Concept Selection

Introduction

After coming up with all the different design concepts mentioned in 1.5 Concept Generation and Appendix D Concept Generation, it was time to decide which design concept could satisfy most of the customer and functional needs of the project. During the selection process it was important that no bias was present in selecting the best individual design concept. To make the project more manageable, the most import customer needs and design functions were selected using the process outlined below. Weighting factors were assigned to each customer need by doing a binary comparison. The binary comparison correlated each of the customer needs against every other customer need. The weight factors were then input into a house of quality which can be seen in Table 4.0. The house of quality correlates the customer needs with the engineering design characteristics and magnifies the correlations with the weighted factors from the binary comparison.

Table 4.0: House of Quality

Imrovement Direction		↓	↑	↑	-	↓	↑	-	↓	↓	↓	↓	↓	↑	↑	↑	↓
Units of EC's		Minutes	Years/Dives	Years	mm	cm^2	Hours	Degrees	mm	mm	m^2	kg	cm	kPa	cm	%	Dollars ($)
Design Requirements / **Customer Requirements**	**Importance**	Time to Attach Device	Time Before Equipment Needs Servicing	Life Expectancy	Thickness of Wetsuit	Amount of Exposed Skin in Lower Extremities	Time in Water	Angle of Diver at Depth and Surface	Distance to Controls	Protective Perimeter Around Diver	Surface Area That Would Affect Diver's Drag	Weight of Equipment	Length Equipment Extends	Pressure Device is Able to Withstand	Allowable Distance Controls Can Be From Pre-existing Scuba Controls	Works With Different Body Compositions	Cost of the Device
Operates in Fresh and Salt Water	6		3	9										1			
Can Handle Repetitive Dragging	4		1	3	1	3				3		1	3			1	3
Pressure Relief Valve if Compressed Gas is Used	9							3	3					3	1		9
Maintenance Schedule	1		9	3									1				9
Does Not Hinder Transferring Diver In and Out of Water	3	1					1	9		3		9	9		1	1	
Compatible With Pre-existing Dive Equipment	9							1	9	9	1	1	3		9	3	
Diver Can Put on Wetsuit By Themselves	4	9			3								1			1	1
Device is Operated by Hands	11							9	9						3	3	
Compact Device	2								1		9	3	3		1		1
Operates at Various Temperatures	4				9	9	1							3			1
Controls Diver's Trim	12				3		9	9	3	3	9	3		3		9	
Does Not Need Assistance While Attaching Device	4	9							1			1	1		1	3	
Prevents Diver's Legs From Dragging	9				3	3	1	9	3	9	9	1				9	
Raw Score (2238)		75	31	69	115	75	124	351	276	147	216	95	81	81	130	272	112
Relative Weight %		3.33	1.38	3.07	5.11	3.33	5.51	15.60	12.27	6.53	9.60	4.22	3.60	3.60	5.78	12.09	4.98
Rank		12	14	13	8	12	7	1	2	5	4	10	11	11	6	3	9

Imrovement Direction		↓	↑	↑	-	↓	↑	-	↓	↓	↓	↓	↓	↑	↑	↑	↓
Units of EC's		Minutes	Years/Dives	Years	mm	cm^2	Hours	Degrees	mm	mm	m^2	kg	cm	kPa	cm	%	Dollars ($)
Design Requirements / **Customer Requirements**	**Importance**	Time to Attach Device	Time Before Equipment Needs Servicing	Life Expectancy	Thickness of Wetsuit	Amount of Exposed Skin in Lower Extremities	Time in Water	Angle of Diver at Depth and Surface	Distance to Controls	Protective Perimeter Around Diver	Surface Area That Would Affect Diver's Drag	Weight of Equipment	Length Equipment Extends	Pressure Device is Able to Withstand	Allowable Distance Controls Can Be From Pre-existing Scuba Controls	Works With Different Body Compositions	Cost of the Device
Operates in Fresh and Salt Water	6		3	9										1			
Can Handle Repetitive Dragging	4		1	3	1	3				3		1	3			1	3
Pressure Relief Valve if Compressed Gas is Used	9							3	3					3	1		9
Maintenance Schedule	1		9	3									1				9
Does Not Hinder Transferring Diver In and Out of Water	3	1					1	9		3		9	9		1	1	
Compatible With Pre-existing Dive Equipment	9							1	9	9	1	1	3		9	3	
Diver Can Put on Wetsuit By Themselves	4	9			3								1			1	1
Device is Operated by Hands	11							9	9						3	3	
Compact Device	2								1		9	3	3		1		1
Operates at Various Temperatures	4				9	9	1							3			1
Controls Diver's Trim	12				3		9	9	3	3	9	3		3		9	
Does Not Need Assistance While Attaching Device	4	9							1			1	1		1	3	
Prevents Diver's Legs From Dragging	9				3	3	1	9	3	9	9	1				9	
Raw Score (2238)		75	31	69	115	75	124	351	276	147	216	95	81	81	130	272	112
Relative Weight %		3.33	1.38	3.07	5.11	3.33	5.51	15.60	12.27	6.53	9.60	4.22	3.60	3.60	5.78	12.09	4.98
Rank		12	14	13	8	12	7	1	2	5	4	10	11	11	6	3	9

House of Quality

In order to insure the voice of the customer is infused in every step of the design selection process, the house of quality shown in Table 4.0 correlates each customer need into each design requirement. With the relative weights calculated, the most influential design characteristics became apparent. The cutoff point of 6.53% relative weight was selected for the design characteristics. This is because the next 4 highest ranked design characteristics were all within 1% of each other implying, while they were individually important, they were more so equally important to each other. Moving forward this allows for more effective differentiation between the most important design requirements without diluting the more highly weighted engineering design characteristics in the Pugh matrices. Based on this cutoff point the five selected engineering design characteristics can be seen highlighted in Table 4.0.

Pugh Matrices

The Pugh matrix is a tool used to compare and narrow down design concepts. The Pugh matrix does this by comparing how well each design concept satisfies each selected engineering characteristic relative to a datum. If a design concept can execute the engineering design characteristic better than the datum the concept is given a "+", if the design is not as good at executing the design characteristic it is given an "- ", and if the design concept and datum are equal, they receive a "s" for satisfactory. The first datum that was used was based on observations from watching paraplegic divers improvise with available resources on the market. Currently, paraplegic divers fasten their legs together, secure their legs somewhere to their dive equipment and add additional weights. This is all done to afford the paraplegic diver more independence while underwater. This datum was termed "MacGyver Style", shown in Table 5.0.

Table 5.0: Pugh Matrix 1

		Concepts						
Selection Criteria	Datum	Secondary Buoyancy	Buoyancy Sticks	Air Tube	Adjustable Lift Location	Weighted Shoulder Pads	Customizable Leg Floats	Rigid Exoskeleton
Angle of Diver at Depth and Surface	MacGyver Style	+	+	+	+	S	-	S
Distance to Controls		S	+	+	+	+	+	-
Works With Different Body Compositions		+	+	+	+	S	-	-
Surface Area That Would Affect Diver's Drag		+	+	+	+	-	+	S
Protective Perimeter Around Diver		-	+	+	+	S	S	+
Number of Pluses	-	3	5	5	5	1	2	1
Number of Minuses	-	1	0	0	0	1	2	2

Table 5.0 shows the Pugh Matrix 1. There were seven concepts compared to the "MacGyver Style" datum. The Customizable Leg Floats and the Rigid Exoskeleton designs were eliminated from the design selection process, because they were out performed by the "MacGyver Style" datum in two categories and they lacked positive outcomes. For Pugh Matrix 2 the datum that was chosen was the Weighted Shoulder Pads concept, because the design concept ranked neutral in Pugh Matrix 1.

Table 6.0: Pugh Matrix 2

		Concepts			
Selection Criteria	Datum	Secondary Buoyancy	Buoyancy Sticks	Air Tube	Adjustable Lift Location
Angle of Diver at Depth and Surface	Weighted Shoulder Pads	+	S	+	+
Distance to Controls		S	-	S	+
Works With Different Body Compositions		+	+	+	+
Surface Area That Would Affect Diver's Drag		-	S	+	+
Protective Perimeter Around Diver		+	+	+	+
Number of Pluses	-	3	2	4	5
Number of Minuses	-	1	1	0	0

Table 6.0 shows the Pugh Matrix 2. The Air Tube and Adjustable Lift Location were the only design concepts that outperformed or was satisfactory with the Weighted Shoulder Pad design in all of the engineering characteristic categories. For this reason, the Air Tube and Adjustable Lift Location were further evaluated in Pugh Matrix 3. The Secondary Buoyancy Compensator was chosen as the datum for Pugh Matrix 3, because of how well it met all of the design characteristics.

Table 7.0 Pugh Matrix 3

		Concepts	
Selection Criteria	Datum	Air Tube	Adjustable Lift Location
Angle of Diver at Depth and Surface	Secondary Buoyancy Compensator	S	+
Distance to Controls		S	S
Works With Different Body Compositions		+	+
Surface Area That Would Affect Diver's Drag		+	+
Protective Perimeter Around Diver		S	S
Number of Pluses	-	2	3
Number of Minuses	-	0	0

Table 7.0 shows the Pugh Matrix 3. The Air Tube and Adjustable Lift Location both outperformed the Secondary Buoyancy Compensator. However, the Adjustable Lift Location excelled in the most engineering design characteristics, so it was chosen as the preferred design for the project. Since the margins of declaring the Adjustable Lift Location were small, an analytical hierarchy process (AHP) was then carried out. The (AHP) was also used to ensure the Adjustable Lift Location was in fact the best design, and there was no bias in the decision-making process.

Analytical Hierarchy Process

AHP tables

After completing the pugh matrices, pairwise comparisons matrices were set up and given different AHP ratings. To set up the pairwise comparison matrix the criteria needed to be inputted into the top row and the first column. From here, the different criteria would be compared to one another. Once the pairwise matrix was set up, the matrix then needed to be normalized. This was done so a consistency check could be completed. When doing the consistency check, the consistency ratio needed to be less than 0.1, but not negative, otherwise there was an error somewhere along the way.

Table 8.0 Pairwise Comparison Matrix

Pairwise Comparison Matrix

Criteria		Angle of diver at depth and surface	Distance to controls	Protective perimeter around diver	Surface area affecting divers drag	Works with different body compositions		
	X	1	2	3	4	5	Total	%
Angle of diver at depth and surface	1	**1.00**	5.00	5.00	3.00	9.00	23.00	40
Distance to controls	2	0.20	**1.00**	0.20	0.33	3.00	4.73	8
Protective perimeter around diver	3	0.20	5.00	**1.00**	0.33	7.00	13.53	24
Surface area affecting divers drag	4	0.33	3.00	3.00	**1.00**	7.00	14.33	25
Works with different body compositions	5	0.11	0.33	0.14	0.14	**1.00**	1.73	3
		1.84	14.33	9.34	4.81	27.00	57.33	100
		3.2	25.0	16.3	8.4	47.1	100	57.33

Table 9.0 Normalizing Pairwise Comparison Matrix

Normalizing Comparison Matrix

Criteria		Angle of diver at depth and surface	Distance to controls	Protective perimeter around diver	Surface area affecting divers drag	Works with different body compositions	
	X	1	2	3	4	5	Total
Angle of diver at depth and surface	1	0.0435	0.2174	0.2174	0.1304	0.3913	1.00
Distance to controls	2	0.0423	0.2113	0.0423	0.0704	0.6338	1.00
Protective perimeter around diver	3	0.0148	0.3695	0.0739	0.0246	0.5172	1.00
Surface area affecting divers drag	4	0.0233	0.2093	0.2093	0.0698	0.4884	1.00
Works with different body compositions	5	0.0642	0.1927	0.0826	0.0826	0.5780	1.00
Criteria Weights {W}		0.0376	0.2400	0.1251	0.0756	0.5217	1.0000

Table 10.0 Consistency Check for Pairwise Matrix

Consistency Check

Weighted Sum Vector	Criteria Weights	Consistecy Vector
0.19378	0.0376	5.154002132
1.45402	0.2400	6.058003328
0.66230	0.1251	5.29494406
0.38459	0.0756	5.089537606
2.98469	0.5217	5.720636996
	Lambda (λ)	5.463424824

Random Index Value (RI)	Consistency Index (CI)	Consistency Ratio
1.11	0.115856206	0.10

Once the consistency check for the pairwise comparison matrix was completed, each of those criteria were then compared to each of the three final concepts from the pugh matrix. The goal for doing this, is to be able to find out which of the three final concepts would work best and make this project be the most successful. The following 15 tables, 11-23 will go through each of the criteria and compare the three final concepts to one another. When reading these tables, it was asked if the concept on the left side of the table was better than the concepts along the top of the table.

Table 11.0 Angle of Diver at Depth and Surface Comparison

Angle of Diver at Depth and Surface			
	Air Tube	Adjustable Lift	Secondary BC
Air Tube	1.00	0.33	1.00
Adjustable Lift	3.00	1.00	7.00
Secondary BC	1.00	0.14	1.00
Sum	5.00	1.48	9.00

Table 12.0 Normalized Comparison

Normalized Angle of Diver at Depth and Surface				
	Air Tube	Adjustable Lift	Secondary BC	**Design Alternative Priorities {Pi}**
Air Tube	0.20	0.23	0.11	0.18
Adjustable Lift	0.60	0.68	0.78	0.69
Secondary BC	0.20	0.10	0.11	0.14
Sum	1.00	1.00	1.00	1.00

Table 13.0 Consistency Check for Angle of Diver at Depth and Surface Comparison

Consistency Check		
Weighted Sum Vector {WS}	**Criteria Weights {Pi}**	**Consistecy Vector**
0.54	0.18	3.04
2.17	0.69	3.17
0.41	0.14	3.04
	Lambda (ʎ)	3.081586606

Random Index Value (RI)	Consistency Index (CI)	Consistency Ratio
0.52	0.040793303	0.07844866

Table 14.0 Distance to Controls Comparison

Distance to Controls			
	Air Tube	Adjustable Lift	Secondary BC
Air Tube	1.00	0.14	3.00
Adjustable Lift	7.00	1.00	9.00
Secondary BC	0.33	0.11	1.00
Sum	8.33	1.25	13.00

Table 15.0 Normalized Distance to Controls Comparison

Normalized Distance to Controls				
	Air Tube	Adjustable Lift	Secondary BC	**Design Alternative Priorities {Pi}**
Air Tube	0.12	0.11	0.23	0.15
Adjustable Lift	0.84	0.80	0.69	0.78
Secondary BC	0.04	0.09	0.08	0.07
Sum	1.00	1.00	1.00	1.00

Table 16.0 Consistency Check for Distance to Controls Comparison

Consistency Check		
Weighted Sum Vector {WS}	Criteria Weights {Pi}	Consistecy Vector
0.47	0.15	3.04
2.48	0.78	3.19
0.21	0.07	3.01
	Lambda (ʎ)	3.082141275

Random Index Value (RI)	Consistency Index (CI)	Consistency Ratio
0.52	0.041070637	0.078981995

Table 17.0 Protective Perimeter Around Diver

Protective Perimeter Around Diver			
	Air Tube	Adjustable Lift	Secondary BC
Air Tube	1.00	5.00	3.00
Adjustable Lift	0.20	1.00	0.33
Secondary BC	0.33	3.00	1.00
Sum	1.53	9.00	4.33

Table 18.0 Normalized Protective Perimeter Around Diver

Normalized Protective Perimeter Around Diver				
	Air Tube	Adjustable Lift	Secondary BC	Design Alternative Priorities {Pi}
Air Tube	0.65	0.56	0.69	0.63
Adjustable Lift	0.13	0.11	0.08	0.11
Secondary BC	0.22	0.33	0.23	0.26
Sum	1.00	1.00	1.00	1.00

Table 19.0 Consistency Check for Protective Perimeter Around Diver

Consistency Check		
Weighted Sum Vector {WS}	Criteria Weights {Pi}	Consistecy Vector
1.95	0.63	3.07
0.32	0.11	3.01
0.79	0.26	3.03

Random Index Value (RI)	Consistency Index (CI)	Consistency Ratio
0.52	0.01935734	0.037225655

Table 20.0 Surface Area Affecting Diver's Drag

Surface Area Affecting Diver's Drag			
	Air Tube	Adjustable Lift	Secondary BC
Air Tube	1.00	0.33	3.00
Adjustable Lift	3.00	1.00	5.00
Secondary BC	0.33	0.20	1.00
Sum	4.33	1.53	9.00

Table 21.0 Normalized Surface Area Affecting Diver's Drag

Normalized Surface Area Affecting Diver's Drag				
	Air Tube	Adjustable Lift	Secondary BC	Design Alternative Priorities {Pi}
Air Tube	0.12	0.22	0.33	0.22
Adjustable Lift	0.36	0.65	0.56	0.52
Secondary BC	0.04	0.13	0.11	0.09
Sum	0.52	1.00	1.00	0.84

Table 22.0 Consistency Check for Surface Area Affecting Diver's Drag

Consistency Check		
Weighted Sum Vector {WS}	Criteria Weights {Pi}	Consistecy Vector
0.68	0.22	3.04
1.66	0.52	3.18
0.27	0.09	2.91
	Lambda (ʎ)	3.042535461

Random Index Value (RI)	Consistency Index (CI)	Consistency Ratio
0.52	0.021267731	0.040899482

Table 23.0 Works with Different Body Compositions

Works With Different Body Compositions			
	Air Tube	Adjustable Lift	Secondary BC
Air Tube	1.00	0.20	0.20
Adjustable Lift	5.00	1.00	1.00
Secondary BC	5.00	1.00	1.00
Sum	11.00	2.20	2.20

Table 24.0 Normalized Works with Different Body Compositions

Normalized Works With Different Body Compositions				
	Air Tube	Adjustable Lift	Secondary BC	Design Alternative Priorities {Pi}
Air Tube	0.12	0.09	0.09	0.10
Adjustable Lift	0.60	0.45	0.45	0.50
Secondary BC	0.60	0.45	0.45	0.50
Sum	1.32	1.00	1.00	1.11

Table 25.0 Consistency Check for Works with Different Body Compositions

Consistency Check		
Weighted Sum Vector {WS}	Criteria Weights {Pi}	Consistecy Vector
0.30	0.10	3.00
1.51	0.50	3.00
1.51	0.50	3.00
	Lambda (ʎ)	3

Random Index Value (RI)	Consistency Index (CI)	Consistency Ratio
0.52	0	0

	Air Tube	Adjustable Lift	Secondary BC
Angle of Diver At Depth and Surface	0.18	0.69	0.14
Distance to Controls	0.15	0.78	0.05
Protective Perimeter Around Diver	0.63	0.11	0.26
Surface Area Affecting Diver's Drag	0.22	0.52	0.09
Works With Different Body Compostions	0.1	0.5	0.5

	Angle of Diver at Depth and Surface	Distance to Controls	Protective Perimeter Around Diver	Surface Area Afftecting Diver's Drag	Works With Different Body Compositions
Air Tube	0.18	0.15	0.63	0.22	0.1
Adjustable Lift	0.69	0.78	0.11	0.52	0.5
Secondary BC	0.14	0.05	0.26	0.09	0.5

Concept	Alternative Value
Air Tube	0.190383
Adjustable Lift	0.527067
Secondary BC	0.317444

Final choice

The Adjustable Lift Location proved to be the best concept for the project. By allowing the diver the ability to fine tune the location of the float, the design can easily adjust the diver's body orientation in the water. Since the design can have different size floats attached to the pulley system, the design proved compatible with many different body compositions. The controls are located along the diver's chest and torso, so they are readily accessible. By incorporating the pulley system into the modified wetsuit, the diver remains streamlined, thus, reducing their drag and allowing the diver to control the location of their legs.