

Team 4 – Final Project

MCHE 201: Introduction to Mechanical Design

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Abstract

In a highly anticipated race against time, the success of the mission for Jake and Neytiri relies on an agile robotic device that can solely operate on gravitational and electrical energy. The goal is to achieve as many objectives as possible in under 30 seconds, without intentionally interfering with other teams. To achieve this, a proactive engineering approach is necessary, which includes a thorough problem understanding analysis using tools such as the House of Quality, Specification Sheet, and Function Tree to visualize a successful end goal. Prioritizing customer requirements, such as safely moving Fauna and bringing back multiple Banshees, allows the team to compare potential engineering characteristics, such as automation coding efficiency and weight reduction. After considering several designs, the team will use the Evaluation Matrix approach to select the most promising design. The resulting robot will feature several admirable feats such as a deployable arm with gears attached to a DC motor, capable of quickly completing two out of five main objectives within the first fifteen seconds. Located in at the core of this solid, durable, rectangular device, is a Linear Actuator that connects to a 4-bar link of two 20-inch-long arms that can extend out nearly 80 degrees in relation to the device to address any remaining objects towards the end of the 30 seconds. Additionally, two strategically placed servo motors at the far ends of these very arms allow it to scoop fauna closer onto the team's zone for an additional 90 points. Ultimately, the agile robotic device reliably and successfully delivers Jake and Neytiri to safety in the rotating Sinking Vessel and can bring back multiple Banshees, fauna and Na'vi Lego men via duct tape within the allotted 30 seconds, showcasing the team's impressive engineering skills and problem-solving abilities.

I. Introduction

The Avatar Way of Water Final Project is a competition between student-built robots that compete for points on a track that holds up to four robots at a time. The robots that compete need to overcome a series of challenges, such as following the given competition guidelines and attending to other customer requirements. According to the rulebook, the dimensions of the robots cannot exceed 12 inches in width, 24 inches in length, and 18 inches in height. Design teams are limited to a given set of sensors provided in individual kits, as well as motors including 1 large DC Motor (referred to as Motor 1), 1 small DC Motor (Motor 2), 1 Linear Actuator, 1 Stepper Motor, and 3 Servomotors. The robot must be fully autonomous and operate within a 30 second window, while not falling off the track. It must be controlled by a programmable Micropython board with code that is triggered by a start button on the track. On the track shown in Figure 1, there are a series of action figures that must be removed from or placed in certain zones to gain points. Some other challenges it must endure include defending against other robots scoring points and being sturdy enough to withstand the forces produced by the motors and the weight or components. Three total designs were created to fulfill these requirements, one main final design and two alternate designs. The next section, Section II, discusses the final robot design and how it compares to the two alternate designs. Section III covers the Problem Understanding and design tools used. Section IV shows the Concept Evaluation of the three designs, and Section V covers the overall results of the competition and the robot's performance.

II. Final Design

The final design, named the "Ikran," has a rectangular, wooden base with four 5 inch in diameter wheels. The device measures 23.5 inches in length, 11.75 inches in width, and 16 inches in height. The tires on the wheels are made of solid rubber and their large diameter allows the robot to drive forward more quickly to the center, where it can quickly rescue Jake Sully and Neytiri and grab the Toy Banshees, as shown in Figure 1. The wheels are connected by a quarter-inch thick wooden dowel that serves as the drive axle, which is powered by Motor 2 that connects to it via two 2.5-inch plastic gears, as seen in the Top View in Figure 3. Sitting on the base of the robot is the Micropython control board, and the Linear Actuator, which extends towards the back end. On the end of the actuator, it is connected to a 4-bar hinge system that causes two 20-inch wooden side arms to swing outwards, as shown in Figure 4. To prevent sagging of the long arms, a support string under tension holds the end of the arms upright. Underneath that string connection on each side arm is a servomotor which swings out another elbow extension of the side arm to add extra length to reach the Fauna on the track's perimeter. Towards the front of the robot, is a 10x6x1-inch block of wood that houses DC Motor 2 and its connection to the Basket Arm with Jake Sully and Neytiri inside. The motor is connected to the end of the 18-inch arm via two 1-inch metal gears that swing the arm forwards and backwards, as seen in Figures 2 and 3. On the other end of the Basket Arm is the light wooden, 8x6-inch basket, whose surface is covered in strips of doubly

folded duct tape and Alien Tape, another strong adhesive, in the intent of grabbing the Banshees or other team's main characters out of the Sinking Vessel. All the motions conducted by the motors on the robot are preprogrammed on the Micropython board, so that it operates fully autonomously during the competition.

The parts of the Ikran are designed in a specific manner that is contingent upon the time-based Python code scripted for the microcontroller board. The robot starts off in an initial position shown in Figures 2 and 4. First, the board is programmed to run DC Motor 1, which drives the front axle, until the robot is a few inches short of the Ocean Wall. Next, the Linear Actuator, which starts in an extended position, retracts, swinging the side arms out about 45 degrees, as shown in Figure 5. It drives forward fully to the Ocean Wall as DC Motor 2 starts swinging the Basket Arm into the Sinking Vessel, where the main characters are dumped and a Banshee sticks to the tape. Next, the Basket Arm swings back to the initial position shown, and the Ikran rolls back another couple inches until the side arms line up with the closest fauna. The Servomotors activate and swing the miniature arms to stick to the outlying fauna. Then the robots backs up until the front end is in the Hidden Sanctuary while the side arms knock the four toy soldiers off the course. Finally, the Actuator extends out again, bringing the arms back to the start position, so that the Na'vi Lego men end up in the Sanctuary and the fauna in the Team Zone. If all goes to plan, the Ikran earns a total of 170 points.

III. Problem Understanding

The House of Quality, shown in Table 1, relates the engineering characteristics and the customer requirements, with the customer requirements relating directly to the competition requirements. These requirements include things such as the dimensions of the device, functions the device must complete, as well as other factors that go into it. The robot must not exceed more than 24 inches long, 12 inches wide, and 18 inches tall. The robot must also operate autonomously, run no longer than 30 seconds, and must start when a start signal is given. These requirements are rated highly on the importance scale because they must be met so the robot cannot be automatically disqualified. The different shapes used in the House of Quality are used to indicate the amount of correlation between the customer requirement and the engineering characteristics. Each shape represents a numerical value with the circle equaling ten, the square equaling six, and the triangle equaling two. These values are then multiplied by the importance factor, and the importance of each is given. The ones that are more important must be prioritized when it comes to the design process. The top part of the House of Quality is the Correlation Matrix, as shown in Table 1, which compares all engineering characteristics by giving them either a negative correlation symbol or a positive correlation symbol.

The Specification Sheet, Shown in Table 2, separates the design details by either giving them a "D" for demand or a "W" for want. For example, the device must not be more than 24 inches long, 12 inches wide, and 18 inches tall is a demand because if the device is over these measurements,

then it will not be allowed to compete and will automatically be disqualified. The device completing tasks around the course such as collecting the Lego Na'vi men, is a wish because it would gain the team points during the competition but is not required for the robot to compete. Wishes are things that would help the device receive a higher score but are not required. Demands are items and actions the robot must do because they are guidelines set.

The Function Tree, shown in Figure 6, breaks down the task the robot has into smaller and simpler components. These broken-down components are then easier to accomplish because it gives a clearer view and idea of what the robot must accomplish during the competition. The main goal given is to win the competition by following all the guidelines and collecting as many points as possible. The goal is then broken down into 4 subcategories that are follow rules, accomplish task to maximize points, successfully navigate track, and be aesthetically pleasing. Each of these tasks can then be broken up into smaller tasks so that the designers are not overwhelmed looking at the big picture but rather a smaller part at a time.

IV. Concept Evaluation

In Figure 7, the alternative design named the Pusher is shown. The Pusher focuses primarily on the task of getting Jake Sully and Neytiri on to the Sinking Vessel. The design for the Pusher is a wooden base with four wheels. DC Motor 1 is used to drive the bot forward and backwards using a gear fixed in place to the motor, and another gear fixed to the rear axle. The Linear Actuator is fixed to a raised platform and the main characters are placed in front of the actuator's extending arm. On the front of the base, there is double-sided sticky tape to grab the two center Lego Na'vi men. The Pusher is designed to drive forward, hit the Lego Na'vi men and pin them up against the Ocean Wall, forcing them to stick to the front. Next, the Pusher stops, and the Linear Actuator pushes the main characters into the Sinking Vessel. Next, the Pusher drives back to the Start Zone, stopping a few inches forward so that the Lego Na'vi are safe within the Hidden Sanctuary. The Pusher is 22 inches long, 10 inches wide, and 17.5 inches in height. The Pusher scores a total of 1232 on the Evaluation Matrix and a relative total of 0.49.

In Figure 8, the second alternative design, named the Spreader is shown. The Spreader focuses on the task of collecting all four Na'vi Lego men and knocking the four enemies off the course. This design uses a wooden base with four wheels. DC Motor 1 is placed in the front of the robot and uses a belt to drive the rear axle. The robot uses the Linear Actuator and wooden paint sticks to create a four-bar link system that swings the arms out to move the figures on the course around. First, the Spreader drives forward and stops before hitting the Ocean Wall. The Linear Actuator then engages, pulling inwards and causing the arms to swing out. Next the robot drives forward again, hitting the four Lego Na'vi men and sticking them to the robot with the double-sided tape that is on both the front and back of the arms. The robot then drives in reverse, knocking off the two toy soldiers on each side of the Hidden Sanctuary. This all occurs while it completes its

programmed Python loop and returns to the start position with the collected toys. Motor 1's code is time-based and stops when the front of the robot is within the Hidden Sanctuary. As the last step in the code, the Linear Actuator extends out, closing the arms and delivering the Lego Na'vi men into the Hidden Sanctuary. The Spreader has a length of 22.3 inches, a width of 11.75 inches, and a height of 8 inches. This design scored a total of 1259 on the evaluation matrix and a relative total of 0.5.

The Evaluation Matrix in Table 3 compares the final design and the two alternative designs to determine which is best suited to accomplish the main goal of winning the Final Competition, as well as all the other subsequent goals displayed in Figure 6. The Pusher focuses mainly on the task of getting the main characters into the Sinking Vessel and grabbing two of the Lego Na'vi men. It does a simple task and is guaranteed to complete it every time, but this also means that its maximum score is relatively low, only 60 points. The Spreader focuses on removing the four enemies from the course and collecting the four Lego Na'vi men. Since the Spreader has no way of getting the main characters into the Sinking Vessel or grabbing the Banshees, it ignores an important task worth up to 210 points. Ultimately, it was determined that the Ikran robot design was best suited for the competition, since it focuses on maximizing the number of points. It can collect the Lego Na'vi men, get the main characters to the Sinking Vessel, collect at least one Banshee, knock the toy Fauna into the team zone, and knock the toy soldiers off the course.

V. Design Performance Evaluation

The Ikran robot ended up coming in last place in the Final Competition. While in the first run of that day the Ikran came in first, it had consistency issues and placed third in the next round and was disqualified in the third round, when its servomotors kept spinning past the 30 second period. The design focused on completing as many tasks as possible to get the most points, but this caused its downfall, because of some overlooked factors. During the design and testing process the test course used was flat on the ground and marked by tape, unlike the actual competition which was raised a few inches from the ground. This was a problem, because the Ikran design has adhesive on the end of its servomotor arms that grab the Fauna and Lego Na'vi. When the robot would drive backwards with the extended arms to knock the toy soldiers off the course, the toy fauna stuck to the ends of the arms would weigh the arms down and prevent the arms from being able to swing back into the close position. They would get caught on the edge of the course. Since the arms would get stuck in the extended position with the fauna outside of the Team Zone, no fauna or Lego men points were earned in the overall competition. The next issue that the Ikran design ran into was the result of a last-minute change. Some of the folded-over duct tape on the flip out arm was replaced with adhesive from a rat trap. The adhesive was placed there so that the robot had a better chance of grabbing the toy banshee and bringing them back to the safe zone. However, this caused an issue on the last run, where the flip out arm got stuck on another team's robot over the Sinking Vessel. This caused the Ikran's motors to get stuck in a loop and not shut off after 30 seconds, disqualifying it.

The Ikran robot design did much better in the presentation aspect of the competition, placing second. The judges were impressed by the overall design of the Ikran and the fact that it focused on completing many different tasks, whereas most teams only focused on completing a few tasks. Some judges did express concern about the robot's consistency during competition, an issue later found to be true. The judges were also impressed with the amount of effort that was put into the table and poster design to prepare for the Final Project presentation.

VI. Conclusion

The Avatar Way of Water Final Project was a competition where robots competed to gain points on a track that held up to four robots at a time. The robots had to meet the competition guidelines and attend to other customer requirements while overcoming a series of challenges. To accomplish these goals, the design teams employed a proactive engineering approach using tools such as the House of Quality, Specification Sheets, and Function Trees. Design teams prioritized customer requirements and compared potential engineering characteristics to select the most promising design using the Evaluation Matrices approach. Team 4's resulting robot, the "Ikran," was a rectangular, wooden-based device powered by gravitational and electrical energy. It had several admirable features such as a deployable arm with gears attached to a DC motor, capable of quickly completing two out of five objectives within the first fifteen seconds, and a linear actuator that connected via 4-bar links to two 20-inch-long arms that could extend out nearly 80 degrees from the device to address any remaining objects. Additionally, two strategically placed servo motors at the far ends of these arms allowed for scooping fauna closer onto the team's zone for an additional 90 points. The final robot reliably and successfully delivered Jake and Neytiri to safety in the rotating sinking vessel, showcasing the team's impressive engineering skills and problem-solving abilities. The report demonstrates the importance of a proactive engineering approach and a thorough problem understanding analysis in achieving success in complex engineering projects.

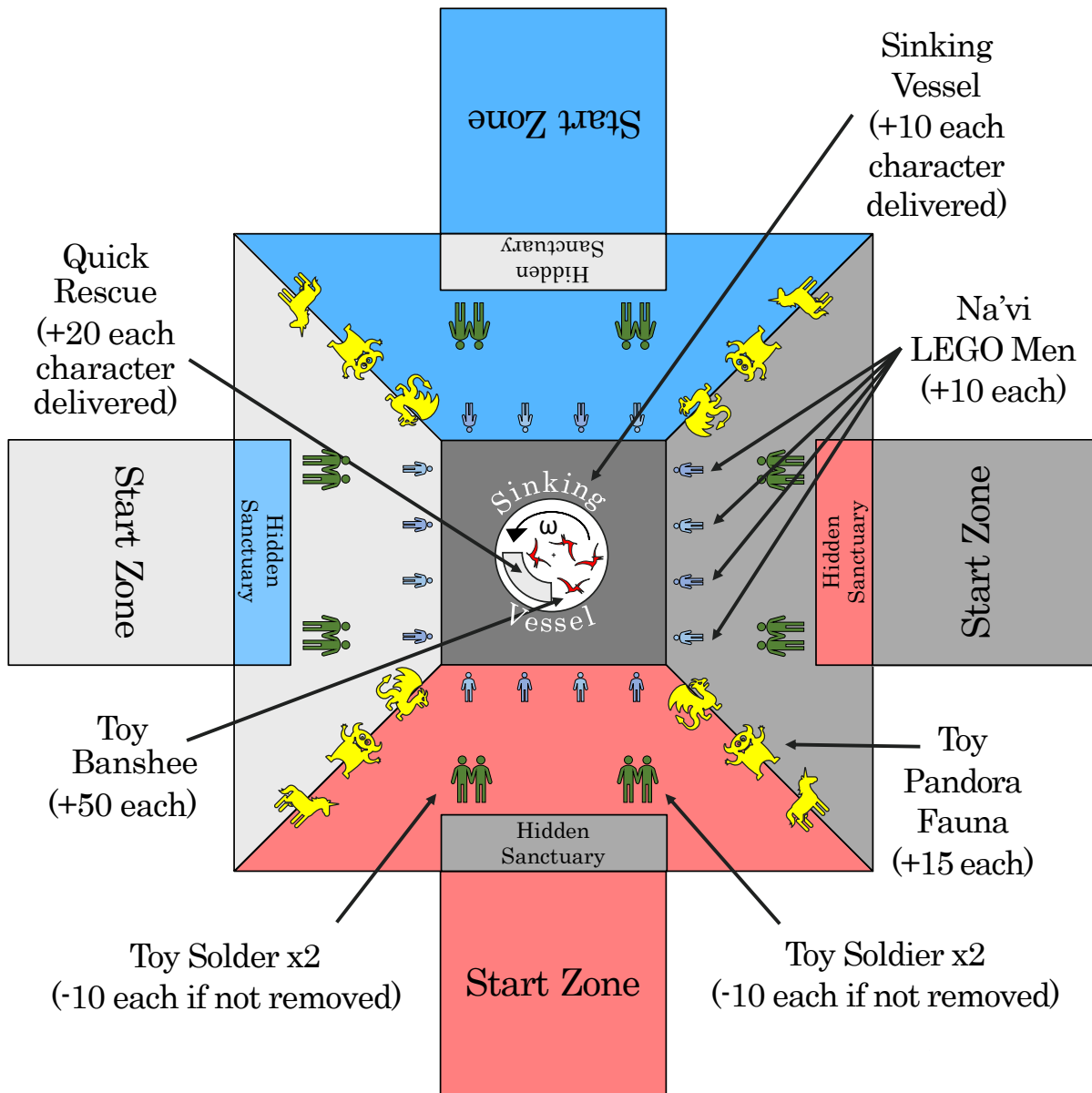


Figure 1: Final Competition Track with Action Figures and Point Totals [MCHE 201 Final Project Handout].

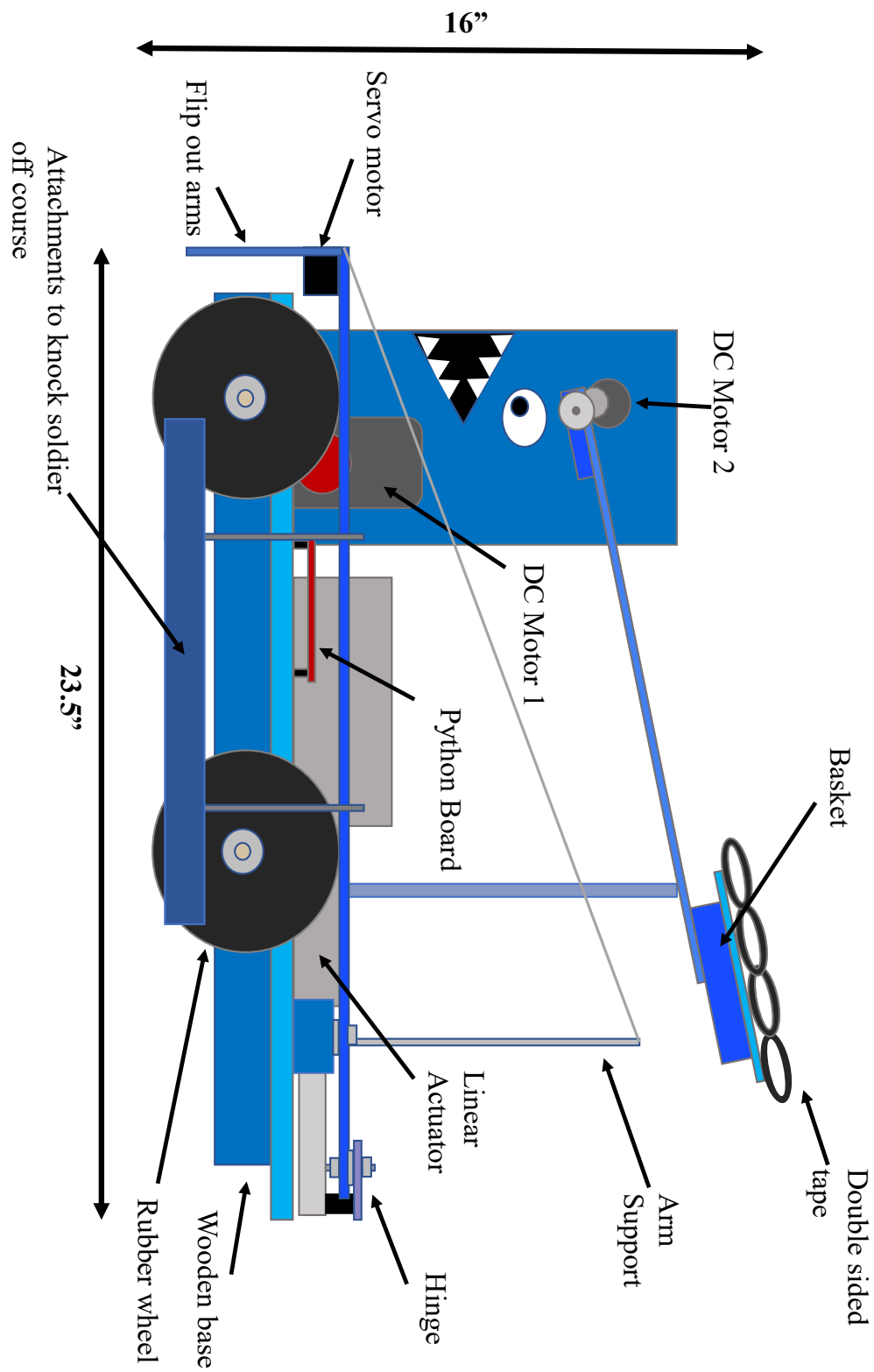


Figure 2: Side View of Ikran, with Part Labels.

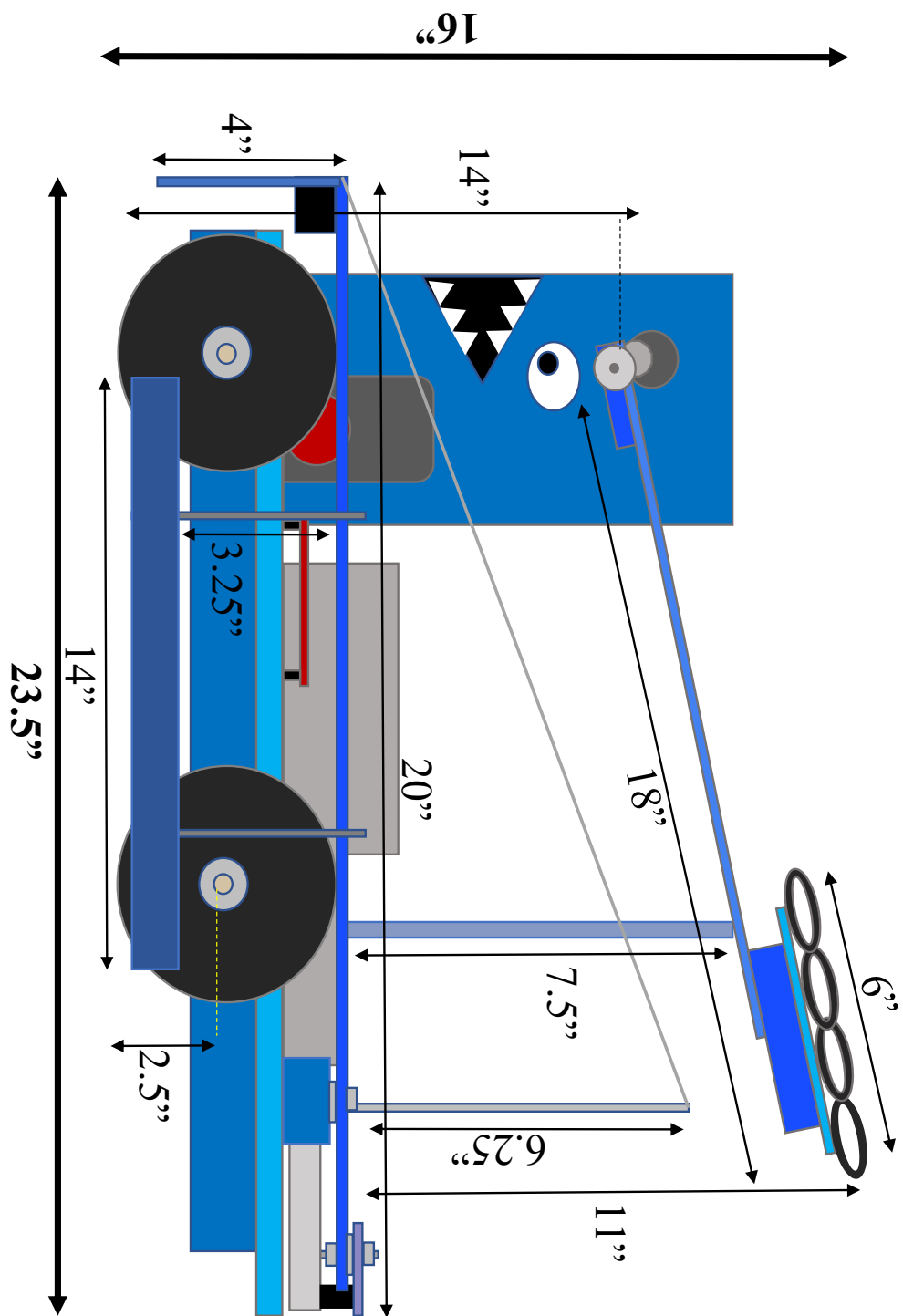


Figure 3: Side View of Ikran, with Dimensions.

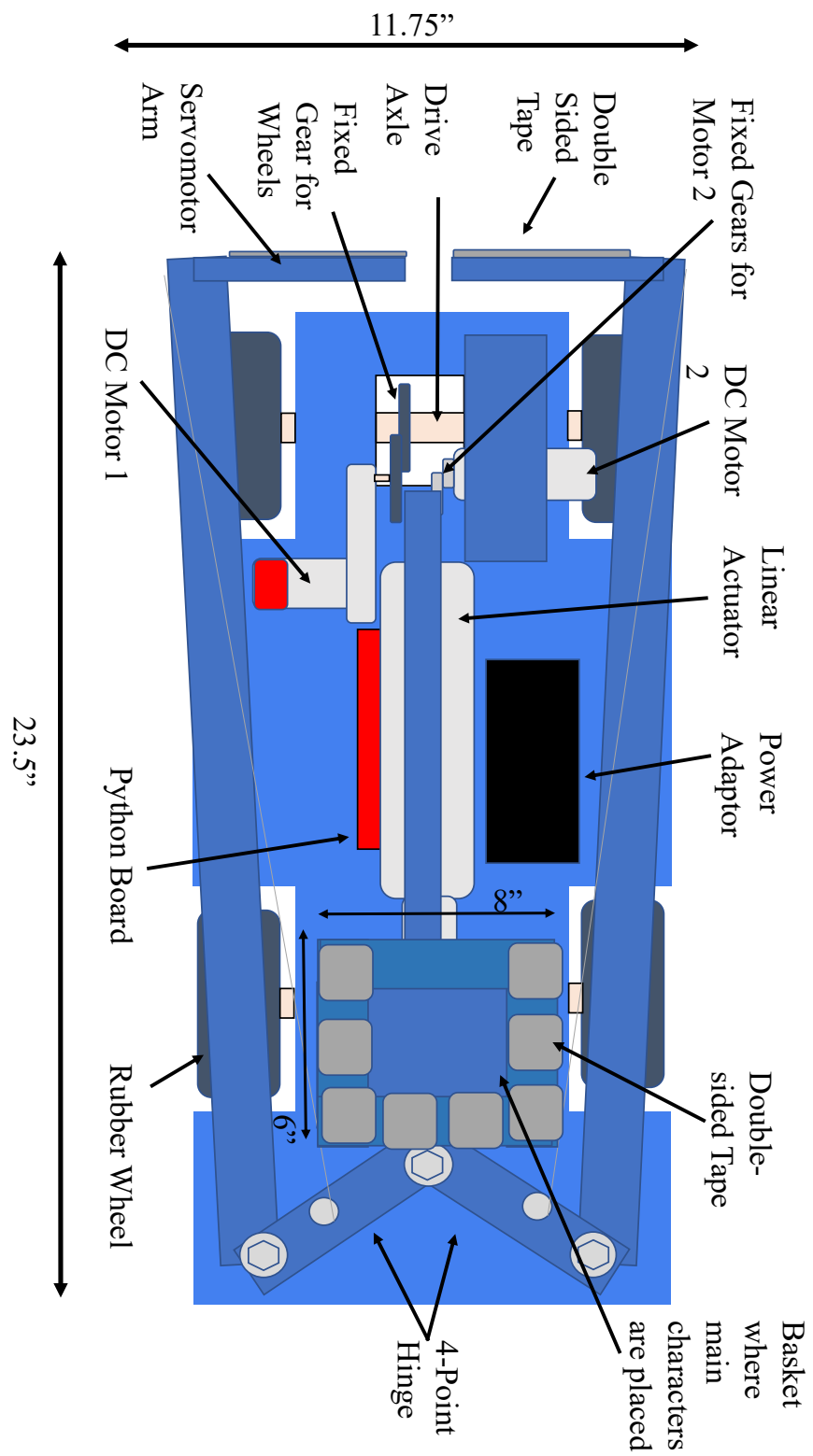


Figure 4: Top View of Ikran, with Arms Folded In,

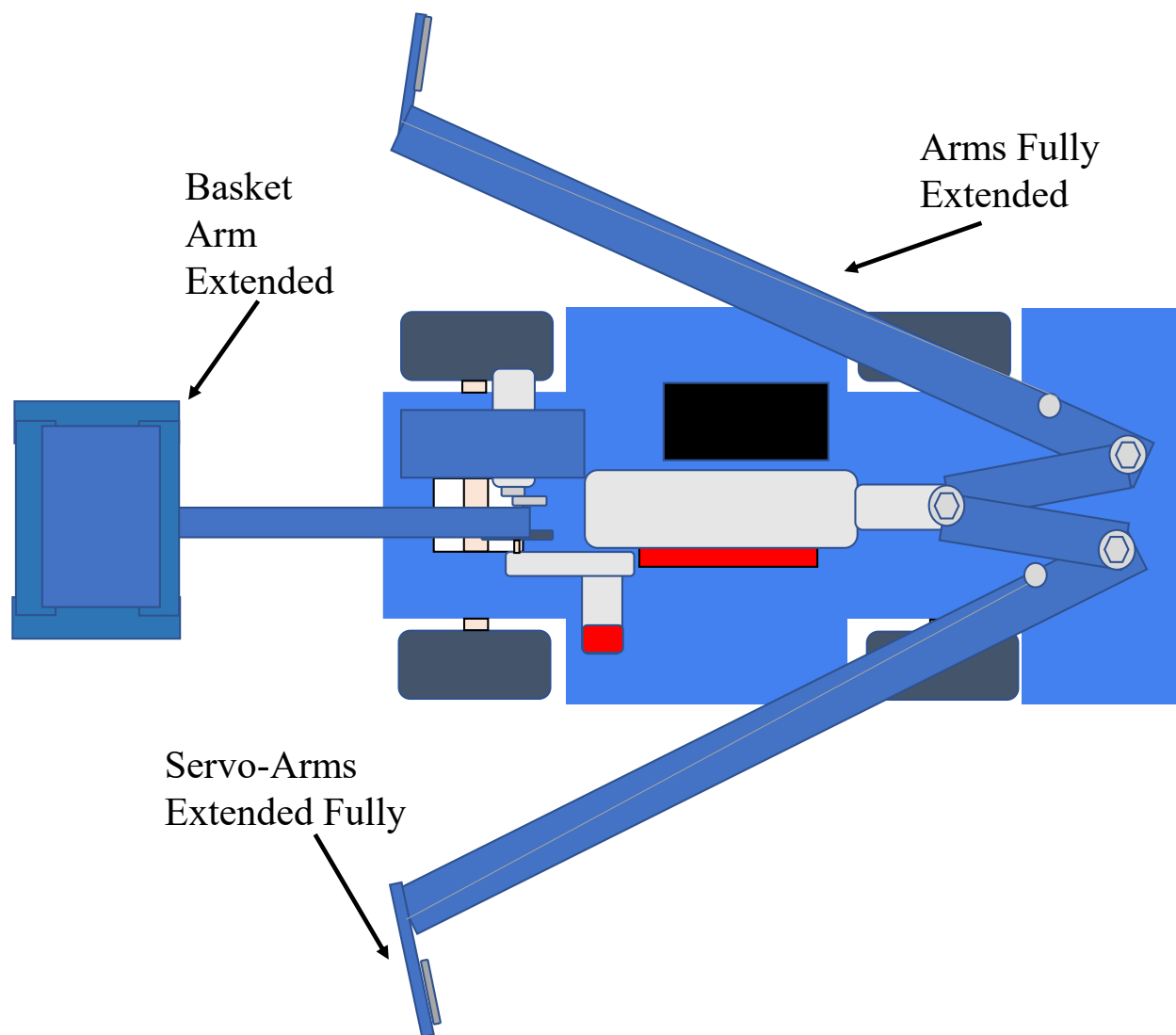


Figure 5: Top View of Ikran, with All Arms Extended Out.

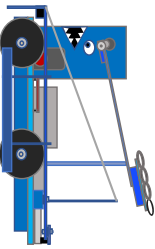
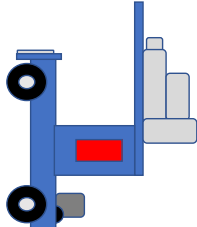
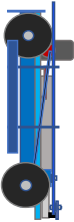
Table 1: House of Quality for Ikran.

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Importance	Customer Requirements	Direction of Improvement																					
		▼	▼	▲	X	▲	▼	▲	X	X	▼	X	▲	▼	▲	▲	▲	▲	▲	▼	▼		
Engineering Characteristics																							
		Device Length (in)	Device Width (in)	Device Height (in)	Strength of Frame's Material (ksi)	Number of Motors	Number of Sensors	Diameter of Wheels (in)	Number of Steps in Code	Motor Power and Time Controls	Cost of Materials (\$)	Number of Wired Components	Number of Parts Requiring Adhesive	Coded Device Run Time	Number of Toy Figures to Collect	Amount of Points Scored	Strength of Adhesive Used To Grab Toys (ksi)	Surface Area of Basket (in^2)	Set Up Time (min)	Post-Round Clean Up Time (min)			
9	Length < 24 inches	●	▲		■	▲		■			▲	▲						▲			●	Strong	10
9	Width < 12 inches	■	●	▲	■	▲		■			▲	▲	▲								■	Medium	6
9	Height < 18 inches	▲	▲	●	●						▲					▲		■			▲	Weak	2
9	Run Time < 30 seconds								■	■				●	▲				▲				
9	Remain on Track	▲							▲	●				●							▲	Maximize	
9	Fully Autonomous								■	▲			▲	■							▼	Minimize	
7	Only Use Given Motors and Sensors					■	■					■									x	Target	
6	Cost of Materials < \$100.00										●						▲	▲					
6	Not Damage Another Robot Intentionally				▲												▲				++	Strong Positive	
6	Not Damage Any Part of Track				▲												▲				+	Positive	
5	Deliver Jake Sully and Neytiri Into Quick Escape	▲		▲		▲	▲		■	■					▲		●		■	▲	▲	-	Negative
8	Deliver Jake Sully and Neytiri Into Sinking Vessel	▲		▲		▲	▲		■	■					▲		●		■	▲	▲	--	Strong Negative
7	Bring Na'vi Lego Men Into Hidden Sanctuary					▲		▲	■	■				●	■	●	●	●		▲			
8	Bring Fauna Into Team Zone or Hidden Sanctuary	●				■			●	●				■	■	●	●	●			▲		
8	Knock Toy Soldiers out of Team Zone or Off Track	■				■			▲	■					■	■	●				▲		
7	Bring Toy Banshees Into Start Zone	▲		▲		▲			▲	▲				●	■	●	●	●	■		▲		
3	Pull Other Team's J.S. and Neytiri Out of Center	▲		▲		▲									■	▲	■	●	■		▲		
9	Device Must Move							▲				▲			▲		●			▲			
8	Withstand Forces of Motors and Structural Weight	■	■	■	●			▲															
8	Use Only Gravity or Mechanical Energy from Motors				●							▲											
9	Start When Button is Pressed								■	▲					●		■			▲			
6	Aesthetically Pleasing	▲	▲	▲								▲					■						
6	Easily Repairable Between Rounds				■	▲	▲		■	■			▲							▲	▲		
5	Set Up Time < 4 min	■	■	▲														■		●			
3	Post-Round Clean Up Time < 2.5 min						▲										▲			●			
	Absolute Importance	264	216	214	294	321	80	156	446	478	120	124	224	566	310	628	322	210	142	154	5269		
	Relative Importance	0.05	0.04	0.04	0.06	0.06	0.02	0.03	0.08	0.09	0.02	0.02	0.04	0.11	0.06	0.12	0.06	0.04	0.03	0.03			

Table 2: Specification Sheet for Ikran.

		Specification for:	Issued:	3/7/2023
			Page # of N	
Changes	D/W	Requirements	Responsibility	Source
		Mechanically design an autonomous coded robot with multiple objectives		
		Geometry		
3/14/2023	D	Legnth less than 24 inches	Design Team	Contest Rules
4/5/2023	W	Legnth less than 23 inches	Design Team	Design Team
3/29/2023	D	Height less than 18 inches	Design Team	Contest Rules
4/5/2023	W	Height less than 17 inches	Design Team	Design Team
3/14/2023	D	Width less than 12 inches	Design Team	Contest Rules
4/5/2023	W	Width less than or equal to 11 inches	Design Team	Design Team
		Kinematics		
3/20/2023	W	Top Speed of 99 % for DC motors 1 and 2	Design Team	Design Team
4/1/2023	W	Reaches 4 Lego Navi men at the ocean within 2 seconds by use of gears via motor 1	Design Team	Design Team
4/1/2023	W	Reach Sinking Vessel with motor 2 swinging arm by 5 seconds	Design Team	Design Team
4/15/2023	D	Stop motors or any mechanical movment after 30 seconds	Design Team	Contest Rules
1/5/1904	W	Linear Actuator extending out 80 degrees 2 foot long arms	Design Team	Design Team
		Forces		
3/22/2023	W	Weight less than 20 lbs	Design Team	Design Team
3/20/2023	D	Must not cause damage to track	Design Team	Contest Rules
		Energy		
3/20/2023	W	Power consumption must be less than 12 V	Design Team	Design Team
3/20/2023	D	Power Supply = 12 V	Design Team	Contest Rules
		Materials		
3/20/2023	D	Use of 1 pyboard microcontroller	Design Team	Contest Rules
3/30/2023	W	Use of 1 Linear Actuator	Design Team	Contest Rules
3/20/2023	D	Contains no more than 3 servomotors	Design Team	Contest Rules
3/21/2023	D	Contains no more than 2 DC motors	Design Team	Contest Rules
		Signals		
3/20/2023	D	Robot begins at start signal	Design Team	Contest Rules
4/14/2023	W	Robot initiates sleep loop at 28 seconds	Design Team	Design Team
3/20/2023	W	Robot does not get a false before signal	Design Team	Design Team
		Safety		
3/29/2023	D	No intentional damage to the track or to surrounding competitors	Design Team	Contest Rules
3/29/2023	W	No entanglement with surrounding robots	Design Team	Design Team
		Quality Control		
4/6/2023	W	Ensure bolts on actuator arms arent loose	Design Team	Design Team
3/20/2023	D	Avoid damage to track	Design Team	Contest Rules
3/20/2023	D	Avoid damage to surrounding teams' device's	Design Team	Contest Rules
		Transport		
3/20/2023	D	Deliver Jake and Netiri into Sinking Vessel	Design Team	Contest Rules
4/13/2023	W	Launch Jake and Netiri over Sinking Vessel via swinging arm using motor 2	Design Team	Design Team
		Operation		
3/29/2023	D	Collect 4 Na'vi Lego Men		
3/29/2023	D	Complete tasks in less than 30s	Design Team	Contest Rules
4/5/2023	W	Complete task within at least 28 seconds	Design Team	Design Team
4/5/2023	W	Autonomously operate in correlation to prior code loop	Design Team	Design Team
3/29/2023	D	Remove Toy Soldiers from Team Zone	Design Team	Contest Rules
3/24/2023	W	Drag Toy Soldiers off track upon reversal	Design Team	Design Team
3/29/2023	D	Bring Banshees from rotating Sinking Vessel back into the Start Zone	Design Team	Contest Rules
4/2/2023	W	Stick at least 1 Banshee on basket arm after Jake and Neytiri rescue	Design Team	Design Team
		Maintenance		
4/4/2023	D	Boxed and ready to operate in less than 3.5 minutes	Design Team	Contest Rules
4/2/2023	W	Boxed and ready to operate in less than 1 minute	Design Team	Design Team
		Costs		
3/20/2023	D	Extra materials cost less than \$100	Design Team	Contest Rules
4/2/2023	W	Extra materials cost less than \$95	Design Team	Design Team
		Schedules		
3/23/2023	D	Ready for Preliminary Contest before March 23, 2023	Design Team	Contest Rules
4/6/2023	D	Ready for Qualifying Round before April 6 , 2023	Design Team	Contest Rules
4/20/2023	D	Ready for Final Contest before April 20, 2023	Design Team	Contest Rules

Table 3: Evaluation Matrix for Ikran.

				
Importanace				
Customer Requirements				
9	Length < 24 inches	8	8	8
9	Width < 12 inches	7	8	7
9	Height < 18 inches	7	7	9
9	Run time < 30 seconds	9	9	9
9	Remain on Track	9	9	9
9	Fully Autonompus	9	9	9
7	Only Use Given Motors and Sensors	9	9	9
6	Cost of Materials < \$100.00	9	9	9
6	Not Damage Another Robot Intentionally	9	9	9
6	Not damage Any Part of Track	9	9	9
5	Deliver Jake Sully and Neytiri into Quick Escape	9	5	1
8	Deliver Jake Sully and Neytiri into Sinking Vessel	9	9	1
7	Bring Na Vi Lego Men into Hidden Sanctuary	9	4	8
8	Bring Fauna into team zone or Hidden Sanctuary	9	1	3
8	Knock Toy soldiers out of Team Zone or Off Track	9	2	8
7	Bring Toy Banshee into Start Zone	6	1	1
3	Pull Other Team's J.S. and Neytiri Out of Center	5	1	1
9	Device must move	9	9	9
8	Withstand Force of Motors and Structural Weight	7	6	7
8	Use Only Gravity or Mechanical Energy from Motors	8	8	8
9	Start When Button is Pressed	8	8	8
6	Aestetically Pleasing	8	5	7
6	Easily Repairable Between Rounds	4	7	6
5	Set up Time < 4 min	7	8	7
3	Post-Round Cleanup atime < 2.5 min	7	7	7
	Total	1448	1232	1258
	Relative Total = Total/Number of Criteria	0.58	0.49	0.50

Pts.	Meaning			
0	Unsatisfactory			
1	Inadequate			
2	Weak			
3	Tolerable			
4	Adequate			
5	Satisfactory			
6	Good, but drawbacks			
7	Good			
8	Very Good			
9	Exceeds Req.			
10	Ideal Solution			

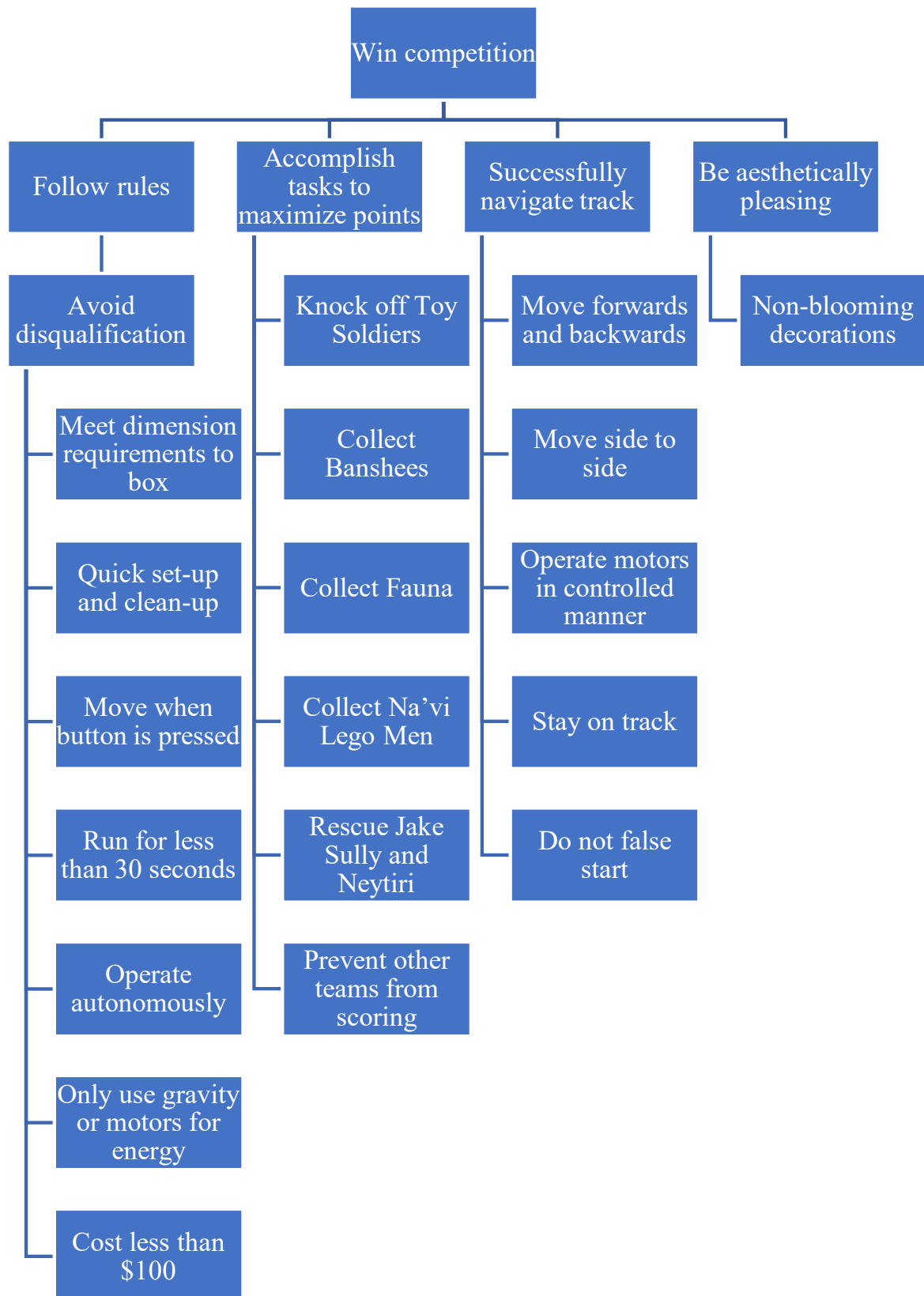


Figure 6: Function Tree for Ikran.

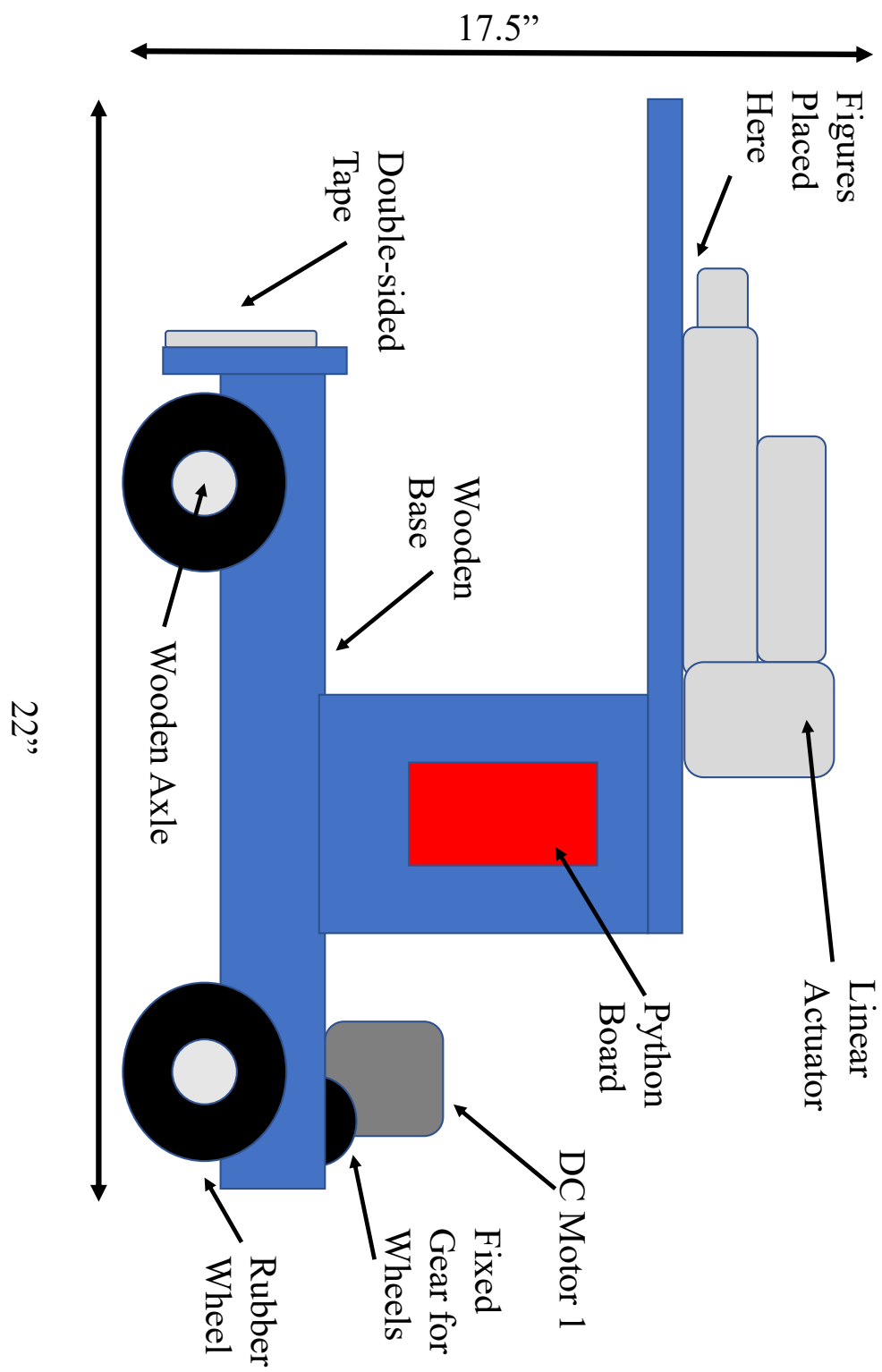


Figure 7: Side View of Alternate Design 1, the Pusher.

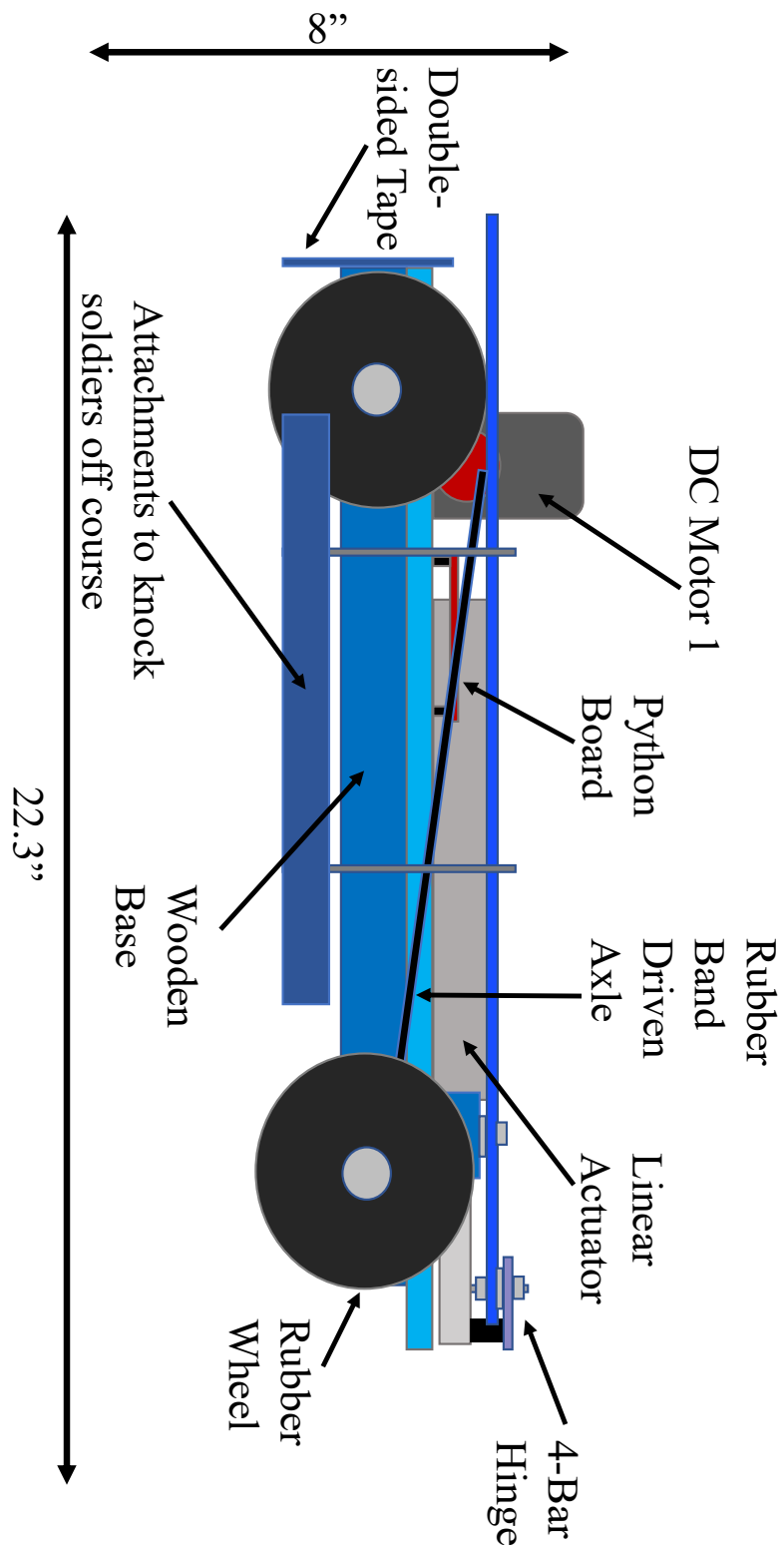


Figure 8: Side View of Alternate Design 2, the Spreader.