1.6 Concept Selection

Pairwise Comparison and House of Quality

The CIA's needs and the medium and high-fidelity concepts from the previous section were examined using different methods to determine the ideal concept for the final design. A binary pairwise comparison was conducted for the customer needs chart in Table 10. The values in the left columns are compared to the corresponding values in the top row. A "1" indicates the former need is more important, and a "0" indicates it is less important. The results from the comparison chart were totaled for each row and column to show which needs have the highest relative importance for the final design.

Table 10: Binary Pairwise Comparison

Customer Need	1	2	3	4	5	6	7	8	9	Total
1) Optimized Pathing	-	1	0	0	1	1	0	0	0	3
2) Point A to B in 5 minutes	0	-	0	0	1	1	0	0	0	2
3) Autonomously Controlled	1	1	-	0	1	1	0	0	0	4
4) Reduce inertial losses	1	1	1	-	1	1	0	1	1	7
5) Carries Payload	0	0	0	0	-	1	0	0	0	1
6) Handles Road Grade	0	0	0	0	0	-	0	0	0	0
7) Simulated Environment	1	1	1	1	1	1	-	1	1	8
8) Maintaining optimal velocity	1	1	1	0	1	1	0	-	0	5
9) Fully Integrated with Team 504s Project	1	1	1	0	1	1	0	1	-	6
Total	5	6	4	1	7	8	0	3	2	n-1=8

After determining the relative importance of the customer needs, the engineering characteristics of our proposed design were then ranked in a House of Quality (HoQ) using the values from the pairwise comparison as weights. The HoQ indicates how the process of incorporating each engineering characteristic correlates with meeting the customer's needs. A "0" indicates no correlation, and "1", "3", and "9" indicate weak, medium, and strong correlation respectively. The improvement direction shows how the characteristics should be changed to improve design performance. The ranking from the HoQ shows that constant velocity and successful simulation testing are the most important characteristics, while resisting roll motion and carrying a payload are least important.

The Improvement Direction is a method in determining how our customer needs should be improved on providing an arrow in each column signifying whether the customer need should be decreased, increased, or blank no change. Finally, after assigning the correct weighted values, a relative weight can be developed from taking the combined value from the column and dividing that by the raw score. By sorting the relative weight percent from smallest value to largest and calculating the consecutive difference between points and developing a cutoff threshold.

Table 11: House of Quality

		Engineering Characteristics												
Improvement Direction		↑	↑	↓	↓	↓	↑	↑	↓	↑			↑	↓
Units		s	m	kg	cm	PPR	Hz	rad/s	rad/s	m/s	J	Iterations	m/s	m
Customer Requirements	Importance Weight Factor	Generates Force	Removes Force	Carries Payload	Fits Payload	Measure tire speed	Gather & Update position data	Resist roll motion	Induce yaw rate	Top speed	Battery size	Simulation runs	Maintained velocity	Turning radius
1) Optimized Pathing	3	3	3	0	0	3	9	0	3	3	9	9	3	9
2) Point A to B in 5 minutes	2	9	3	3	0	9	9	0	3	9	9	3	3	3
3) Autonomously Controlled	4	3	3	0	0	9	3	3	9	3	1	9	9	3
4) Reduce inertial losses	7	9	9	3	3	9	3	0	3	9	9	9	9	9
5) Carries Payload	1	9	9	9	9	0	0	3	1	0	3	0	9	1
6) Handles Road Grade	0	3	3	1	0	0	3	3	0	0	0	3	9	1
7) Simulated Environment	8	3	3	0	0	9	3	0	9	3	0	9	9	3
8) Maintaining optimal velocity	5	9	9	3	0	9	9	1	3	9	9	9	9	9
9) Fully Integrated with Team 504s Project	6	3	3	0	0	0	9	0	3	0	3	3	9	3
Raw Score	2213	198	186	51	30	243	201	20	178	171	178	267	294	196
Relative Weight %		8.947	8.405	2.305	1.356	10.981	9.083	0.904	8.043	7.727	8.043	12.065	13.285	8.857
Rank Order		5	7	10	11	3	4	12	8	9	8	2	1	6

Pugh Chart

Pugh charts are a way of design selection that uses our medium and high-fidelity concepts select and compares them to a datum. To initially begin we set our datum to an existing product that is the most identical to our goal design. This was chosen to be the F1tenth competitive race car because these automobiles are designed to maintain a velocity and race autonomously. It is imperative in the F1tenth competition that a path is optimized due to the car operating autonomously to reach the finish line.

Figure 2 Model F1Tenth Race Car

Our engineering characteristics are referenced when comparing each design to the datum determining whether that target is better noted by a plus (+), not as good noted by a minus (-), or rather significantly the same noted by a (S). To achieve consistency within our results we eliminated designs that did not meet an efficient ratio. Once down to the last chart, the selected datum of even weight distribution, our final ratio proved once again that the Ackerman - Regenerative - MBPC + PID could be considered the best fidelity concept to pursue. The final Pugh chart is seen in Table 12.

Table 12: Pugh Chart of desired datum

		Concepts		
Selection Criteria	86	28	29	47
Generates Force	Datum	S	+	+
Removes Force		S	+	+
Carries Payload		S	S	S
Fits Payload		S	S	S
Measure Tire Speed		S	S	-
Gather and Update Position Data		S	S	-
Resist Roll Motion		S	S	S
Induce Yaw Rate		+	+	-
Top Speed		S	-	-
Battery Size		S	+	+
Simulations		+	+	+
Maintain Velocity		+	+	-
Turning Radius		S	S	-
	# of Plus(+)	3	6	4
	# of Minus(-)	0	0	6

Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) uses the top three concepts selected from the Pugh Charts to select the final design. Before comparing the concepts, the design team compared the selection criteria to each other in a Criteria Comparison Matrix to determine which of the engineering characteristics are the most critical to completion of the project. The criteria were listed as the rows and columns of the Criteria Comparison Matrix, and the rows were compared to the columns. Values were assigned on a scale of 1, 3, 5, 7, and 9. The values increase in significance with 1 being the least and 9 being the most significant. The inverse of these rankings was mirrored across the main diagonal. The columns were summed and used to normalize each column by dividing by the sum, and the average of the normalized row values were used to determine the Criteria Weights. If this is done correctly, both the sum down the columns should equal 1. Table 13 below shows the Normalized Criteria Comparison Matrix, and the original matrix can be found in Appendix E.

Table 13: Normalized Criteria Comparison Matrix

Normalized Criteria Comparison Matrix [NormC]										
Customer Need	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	Criteria Weights
1) Optimized Pathing	0.031	0.015	0.014	0.143	0.036	0.058	0.127	0.146	0.006	0.064
2) Point A to B in 5 minutes	0.215	0.102	0.291	0.184	0.108	0.058	0.228	0.204	0.204	0.177
3) Autonomously Controlled	0.092	0.015	0.042	0.102	0.046	0.042	0.127	0.087	0.041	0.066
4) Reduce inertial losses	0.004	0.011	0.008	0.020	0.036	0.032	0.025	0.010	0.008	0.017
5) Carries Payload	0.277	0.305	0.291	0.184	0.323	0.291	0.228	0.204	0.285	0.265
6) Handles Road Grade	0.154	0.508	0.291	0.184	0.323	0.291	0.228	0.087	0.122	0.243
7) Simulated Environment	0.006	0.011	0.008	0.020	0.036	0.032	0.025	0.087	0.285	0.057
8) Maintaining optimal velocity	0.006	0.015	0.014	0.061	0.046	0.097	0.008	0.029	0.008	0.032
9) Fully Integrated with Team 504s Project	0.215	0.020	0.042	0.102	0.046	0.097	0.004	0.146	0.041	0.079
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

To ensure that there was no bias in the weighting of the criteria, a consistency ratio was calculated for each of the criteria and must be less than 0.1. This check is shown in Appendix E. The results confirm that maintaining optimal velocity and reducing the inertial losses are the most important, while simulated environment and optimized pathing are close behind. With the criteria ranked, the concepts were rated using a similar process. The matrices and equations are the same except the concepts were compared against each other in each of the selection criteria. The specific matrices can be found in Appendix E. The former Criteria weights are now called Design Alternative Priorities, and these values were tabulated in a Final Rating Matrix, which shows how well each design did in each category; however, each category is not weighted equally so the final Alternative Value was calculated by multiplying the transpose of the Final Rating Matrix by the Criteria Weights. Table 14 shows the Alternative Values, and the intermediate steps are in Appendix E.

Table 14: Final Alternative Values

Concept	Alternate Value
# 28	1.64
# 29	1.68
# 47	1.02

Based on the values in Table 14, our Ackermann-ROS2-MBPC+PID-Regenerative design is the best alternative. This system uses an Ackermann style steering mechanism, along with a ROS2 operating system, which will allow communication between team 503 and 504's projects. Along with that this model uses a combination of Lateral and Longitudinal control in the form of MBPC + PID controllers (Model Based Predictive Controller), and a regenerative braking system. The regenerative braking system was an idea that was generated to go along with the reduces inertial loses requirement, which is why the regenerative braking beat the resistive braking system. Currently, there is uncertainty if the regenerative braking system will be a viable option, weight and cost-wise, however at this point in the design it theoretically fills most of the customer requirements and engineering criteria.

Figure 3 Selected Design