1.6 Concept Selection

The concept generation phase yielded 8 viable options for devices that can be used to meet our objectives. In order to narrow these choices down to the best design, concept selection tools were used to minimize bias and analyze each engineering characteristic and concept to determine which design showed the best performance. A House of Quality, Pugh charts, and Analytical Hierarchy Process were used in order to analytically decide upon the best option.

House of Quality

The House of Quality is a tool that can be used to evaluate a series of engineering characteristics with the customer needs. The House of Quality consists of the engineering characteristics inspired by our functional decomposition chart that aligns with our Targets and Metrics section. A pairwise analysis was conducted in order to compare customer requirements against each other, to determine each requirement's respective Weight Factor. The results of this pairwise comparison can be seen in Table 3. As can be seen in this table, the *Attract Victim* requirement was deemed to be the most heavily weighted requirement. This is because without this requirement, the device is obsolete. Also, the *Allow 2 Way Communication* requirement received a weight of 0 because it was deemed the least important requirement when compared to any other requirement.

Table 3 *Pariwise Analysis*

Importance Weight Factor									
Customer Requirements	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
1. Discrete	-	0	0	1	0	0	0	0	**1**
2. Attract Victim	1	-	1	1	1	1	1	1	**7**
3. Easy User Interface	1	0	-	1	0	0	0	0	**2**
4. Allow 2 Way Communication	0	0	0	-	0	0	0	0	**0**
5. Avoid False Alarms	1	0	1	1	-	0	0	0	**3**
6. Surveillance	1	0	1	1	1	-	0	0	**4**
7. Alert Authorities	1	0	1	1	1	1	-	0	**5**
8. Tracks Child	1	0	1	1	1	1	1	-	**6**
Total	**6**	**0**	**5**	**7**	**4**	**3**	**2**	**1**	**28**

The weight factors determined in the pairwise comparison chart were used in the House of Quality (Table 4) to compare the customer requirements to the engineering characteristics established in the targets and metrics section of the design process. Then we conducted a comparison between the engineering characteristics and customer requirements that indicate the correlation between each customer requirement and engineering characteristic. The House of Quality displays relationships between design targets (columns) and customer requirements (rows), based on a scale 9-0, 9 meaning that the requirement and characteristic were highly correlated, 5 meaning that they were moderately correlated, 1 being that they were minimally correlated, and 0 indicating that they weren't correlated at all. Each respective ranking was multiplied by the importance weight factor for that customer need. The results were added together, normalized by the total raw score, and a relative weight was established to determine which engineering characteristics were the most important. This helped us to determine which engineering requirements should be focused on to better integrate the customer's need into the design. This was used later on in the Pugh Charts.

This comparison showed us that the *Percentage of People Who can See the Sign* characteristic is the most important factor. This is not a surprise to us because it is vital for the victims to be able to see the sign for the device to serve its purpose, which is saving the young adults. The *Time Taken to Initiate Communication* characteristic is the second most important factor. This characteristic is very important as well because the quicker it is for the victim to interact with our device, the quicker law enforcement will be there to rescue them. The third most important factor is the *Percentage of Valid Alarms.* Ensuring that our device has little to no false alarm is crucial in order for us to target the correct victims. The device will include a surveillance feature, which will provide law enforcement access to view the victim and the surrounding area to confirm that in fact the situation it's not a false alarm. Saving the victim and maintaining their safety is one of our goals. The relative weight for the other factors isn't too far apart from these three main factors. The rankings determined in the House of Quality were used in order to better evaluate the Pugh Charts.

		Engineering Characteristics										
	Improvement Direction	↑	↓	↑	↑	↑	↓	↑	↓	↓	↑	↓
	Units	m	n/a	%	min	GB	sec	%	s	s	m	s
Customer Requirements	Importance Weight Factor	Height of Sign Asking if the Victim Needs Help	Required Comprehension Level	Percentage of People Who can See the Sign	Duration of Video Recording	System Memory for Images and Videos	Time Taken to Initiate Communication	Percentage of Valid Alarms	Output Response Time to Notify Authorities	Response Time of Authorities	Accuracy Associated with GPS Tracker	Response Time Needed to Communicate with Other Systems
Discrete	**1**	3	0	9	0	0	1	0	0	0	3	0
Attract Victim	**7**	3	3	9	0	0	1	1	0	0	0	1
Easy User Interface	**2**	3	9	3	0	0	0	1	0	0	0	0
Allow 2 Way Communication	**0**	3	9	9	1	0	3	3	1	0	0	3
Avoid False Alarms	**3**	1	1	3	1	1	3	9	0	0	0	1
Surveillance	**4**	0	0	0	9	9	1	3	3	0	0	3
Alert Authorities	**5**	0	0	0	1	3	9	3	9	1	1	1
Tracks Child	**6**	0	1	1	1	1	1	0	0	0	9	1
	Raw Score (576)	33	48	93	50	60	72	63	57	5	62	33
	Relative Weight %	5.729	8.333	16.146	8.681	10.417	12.500	10.938	9.896	0.868	10.764	5.729
	Rank Order	9	8	1	7	5	2	3	6	11	4	9

Table 4 *House of Quality Chart*

Pugh Charts

Rather than selecting a concept to execute our project based on favoritism (which would introduce bias into the design), we used the Pugh Chart to compare concepts together, dependent on engineering characteristics. This allows for the quantification of qualitative concepts, to see which will be the most successful in achieving the key purposes of a project. To make the comparison of several concepts possible, a baseline datum is needed. A datum is a product that solves a problem similar (or the same) to the one we are trying to solve.

For our initial Pugh Chart, the datum we used was the ANAR lenticular lens sign. It is only fitting that the ANAR lenticular sign be used as a datum, because it was the inspiration behind this project and its points of failure (such as relying on a child's memory for rescue) are the foundation of our customer needs. After selecting the datum, the engineering characteristics were ordered based on their respective House of Quality rankings. The higher each characteristic ranked, the more attention it was given during the comparison between concepts.

When comparing each key characteristic with the datum and the concept, we to put a '+' next to each concept that displayed a key characteristic better than the datum, an 'S' when the concept and the datum performed the same in regards to the specified characteristic, and a '-' when the datum outperformed in regards to the specified characteristic. In the initial Pugh Chart, Table 5, the 5 medium fidelity concepts and 3 high fidelity concepts determined during the concept generation phase were compared against the ANAR lenticular lens. From the first Pugh Chart, concepts 3 and 8 were ruled out immediately due to their poor performance when compared to the datum (high amount of minuses in the top three ranked engineering characteristics). Concepts 4 and 6 tied in the ranking with an equal amount of positives, but ultimately concept 4 was chosen as the new datum for the next iteration of the Pugh chart due to its more mediocre ranking when compared to the datum. It was able to perform at or above the datum regarding the higher ranked engineering characteristics.

Table 5 *First Pugh Chart*

		Concepts							
Engineering Characteristics	Datum: ANAR Sign	Concept 1: Vending Machine	Concept 2: GPS Burr	Concept 3: Cellular Tracker	Concept 4: GPS Pills	Concept 5: Two-Way Mirror	Concept 6: Park Binoculars	Concept 7: Weight Scale	Concept 8: Fluid Scanner
Percentage of People Who can See the Sign	Datum	S	S	S	S	+	+	+	S
Time Taken to Initiate Communication		+	+	-	+	+	+	+	-
Percentage of Valid Alarms		+	+	-	+	+	-	-	-
Accuracy Associated with GPS Tracker		+	+	+	+	S	S	S	S
System Memory for Images and Videos		+	S	+	S	S	+	+	+
Output Response Time to Notify Authorities		+	+	+	+	+	-	+	-
Duration of Video Recording		+	+	+	+	S	+	+	+
Required Comprehension Level		+	+	+	-	+	S	S	+
Height of Sign Asking if the Victim Needs Help		S	S	S	S	+	+	+	S
Response Time of Authorities		+	+	-	+	+	+	+	-
Sum of Pluses		8	7	5	6	7	6	7	3
Sum of Minuses		0	0	3	1	0	2	1	4
Rank		1	2	7	5	2	5	2	8

After the first Pugh Chart was able to identify the top four concepts, the next iteration of the Pugh Chart, Table 6, was used in order to identify the next datum and accurately rank the top three concepts. All remaining concepts were compared against the new datum, concept 4, GPS Pills. This comparison indicated an obvious concept to be used as the new datum: concept 2, GPS Burr. When compared against this datum, the other three concepts all were tied in terms of ranking. These three concepts were used later on in the Analytical Hierarchy Process.

Table 6 *Second Pugh Chart*

The final iteration of the Pugh Chart, Table 7, allowed for the best concept to be selected. When comparing the top three concepts to the newest datum, concept 7 performed mediocrely and was ranked satisfactorily on two of the top three highest ranking engineering characteristics. Concept 5 garnered the largest amount of minuses, but was ranked higher than concept 7 due to its greater amount of pluses. Based on the Pugh Chart, concept 5 ended up coming in second and concept 7 came third. Receiving only one satisfactory on the final iteration of the Pugh Chart, concept 1 was identified as the clear winner due to its high amount of pluses and minimum amount of minuses. Concept 1 was ranked the best concept to carry out the scope of our project.

Table 7 *Third Pugh Chart*

		Concepts		
Engineering Characteristics	**Concept 2: GPS Burr**	**Concept 1: Vending Machine**	**Concept 5: Two-Way Mirror**	**Concept 7: Weight Scale**
Percentage of People Who can See the Sign	Datum	+	+	+
Time Taken to Initiate Communication		+	+	S
Percentage of Valid Alarms		+	+	S
Accuracy Associated with GPS Tracker		+	-	-
System Memory for Images and Videos		+	+	+
Output Response Time to Notify Authorities		+	-	+
Duration of Video Recording		+	+	+
Required Comprehension Level		+	+	S
Height of Sign Asking if the Victim Needs Help		S	S	S
Response Time of Authorities		+	S	S
Sum of Pluses		**9**	**6**	**4**
Sum of Minuses		**0**	**2**	**1**
Rank		**1**	**2**	**3**

In order to compare the concepts in a more analytical, less biased manor, a second concept selection tool was used in order to reevaluate the results of the Pugh Charts.

AHP

Instead of relying on subjectivity to select the final concept, an Analytical Hierarchy Process (AHP) was used. This process is a mathematical way of deciding on the final concept. The first step in this process is to compare the importance of the engineering characteristics against one another. This is shown in Criteria Comparison Matrix [C] labeled as Table 8 below. The values in this table were then normalized to produce Table 9. This normalization is significant because it allows for criteria weights – how each engineering characteristic is weighted against others – to be established. We can observe from this table the importance of the engineering characteristics by looking at the Criteria Weights {W}. *The Accuracy Associated with the Tracker* is the most important followed by *The Required Comprehension Level to Interact with the Device*, *Output Response Time to Notify Authorities*, *Time Taken to Initiate Communication,* and the *Percentage of Valid Alarms*. These weights came into play later, when analyzing how each of the top three concepts performed in respect to each engineering characteristic.

Table 8 *Criteria Comparison Matrix*

Development of Candidate Set of Criteria Weights {W}								
Criteria Comparison Matrix [C]								
Engineering Characteristics	Percentage of People Who can See the Sign	Time Taken to Initiate Communication	Percentage of Valid Alarms	Accuracy Associated with GPS Tracker	System Memory for Images and Videos	Output Response Time to Notify Authorities	Duration of Video Recording	Required Comprehension Level
Percentage of People Who can See the Sign	1.000	0.200	0.333	0.143	3.000	0.111	3.000	0.200
Time Taken to Initiate Communication	5.000	1.000	3.000	0.333	7.000	1.000	5.000	1.000
Percentage of Valid Alarms	3.000	0.333	1.000	0.200	7.000	0.333	5.000	0.143
Accuracy Associated with GPS Tracker	7.000	3.000	5.000	1.000	5.000	3.000	9.000	3.000
System Memory for Images and Videos	0.333	0.143	0.143	0.200	1.000	0.143	1.000	0.200
Output Response Time to Notify Authorities	9.000	1.000	3.000	0.333	7.000	1.000	7.000	0.333
Duration of Video Recording	0.333	0.200	0.200	0.111	1.000	0.143	1.000	0.200
Required Comprehension Level	5.000	1.000	7.000	0.333	5.000	3.000	5.000	1.000
Sum	**30.667**	**6.876**	**19.676**	**2.654**	**36.000**	**8.730**	**36.000**	**6.076**

Table 9 *Normalized Criteria Comparison Matrix*

The next step in the AHP is to determine the consistency of the values determined by the team in Table 8. This is to evaluate the potential bias that could have been introduced into our concept selection. This consistency check was done by conducting vector and matrix calculations shown in Table 10. From this table, we were able to determine our consistency ratio (CR) which is the value where we can determine if our concept selection introduced any bias. The CR was determined to be 0.098. Since this value is less than 0.10, this shows that our evaluation of engineering characteristics didn't show significant bias.

Table 10 *Consistency Check*

Consistency Check		
{Ws} = [C]{W} Weighted Sum Vector	{W} Criteria Weights	Cons = {Ws}./{W} Consistency Vector
0.359	0.043	8.330
1.392	0.150	9.287

0.722	0.083	8.650
2.911	0.315	9.236
0.225	0.027	8.212
1.482	0.159	9.298
0.210	0.025	8.544
1.990	0.197	10.101
	λ=	**8.957**
	RI=	**1.400**
	CI=	**0.137**
	CR =	**0.098**

This same process was then conducted for the engineering characteristics in reference to the final concepts where we were able to determine the importance of each individual characteristics relative to the other engineering characteristics and if any bias was introduced. It is important to note that many of our engineering characteristics yielded consistency checks that indicated there was some level of biased introduced. This bias, while unfavorable, is important due to the gravity of the project's background. Especially since there is potentially a person's life at stake in this project, it is important that we employ our ethical beliefs to yield the most optimum results. For an example, the consistency check for the *Time Taken to Initiate Communication* engineering characteristic yielded a CR of 0.294. While this was deemed to be biased (the threshold is approximately CR = 0.10) it was a significant engineering characteristic because it defines the threshold that communication must be established; if the victim leaves before communication is established, they will not be saved. Concepts such as the two-way mirror and scale have wait times associated with them (leaving the bathroom to verify identity and time taken to verify weight, respectively). These wait times could, in practice, prevent the rescue of the victim. From this process we were able to develop a Final Rating Matrix shown in Table 11. This table shows that in every single engineering characteristic evaluation, concept 1 was deemed to be the most applicable for said characteristic. From this table we were able to derive the alternative values of the concepts by weighing said values with respect to the criteria weights of each engineering characteristic, established earlier in the AHP process. As seen in Table 12, the results of the analytical hierarchy process indicate that the concept that best fulfills the engineering characteristics is concept 1: the vending machine.

Table 11 *Final Rating Matrix*

Final Rating Matrix

Selection Criteria	Concept 1: Vending Machine	Concept 5: Two-Way Mirror	Concept 7: Weight Scale
Percentage of People Who can See the Sign	0.481	0.236	0.283
Time Taken to Initiate Communication	0.623	0.239	0.138
Percentage of Valid Alarms	0.481	0.236	0.283
Accuracy Associated with GPS Tracker	0.797	0.097	0.106
System Memory for Images and Videos	0.368	0.299	0.333
Output Response Time to Notify Authorities	0.633	0.106	0.260
Duration of Video Recording	0.480	0.115	0.405
Required Comprehension Level	0.666	0.222	0.113

Table 12 *Alternative Value*

Concept	Alternative Value
Concept 1: Vending Machine	**0.660**
Concept 5: Two-Way Mirror	**0.168**
Concept 7: Weight Scale	**0.173**

Final Selection

There were several different concept selection tools were used in order to choose the best concept for our project. As stated at the beginning of the Concept Selection section, the first concept selection tool used was the Importance Weight Factor. This chart determined which customer need was the most important for the overall scope of the project. This is significant because it allowed for each customer need to be weighted according for evaluation in the House of Quality. In our case, the *Attract Victim* was the most important weighted factor while, *Allow 2 Way Communication* was the least weighted factor. After the Weight Factors were determined, they were inputted into the House of Quality Chart. The House of Quality Chart evaluates a series of engineering characteristics with the customer needs where a pairwise analysis was conducted in order to compare customer requirements against each other, to determine each requirement's respective Weight Factor. The top three costumer requirements that were found were, the *Percentage of People that Can See the Sign*, then the *Time Taken to Initiate Communication* and lastly, the *Percentage of Valid Alarms.*

After the House of Quality Chart was conducted and the rankings were determined, we used them to compute the Pugh Charts. The Pugh Chart compares concepts together, dependent on engineering characteristics. This will allow us to determine which concepts will be the most successful in achieving the key purposes of a project. As seen in Table 5, we originally started with 8 different concepts. After the first Pugh Chart was conducted, the number of concepts was narrowed down to 5 concepts, with one becoming the datum for the next Pugh Chart. The top 5 concepts gathered from the first Pugh Chart were, concept 1: Vending Machine, concept 2: GPS Burr, concept 5: Two-Way Mirror, concept 7: Weight Scale, and lastly as the datum, concept 4: GPS Pills. A second Pugh Chart was evaluated to keep narrowing down the number of concepts. The second Pugh Chart narrowed down our answer to have three different concepts that were concept 1: Vending Machine, concept 5: Two-Way Mirror, concept 7: Weight Scale and our datum concept 2: GPS Burr. Lastly, we had a third and final Pugh Chart that determined our top three concepts that will be later used for the AHP Chart. The top three concepts that were chosen were, concept 1: Vending Machine ranked as number one, then concept 5: Two-Way Mirror as number two and lastly, concept 7: Weight Scale as our third. The Pugh chart was able to determine that the strongest concept evaluated was concept 1: Vending Machine. Further analysis, the Analytical Hierarchy Process, was performed in order to assess whether this selection was valid, if there was bias in the choice, and to re-evaluate the top three concepts to see if the same result was reached.

After determining the top 3 concepts, an Analytical Hierarchy Process (AHP) was performed. An AHP is a mathematical way of deciding on the final concept. After all the mathematical process was done and different AHPs were conducted, an *Alternative Value* was obtained, and we were able to determined our top concept (Table 12). Concept 1: Vending Machine had the highest alternative valued of 0.660 while concept 7: Weight Scale had a value of 0.173 and concept 5: Two-Way Mirror had a value of 0.168. Based on these numbers, the AHP determined that the best concept to satisfy the scope is concept 1: Vending Machine.

After weighing the customer requirements, ranking the engineering characteristics, and evaluating the top 8 concepts using the Pugh Charts, concept 1: Vending Machine, was determined to be the best concept to fulfill the customer needs. In order to assess bias and re-evaluate the top three concepts, the engineering characteristics were weighted against themselves, and each of the top three concepts were ranked with respect to the engineering characteristics using the Analytical Hierarchy Process. This process also indicated that concept 1: Vending Machine was the best concept to satisfy the scope of the project. While some bias was indicated when comparing the concepts against each other with respect to the engineering characteristics, this bias was determined necessary due to the gravitas of this project. It is important that, above all, the child remains safe. If this factor introduces bias into the process, then so be it. Ultimately, both concept selection tools indicated that the Vending Machine Concept will allow for the best implementation of the scope.