Concept Selection:

Improved Design of Mobility Devices

Team 526

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Submission Date: 11/02/2018

Table of Contents

1.0 House of Quality

A house of quality (HoQ) was used to ensure that our customer requirements were thoroughly infused into our engineering characteristics. The ultimate goal of a HoQ is to establish an importance ranking order with respect to the engineering characteristics. Before establishing this ranking order, however, a binary comparison was used to establish the importance weight factors of the customer requirements. This binary comparison can be seen in the appendix. These weight factors distinguish the importance of different requirements. After the necessary precursors for the HoQ had been determined, the engineering characteristics were individually analyzed with each customer requirement receiving a rating of 1, 3, or 9. The lower the rating number, the less a specific customer requirement can be fulfilled by a certain engineering characteristic. If a cell is blank it means that the engineering characteristic is not associated with that specific customer requirement. Once this process was completed for all rows and columns, the results were tabulated and can be seen at the bottom of Table 1 below.

Table 1: House of Quality Chart

		Engineering Characteristics					
Improvement Direction		↑	↓	↑	↑	↓	↑
Units		lbs	%	°/in.	bpm	$	in.
Customer Requirements	**Importance Weight Factor**	**Weight Reduction**	**Natural Gait Variation**	**Adjustability**	**Change of Heart Rate**	**Price**	**Compactability**
Affordable	3			3		9	3
Lightweight	1	1	1			3	
Provides Support	6	9	1	3			
Easily Maneuverable	5		3				
Uses Cardiovascular Activity	3	3	1		9		
Doesn't Affect Walking Pattern	3	1	9	3			
Raw Score (221)		67	52	36	27	30	9
Relative Weight %		30.3	23.5	16.3	12.2	13.6	4.1
Rank Order		1	2	3	5	4	6

The HoQ depicted above shows the importance ranking order from 1-6 of each of the 6 engineering characteristics. As expected, weight reduction and natural gait variation ended up being the most important characteristics. Price, however, was expected to be the next most important but was determined to be the 4th most important after adjustability. These important ratings were used throughout the rest of the concept selection process to determine which concept best met the customer requirements.

2.0 Pugh Chart

To gain a better understanding of how our different design concepts compare to products already on the market, and each other, two Pugh Charts were utilized. The purpose of this step was to highlight the advantages and disadvantages of our different concepts. These four different concept ideas are clarified and labeled in Figure 1 below.

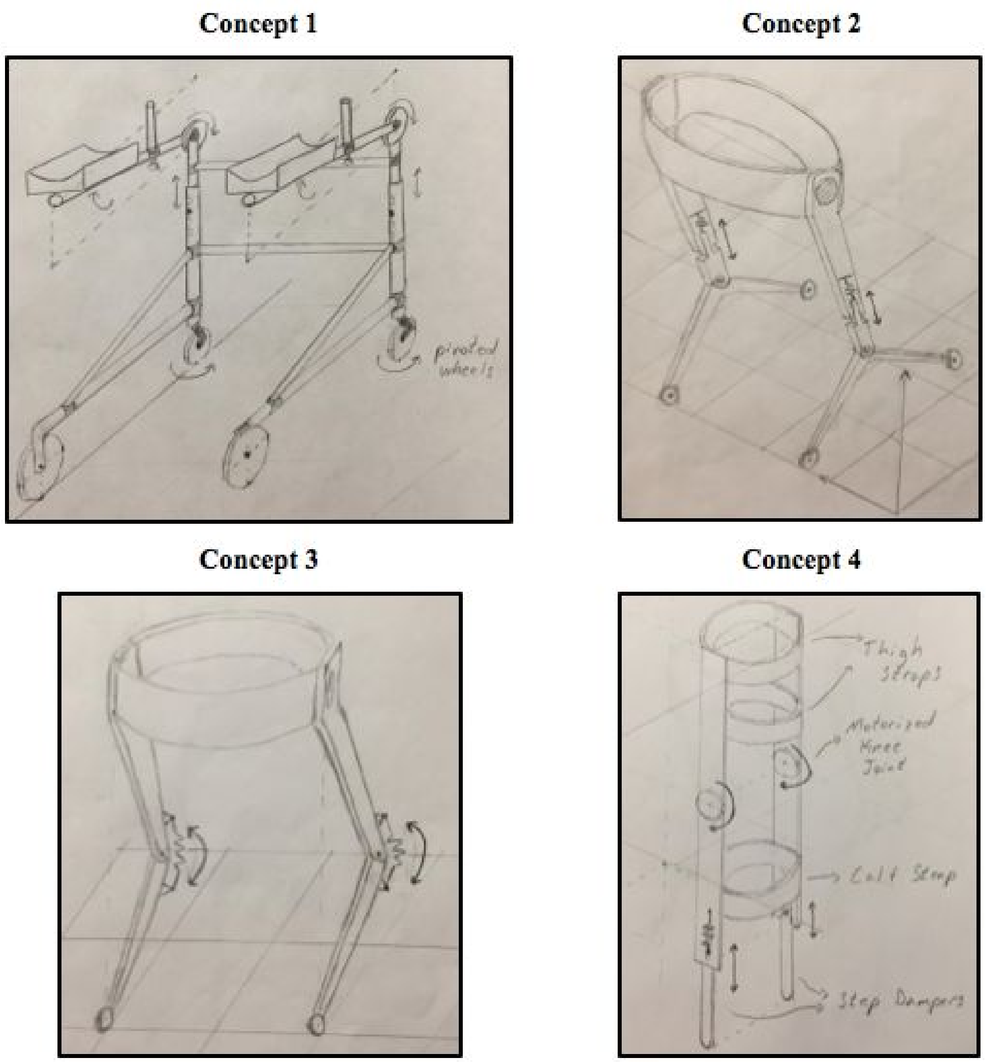

Figure 1: Design Concepts

The product chosen for the initial datum was the UpWalker, the closest competitor of the devices already on the market. The engineering characteristics of design concepts 1 through 4, depicted above, were then individually compared to those of the UpWalker. If a devices characteristic were better than the datum, the concept would receive a ‘+’, and if it was worse, a “-”. An ‘S’ was given if there was not a substantial difference. The first Pugh Chart is shown below.

Table 2: Closest Competitor Pugh Chart

		Pugh Chart			
		Concept			
Selection Criteria	**UPWalker**	**1**	**2**	**3**	**4**
Weight Reduction	Datum	S	+	-	-
Natural Gate Variation		+	+	+	-
Adjustability		+	+	+	+
Change of Heart Rate		S	-	-	-
Price		+	-	+	-
Compactability		S	+	+	+
	# of Pluses	3	4	4	2
	# of Minuses	0	2	2	4

After comparing all of our concepts to the datum, the ratings were totaled and can be seen in Table 2 above. Concept 2 was favored by the group going into this process, and after comparing each of them to the closest competitor, this bias gained legitimacy. This concept, along with its similar counterpart Concept 3, had the most superior characteristics compared to the UpWalker. An important note to make, however, is that Concept 1 had no inferior characteristics compared to the UpWalker, whereas Concepts 2 & 3 both had 2 inferior characteristics. To further highlight the different concepts’ strengths and weaknesses, our top concept from the previous Pugh chart, Concept 2, was made our datum, and the comparison process was repeated with the other concepts.

Table 3: Concept 2 Pugh Chart

		Pugh Chart		
		Concept		
Selection Criteria	2	1	3	4
Weight Reduction	Datum	+	S	-
Natural Gate Variation		+	S	-
Adjustability		+	S	-
Change of Heart Rate		-	-	-
Price		+	+	-
Compactability		S	+	+
	# of Pluses	4	2	1
	# of Minuses	1	1	5

The Pugh Chart in Table 3 above compares the engineering characteristics of Concepts 1, 3, & 4 to those of Concept 2. Concept 2, when compared to the UpWalker, looked to be the best concept. However, when it was compared to our other concepts, Concept 1 was shown to have 4 superior characteristics to Concept 2. Also, Concepts 3 & 4 were determined to have very few superior characteristics to 2. Concept 3, is a similar variation of Concept 2, had numerous characteristics that were no better or worse. Concept 4 however, appeared to not only have 1 superior characteristic but had 5 inferior characteristics. According to this Pugh Chart, concept 1 is the superior design when relating how it satisfies the engineering characteristics to the other concepts.

3.0 Analytic Hierarchy Process

In order to find the best design that suits our specific goals for this project, the Analytic Hierarchy Process (AHP) was used. By making comparisons between the top three most important engineering characteristics as well as the concepts with respect to those characteristics, we were able to obtain concrete data that shows which concept we should select for our final design. One other important thing to note, however, is the consistency ratio (CR). If the calculated CR is less than 0.10, the comparison is unbiased. Similarly, if it is higher than 0.10, it is biased. These calculations and comparisons were included below and can be assumed to follow the same process for each group of tables.

The first group of tables compares and analyzes these engineering characteristics: weight reduction, natural gait variation, and adjustability. The calculated CR was 0.0372 which shows that our comparisons were not biased when relating the engineering characteristics. These tables are shown below:

Table Set 1: AHP with Engineering Characteristics

	Criteria Comparison Matrix [C]		
Engineering Characterisitics	Weight Reduction	Natural Gait Variation	Adjustability
Weight Reduction	1	3	5
Natural Gait Variation	0.3333	1	3
Adjustability	0.2000	0.3333	1
Sum	1.5333	4.3333	9

	Normalization Criteria Comparison Matrix [NormC]			
Engineering Characterisitics	Weight Reduction	Natural Gait Variation	Adjustability	Criteria Weights
Weight Reduction	0.6522	0.6923	0.5556	0.6333
Natural Gait Variation	0.2174	0.2308	0.3333	0.2605
Adjustability	0.1304	0.0769	0.1111	0.1062
Sum	1.0000	1.0000	1.0000	1.0000

Consistency Check		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Cons={Ws}./{W} Consistency Vector
1.9458	0.6333	3.0725
0.7902	0.2605	3.0333
0.3197	0.1062	3.0102

Avg. Consistency	3.0387
CI	0.0193
CR	0.0372

The first engineering characteristic we analyzed against our concepts was weight reduction. According to our calculations, concept 1 and concept 2 had higher weighted values indicating these concepts were most capable of reducing weight. The CR calculated was less than 0 which indicates that we were very unbiased when comparing the concepts. These values can be seen in the following table set.

Table Set 2: AHP with Weight Reduction Comparison

	Weight Reduction Comparison		
	Criteria Comparison Matrix [C]		
Concepts	1	2	3
1	1	1	3
2	1	1	3
3	0.3333	0.3333	1
Sum	2.3333	2	7

	Normalization Criteria Comparison Matrix [NormC]			
Concepts	1	2	3	Criteria Weights
1	0.4286	0.4286	0.4286	0.4286
2	0.4286	0.4286	0.4286	0.4286
3	0.1429	0.1429	0.1429	0.1429
Sum	1.0000	1.0000	1.0000	1.0000

Consistency Check		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Cons={Ws}./{W} Consistency Vector
1.2859	0.4286	3.0002
1.2859	0.4286	3.0002
0.4286	0.1429	2.9993

Avg. Consistency	2.9999
CI	0.0000
CR	-0.0001

The next engineering characteristic that was compared to our concepts was natural gait variation. We analyzed the concept against each other and obtained a CR value of 0.1336. Although this indicates that we are slightly biased in our calculations, the value isn't much higher than 0.10. This biased opinion could stem from the particular design characteristics that are present in concept 1 (the adjustable and spring loaded forearm support) that we think is the best option to help maintain the users' natural gait. These discussed values can be seen in the following table set.

Table Set 3: AHP with Natural Gait Variation Comparison

Natural Gait Variation Comparison			
	Criteria Comparison Matrix [C]		
Concepts	1	2	3
1	1	5	5
2	0.2000	1	0.3333
3	0.2000	3	1
Sum	1.4000	9	6.3333

	Normalization Criteria Comparison Matrix [NormC]			
Concepts	1	2	3	Criteria Weights
1	0.7143	0.5556	0.7895	0.6864
2	0.1429	0.1111	0.0526	0.1022
3	0.1429	0.3333	0.1579	0.2114
Sum	1.0000	1.0000	1.0000	1.0000

Consistency Check		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Cons={Ws}./{W} Consistency Vector
2.2544	0.6864	3.2844
0.3099	0.1022	3.0327
0.6553	0.2114	3.0997

Avg. Consistency	3.1389
CI	0.0695
CR	0.1336

The final engineering characteristic that we analyzed our concepts against was adjustability. Concept 1 calculated to have the highest criteria weight, indicating that it was far more superior in providing adjustability than the other two concepts. The CR for this comparison was found to be 0.1350, similar to the natural gait variation comparison. This outcome can be attributed to the same fact that our original concept 1 does indeed provide much more adjustability to the user.

Table Set 4: AHP with Adjustability Comparison

	Adjustability Comparison		
	Criteria Comparison Matrix [C]		
Concepts	1	2	3
1	1	7	7
2	0.1429	1	3
3	0.1429	0.3333	1
Sum	1.2857	8.3333	11

	Normalization Criteria Comparison Matrix [NormC]			
Concepts	1	2	3	Criteria Weights
1	0.7778	0.8400	0.6364	0.7514
2	0.1111	0.1200	0.2727	0.1679
3	0.1111	0.0400	0.0909	0.0807
Sum	1.0000	1.0000	1.0000	1.0000

Consistency Check		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Cons={Ws}./{W} Consistency Vector
2.4916	0.7514	3.3159
0.5174	0.1679	3.0814
0.244	0.0807	3.0240

Avg. Consistency	3.1404
CI	0.0702
CR	0.1350

After finding all of the above data, the final rating matrix was created. This showed the criteria weights for all of the 3 concepts with respect to the engineering characteristics. Once these values were tabulated, the alternative values for each concept were calculated. According to the calculation, concept 1 is the most superior in successfully satisfying the engineering characteristics. The tables and values can be seen below.

Table Set 5: Final Rating Matrix and Alternative Values

	Final Rating Matrix		
Selection Criteria	1	2	3
Weight Reduction	0.4286	0.4286	0.1429
Natural Gait Variation	0.6864	0.1022	0.2114
Adjustability	0.7514	0.1679	0.0807

Concept	Alternative Value
1	0.53
2	0.3169
3	0.1541

4.0 Final Decision

The 3 concept selection tools (HoQ, Pugh Chart, and AHP) utilized for this project and discussed above, were thoroughly analyzed to determine which of our 4 design concepts provided the best solution.

The house of quality was useful at determining the ranking order of our engineering characteristics. Although we initially thought various characteristics were of more importance, for example, the price of the design, it turns out that other ones are better at satisfying the customer requirements. The most important engineering characteristic we found from the HoQ was weight reduction while the least important characteristic was the ability to compact. The importance of the HoQ was to narrow down the characteristics into a handful of them to use in the Pugh Chart but since we only had 6, to begin with, we went ahead with the next concept selection tool using all of them.

The first Pugh chart, comparing each concept to the UpWalker, suggested that concepts 2 & 3 had more superior characteristics but also showed that concept 1 was a contender because it had no inferior characteristics. The second Pugh chart, comparing each concept to concept 2, showed a much clearer winner. This chart suggested that concept 1 had a number of superior characteristics to concept 2 and also clarified that the other two concepts, 3 & 4, were overall inferior to 1 & 2.

The Analytic Hierarchy Process (AHP) is ultimately what decided the best concept that suits our most important engineering characteristics. Although our calculated data shows a slight bias when choosing concept 1 with respect to natural gait variation and adjustability, the consistency ratio is not much higher than the preferred 0.10 value. Once creating the final rating matrix and the alternative value, the values were compared between each of the concepts. The alternative value for concept 1 was the highest and therefore selected to be our final decision.

After using all of these concept selection tools to compare our various designs, we are confident that the final design we chose will best satisfy the customer requirements as well as accomplishing our engineering characteristics goals.

5.0 Appendix

UpWalker:

Website: https://tryupwalker.com

Binary Comparison Table:

Customer Needs	Affordable	Lightweight	Provides Support	Easily Maneuverable	Uses Cardiovascular Activity	Doesn't Affect Walking Pattern
Affordable	1	0	1	1	1	0
Lightweight	1	1	1	1	1	1
Provides Support	0	0	1	0	0	0
Easily Maneuverable	0	0	1	1	0	0
Uses Cardiovascular Activity	0	0	1	1	1	1
Doesn't Affect Walking Pattern	1	0	1	1	0	1
Sum	**3**	**1**	**6**	**5**	**3**	**3**