comp. Air, Suction Cup, HD Camera	0.13	0.08	0.11	0.11
Sum	1.00	1.00	1.00	1.00

Table 19: Secure Position Normalized Criteria Comparison Matrix

Normalized Secure Position Comparison [NormC]				
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera	Design Alt. Priorities {Pi}
Slider Linkage, Comp Air HD Camera	0.33	0.33	0.33	0.33

Comp. Air Clamped Borescope	0.33	0.33	0.33	0.33
Vacuum + Comp. Air, Suction Cup, HD Camera	0.33	0.33	0.33	0.33
Sum	1.00	1.00	1.00	1.00

Table 20: Secure Angle Normalized Criteria Comparison Matrix

Normalized Secure Angle Comparison [NormC]				
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera	Design Alt. Priorities {Pi}
Slider Linkage, Comp Air HD Camera	0.33	0.33	0.33	0.33
Comp. Air Clamped Borescope	0.33	0.33	0.33	0.33
Vacuum + Comp. Air, Suction Cup, HD Camera	0.33	0.33	0.33	0.33
Sum	1.00	1.00	1.00	1.00

Table 21: Transmit Visuals Normalized Criteria Comparison Matrix

Normalized Transmit Visuals Comparison [NormC]				
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera	Design Alt. Priorities {Pi}
Slider Linkage, Comp Air HD Camera	0.33	0.33	0.33	0.33
Comp. Air Clamped Borescope	0.33	0.33	0.33	0.33

Vacuum + Comp. Air, Suction Cup, HD Camera	0.33	0.33	0.33	0.33
Sum	1.00	1.00	1.00	1.00

Table 22: Store Visuals Normalized Criteria Comparison Matrix

Normalized Store Visuals Comparison [NormC]				
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera	Design Alt. Priorities {Pi}
Slider Linkage, Comp Air HD Camera	0.33	0.33	0.33	0.33
Comp. Air Clamped Borescope	0.33	0.33	0.33	0.33
Vacuum + Comp. Air, Suction Cup, HD Camera	0.33	0.33	0.33	0.33
Sum	1.00	1.00	1.00	1.00

Table 23: Replay Visuals Normalized Criteria Comparison Matrix

Normalized Replay Visuals Comparison [NormC]				
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera	Design Alt. Priorities {Pi}
Slider Linkage, Comp Air HD Camera	0.45	0.45	0.45	0.45
Comp. Air Clamped Borescope	0.09	0.09	0.09	0.09
Vacuum + Comp. Air, Suction Cup, HD Camera	0.45	0.45	0.45	0.45
Sum	1.00	1.00	1.00	1.00

Table 24: Record Time Normalized Criteria Comparison Matrix

Normalized Record Time Comparison [NormC]				
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera	Design Alt. Priorities {Pi}
Slider Linkage, Comp Air HD Camera	0.33	0.33	0.33	0.33
Comp. Air Clamped Borescope	0.33	0.33	0.33	0.33
Vacuum + Comp. Air, Suction Cup, HD Camera	0.33	0.33	0.33	0.33
Sum	1.00	1.00	1.00	1.00

Table 25: Control Temperature Normalized Criteria Comparison Matrix

Normalized Control Temperature Comparison [NormC]				
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera	Design Alt. Priorities {Pi}
Slider Linkage, Comp Air HD Camera	0.14	0.14	0.14	0.14
Comp. Air Clamped Borescope	0.14	0.14	0.14	0.14
Vacuum + Comp. Air, Suction Cup, HD Camera	0.71	0.71	0.71	0.71
Sum	1.00	1.00	1.00	1.00

Table 26: Control Humidity Normalized Criteria Comparison Matrix

Normalized Control Humidity Comparison [NormC]

	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera	Design Alt. Priorities {Pi}
Slider Linkage, Comp Air HD Camera	0.20	0.20	0.20	0.20
Comp. Air Clamped Borescope	0.20	0.20	0.20	0.20
Vacuum + Comp. Air, Suction Cup, HD Camera	0.60	0.60	0.60	0.60
Sum	1.00	1.00	1.00	1.00

Table 27: Supply Power Normalized Criteria Comparison Matrix

Normalized Supply Power Comparison [NormC]				
	Slider Linkage, Comp Air HD Camera	Comp. Air Clamped Borescope	Vacuum + Comp. Air, Suction Cup, HD Camera	Design Alt. Priorities {Pi}
Slider Linkage, Comp Air HD Camera	0.33	0.33	0.33	0.33
Comp. Air Clamped Borescope	0.33	0.33	0.33	0.33
Vacuum + Comp. Air, Suction Cup, HD Camera	0.33	0.33	0.33	0.33
Sum	1.00	1.00	1.00	1.00

Consistency Checks

Table 28: Provide Stability Consistency Check

Provide Stability Consistency Check (n=3)		
Weighted Sum Vector {Ws}	Criteria Weights {Pi}	Consistency Factor (Cons)
1.94	0.63	3.07
0.79	0.26	3.03
0.32	0.11	3.01
Average Consistency Vector (λ)		3.03
Consistency Index (CI)		0.02
RI Value (3 Criteria)		0.52
Consistency Ratio (CR)		0.03

Table 29: Provide Stability Consistency Check

Provide Stability Consistency Check (n=3)		
Weighted Sum Vector {Ws}	Criteria Weights {Pi}	Consistency Factor (Cons)
1.94	0.63	3.07
0.79	0.26	3.03
0.32	0.11	3.01
Average Consistency Vector (λ)		3.03
Consistency Index (CI)		0.02
RI Value (3 Criteria)		0.52
Consistency Ratio (CR)		0.03

Table 30: Secure Position Consistency Check

Secure Position Consistency Check (n=3)		
Weighted Sum Vector {Ws}	Criteria Weights {Pi}	Consistency Factor (Cons)
1.00	0.33	3.00
1.00	0.33	3.00

1.00	0.33	3.00
Average Consistency Vector (λ)		3.00
Consistency Index (CI)		0.00
RI Value (3 Criteria)		0.52
Consistency Ratio (CR)		0.00

Table 31: Secure Angle Consistency Check

Secure Angle Consistency Check (n=3)		
Weighted Sum Vector {Ws}	Criteria Weights {Pi}	Consistency Factor (Cons)
1.00	0.33	3.00
1.00	0.33	3.00
1.00	0.33	3.00
Average Consistency Vector (λ)		3.00
Consistency Index (CI)		0.00
RI Value (3 Criteria)		0.52
Consistency Ratio (CR)		0.00

Table 32: Capture Visuals Consistency Check

Capture Visuals Consistency Check (n=3)		
Weighted Sum Vector {Ws}	Criteria Weights {Pi}	Consistency Factor (Cons)
1.35	0.45	3.00
0.27	0.09	3.00
1.35	0.45	3.00
Average Consistency Vector (λ)		3.00
Consistency Index (CI)		0.00
RI Value (3 Criteria)		0.52
Consistency Ratio (CR)		0.00

Table 33: Transmit Visuals Consistency Check

Transmit Visuals Consistency Check (n=3)		
Weighted Sum Vector {Ws}	Criteria Weights {Pi}	Consistency Factor (Cons)
1.00	0.33	3.00
1.00	0.33	3.00
1.00	0.33	3.00
Average Consistency Vector (λ)		3.00
Consistency Index (CI)		0.00
RI Value (3 Criteria)		0.52
Consistency Ratio (CR)		0.00

Table 34: Store Visuals Consistency Check

Store Visuals Consistency Check (n=3)		
Weighted Sum Vector {Ws}	Criteria Weights {Pi}	Consistency Factor (Cons)
1.00	0.33	3.00
1.00	0.33	3.00
1.00	0.33	3.00
Average Consistency Vector (λ)		3.00
Consistency Index (CI)		0.00
RI Value (3 Criteria)		0.52
Consistency Ratio (CR)		0.00

Table 35: Replay Visuals Consistency Check

Replay Visuals Consistency Check (n=3)		
Weighted Sum Vector {Ws}	Criteria Weights {Pi}	Consistency Factor (Cons)
1.35	0.45	3.00
0.27	0.09	3.00
1.35	0.45	3.00
Average Consistency Vector (λ)		3.00
Consistency Index (CI)		0.00
RI Value (3 Criteria)		0.52
Consistency Ratio (CR)		0.00

Table 36: Record Time Consistency Check

Record Time Consistency Check (n=3)		
Weighted Sum Vector {Ws}	Criteria Weights {Pi}	Consistency Factor (Cons)
1.00	0.33	3.00
1.00	0.33	3.00
1.00	0.33	3.00
Average Consistency Vector (λ)		3.00
Consistency Index (CI)		0.00
RI Value (3 Criteria)		0.52
Consistency Ratio (CR)		0.00

Table 37: Control Temperature Consistency Check

Control Temperature Consistency Check (n=3)		
Weighted Sum Vector {Ws}	Criteria Weights {Pi}	Consistency Factor (Cons)
0.43	0.14	3.00
0.43	0.14	3.00

2.14	0.71	3.00
Average Consistency Vector (λ)		3.00
Consistency Index (CI)		0.00
RI Value (3 Criteria)		0.52
Consistency Ratio (CR)		0.00

Table 38: Control Humidity Consistency Check

Control Humidity Consistency Check (n=3)		
Weighted Sum Vector {Ws}	Criteria Weights {Pi}	Consistency Factor (Cons)
0.60	0.20	3.00
0.60	0.20	3.00
1.80	0.60	3.00
Average Consistency Vector (λ)		3.00
Consistency Index (CI)		0.00
RI Value (3 Criteria)		0.52
Consistency Ratio (CR)		0.00

Table 39: Supply Power Consistency Check

Supply Power Consistency Check (n=3)		
Weighted Sum Vector {Ws}	Criteria Weights {Pi}	Consistency Factor (Cons)
1.00	0.33	3.00
1.00	0.33	3.00
1.00	0.33	3.00
Average Consistency Vector (λ)		3.00
Consistency Index (CI)		0.00
RI Value (3 Criteria)		0.52
Consistency Ratio (CR)		0.00