Concept Selection

After the generation of 100 different concepts for a possible design of the project, it was necessary to decide which concept would be the "winner." The winner would be the design concept that Team 503 would move forward with in designing. The team used a number of concept selection techniques to determine which concept would be the most appropriate to satisfy the objective of the project. These techniques include: binary pairwise comparison, house of quality, pugh charts, and analytical hierarchy process.

Binary Pairwise

The following is the binary pairwise classification of the various customer requirements defined for the project.

Customer Requirements	1	2	3	4	5	6	Total
1. Strong and Resilient	-	1	1	1	1	1	5
2. Defined Mechanical Metrics	0	-	1	1	1	1	4
3. Each Production is Identical	0	0	-	0	1	1	2
4. Improved Vehicle Handling	0	0	1	-	1	1	3
5. Modularity of Components	0	0	0	0	-	0	0
6. Ease of Access to I/O and Battery	0	0	0	0	1	-	1
Total	0	1	3	2	5	4	n - 1 = 5

Table 1: Binary Pairwise

The binary pairwise matrix compares the importance of one customer requirement vs. another. The column and row titles are identical, however the intersecting box between different customer requirements contains either a 1 or a 0. If the row customer requirement is considered more important than the column, a number 1 will denote this triumph, and a zero would denote the opposite. The “Total” column in green is the ranking of the importance of the customer requirements, 5 being the most important and 1 being the least, with the customer requirement finishing at 0 being removed. Team 503’s customer requirements ranked from most important to least important is strong and resilient, defined mechanical metrics, improved vehicle handling, and ease of access to I/O and battery.

House of quality

The House of Quality tool evaluates how well the different functions of the F1TENTH Car align with our customer needs. It highlights the features and compares them to the customer’s requirements. By considering the importance assigned by the customer to each requirement, the tool ranks how effectively the most critical Engineering Characteristics or functions that the F1TENTH Car should prioritize to best fulfill the customer’s requirements. From the House of Quality table shown below we can see that our most important functions are: *Protect Against Rollover, Clears Maximum Turn Radius, Limits Height,* and, *Protects Against Collisions.* The least important functions are: *Dampens Components Vibrations, Influence Fluid About Body, Allows for Easily Accessible I/O Ports* and, *Generates Downforce.* This process aids in a more thorough assessment of concept viability. Sometimes, a concept might seem superior at first glance, but when we consider the importance assigned to each characteristic, the true picture emerges. Weighting the characteristics helps reveal whether a concept is genuinely superior or if certain key features make it more viable and aligned with the desired outcomes.

Engineering Characteristic														
Improvement Direction		-	-	-	-	-	-	-	-	-	-	-	-	-
Units		deg	deg	cm	N	N	N	deg	cm	N	N*m/N*m	cm	m/s	N
Customer Requirements	Importance Weight	Limits Body Roll	Clears Maximum Turn Radius	Limits Height	Supports Weight of Components	Withstands Forces from Crash	Dampens Component Vibrations	Handles Rough Treatment	Allows for Easily Accessible I/O Ports	Protects Against Collisions	Protects Against Roll-Over	Ground Clearance	Influences Fluid About Body	Generates Downforce
Strong and Resilient	5	1		1	9	9	3	9	3	9	9	1	1	1
Defined Mechanical Metrics	4	3	3	9	1	1						3	1	1
Improved Vehicle Handling	3	9	9	9	3		1			3	9	9	3	9
Each Production is Identical	2													
Ease of Access to I/O and Battery	1							3	9					
Raw Data (572)		44	39	68	58	49	18	48	24	54	72	44	18	36
Relative Weight %		7.69	6.82	11.89	10.14	8.57	3.15	8.39	4.20	9.44	12.59	7.69	3.15	6.29
Rank Order		7	9	2	3	5	13	6	11	4	1	8	12	10

Table 2: House of Quality

Pugh Charts

For the corresponding pugh charts, initially the open-source vehicle model by F1TENTH was used as the datum concept. The engineering characteristics selected for the charts were taken from the previously top 5 ranked results from the House of Quality. Within the pugh chart, concepts are to be deemed better (+), worse (-), or same (S) as the datum. Resulting from the comparison between concepts and datum against the engineering characteristic was four concepts tying with most pluses. The tying four concepts include: Recessed Camera housing chassis, screwed down mag., screwed down uniform mount., and the roll cage chassis. These resulting concepts have an improvement in the top engineering characteristics compared to the open-source model.

x		Concepts							
Engineering Characteristics	F1TENTH Open Source Vehicle Model	Cable Organizer Chamber Chassis	Quick Release Shell Chassis	Recessed Camera Housing Chassis	Moving Mass Inside Chassis	Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fasteners, Increased Spring Stiffness Chassis	Centralized Electronics Hub Chassis	Screwed Down, Uniform Mounting Holes, Subframe Bumpers, Dampening on Fasteners, Increased Spring Stiffness Chassis	Roll Cage Chassis
Protects Against Roll-Over	- DATUM -	+	S	+	+	+	S	+	+
Limits Height		-	-	-	S	-	-	-	-
Supports Weight of Components		S	S	+	S	+	S	+	+
Protects Against Collisions		S	-	+	S	+	S	+	+
Withstands Forces from Crash		S	-	+	S	+	+	+	+

Total Pluses	1	0	4	1	4	1	4	4
Total Satisfactory	3	2	0	4	0	3	0	0
Total Minuses	1	3	1	0	1	1	1	1
	Datum	No	Yes	No	Yes	No	Yes	Yes

Table 3: Pugh chart Open-Source Vehicle Model Datum

		Concepts			
Engineering Characteristics	Cable Organizer Chamber Chassis	Recessed Camera Housing Chassis	Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fastners, Increased Spring Stiffness Chassis	Screwed Down, Uniform Mounting Holes, Subframe Bumpers, Dampening on Fasteners, Increased Spring Stiffness Chassis	Roll Cage Chassis
Protects Against Roll-Over	- DATUM -	+	+	+	+
Limits Height		S	S	S	S
Supports Weight of Components		S	+	+	+
Protects Against Collisions		+	+	S	+
Withstands Forces from Crash		+	S	S	+
Total Pluses		3	3	2	4
Total Satisfactory		2	2	3	1
Total Minuses		0	0	0	0

	Yes	Yes	No	Yes

Table 4: Pugh chart Cable Organizer Chamber Chassis Datum

Subsequently, one of the concepts from the open-source vehicle model pugh chart was selected as the new datum. The concept was chosen from the resulting values closer to the satisfactory compared to the original datum, not necessarily better or worse. Either cable organizer chamber chassis or centralized electronics hub chassis were options as they tied for satisfactory, for the table Cable Organizer Chamber Chassis was chosen. With selecting datum, the secondary pugh chart was to compare the top four concepts against engineering characteristics to determine the top three competing concepts. The resulting three concepts included: Recessed Camera housing chassis, screwed down mag., and the roll cage chassis.

Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) was utilized to compare the importance of the engineering characteristics used in the Pugh Chart. A comparison was made between all of these characteristics, using a scale of 1-9 (Fig.1) to determine the relative importance of any two engineering characteristics in the lens of importance to product success. This initial comparison chart (Table 5) gives a score for each engineering characteristic’s relative importance.

[C] Matrix						
	Analytical Hierarchy Process	A	A	A	A	A
B	**Engineering Charactersitic**	Protects Against Roll-Over	Limits Height	Supports Weight of Componen ts	Protects Against Collisions	Withstand s Forces from Crash
B	Protects Against Roll-Over	1	0.200	3.000	1.000	5.000
B	Limits Height	5.000	1	9.000	5.000	7.000
B	Supports Weight of Components	0.333	0.111	1	0.200	3.000
B	Protects Against Collisions	1.000	0.200	5.000	1	3.000
B	Withstands Forces from Crash	0.200	0.143	0.333	0.333	1
	Total	7.533	1.654	18.333	7.533	19.000
	Average	1.507	0.331	3.667	1.507	3.800

Table 5: Initial Comparison [C] Matrix

Rating Factor	Relative Rating of Importance of Two Selection Criteria A and B	Explanation of Rating
1	A and B have equal importance.	A and B both contribute equally to the product’s overall success.
3	A is thought to be moderately more important than B.	A is slightly more important to product success than B.
5	A is thought to be strongly more important than B.	A is strongly more important to product success than B.
7	A is thought to be very much more important than B, or is demonstrated to be more important than B.	A’s dominance over B has been demonstrated.
9	A is demonstrated to have much more importance than B.	There is the highest possible degree of evidence that proves A is more important to product success than B.

Figure 1: Rating Factor Explanation.

The [C] Matrix is then normalized as shown in Table 6, making all of the sums of the importance factors equal to one for each engineering characteristic, which provides a more clear value to compare the importance of each characteristic.

norm[C] Matrix							
	Analytical Hierarchy Process	A	A	A	A	A	
B	Engineering Charactersitic	Protects Against Roll-Over	Limits Height	Supports Weight of Components	Protects Against Collisions	Withstands Forces from Crash	Critical Weight {W}
B	Protects Against Roll-Over	0.133	0.121	0.164	0.133	0.263	0.163
B	Limits Height	0.664	0.605	0.491	0.664	0.368	0.558
B	Supports Weight of Components	0.044	0.067	0.055	0.027	0.158	0.070
B	Protects Against Collisions	0.133	0.121	0.273	0.133	0.158	0.163
B	Withstands Forces from Crash	0.027	0.086	0.018	0.044	0.053	0.046
	Total	1.000	1.000	1.000	1.000	1.000	1.000

Table 6: Normalized [C] Matrix

A consistency check is the performed to ensure that the values used in the initial comparisons are not biased. The value of the consistency ratio is expected to be below 0.1 for a consistent, unbiased [C] matrix. A value of 0.086 was achieved for the consistency ratio, which is within the targeted range (Table 7).

Consistency Check					
Weighed Sum Vector {Ws} = [C]{W}	{W}	Cons = {Ws}./{W}	Average Consistency (λ)	Consistency Index (CI)	Consistency Ratio (CR)
0.876	0.163	5.386	5.383	0.096	0.086
3.138	0.558	5.622			
0.356	0.070	5.077			
0.925	0.163	5.660			
0.236	0.046	5.169			

Table 7: Consistency Check

The next step taken in the AHP was to bring in the best concepts from the Pugh chart and assign them a value based on how well each fulfills the engineering characteristics and accounting for the critical weights from the norm[C] matrix. This is called the [Pi] matrix (Table 8).

[Pi] Matrix				
	Analytical Hierarchy Process	A	A	A
B	**Engineering Charactersitic**	Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fastners, Increased Spring Stiffness Chassis	Recessed Camera Housing Chassis	Roll Cage Chassis
B	Protects Against Roll-Over	0.106	0.260	0.633
B	Limits Height	0.200	0.200	0.600
B	Supports Weight of Components	0.187	0.158	0.655
B	Protects Against Collisions	0.077	0.231	0.692
B	Withstands Forces from Crash	0.083	0.193	0.724

Table 8: [Pi] Matrix

The result of the AHP is a table which gives a value for each design that describes how well it fulfills the engineering characteristics from the House of Quality. These alternative values (Table 9), show that the concept which best fulfills all of the engineering characteristics from the Pugh Chart is the Roll Cage Chassis design, which has the highest alternative value by almost 3 times the other concepts.

Concept	Alternative Value
Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fastners, Increased Spring Stiffness Chassis	0.158
Recessed Camera Housing Chassis	0.212
Roll Cage Chassis	0.630

Table 9: Alternative Value Matrix

The result of the AHP when applied to an F1TENTH car is that a roll cage chassis is the best conceptual design of those presented by Team 503.

[C] Matrix for Protect Against Roll-Over					
	Analytical Hierarchy Process	**A**	**A**	**A**	
		Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fasteners, Increased Spring Stiffness Chassis	Recessed Camera Housing Chassis	Roll Cage Chassis	**Average**
B	Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fasteners, Increased Spring Stiffness Chassis	1	0.333	0.200	0.511
B	Recessed Camera Housing Chassis	3.000	1	0.333	1.444
B	Roll Cage Chassis	5.000	3.000	1	3.000
	Total	9.000	4.333	1.533	4.956
	Average	3.000	1.444	0.511	

AHP EC

AHP EC or Analytical Hierarchy Process Engineering Characteristics is very similar to AHP shown above. However, instead of comparing concepts with concepts, it is comparing concepts to concepts with the engineering characteristics in mind. The AHP EC is a table with concepts on both vertical and horizontal cells. The top of the table has a listed engineering characteristic. Engineering characteristics are taken into account for deciding which concept is more important.

Table 10: AHP EC [C] Matrix for Protect Against Roll-Over

As shown in Table 10, one of the AHP EC tables is given as an example. The whole table is for the purpose of one engineering characteristic: Protect Against Roll-Over. The vertical cells and horizontal cells are both the listed concepts. Adding a 1 in the cell represents equality, as they are the same concept. This is shown diagonally down for each concept. If the column is more important than the row, then a big number is placed down. If the row is more important than the column, then a reciprocal number is placed down. The scoring factor is 1, 3, 5, 7, and 9, where 1 is equal, 3 is least important, and 9 is the most important. The average is taken both vertically and horizontally.

There is a normal matrix that uses the total sum of the column and divides it by the cell. The equation is listed below:

$$Norm\ Element_{m,n} = \frac{element_{m,n}}{sum_m}$$

norm[C] Matrix for Protect Against Roll-Over					
	Analytical Hierarchy Process	**A**	**A**	**A**	
		Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fasteners, Increased Spring Stiffness Chassis	Recessed Camera Housing Chassis	Roll Cage Chassis	**Design Alternative Priorities {Pi}**
B	Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fasteners, Increased Spring Stiffness Chassis	0.111	0.077	0.130	0.106
B	Recessed Camera Housing Chassis	0.333	0.231	0.217	0.260
B	Roll Cage Chassis	0.566	0.692	0.652	0.633
	Total	1.000	1.000	1.000	1.000

Table 11: AHP EC norm[C] Matrix for Protect Against Roll-Over

The matrix is used to find the Design Alternative Priorities. The priorities help the team find out which design is best. As shown in Table 11 above, the table is a norm matrix that divides the previous total of the original matrix to the selected elemental cell. The quotient is displayed in the corresponding cell of the norm matrix. The total is then added up, equaling to 1.000. The Design Alternative Priorities are calculated with the equation listed below:

$$Alternative\ Value = [Final\ Rating\ Matrix]^T .\cdot \{P_i\}$$

Finally, there is a consistency check table to calculate the consistency ratio or {CR} for short. The table uses values such as Weighed Sum Vector {Ws}, {Pi}, {Ws}. /{Pi}, Average

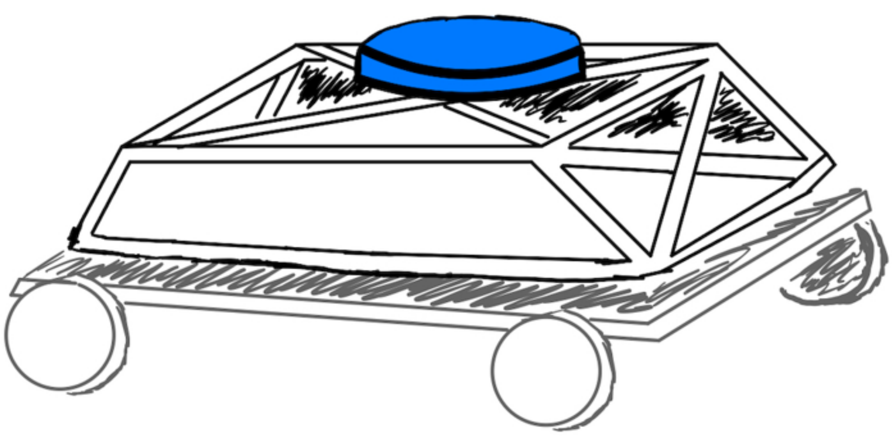
Consistency {λ}, and Consistency Index {CI}. There is a new consistency check table for each engineering characteristic.

Consistency Check					
Weighed Sum Vector {Ws} = [C]{Pi}	{Pi}	Cons = {Ws}. /{Pi}	Average Consistency {λ}	Consistency Index {CI}	Consistency Ratio {CR}
0.320	0.106	3.011	3.039	0.019	0.037
0.790	0.260	3.033			
1.946	0.633	3.072			

Table 12: Consistency Check for Protect Against Roll-Over

Table 12 shows an example of a consistency check for one of the team's engineering characteristics. It uses the listed variables above and calculates the {CR}. The values of {CR} vary depending on the values of the variables and the engineering characteristic. The value of {CR} is to be expected to be below 0.1. The value listed in the table above is 0.037, which means it is within the target range. This process is repeated for all engineering characteristics. None of the {CR} were above 0.1. Therefore, they are all within the target range.

Final Selection



The completion of the binary pairwise comparison, house of quality, pugh charts, and analytical hierarchy process, resulted in a final selection of the design concept, “Roll Cage Chassis.” The choice was derived from the analytical hierarchy process and having the highest alternate value. This concept is considered to have the strongest qualities that satisfy the customer requirements and critical functions. The roll cage chassis will be most similar to a tube frame chassis as seen on most racecars to protect against collisions, roll-over, support weight of components, and for overall structural integrity. It will consist of welded tubes placed in the most appropriate position for the most optimal structural integrity. Team 503 considered this to be one of the strongest concepts going into the process and was in agreement with the conclusion found from the concept selection process.