EML2322L – Design and Manufacturing Laboratory

Design Report 2 Resubmission

Team Number 11A

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Concept Selection Checklist / DR2 Grade Sheet

Group Number: 11A　　**TA** or **Group Performing Evaluation:** ____________

First Review / Grading or **Final Grading** (circle one)

EVALUATION MATRICES.

☑ YES ☐ NO　**1. Are separate matrices used for different parts of the design** (i.e. mobile platform, object manipulator, ball sorter, ball hopper, ball dispensing mechanism, etc.)?

☑ YES ☐ NO　**2. Does each matrix contain an appropriate number of objectives (typically 5 or 6)?**

☑ YES ☐ NO　**3. Are appropriate objectives used for each matrix?** It rarely makes sense to use the exact same objectives for all matrices, so select appropriate objectives for each. As an example, the time required for a motor to operate a mechanism which grabs or releases balls is much more meaningful than the speed of the motor.

☑ YES ☐ NO　**4. Does each objective have a clearly written and meaningful definition and evaluation criteria?** If evaluating speed, for example, does the fastest robot receive the highest score or are scores based on how close the conceptual designs are to a predetermined target velocity established during testing?

☑ YES ☐ NO　**5. Are weighting factors for each matrix justified and do they sum to one** (or 100%)?

☑ YES ☐ NO　**5.5. Is meaningful representative model testing performed for each concept?**

☑ YES ☐ NO　**6. Do quantitative objectives use quantitative assessments?** Never score objectives like *speed, size, material cost, manufacturing time, etc.* using qualitative assessments. If an objective can be quantified, **effort must be invested to do so, without exception.**

☑ YES ☐ NO　**7. Do quantitative assessments include complete, correct, and clear calculations?** Magnitudes for quantitative assessments must be computed and justified. Assessment data lacking clear justifications will receive no credit, so include explicit quantitative assessments by presenting one example formula with units and present the results of identical calculations in tabular format using Excel.

☑ YES ☐ NO　**8. Is quantitative assessment data presented in a clear and consistent tabular format and does it include appropriate explanations?** Example formulas and summary tables containing calculation results must be formatted consistently and placed in the report appendix. Each example formula must be accompanied by a typed description clearly explaining the logic between each step and defining all variables.

☑ YES ☐ NO　**9. Do all quantitative magnitude assessments use linear score assignments?** In this course assign the best concept a score of 10 and use linear ratios to rank other designs. If, for example, *material cost* is an objective and one design costs twice as much as the cheapest design, the cheapest design must receive the highest score (10) and the more expensive design must receive half the score assignment (5) since it costs twice as much.

☑ YES ☐ NO　**10. Are quantitative score assignments interpreted correctly?** If, for example, *manufacturing time, material cost* and *mobile platform size* are listed as objectives, the LOWEST magnitudes should receive the HIGHEST scores.

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☑ YES ☐ NO **13. Is the design with the highest composite score selected?** Occasionally a group misses the point of the evaluation matrices and selects a design that does not achieve the highest score. The matrices should determine the best design, not the group. Once the group chooses the objectives used to evaluate the designs and the associated weighting factors, the design with the highest score MUST be selected for each matrix. The best designs from each matrix are then combined to form the overall best hybrid design.

☐ YES ☑ NO **14. Are new design ideas properly incorporated into the evaluation matrix?** If a new idea develops while working through this phase of the design process, simply add another column to the relevant matrix (i.e. "Design 5") and compare the new idea to the others, as shown in the *Decision Matrix Example*.

☑ YES ☐ NO **15. Are reasonable and consistent significant figures reported in the matrices?** Do not report estimated robot speed to 5 decimal places, as an estimate never has that level of precision. Since robot size cannot be measured to 0.001", or manufacturing time to 0.1s, never report magnitudes and scores with inappropriate precision.

☑ YES ☐ NO **16. Are grammar and formatting at a collegiate level?** Take pride in your work: check grammar and spelling; use the provided templates and format the matrices to fit nicely across the page without using small font sizes; highlight the winning designs; avoid screen captures; and submit a quality pdf.

ROBOT SPEED, TIME & TORQUE CALCULATIONS.

☐ YES ☑ NO **17.** Do the **computer-generated path illustrations** clearly show the **complete** path trajectories with **clearly** labeled distance and speed vectors in tabular format for each concept? Are all illustrations presented in a consistent manner?

☑ YES ☐ NO **18.** Do the robot **wheel motor speed calculations** for each concept use the provided Excel template and course notes on motor calculations ($V_{LOADED} = 0.75\times\pi\times D\times N$)?

☑ YES ☐ NO **19.** Are **minimum and maximum drive times** reasonable and do they illustrate the tradeoff between motor speed and robot controllability?

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☑ YES ☐ NO **21.** Are the percentages used to compute the **Average Robot Velocity parameter** clearly explained in the report appendix (not just listed on the spreadsheet)?

☑ YES ☐ NO **22.** Is **Estimated Competition Time** for the final design reasonable and conservative?

☑ YES ☐ NO **23.** Do all calculations have **reasonable & consistent use of significant figures?**

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☑ YES ☐ NO **27.** Is the proper material included in each appendix?

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MOBILE PLATFORM			Design 1			Design 2			Design 3			Design 4		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Speed	0.30	feet / sec	3.0	10.0	3.0	3.0	10.0	3.0	1.5	5.0	1.5	1.5	5.0	1.5
Controllability	0.35	seconds	48.0	4.5	1.6	48.0	4.5	1.6	26.0	10.0	3.5	26.0	10.0	3.5
Manufacturing Time	0.15	hours	18.0	6.5	1.0	15.0	8.6	1.3	13.1	10.0	1.5	15.0	8.6	1.3
Modularity	0.10	fasteners	24.0	9.0	0.9	28.0	7.0	0.7	25.0	8.5	0.9	22.0	10.0	1.0
Material Cost	0.10	$	8.7	10.0	1.0	11.4	9.5	1.0	22.8	7.1	0.7	27.0	6.3	0.6
Overall value					**7.5**			**7.5**			**8.1**			**7.9**

BALL MANIPULATOR			Design 1			Design 2			Design 3			Design 4		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Controllability	0.30	time (seconds)	19.3	8.9	2.7	25.0	4.9	1.5	18.4	9.5	2.9	17.7	10.0	3.0
Speed	0.25	time (seconds)	102.3	6.8	1.7	89.2	10.0	2.5	101.5	7.0	1.8	109.1	5.1	1.3
Manufacturing Time	0.15	hours	1.5	10.0	1.5	4.3	8.5	1.3	4.4	8.5	1.3	2.0	9.8	1.5
Security	0.20	percentage	1.0	10.0	2.0	0.8	6.0	1.2	0.8	6.0	1.2	0.9	8.0	1.6
Material Cost	0.10	$	4.8	9.8	1.0	34.3	1.0	0.1	4.3	10.0	1.0	4.6	9.9	1.0
Overall value					**8.8**			**6.5**			**7.0**			**8.3**

BALL HOPPER			Design 1			Design 2			Design 3			Design 4		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Size	0.25	ball capacity	5.0	7.1	1.8	5.0	7.1	1.8	5.0	7.1	1.8	7.0	10.0	2.5
Stability	0.35	percentage	0.8	10.0	3.5	0.7	8.8	3.1	0.7	8.8	3.1	0.7	8.8	3.1
Manufacturing Time	0.15	hours	3.2	9.1	1.4	3.0	9.2	1.4	1.4	10.0	1.5	3.5	9.0	1.3
Flow	0.15	percentage of balls stuck	0.5	6.3	0.9	0.8	10.0	1.5	0.7	8.8	1.3	0.8	10.0	1.5
Material Cost	0.10	$	8.0	8.0	0.8	1.2	10.0	1.0	9.3	7.6	0.8	8.0	8.0	0.8
Overall value					**8.4**			**8.7**			**8.4**			**9.2**

BALL RELEASE MECHANISM			Design 1			Design 2			Design 3			Design 4		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Speed	0.15	time (seconds)	12.6	10.0	1.5	58.7	5.4	0.8	12.6	10.0	1.5	14.9	9.8	1.5
Efficiency	0.25	height (cm)	8.0	10.0	2.5	8.0	10.0	2.5	8.5	9.3	2.3	13.0	7.5	1.9
Manufacturing Time	0.15	hours	1.0	10.0	1.5	4.3	8.4	1.3	2.3	9.4	1.4	2.0	9.5	1.4
Controllability	0.35	time (seconds)	10.0	10.0	3.5	12.5	8.8	3.1	13.0	8.5	3.0	12.1	9.0	3.1
Material Cost	0.10	$	5.0	10.0	1.0	17.2	7.6	0.8	6.9	9.6	1.0	8.7	9.2	0.9
Overall value					**10.0**			**8.4**			**9.2**			**8.8**

Objective Definitions and Weighting Factor Justifications

Mobile Platform

Speed - This will be measured by how fast the mobile platform moves in feet per second on flat ground with 5 tennis balls being stored in the ball hopper. Speed is given a weight of 30% for multiple reasons, one being the completion time of the entire course will depend largely on the speed of the mobile platform. A large majority of the time will be spent on manipulating and storing the tennis ball inside the hopper which is why speed was given only 30%. This will be calculated by using the *Wheel Motor Speed Calculations* graph provided for the course. A table for comparisons between the designs is on *Appendix A*. The design with the highest loaded linear velocity scores 10 out of 10 possible points.

Controllability- How easily the model is objectively, to maneuver through the course as well as setting up the ball manipulator in position. Each design score will be calculated by using the *Speed vs Controllability* video provided. The test had basic robots with different motors run a course where five balls must be knocked off a source tree to complete the run, the times recorded in the video would become the trial times for our designs based on their motors. Controllability is essential to drive through the course properly and position the model for ball retrieval, so controllability is weighted at 35%. A comparison of each of the design's times can be seen on *Appendix A*. The designs with the best motors for driving will be given 10 points out of 10.

Manufacturing Time - An estimation of the time it takes to manufacture the parts of the platform using the provided *Time Estimations for Manufacturing Lab Parts*. This is weighted at 15% because it is important to remain on schedule with the project, but not more valuable than the usability of the platform defined by the speed and controllability. A comparison of each of the design's manufacturing times and more specific can be seen on *Appendix A*. The design with the lowest manufacturing time is the one that receives 10 points out of 10.

Modularity – This is a measure of how easy it would be to modify a mobile platform with other design's ball manipulator, hopper, and release mechanism parameterized by the number of fasteners that are used. Given a weight of 10% since the design will need to be used with the other mechanisms if they are chosen, but it would be beneficial if it were easier. This also makes it lower weighted compared to the other factors. A comparison of each of the design's number of fasteners can be seen on *Appendix A*. The design with the fewest number of fasteners scores 10 out of 10 possible points.

Material Cost - The cost of the materials required to build the mobile platform of the robot. We weighted the cost of the mobile platform at 10% because certain materials commonly used for a mobile platform are already provided. This makes it have less weight than the other components. The cost will be measured by adding up all the excess costs needed for this mechanism. It is better to allocate the budget provided towards wheels, motors and materials that are not given beforehand. A comparison of each of the design's material cost and more specific part costs. can be seen on *Appendix A*. The design with the lowest budget designated to the mobile platform scores a 10 out of 10.

Score Assignments:

Speed

Design 1 uses a 150RPM Denso Motor and 6" drive wheels as its motor and wheel combination. According to the Robot Speed Plot the maximum speed of the robot is approximately 3m/s. Since 3m/s is the maximum speed this design received a score of 10.

Design 2 uses a 150RPM Denso Motor and 6" diameter drive wheels as its motor and wheel combination. Based on the Robot Speed Plot the maximum speed of the robot is approximately 3m/s. Since this speed is tied for the fastest it also receives a score of 10.

Design 3 uses the 44 RPM Entstort Motor for each of the 10” drive wheels. This resulted in a maximum speed of 1.5 m/s (*As seen in Appendix B: Wheel Speed Calculations).* Since this is 50% of the speed of the fastest design, it received a score of 5 out of 10.

Design 4 uses 44 RPM Entstort Motors and 10” drive wheels as the wheel and motor combination. Based off the Robot speed plot, the maximum speed of the robot is approximately 1.5 m/s. Since design 4 travels at 50% of the fastest design, this mobile platform received a score of 5 out of 10.

Controllability

Design 1 uses the 150RPM Denso Motor as the motor for the drive wheels on the mobile platform. According to the EML2322L Speed vs. Controllability Video, the time to complete a basic course was 48 seconds. Since this is 22 seconds longer than the lowest time the design will score a 5 out of 10.

Design 2 uses the same wheel design as design 1, so they receive the same score because they have the same time of 48 seconds according to the EML2322L Speed vs. Controllability Video. This score is 5 points out of 10.

Design 3 uses the 44 RPM Entstort gear motor for the 10” drive wheels. The EML2322L Speed vs Controllability video shows this combination taking 26 seconds to complete the course. This tied for the fastest design so it receives a 10 out of 10.

Design 4 uses the 44 RPM Entstort right angle gear motor for the drive wheels of the mobile platform. The EML2322L Speed vs Controllability video shows that this motor takes 26 seconds to complete a basic course. This was the fastest of the designs, so it receives a score of 10 out of 10.

Manufacturing Time

Design 1 takes 18 hours to manufacture, after creating the two wheel hubs, two motor mounts, and the 80/20 frame. The fastest time to manufacture was 13 hours and each extra hour of manufacturing deducts 0.7 points from the score, giving Design 1 a 6.5 out of 10.

Design 2 has a manufacturing time of 15 hours, which is the 2 hours longer than the best design, so deducting 0.7 points per hour gives design 2 an 8.6 out of 10. This time was calculated using the graph found in Appendix A.

Design 3 has a manufacturing time of 13 hours, shown in *Appendix A*, for creating two motor mounts, wheels hubs, and assembling the frame. This was the fastest time out of all the designs, so this design receives a 10.

Design 4 takes about 17 hours to manufacture (as seen in *Appendix A*), including the wheel hubs, motors mounts and 80/20 base. This design is 4 hours more than the fastest manufacturing time, with each hour extra deducting 0.7 points. For this reason, a score of 7.2 out of 10 was given to the manufacturing time of design 4.

Modularity

Design 1 had 24 fasteners that attached the parts of the mobile frame to each other. Design 4 with the least number of fasteners had 22 fasteners, and for every extra fastener on each design compared to the best design, 0.5 points were deducted. This gives Design 1 a score of 9 out of 10

Design 2 had 28 fasteners used in the design. Each fastener greater than the smallest amount of 22 decreased the score by 0.5 points, so this design received 7 points out of 10.

Design 3 took 25 fasteners to put together the mobile platform. Each extra fastener from the lowest number was docked 0.5 points, so this design received an 8.5 out of 10.

Design 4 uses 22 fasteners to complete the mobile platform. Since this was the least number of fasteners used for any of the robot models, design 4 received a 10 out of 10 for modularity.

Material Cost
Design 1 cost $8.67 to create the mobile frame, including the wheel hub and motor mount materials. This makes design 1 the lowest costing design and it receives 10 points out of 10. A breakdown of the cost to manufacture this part can be found in *Appendix A*.

Design 2 had a total cost of $11.37 so it receives 9.5 points out of 10. It was deducted 0.2 points for every dollar over the cheapest design. The cost breakdown for manufacturing can be found in the time breakdowns for mobile platforms in *Appendix A*.

Design 3 had an overall material cost of $22.75. The material list and unit prices are shown in *Appendix A*. Subtracting 0.2 points for every dollar off the lowest score resulted in this design receiving a 7.1 out of 10.

Design 4 has a mobile platform that costs 27 dollars to build with the breakdown being found in *Appendix A*. The cheapest design was $5.54 and each dollar extra was deducted 0.2 points. This design was an extra $18, so a score of 6.3 out of 10 was given for cost of the mobile platform.

<u>Ball Manipulator</u>

Controllability- This is a measure of how simple the controls to lift, maneuver, and release the balls are. This will be tested based off the time it takes for the manipulator to get into position to pick a tennis ball up and transfer it to the hopper. Since the retrieval and manipulating of balls into the hopper is vital to success of the design, controllability of the ball manipulator is weighted highest at 30% since it determines the success or failure of the design. A comparison of each of the design's controllability can be seen on *Appendix A.* The design with the most controllable bucket manipulator receives a 10 out of 10 points.

Speed- This is a measurement of the time it takes to move 5 balls from the tree to the ball hopper. This is where most of the time will be spent so it is particularly important at 25%, but the controllability is more important to minimize the time spent moving the balls to the hopper and reduce the risk of dropping them. This will be tested by a member timing themselves and taking their ball manipulator and grabbing and moving 5 tennis balls into a bucket like hopper. A comparison of each of the design's speed trials can be seen on *Appendix A.* The manipulator with the lowest time to move 5 balls into the hopper receives 10 points out of 10.

Manufacturing Time - It is an estimation of the time to create the parts of the manipulator using the provided *Time Estimations for Manufacturing Lab Parts*. It is weighted at 15% because it is important to the time constraints of the project, but one of the least important factors for this mechanism. The most time in the project should be spent making this part as best as possible, so long times are not as much of a concern. A comparison of each of the design's manufacturing times and specific part times can be seen on *Appendix A.* The design with the lowest manufacturing time receives 10 points out of 10.

Security – Is the measurement of how securely the ball is held by the manipulator as the ball is moved from the tree to the hopper. This will be assessed with trials shown in *Appendix A* that show how many balls fall out from the manipulator as they are being transported. If the balls are dropped during transportation, then time will be wasted during the run, so security is weighted at 20%. A comparison of each of the design's security can be seen on *Appendix A.* Manipulators with the least number of balls dropped during trials with score 10 out of 10 points.

Material Cost - This objective is measured in the total dollar cost of any additional parts not provided by the lab. This is given a weight of 10% as most ball hoppers use external parts not provided by the lab and costs should be kept low. A comparison of each of the design's material costs can be seen on *Appendix A.* The design with the lowest material cost scores 10 out of 10 possible points.

<u>Score Assignments:</u>

Controllability

Design 1 uses the 4.5RPM Globe Gear motor to turn the arm of the manipulator, and when tested with the representative models to see how fast the arm took to move a ball from the tree to the hopper, Design 1 took 19.3 seconds. Compared to Design 4's 17.7 seconds, Design 1 is approximately 1.5 seconds longer. Each second deducts 0.7 points so Design 1 scored 8.9 points.

Design 2 uses the 4.5 RPM Globe gearmotor to lift the main arm and turning it 45 degrees takes around 5 seconds. The other 20 seconds on average were used to align the arm with the ball before moving the grabber to pick up the ball. This puts the average time of the testing to 25 seconds, and it receives 4.9 points out of 10.

Design 3 The ball manipulator is equipped with a 17.5 RPM Molon motor for tilting the arm and releasing the ball to the hopper and a 30 IPM Linear Actuator for vertical motion. This combination allows the design to grab one tennis ball and release it into the hopper in 18 seconds. Every second off the fastest time was deducted 0.7 points giving this design a 9.5 out of 10.

Design 4 uses the 4.5 RPM Globe Gear Motor to turn the manipulator. The representative model was tested to see how long it took for the manipulator to control the ball and deposit it into the hopper. The average time was 17.7 seconds for each ball, which was the fastest time resulting in design 4 receiving a 10 out of 10 for controllability.

Speed

Design 1 timed 102.3 seconds when picking up 5 balls and moving them to the hopper. This was approximately 13 seconds longer than the fastest time. Since each extra second deducts 0.25 off the score, Design 1 scores a 7.

Design 2 had an average time of 89.2 seconds for the time to grab and move 5 balls to the hopper. This time is broken down into the steps to move the grabber along the arm both ways, fine tune the position and grab and release the ball. This puts design 2 as the fastest time so it receives 10 points out of 10.

Design 3 had an average time of 101.5 seconds for picking up and storing 5 tennis balls. Each second slower than the fastest design lost 0.25 points. So, this design receives a 7 out of 10 being just over 10 seconds off the fastest time.

Design 4 had an average time of 109.1 seconds to pick up and deposit five tennis balls into the hopper. This was 20 seconds longer than the fastest design took, with each second more having a 0.25-point reduction. Design 4 was given a 5 out of 10 for speed of the manipulator.

Manufacturing Time

Design 1 takes approximately 1.5 hours to complete manufacturing of the ball manipulator including the 80/20 frame and the PVC ring. This is the fastest manufacturing time out of all the designs. This means Design 1 scores a 10.

Design 2 is a very complicated design that takes 9.5 hours to make. The time for this section is half of that because it is used as both the ball manipulator and the release mechanism. This still puts the time as the highest with 4.3 hours and receives 8.5 points out of 10 because 0.5 points are deducted for every hour above the lowest time of 1.5 hours.

Design 3 is a straightforward design and takes 4.4 hours to manufacture. One small piece of sheet metal is made and then a simple combination of 80/20 is assembled. This results in an 8.5 out of 10 because it is 3 hours longer than the fastest design.

Design 4 takes approximately 2 hours to build. This design requires cutting of sheet metal and attaching the motor. The fastest manufacturing time was design 1, with it taking 1.5 hours to manufacture, and each extra hour resulted in a 0.5-point reduction. This design was given a 9.8 out of 10 for manufacturing time since it was 0.5 hours longer.

Security

Design 1 had tested with the representative models, the security of the ball when transported. The percentage of balls that stayed in were 100% which is the highest score. This means that Design 1 receives the highest score of 10 out of 10 points.

Design 2 found with testing that 80% of the balls were successful in being grabbed and moved from the tree to the hopper. 2 points were deducted for every 10 percent, so this design receives 6 points out of 10.

Design 3 was tested and was able to securely delivery the ball with an accuracy of 80%, as seen in *Appendix A*. Every 10% off the highest score was deducted 2 points. This results in a score of 6 out of the possible 10.

Design 4 found through testing that 90% of the balls were successful in being transitioned from the tree to the hopper. Design 1 had 100% effectiveness, resulting in a 2-point reduction for every 10% below this mark. Therefore, design 4 was given an 8 out of 10 for ball security.

Material Cost

Design 1 cost $4.80 to gather materials to build the ball manipulator. The lowest cost was $4.26 from Design 3. Each extra dollar on the material cost deducts 0.3 points from the score. Thus, Design 1 scores a 9.8 out of 10 points.

Design 2 has a total cost of $34.30 for this two-part mechanism, so the cost for this part was recorded as half of that $17.50. This was by far the most expensive mechanism and 0.3 points were deducted for every dollar greater than the lowest cost of $4.26. This made the design receive 6.2 points out of 10.

Design 3 cost a total of $4.26 including the sheet metal and motor mount. For this score a deduction of 0.3 points for every dollar off the lowest was applied. This design received a 10 out of 10 points because it has the lowest material cost.

Design 4 has a cost of $4.60 for the manufacturing of the ball manipulator. The lowest cost of the designs was $4.26 ad each extra dollar was a 0.3-point reduction. In the end, design 4 received a 9.9 out 10 for the cost.

<u>Ball Hopper</u>

Size- is the measurement of how many balls the hopper can hold at once during the running of the course. Each design will be tested by placing tennis balls in the hopper and seeing how many each can hold. This will be assessed quantitatively with the most balls being held assessed as the highest score, since extra balls are considered extra points but 5 is the requirement for the design project and all designs hold at least five. Since the larger number of balls carried at once reduces the time spent running the course back and forth, the size of the ball hopper is weighted at 25% since it will drastically reduce time spent on the course and extra balls will be rewarded a lower time. Comparisons of the number of balls each design can hold are on *Appendix A*. Hoppers that can hold the most balls at once receive a 10 out of 10 possible points.

Stability - This is a measurement as to how secure the balls will be while being transported in the hopper. The balls are unable to touch the ground, which is why we weighted the stability the highest at 35%. With the ramps in the middle of the arena and the transfer of the balls from the manipulator, the tennis balls can make small bounces or move just enough to fall out of the hopper. This assessment will be based on trials done with the representative models to see how easily the balls will fall out following simulations of the course. More on the methodology can be found in *Appendix A*. The design with the most stability will be given a 10 out of 10.

Manufacturing Time – This is an estimated time in hours that the part will take to manufacture and be ready for assembly. Manufacturing times will be estimated using the provided *Time Estimations for Manufacturing Lab Parts.* Given a weight of 15% because the part must be manufactured in the time allowed however it only needs to be able to hold 5 balls in a simple shape, so manufacturing time will be low and other factors are more important. Comparisons of the times spent for each design and each specific part are shown on *Appendix A*. The design with the fewest required hours scores 10 out of 10 possible points.

Flow – This is a measure of how easily the balls exit the hopper and start to get released by the ball release mechanism. Given a weight of 15% because in the event a ball gets stuck or blocks the exit, none of the balls will be able to exit resulting in huge losses in score. This will be tested by each member releasing 5 tennis balls from their ball hoppers multiple times and recording whether the balls ever get stuck. Comparisons of the results of the trials for each design are on *Appendix A*. Hoppers that do not cause the balls to get stuck on any tests will receive 10 points out of 10.

Material Cost - This is the estimated cost of fabricating the parts of the ball hopper. It is weighted at 10% because it is something that will need to be manufactured or bought from materials that were not directly provided. This will probably not be an exceptionally large cost, so the other components of how well the design functions are more highly weighted. Comparisons of the costs of the design and specific parts are on *Appendix A*. The design with the lowest estimated cost will receive 10 points out of 10.

<u>Score Assignments:</u>

Size-
Design 1 was tested to see the maximum balls that the hopper could store to transport to the goal bucket. The tennis balls were placed until they fell out when moving at the speed of the mobile platform, and design 1 was able to store 5 balls without dropping any. This was 2 balls less than the maximum balls held by any design, and proportionally to a 7 scoring a 10, 5 balls scores a 7.1 out of 10.

Design 2 was tested to determine the maximum number of balls that could be stored in the hopper. This design was able to store 5 balls and this was compared to the design that held the highest number of 7 balls. This proportionally was 5 out of 7, so it scored 7.1 points out of 10.

Design 3 was tested and the amount of total tennis balls that could fit inside the hopper was recorded to be 5. The maximum number of balls out of any hopper was 7. Using a proportion to the maximum number, this design received a 7.1 out of 10 possible points.

Design 4 was tested to see how many balls could be stored in the hopper. The tennis balls were placed side by side into the hopper and design 4 showed it was able to hold 7 tennis balls. This was the most of the designs created, so a score of 10 out of 10 was given to this design.

Stability-

Design 1 was tested to find if balls would stay in the hopper as it is transported on the mobile platform. The trials show that the balls would stay in the hopper 80% of the time which is the highest percentage out of all the designs. Thus, design 1 receives a 10 out of 10 possible points.

Design 2 was tested and through the trials determined that 70% of the tests resulted in no balls falling out of the hopper when driving conditions were mimicked. This was compared to the best design of design 1 and scored proportionally so it was given 8.8 out of 10 points.

Design 3 concept was tested with multiple trials for how stable the tennis balls were inside the hopper while moving. The testing is described below in the Ball Hopper Testing Evidence / Explanation. Since a ball did not remain inside the hopper for 3 of the tests and the concept with the highest score was recorded falling out twice, this design received a score of 8.8 out of 10 points.

Design 4 found through testing that 70% of the trials resulted in no balls falling out of the hopper while enduring ramps and bumps. Design 1 had an 80% effectiveness, and the rest of the scores were made proportional to this value. Therefore, design 4 was given an 8.8 out of 10 for ball security.

Manufacturing Time-

Design 1 requires 3.2 hours to manufacture. This design requires welding of the steel sheets into a box for the hopper frame. Compared to the fastest time, 1.4 hours, design 1 is nearly 2 hours longer. Since each extra hour is 0.5 points, design 1 receives a 9.1 out of 10

Design 2 has an estimated manufacturing time of 3 hours. This is broken into cutting sheet metal and welding plates together. This is 1.6 hours longer than the fastest design, which was design 3. 0.5 points were deduced for each hour over the shortest time so it received 9.2 out of 10 points.

Design 3 requires approximately 1.4 hours to manufacture and assemble. Since the longer the manufacturing time, the lower the score, we subtracted 0.5 points for every hour longer than the fastest from the total. Since this design was the fastest, it received 10 out of 10 points.

Design 4 takes approximately 3.5 hours to build. This design requires cutting and folding sheet metal and attaching it to the robot. The fastest manufacturing time was design 3, which takes 1.4 hours to manufacture, and each extra hour resulted in a 0.5-point reduction. This design was given a 9 out of 10 for manufacturing time since it was 2 hours longer.

Flow-

Design 1 was measured to see how many balls got stuck when exiting the hopper. When tested design 1 got stuck 50% of the time, which is 30% lower than the highest percentage. Proportional to 80% being a 10, 50% receives a 6.25 out of 10.

Design 2 was tested and tied with design 4 for having the highest percentage of successful trials without having a ball get stuck. This percentage was 80% and it receives 10 points out of 10.

Design 3 went through multiple trials and recorded the number of balls that got stuck as they were moving around the hopper. Since this design had one or more tennis balls get stuck on 3 of the trials it received a magnitude of 0.7. Comparing this to the best design with a score of 0.8, this design received a score of 8.8 out of 10 points.

After 10 trial runs, design 4 was 80% successful in balls not getting stuck or blocking the release mechanism. Design 4 and design 2 both have 80% effectiveness rates, which was the highest of the scores. Therefore, design 4 was given a 10 out of 10.

Material Cost-
Design 1 costs approximately $8.00 to manufacture the hopper. Compared to the lowest cost of $1.18, design 1 was around $7 more expensive. Since each dollar is 0.3 points deducted, design 1 scores an 8 out of 10.

Design 2 has an estimated cost of $1.18 to manufacture the hopper. This was the lowest cost so this design received the maximum of 10 points out of 10.

Design 3 calls for $9.31 of material costs in total. Each design score was subtracted 0.3 for each dollar above the minimum. Since the lowest cost was $1.18, this design received a score of 7.6 out of 10 points

Design 4 has a cost of $8.00 for the manufacturing of the ball manipulator. The lowest cost of the designs was $1.18 with each extra dollar resulting in a 0.3-point reduction. In the end, design 4 received an 8 out 10 for the cost.

<u>Ball Release Mechanism</u>
Speed - This is the time in seconds it will take for the ball release mechanism to be activated and drop all five tennis balls into the bucket. The test will time when the release mechanism begins to move to when the final ball has dropped to the ground. Weighted at 15% because it is important that the balls release at a fast rate, but overall, the time it takes for the balls to be released is marginal compared to the other sections of the course that need to be completed. The trials for each design's tests for speed are shown in *Appendix A.* The design with the lowest time in seconds will receive a 10 out of 10.

Efficiency - The efficiency is a measure of how the balls will enter the bucket. This is weighted at 25% because if the ball comes in at a certain angle, it can knock the bucket over. If a ball gets released from too high up, it could also bounce out of the bucket, making it particularly important that proper calculations are made for the release of the tennis balls. The designs will have several trial runs where the bounce and the exiting angle will be measured relative to the middle point of a bucket. The trials for each design's tests for efficiency are shown in *Appendix A.* The release mechanism with the least amount of bounce and smallest angle from upright will be given a 10 out of 10.

Manufacturing Time - An estimation of the time required to fabricate the release mechanism using the provided *Time Estimations for Manufacturing Lab Parts*. It is weighted at 15% because it important for the design schedule and more important than the time, but how well the balls are released is more important. The comparisons between design manufacturing times and specific part manufacturing times are shown in *Appendix A.* The design with the lowest estimated time will receive 10 points out of 10.

Controllability – This is a measure of how easy it is to position the release mechanism to the necessary spot to release the balls into the bucket. If the balls hit the floor or knock the bucket over, they no longer count, so it is important this is not difficult, which is why it is weighted at 35%. We will test this by timing how long it takes for the robot to position itself correctly once it has arrived at the bucket. The trials for each design's tests for controllability are shown in *Appendix A.* Designs with the lowest time will receive 10 out of 10 points.

Material Cost - This is the cost of any extra materials that need to be purchased outside of what is given by the lab. Weighted at 10% because the cost of this piece needs to be kept low to allow for other parts to be more expensive. Since it is a relatively simple piece, the cost can be kept to a minimum easily. The comparisons between design costs and specific part costs are shown in *Appendix A.* The design with the lowest cost will receive 10 out of 10 points.

<u>Score Assignments:</u>

Speed -
Design 1 took approximately 12.6 seconds to drop all five balls after activating the release mechanism according to the trials. Since this was the fastest time to release all balls along with design 3, design 1 scores a 10.

Design 2 uses the ball manipulator to move the balls out of the hopper, so it is slow. This time is less than the time to retrieve the balls because once it is in position additional time is not needed to move the arm and it does not need to go the full length before dropping the balls. 0.1 points were deducted for every second over the shortest time of 12.6 seconds, so this design receives 5.4 points out of 10.

Design 3 was tested over multiple trails and received an average score of 12.6 seconds for the balls to be released. Comparing to the other design scores, this one tied for the lowest score. So, this design received a 10 out of 10 points in this category.

Design 4 took an average if 14.9 seconds to dispense five balls into the bucket once it was in position. This was 2.3 seconds longer than the fastest design. Each extra second counted as a 0.1-point reduction, resulting in design 4 receiving a 9.8 out of 10.

Efficiency -
Design 1 releases the ball at 8 inches above the ground. Since efficiency tests the height of the bounce of the ball to ensure the ball does not bounce out when dropped into the goal bucket, the lowest height scores the highest. Since 8 inches is the lowest, design 1 scores a 10 out of 10.

Design 2 releases the balls 8 inches above the ground. This height determines the bounce of the ball and design 2 it is tied with design 1 for having the lowest height. This means it receives 10 points out of 10.

Design 3 efficiency was measured to be 8.5 inches of the ground. This affects how well the balls stay in the bucket when released. Compared to the lowest height of 8 inches and subtracting 0.5 from the score for every inch above that, this design received a score of 9.3 out of 10 points.

Design 4 releases the balls about 13 inches above the ground, creating a larger bounce than would be ideal. The best designs were dropped 8 inches above the ground creating a small bounce. A 0.5-point deduction was given for every extra inch, giving this design a 7.5 out of 10.

Manufacturing time -
Design 1 takes around 1 hour to manufacture the release mechanism. This is the lowest time to manufacture out of all the designs, so design 1 scores a 10 out of 10.

Design 2 uses half the time it takes to manufacture the ball manipulator since they are the same part to have a time of 4.3 hours. This is 3.3 hours over the lowest time of 1 hour and 0.5 points were deducted for every hour over the lowest time. This means that it receives a score of 8.4 points out of 10.

Design 3 was estimated to take 2.3 hours to manufacture and assemble the mechanism. We subtracted 0.5 from the total score for each hour extra a part took to manufacture compared to the fastest. This design received a score of 9.4 out of 10 points.

It takes approximately 2 hours to build the release mechanism of design 4. This includes the cutting of PVC pipe and attaching it to the hopper. The fastest manufacturing process was design 1, which took 1 hour to complete. Each extra hour was given a 0.5-point reduction, which means that this design was given a 9.5 out of 10.

Controllability -
Design 1 tested the time to maneuver the release mechanism over the bucket in preparation for release. The average of ten trials showed that design 1 takes approximately 10 seconds to maneuver. This is the shortest time so design 1 scores a 10 out of 10.

Design 2 had an average controllability time of 12.5 seconds as determined through the trials. This was 2.5 seconds greater than the lowest time of 10 seconds and 0.5 points were deducted for every second over, so it receives 9 out of 10 points.

Design 3 was tested and measured to have an average controllability of 13 seconds. Compared to the best design which averaged at 10 seconds. A penalty of 0.5 points was deducted for every second above 10. This resulted in the design receiving a score of 8.5 out of 10 points.

Each design was placed through 10 trials to see how long it would take to adjust the release mechanism over the bucket, with the average time of design 4 being 12.1 seconds. This was 2.1 seconds behind the fastest time, with each extra second deducting 0.5 points. Therefore, design 4 was given a 9 out of 10.

Material Cost -
Design 1 material cost was approximately $5.00 to gather parts for the release mechanism. This is the lowest cost for all designs, so design 1 scores a 10 out of 10.

Design 2 had an estimated material cost of $17.15 since it was half of the cost to design the ball manipulator mechanism. 0.2 points were deducted for every second over the lowest cost of $5.00, so design 2 receives 7.6 points out of 10.

Design 3 requires $6.93 to pay for the materials. Comparing this price to the lowest and subtracting 0.2 points for every dollar over the best, this design received a score of 9.6 out of 10.

Design 4 has a cost estimate of $8.68 for the ball release mechanism. The lowest cost of the designs was $5.00 with each extra dollar resulting in a 0.2-point reduction. Since design 4 was $3.68 more than the lowest amount, it received a 9.2 out of 10.

Appendix A: Decision Matrix Calculations & Justification Data

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Mobile Platform / EML2322L-A-11

MANUFACTURING / ASSEMBLY PROCESS	Est. Time [min]	Quantity [-]	Subtotal [min]	[hr]
DESIGN 1				
Gather and cut materials into workable pieces	120	1	120	2.0
Manufacture 80/20 mobile frame	120	1	120	2.0
Manufacture motor mount	90	2	180	3.0
Manufacture wheel hub	215	2	430	7.2
Manufacture rods for motor placement	60	1	60	1.0
Attach 80/20 support for hopper and manipulator	40	1	40	0.6
Attach wheels, wheel hubs, motor, and mounts	45	2	90	1.5
attach caster wheel to robot frame	15	1	15	0.3
attach and wire control box for first time	20	1	20	0.3
TOTAL:			**1075**	**17.9**
DESIGN 2				
Retrieve pre-cut pieces of 80/20	5	6	30	0.5
Mark & cut remaining 80/20	9	2	16	0.3
Manufacture motor mount	75	3	225	3.8
Manufacture wheel hub	215	2	430	7.2
Manufacture hopper attachment	60	1	60	1.0
Attach motor mounts to frame	5	3	15	0.3
Attach motor to motor mount	8	3	24	0.4
Attach wheel hub to motor	9	2	18	0.3
Attach wheel to wheel hub	10	2	20	0.3
Attach caster wheel to robot frame	15	1	15	0.3
Attach and wire control box for first time	20	1	20	0.3
Weld steel on steel for additional stability	30	1	25	0.4
TOTAL:			**898**	**15.0**
DESIGN 3				
retrieve pre-cut pieces of 80/20	10	7	70	1.2
attach pieces of 80/20	10	9	90	1.5
manufacture motor mount	72	2	144	2.4
manufacture wheel hub	205	2	410	6.8
attach motor to motor mount	8	2	15	0.3
attach motor mount to robot frame	5	2	10	0.2
attach wheel hub to motor	8	2	16	0.3

attach wheel to wheel hub	8	2	16	0.3
attach caster wheel to robot frame	10	1	10	0.2
TOTAL:			**781**	**13.1**

DESIGN 4				
Retrieve pre-cut pieces of 80/20	5	16	80	1.3
Mark & cut remaining 80/20	8	11	88	1.5
Manufacture motor mount	72	2	144	2.4
Manufacture wheel hub	215	2	430	7.2
Retrieve and attach fasteners	3	22	66	1.1
Attach motor to motor mount	8	3	24	0.4
Attach motor mount to robot frame	5	3	15	0.3
Attach wheel hub to motor	9	2	18	0.3
Attatch wheel to wheel hub	10	2	20	0.3
Attach caster wheel to robot frame	15	1	15	0.3
Attach and wire control box for first time	20	1	20	0.3
TOTAL:			**900**	**15.0**

Entstort Wheel Hub / EML2322L-11A

MANUFACTURING PROCESS	TIME [min]
mark & cut 2" dia. bar stock on bandsaw	12
load part and cutting tool into lathe	8
face first end of part	5
turn main shoulder on part	35
cut chamfers on front (2) edges of part	5
mark & cutoff part to ~1.6" on bandsaw	12
reload part into lathe and face second end of part	7
drill and ream precision center hole, 1.5" deep	25
bore 3/4" dia center hole, 0.9" deep	12
rotate part 180-deg and reclamp in lathe chuck	3
drill 10mm dia center hole, 0.4" deep	8
load part and drill chuck into mill	8
find X, Y zeros using edgefinder	10
drill and tap (3) 10-24 threaded holes, 0.5" deep	30
misc. time to debur part between steps	5
time to clean machines when finished	20
ESTIMATED MANUFACTURING TIME:	**205** **3.4**

Denso Wheel Hub / EML2322L-11A

MANUFACTURING PROCESS	TIME [min]
mark & cut 2" dia. bar stock on bandsaw	12
load part and cutting tool into lathe	8
face first end of part	5
turn main shoulder on part	35
cut chamfers on front (2) edges of part	5
mark & cutoff part to ~1.6" on bandsaw	12
reload part into lathe and face second end of part	7
drill and ream precision 5/16" center hole, 1.5" deep	25
load part and drill chuck into mill	8
find X, Y zeros using edgefinder	10
drill and tap (3) 10-24 threaded holes, 0.5" deep	30
turn part 90-deg and reload into vise	3
find X, Y zeros using edgefinder	10
drill and tap (2) 10-24 threaded hole, 0.5" deep	20
misc. time to debur part between steps	5
time to clean machines when finished	20
ESTIMATED MANUFACTURING TIME:	**215** **3.6**

Motor Mount / EML2322L-11A

MANUFACTURING PROCESS	TIME [min]
mark & cut 3/16" x 2.5" bar stock on bandsaw	10
load part(s) into milling machine vise	5
find X, Y zeros using edgefinder	10
drill (3) clearance holes for motor mounting, thru	20
drill (1) clearance hole for motor shaft clearance, thru	15
drill (2) clearance holes for bracket mounting, thru	10
time to debur part between steps	5
time to clean machine when finished	7
ESTIMATED MANUFACTURING TIME:	**82** **1.4**

MOBILE PLATFORM MATERIAL COST ESTIMATES

MATERIAL	Unit of Cost [-]	Quantity [-]	Unit Cost [$]	Total Cost [$]
DESIGN 1				
2" AL round bar stock	ft	0.33	$20.00	$6.67
3/16" x 2" AL rectangular bar stock	ft	1.0	$2.00	$2.00
			TOTAL:	**$8.67**
DESIGN 2				
2" AL round bar stock	ft	4	$20.00	$6.67
0.035" (20 GA) steel sheet	ft^2	2	$2.35	$4.70
			TOTAL:	**$11.37**
DESIGN 3				
80/20 1" x 1" AL square extrusion	ft^2	2.50	$3.00	$7.50
3/16" x 3.5" AL rectangular bar stock	ft	2.6	$2.00	$5.25
2" AL round bar stock	ft	0.50	$20.00	$10.00
			TOTAL:	**$22.75**
DESIGN 4				
1" x 1" 80/20 extrusion	ft	8.5	$3.00	$25.50
0.125"x 2" AL rectangular bar stock	ft	0.75	$2.00	$1.50
			TOTAL:	**$27.00**

NOTE: Cost calculated using provided Material Price List

Ball Manipulator / EML2322L-A-11

MANUFACTURING / ASSEMBLY PROCESS	Est. Time [min]	Quantity [-]	Subtotal [min]	Subtotal [hr]
DESIGN 1				
Gather motor, linear actuator and materials	15	1	15	0.3
Cut materials into workable pieces	20	1	20	0.3
Manufacture 80/20	24	1	24	0.4
Attach linear actuator to arm	10	1	10	0.2
Attach steel sheet to actuator	5	1	5	0.1
Attach PVC pipe to arm	10	1	10	0.2
Attach manipulator to motor	8	1	8	0.1
TOTAL:			**92**	**1.5**
DESIGN 2				
Select sheet metal	10	1	10	0.2
Layer cut lines for cutting sheet metal	20	4	80	1.3
Cut parts to size on bandsaw	7	10	70	1.2
Mark lines to center holes for cutting and cut	5	10	50	0.8
Weld corners of mild steel for stability	15	4	60	1.0
Weld metal rods for bike chain on end plates	15	2	30	0.5
Mark lines to center holes on tube	3	4	12	0.2
Cut holes through both sides of the tube	5	4	20	0.3
Construct the grabber sub assembly	200	1	200	3.3
Mount grabber to bike chain	40	1	40	0.7
TOTAL:			**572**	**9.5**
DESIGN 3				
mark and cut 80/20 aluminum extrusion	10	8	80	1.3
assemble 80/20 design with fasteners	10	1	10	0.2
manufacture sheet metal piece	60	1	60	1.0
manufacture motor mount	80	1	80	1.3
attach sheet metal to 80/20	5	1	5	0.1
attach motor mount	5	1	5	0.1
attach motor	5	1	5	0.1
assemble linear actuator to mounts	10	1	10	0.2
attach slide to 80/20 and connect to gripper	10	1	10	0.2
TOTAL:			**265**	**4.4**

Design 4

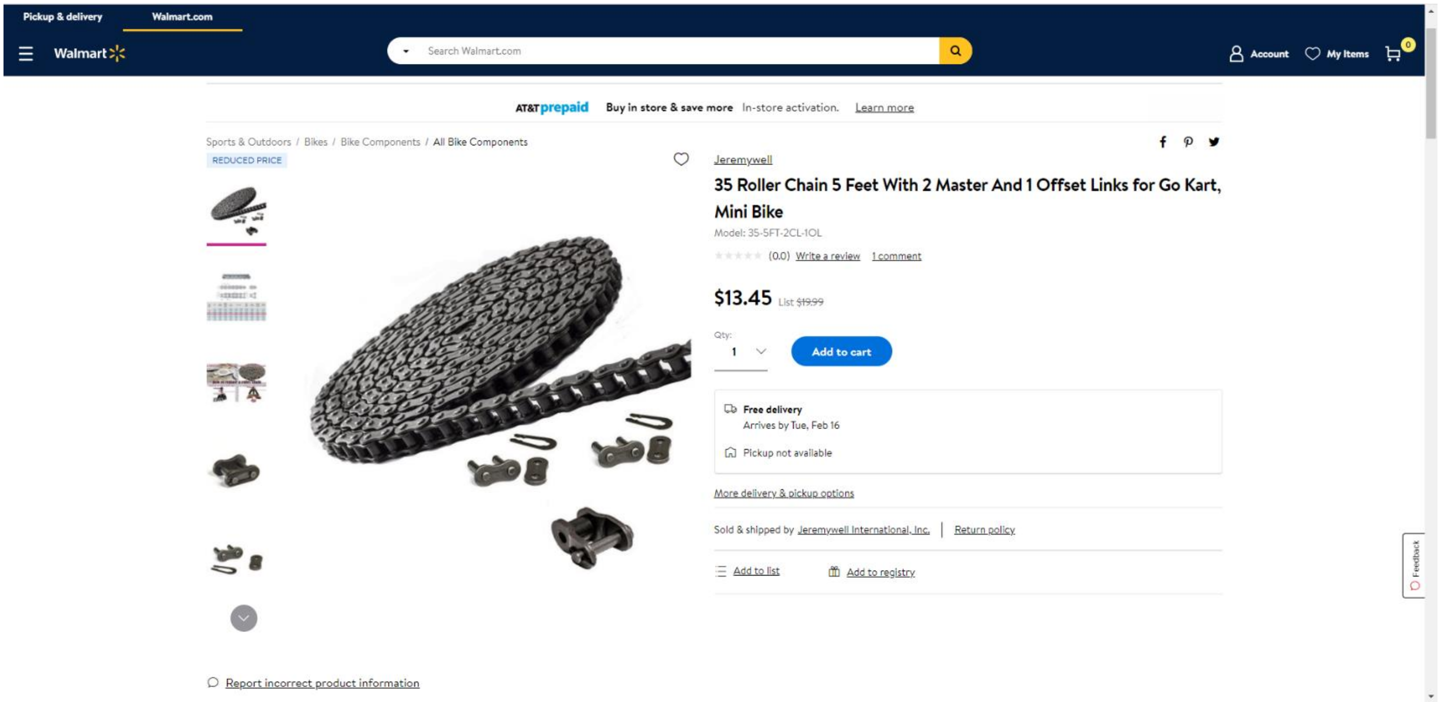
Select sheet metal	10	1	10	0.2
Layer cut lines for cutting sheet metal	10	2	20	0.3
Cut parts to size on bandsaw	7	3	21	0.4
Punch hole out	7	1	7	0.1
Bend sides	5	4	20	0.3
Weld corners of mild steel for stability	15	2	30	0.5
Attach manipulator to motor	10	1	10	0.2
Throw out scraps	3	1	3	0.1
Total:			**121**	**2.0**

BALL MANIPULATOR MATERIAL COST ESTIMATES

MATERIAL	Unit of Cost [-]	Quantity [-]	Unit Cost [$]	Total Cost [$]
DESIGN 1				
3" Schedule 40 PVC pipe	ft	0.25	$3.00	$0.75
80/20 square extrusion	ft	1.10	$3.00	$3.30
0.048" (18 GA) steel sheet	sq ft	0.25	$3.20	$0.80
			TOTAL:	**$4.85**
DESIGN 2				
1"x0.125" AL square tubing	ft	2.50	$1.00	$2.50
0.035" (20 GA) steel sheet	ft^2	1.00	$2.35	$2.35
35 Roller Chain 5 Feet With 2 Master And 1 Offset Links for Go Kart, Minibike	1	1	$13.45	$13.45
Grabber assembly budget	1	1	$15.42	$15.42
Low-Carbon Steel Rod, 1/2" Diameter	ft	2.00	$3.44	$0.58
			TOTAL:	**$34.30**
DESIGN 3				
3/16" x 3.5" AL rectangular bar stock	ft	1.3	$2.00	$2.60
0.048" (18GA) steel sheet	ft^2	0.50	$3.20	$1.60
			TOTAL:	**$4.20**
DESIGN 4				
0.048" (18 GA) steel sheet	sq ft	1.35	$3.20	$4.32
0.125" x 2" AL rectangular bar stock	ft	0.15	$2.00	$0.30
			TOTAL:	**$4.62**

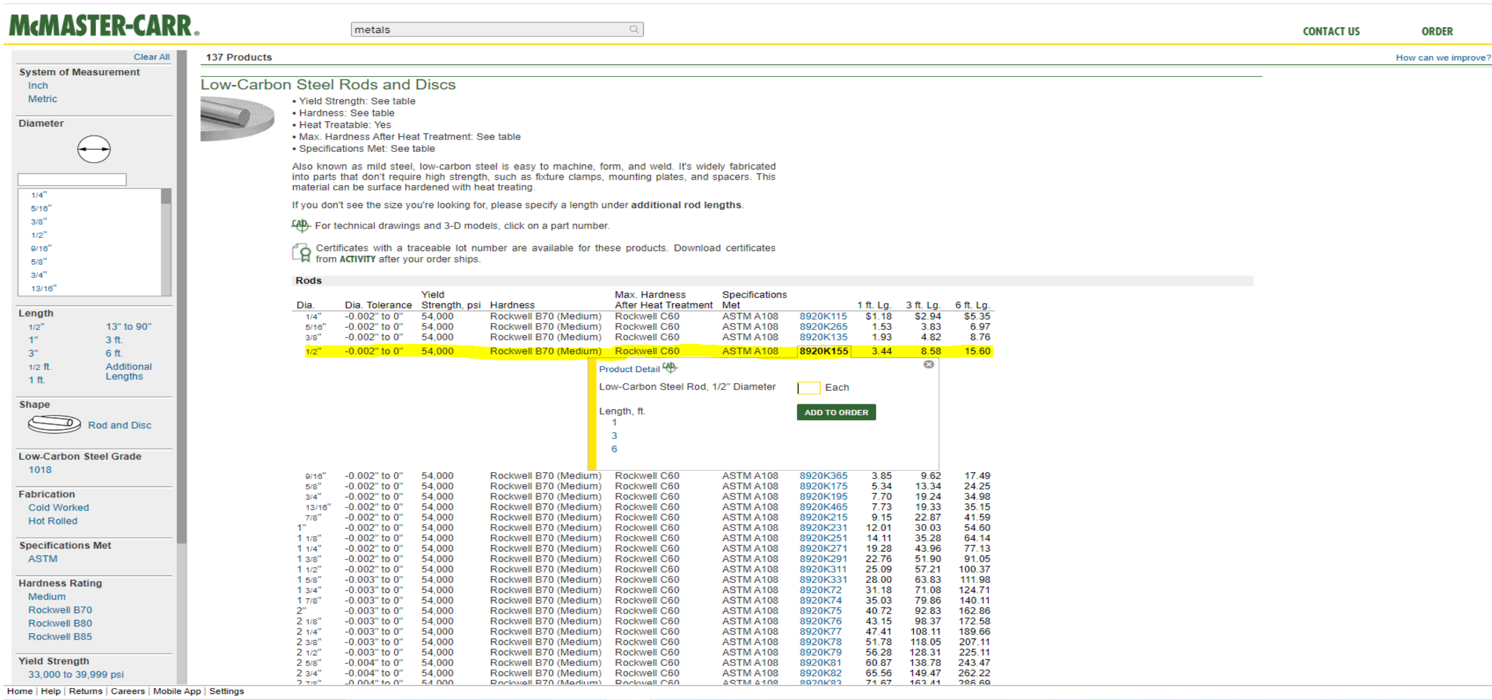
CATALOG OF PARTS NOT FOUND ON MATERIAL PRICE LIST

BIKE CHAIN: (Cheaper than purchasing through McMaster-Carr and free shipping)



LINK: https://www.walmart.com/ip/35-Roller-Chain-5-Feet-With-2-Master-And-1-Offset-Links-for-Go-Kart-Mini-Bike/330728782?wmlspartner=wlpa&selectedSellerId=8288

Low-Carbon Steel Rod, 1/2" Diameter



Dia.	Dia. Tolerance	Yield Strength, psi	Hardness	Max. Hardness After Heat Treatment	Specifications Met		1 ft. Lg.	3 ft. Lg.	6 ft. Lg.
1/4"	-0.002" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K115	$1.18	$2.94	$5.35
5/16"	-0.002" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K265	1.53	3.83	6.97
3/8"	-0.002" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K135	1.93	4.82	8.76
1/2"	-0.002" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K155	3.44	8.58	15.60
9/16"	-0.002" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K365	3.85	9.62	17.49
5/8"	-0.002" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K175	5.34	13.34	24.25
3/4"	-0.002" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K195	7.70	19.24	34.98
13/16"	-0.002" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K465	7.73	19.33	35.15
7/8"	-0.002" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K215	9.15	22.87	41.59
1"	-0.002" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K231	12.01	30.03	54.60
1 1/8"	-0.002" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K251	14.11	35.28	64.14
1 1/4"	-0.002" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K271	19.28	43.96	77.13
1 3/8"	-0.002" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K291	22.76	51.90	91.05
1 1/2"	-0.002" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K311	25.09	57.21	100.37
1 5/8"	-0.003" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K331	28.00	63.83	111.98
1 3/4"	-0.003" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K72	31.18	71.08	124.71
1 7/8"	-0.003" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K74	35.03	79.86	140.11
2"	-0.003" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K75	40.72	92.83	162.86
2 1/8"	-0.003" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K76	43.15	98.37	172.58
2 1/4"	-0.003" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K77	47.41	108.11	189.66
2 3/8"	-0.003" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K78	51.78	118.05	207.11
2 1/2"	-0.003" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K79	56.28	128.31	225.11
2 5/8"	-0.004" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K81	60.87	138.78	243.47
2 3/4"	-0.004" to 0"	54,000	Rockwell B70 (Medium)	Rockwell C60	ASTM A108	8920K82	65.56	149.47	262.22

LINK: https://www.mcmaster.com/metals/steel/multipurpose-low-carbon-steel/low-carbon-steel-rods-and-discs-7/

Ball Hopper / EML2322L-A-11

MANUFACTURING / ASSEMBLY PROCESS	Est. Time [min]	Quantity [-]	Subtotal [min]	Subtotal [hr]
DESIGN 1				
Gather steel sheets	10	1	10	0.2
Cut steel sheets into five for walls and base	90	1	90	1.5
Cut hole into 6"x6" wall for ball exit	30	1	30	0.5
Weld sheet pieces together to assemble hopper	60	1	60	1.0
TOTAL:			**190**	**3.2**
DESIGN 2				
Gather steel sheets	10	1	10	0.2
Layer cut lines	10	1	10	0.2
Cut parts to size on bandsaw	7	8	56	0.9
Welding corners together	30	3	90	1.5
Deburing time and waste cleanup	10	1	10	0.2
TOTAL:			**176**	**2.9**
DESIGN 3				
manufacture ball ramp	60	1	60	1
get ball hopper sheet metal piece and screw onto robot frame	10	1	10	0.2
attach hopper onto 80/20 support piece	5	1	5	0.1
make sure ramp lines up with ball gripper	10	1	10	0.2
TOTAL:			**85**	**1.4**
Design 4				
Select sheet metal	10	2	20	0.3
Layer cut lines for cutting sheet metal	10	4	40	0.7
Cut parts to size on bandsaw	7	4	28	0.5
Punch hole out	7	2	14	0.2
Bend sides	5	7	35	0.6
Weld corners of mild steel for stability	15	4	60	1.0
Attach hopper to robot	10	1	10	0.2
Throw out scraps	3	1	3	0.1
TOTAL:			**210**	**3.5**

Ball Ramp Concept 3 / EML2322L-11A

MANUFACTURING PROCESS	TIME [min]
get 0.048" (18GA) steel sheet metal	5
layout cut and fold lines using full scale paper template	10
cut part to overall size using foot shear or bandsaw	7
center punch hole location using a hammer and punch	3
if possible, punch hole using sheetmetal punch press	7
bend sides or tabs of part using sheetmetal brake(s)	5
weld corners of part for additional strength or stiffness	15
time to debur part between steps	5
time to dispose of material scraps when finished	3
ESTIMATED MANUFACTURING TIME:	**60** **1.0**

BALL HOPPER MATERIAL COST ESTIMATES

MATERIAL	Unit of Cost [-]	Quantity [-]	Unit Cost [$]	Total Cost [$]
DESIGN 1				
0.060" 16GA steel sheet	ft^2	2.0	$4.00	$8.00
			TOTAL:	**$8.00**
DESIGN 2				
0.035" (20 GA) steel sheet	ft^2	72.2	$2.35	$1.18
			TOTAL:	**$1.18**
DESIGN 3				
0.048" (18GA) Steel sheet	ft^2	0.76	$3.20	$2.43
80/20 1" x 1" AL square extrusion	ft	2.3	$3.00	$6.88
			TOTAL:	**$9.31**
DESIGN 4				
0.060" (16 GA) steel sheet	sq ft	2.0	$4.00	$8.00
			TOTAL:	**$8.00**

Ball Release / EML2322L-A-11

MANUFACTURING / ASSEMBLY PROCESS	Est. Time [min]	Quantity [-]	Subtotal [min]	[hr]
DESIGN 1				
Gather 80/20 Extrusion	10	1	10	0.2
Cut into two 10" pieces of 80/20	40	1	40	0.6
Screw together onto motor for assembly	10	1	10	0.2
TOTAL:			**60**	**1.0**
DESIGN 2				
Select sheet metal	10	1	10	0.2
Layer cut lines for cutting sheet metal	20	4	80	1.3
Cut parts to size on bandsaw	7	10	70	1.2
Mark lines to center holes for cutting and cut	5	10	50	0.8
Weld corners of mild steel for stability	15	4	60	1.0
Weld metal rods for bike chain on end plates	15	2	30	0.5
Mark lines to center holes on tube	3	4	12	0.2
Cut holes through both sides of the tube	5	4	20	0.3
Construct the grabber sub assembly	200	1	200	3.3
Mount grabber to bike chain	40	1	40	0.7
TOTAL:			**572**	**9.5**
DESIGN 3				
Manufacture motor mount	77	1	77	1.3
Manufacture ball stopper	40	1	40	0.7
Attach motor to motor mount	10	1	10	0.2
Attach motor mount to robot frame	5	1	5	0.1
Attach sheet metal piece to motor	5	1	5	0.1
TOTAL:			**137**	**2.3**
DESIGN 4				
Grab 3" PVC Pipe	5	1	5	0.1
Grab 90 degree elbow	5	1	5	0.1
Measure and cut PVC pipe	7	2	14	0.2
Drill 1/4" holes through PVC pipe	5	2	10	0.2

Connect the PVC pipe parts	10	2	20	0.3
Select sheet metal	10	1	10	0.2
Layer cut lines for cutting sheet metal	10	1	10	0.2
Cut parts to size on bandsaw	7	2	14	0.2
Punch holes in sheet metal	7	4	28	0.5
Connect release to hopper	5	1	5	0.1
TOTAL:			**121**	**2.0**

Ball Release Door Concept 3 / EML2322L-11A

MANUFACTURING PROCESS	TIME [min]
get 0.048" (18GA) steel sheet metal	5
layout cut and fold lines using full scale paper template	10
cut part to overall size using foot shear or bandsaw	7
center punch hole location using a hammer and punch	3
drill hole to correct shape for motor	7
time to debur part between steps	5
time to dispose of material scraps when finished	3
ESTIMATED MANUFACTURING TIME:	**40** **0.7**

Motor Mount Concept 3 / EML2322L-11A

MANUFACTURING PROCESS	TIME [min]
mark & cut 3/16" x 2" rectangular bar stock on bandsaw	10
load part(s) into milling machine vise	5
find X, Y zeros using edgefinder	10
drill clearance holes for motor mounting	20
drill clearance hole for motor shaft clearance	15
drill clearance holes for bracket mounting	5
time to debur part between steps	5
time to clean machine when finished	7

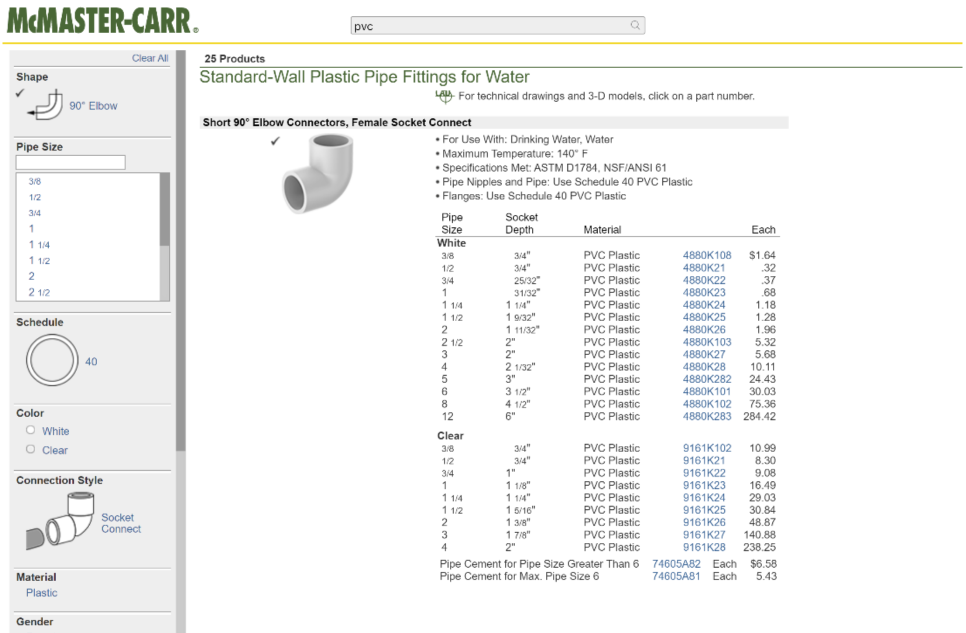
ESTIMATED MANUFACTURING TIME:	77 1.3

BALL RELEASE MATERIAL COST ESTIMATES

MATERIAL	Unit of Cost [-]	Quantity [-]	Unit Cost [$]	Total Cost [$]
DESIGN 1				
80/20 AL Square Extrusion	ft	1.7	$3.00	$5.01
			TOTAL:	**$5.01**
DESIGN 2 (Same as Ball Manipulator)				
1"x0.125" AL square tubing	ft	2.5	$1.00	$2.50
0.035" (20 GA) steel sheet	ft^2	1	$2.35	$2.35
35 Roller Chain 5 Feet With 2 Master And 1 Offset Links for Go Kart, Minibike	1	1	$13.45	$13.45
Grabber assembly budget	1	1	$15.42	$15.42
Low-Carbon Steel Rod, 1/2" Diameter	ft	2	$3.44	$0.58
			TOTAL:	**$34.30**
DESIGN 3				
0.5" x 2" AL rectangular bar stock	ft	0.2	$8.00	$1.68
3/16" x 3.5" AL rectangular bar stock	ft	2.6	$2.00	$5.25
			TOTAL:	**$6.93**
DESIGN 4				
3" Schedule 40 PVC pipe	ft	1.0	$3.00	$3.00
3" short 90 degree elbow connector	quantity	1	$5.68	$5.68
			TOTAL:	**$8.68**

CATALOG OF PARTS NOT FOUND ON MATERIAL PRICE LIST

Short 90-degree Elbow Connector (3” diameter with 2” socket depth)


McMASTER-CARR

pvc

Clear All

Shape

90° Elbow

Pipe Size

3/8
1/2
3/4
1
1 1/4
1 1/2
2
2 1/2

Schedule

40

Color

White

Clear

Connection Style

Socket Connect

Material

Plastic

Gender

25 Products

Standard-Wall Plastic Pipe Fittings for Water

For technical drawings and 3-D models, click on a part number.

Short 90° Elbow Connectors, Female Socket Connect

- For Use With: Drinking Water, Water
- Maximum Temperature: 140° F
- Specifications Met: ASTM D1784, NSF/ANSI 61
- Pipe Nipples and Pipe: Use Schedule 40 PVC Plastic
- Flanges: Use Schedule 40 PVC Plastic

Pipe Size	Socket Depth	Material		Each
White				
3/8	3/4"	PVC Plastic	4880K108	$1.64
1/2	3/4"	PVC Plastic	4880K21	.32
3/4	25/32"	PVC Plastic	4880K22	.37
1	31/32"	PVC Plastic	4880K23	.68
1 1/4	1 1/4"	PVC Plastic	4880K24	1.18
1 1/2	1 9/32"	PVC Plastic	4880K25	1.28
2	1 11/32"	PVC Plastic	4880K26	1.96
2 1/2	2"	PVC Plastic	4880K103	5.32
3	2"	PVC Plastic	4880K27	5.68
4	2 1/32"	PVC Plastic	4880K28	10.11
5	3"	PVC Plastic	4880K282	24.43
6	3 1/2"	PVC Plastic	4880K101	30.03
8	4 1/2"	PVC Plastic	4880K102	75.36
12	6"	PVC Plastic	4880K283	284.42
Clear				
3/8	3/4"	PVC Plastic	9161K102	10.99
1/2	3/4"	PVC Plastic	9161K21	8.30
3/4	1"	PVC Plastic	9161K22	9.08
1	1 1/8"	PVC Plastic	9161K23	16.49
1 1/4	1 1/4"	PVC Plastic	9161K24	29.03
1 1/2	1 5/16"	PVC Plastic	9161K25	30.84
2	1 3/8"	PVC Plastic	9161K26	48.87
3	1 7/8"	PVC Plastic	9161K27	140.88
4	2"	PVC Plastic	9161K28	238.25

Pipe Cement for Pipe Size Greater Than 6	74605A82	Each	$6.58
Pipe Cement for Max. Pipe Size 6	74605A81	Each	5.43

Link: https://www.mcmaster.com/pvc/standard-wall-plastic-pipe-fittings-for-water/shape~90-elbow/

Material Price List

Description	Price/ft
80/20 1"x1" AL square extrusion	$3.00
1"x0.125" AL square tubing	$1.00
0.125"x1" AL rectangular bar stock	$1.00
0.125"x2" AL rectangular bar stock	$2.00
0.5"x2" AL rectangular bar stock	$8.00
1"x2" AL rectangular bar stock	$16.00
1"x1"x0.125" AL angle	$3.00
1.5"x1.5"x0.125" AL angle	$4.50
2"x2"x0.125" AL angle	$6.00
1" AL round bar stock	$5.00
2" AL round bar stock	$20.00
1" Schedule 40 PVC (plastic) pipe	$1.00
2" Schedule 40 PVC (plastic) pipe	$2.00
3" Schedule 40 PVC (plastic) pipe	$3.00
4" Schedule 40 PVC (plastic) pipe	$4.00

Sheetmetal Price List

Description	Price/ft^2
0.035" (20 GA) steel sheet	$2.35
0.048" (18 GA) steel sheet	$3.20
0.060" (16 GA) steel sheet	$4.00
0.035" (20 GA) alum sheet	$3.20
0.048" (18 GA) alum sheet	$4.00
0.060" (16 GA) alum sheet	$5.00

<u>Model Testing Data</u>

Mobile Platform Speeds

Mobile Platform Speed was calculated using the Robot Speed Graph provided earlier in the semester. The graph shows specific engine RPM and drive wheel diameters and the corresponding approximate maximum speed for each combination. Using this, we calculated the maximum speed our robots could operate at. In the end, we were able to conclude that higher wheel diameters produced a higher linear speed and higher RPM motors also produce a higher linear speed. This can be seen in the Mobile Platform Speed table.

	Total
Design 1	3.0ft/s
Design 2	3.0 ft/s
Design 3	1.5 ft/s
Design 4	1.5 ft/s

Table of Mobile Platform Speeds for each design

Mobile Platform Controllability (according to *Speed vs. Controllability Comparison* video)

Mobile Platform Controllability was calculated using the EML2322L Robot Speed vs. Controllability video provided by the TA's. The video took trials of different engines operating the drive wheels of robots as they attempted to knock down 5 balls off a starting tree. The times recorded in the video were our calculated times for controllability. Based off the results of the video, Enstort motors have the most control, while Densos have the least control, which correlate with the results shown in the Mobile Platform Controllability table.

	Total
Design 1	48 sec
Design 2	48 sec
Design 3	26 sec
Design 4	26 sec

Table for controllability of Mobile Platform for each design

Mobile Platform Manufacturing Time

Mobile Platform Manufacturing Time was calculated taking estimates of duration spent machining as well as assembling parts of the mobile frame. We used the EML2322L Time Estimation for Parts to approximate the total time needed. These parts include the wheel hubs, motor mounts, and 80/20 frames which must all be machined in the lab.

	Total
Design 1	~18 hours
Design 2	~14 hours
Design 3	~15 hours
Design 4	~ 17 hours

Table of manufacturing times for each design

Mobile Platform Modularity

Mobile Platform Modularity was measured by the number of fasteners needed to break down the robot in a timely fashion. The design sketches from DR1 were reviewed to see how many fasteners would be required to hold the mobile platform and robot together. After looking over the sketches we would compare the number of fasteners, with the least number of fasteners resulting in the best modularity.

	Total
Design 1	24 fasteners
Design 2	28 fasteners
Design 3	25 fasteners
Design 4	22 fasteners

Table of modularity of each design

Mobile Platform Material Cost

Mobile Platform Cost was calculated using the Material Price List provided. Certain materials have a higher cost than others. We measured the length or area needed of a material for each mobile platform design. We took these measurements and multiplied them by the cost given for the basic units and added them together.

	Total
Design 1	$8.67
Design 2	$11.37
Design 3	$22.75
Design 4	$ 27.00

Table of material cost for each design

<u>Ball Manipulator Testing Data</u>

Ball Manipulator Controllability

Ball Manipulator Controllability was tested by using the representative models to see how long it would take to move the manipulators in place to pick up a ball. This test was repeated 10 times with the average being chosen for the time to compare. The measurements can be found in the table Ball Manipulator Controllability in *Appendix A*.

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Avg
Design 1	19s	19s	23s	17s	16s	21s	22s	17s	20s	19s	19.3s
Design 2	26s	26s	23s	25s	23s	25s	27s	25s	24s	26s	25s
Design 3	21s	17s	18s	15s	20s	19s	19s	17s	22s	16s	18.4s
Design 4	16s	17s	19s	17s	20s	19s	17s	18s	16s	18s	17.7s

Table of test results for controllability for each design

Design 1

Design 2

Design 3

Design 4

Ball Manipulator Speed

Ball Manipulator Speed was testing using the representative models to see how long it would take to move 5 balls from the tree to the hopper using the ball manipulators. This test was repeated 10 times with the average speed being compared between designs. The measurements can be found in then table Ball Manipulator Speed in *Appendix A*.

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Avg
Design 1	106s	100s	97s	108s	102s	99s	103s	103s	106s	99s	102.3s
Design 2	87	90	93	89	86	91	85	87	94	90	89.2s
Design 3	101s	95s	108s	110s	99s	100s	96s	103s	107s	96s	101.5s
Design 4	109s	106s	111s	109s	107s	105s	110s	112s	114s	108s	109.1s

Table of speed for each design

Design 1

Design 2

Design 3

Design 4 – Occurs five times for total speed

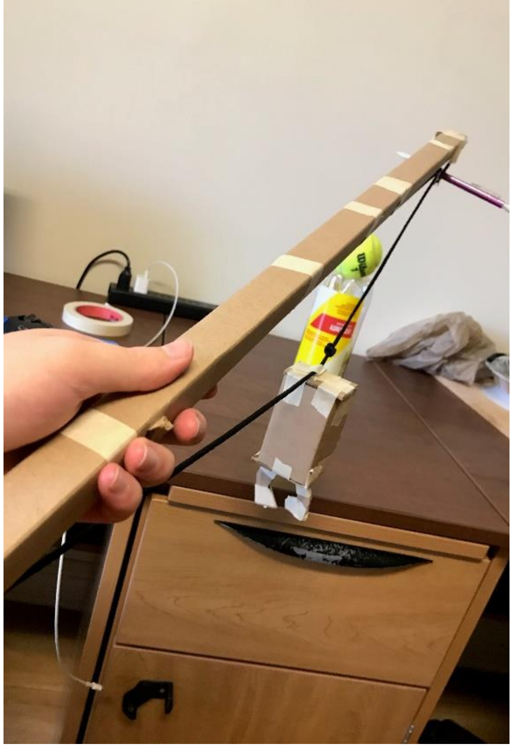
Ball Manipulator Security (Pass=1 Fail=0)

Ball Manipulator Security was tested using the representative models. The models were moved in a way similar to that during the actual course and at the closest speed the user could emulate. If the ball fell out of the desired position on the gripper during this time, that test received a 0 out of 1. Measurements can be found in *Appendix A*.

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Avg
Design 1	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	1
Design 2	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Fail	Pass	Pass	0.8
Design 3	Pass	Pass	Pass	Pass	Pass	Fail	Pass	Pass	Pass	Fail	0.8
Design 4	Pass	Pass	Pass	Pass	Pass	Pass	Fail	Pass	Pass	Pass	0.9

Table for security of each design

Design 1



Design 2

Design 3

Design 4 – Supported by walls

Ball Manipulator Manufacturing Time

Ball Manipulator Manufacturing Time was estimated using the EML2322L Time Estimation for Parts. One of the main estimates used from that data sheet was the example sheet metal part because many of the ball manipulators had sheet metal parts of various complexity. A breakdown of the time estimates for each design is listed under the table Ball Manipulator Manufacturing Time in *Appendix A*.

	Total
Design 1	1.5 hours
Design 2	4.3 hours*
Design 3	1.3 hours
Design 4	2 hours

Table of estimated manufacturing times for each design

*Design 2 uses this same assembly for the Ball release mechanism, so the manufacturing time is divided between the two.

Ball Manipulator Material Cost

Ball Manipulator Material Cost was calculated using the Material Price List provided. Areas or Volumes were calculated for each piece that had a material cost associated with it and that was then multiplied by the unit cost per length to find the price. Each price was then added up for a total as seen in *Appendix A*.

	Total
Design 1	$4.75
Design 2	$17.15
Design 3	$4.26

Design 4	$4.62

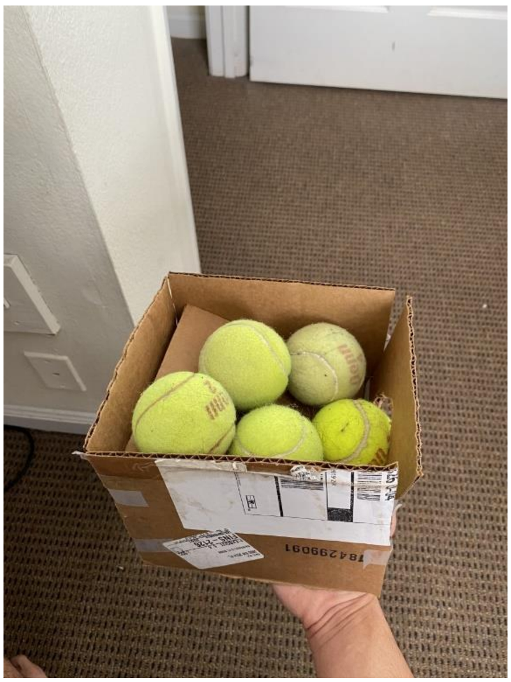
Table of material cost for each design

Ball Hopper Testing Data

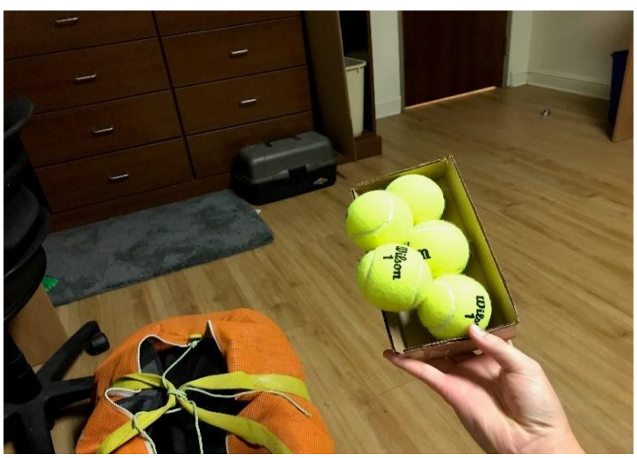
Ball Hopper Size

Ball Hopper Size was tested with the representative models. Each model was loaded with as many tennis balls as it could hold. The max number was recorded and put into a table to be compared with the other models.

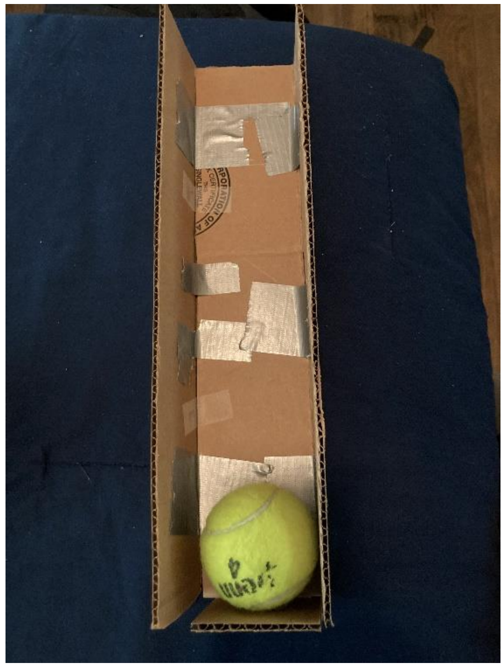
	Ball Capacity
Design 1	5 balls
Design 2	5 balls
Design 3	5 balls
Design 4	7 balls



Design 1



Design 2



Design 3 – Ball position was marked and move to calculate total.

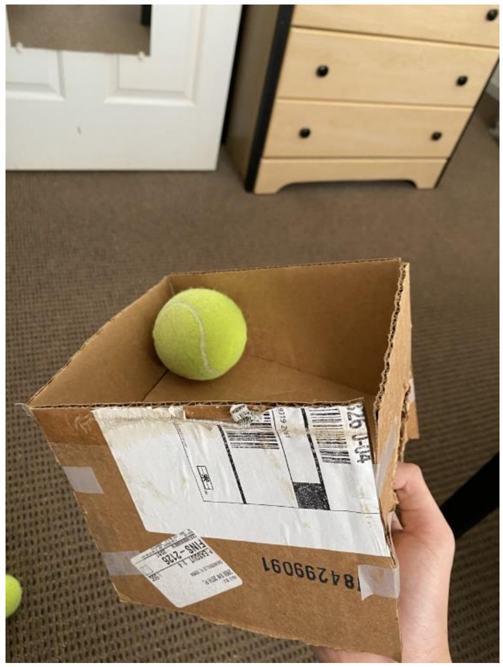
Design 4

Ball Hopper Stability (1 = All balls remained inside hopper 0 = any amount of balls fell out)

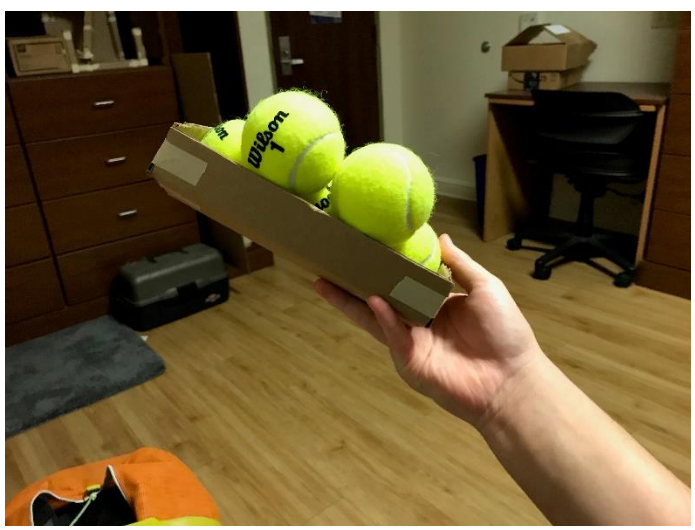
Ball Hopper Stability was measured by moving the representative models in the same way they would be moved during the course. This includes lateral movement, spinning, and tilting the hoppers. If a ball fell out of the ball hopper, it received a 0 on that trail. 10 trials were conducted for each model and the average was taken as the score.

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Avg

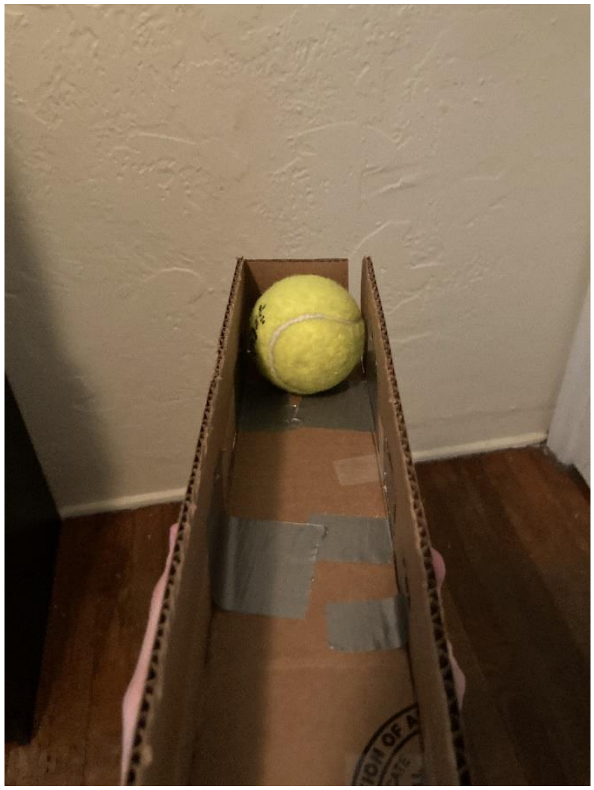
Design 1	1	1	0	1	1	1	0	1	1	1	0.8
Design 2	0	1	1	1	1	0	0	1	1	1	0.7
Design 3	1	1	1	1	1	1	0	1	0	0	0.7
Design 4	1	1	0	1	1	0	1	0	1	1	0.7



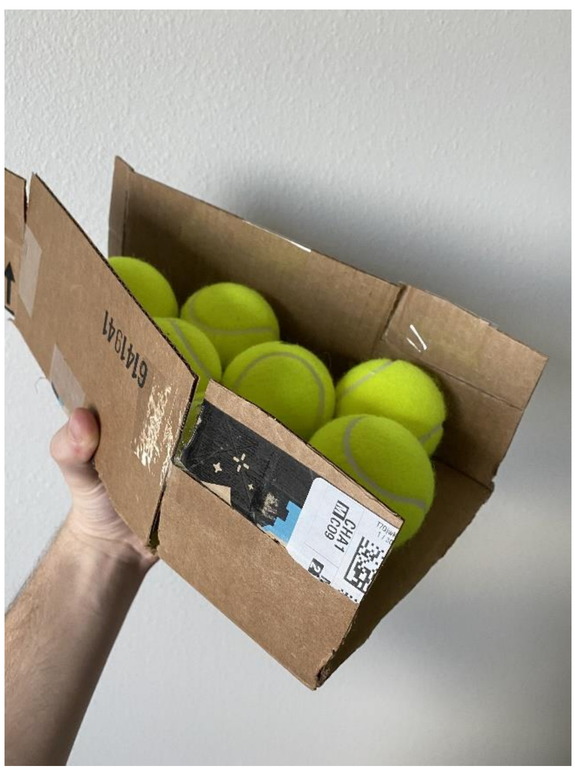
Design 1



Design 2



Design 3



Design 4

Ball Hopper Manufacturing Time

Ball Hopper Manufacturing Time was calculated using the *Time Estimation Guide* and the *Manufacturing Time Estimation Templates.* Each part added in the mechanism had its manufacturing time estimated and the overall assembly was calculated after. The total manufacturing and assembly time was recorded in the table for each design.

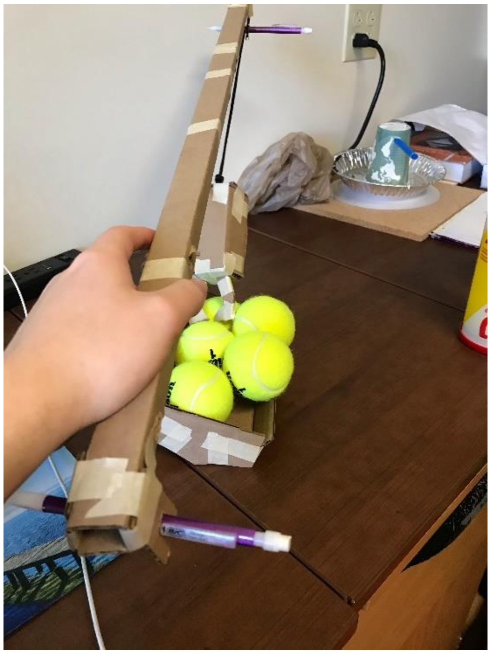
	Time
Design 1	3.2 hours
Design 2	3.0 hours
Design 3	1.4 hours
Design 4	3.5 hours

Ball Hopper Flow (1 = All balls exit the hopper 0 = any amount of balls got stuck)

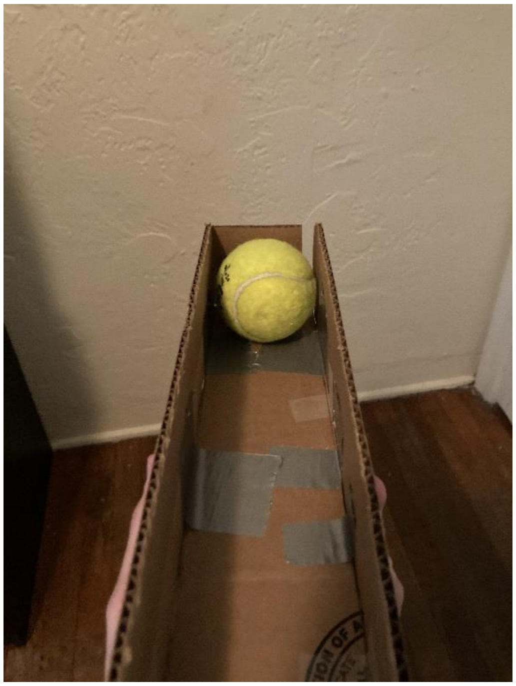
Ball Hopper Flow was calculated by adding and releasing tennis balls from the hopper and checking if they every got stuck or trapped. The release did not include the Ball Release mechanism just the exit space of the ball hopper. If any of the balls got stuck on entry or exit, that trail received a score of 0. If no balls got stuck that trail received a score of 1. The average of 10 trials was given as the score for each design.

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Avg
Design 1	1	1	0	0	1	0	1	0	0	1	0.5
Design 2	1	0	1	1	1	1	1	1	0	1	0.8
Design 3	1	1	0	1	0	1	1	0	1	1	0.7
Design 4	1	1	0	1	1	1	1	1	1	0	0.8

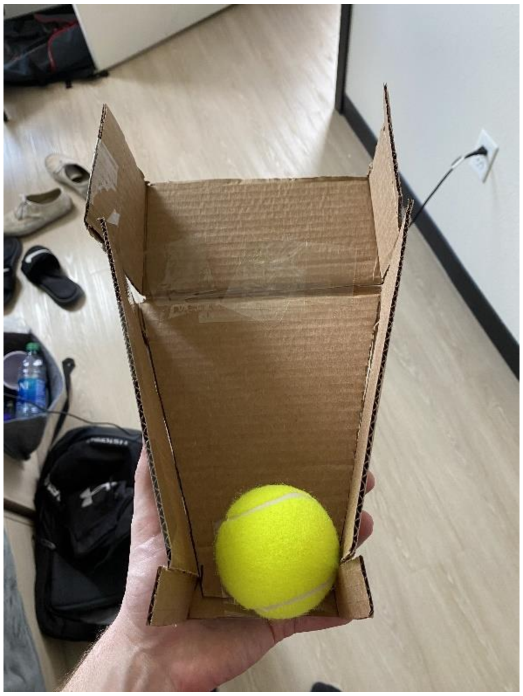
Design 1



Design 2



Design 3



Design 4

Ball Hopper Material Cost

Ball Hopper Material Cost was recorded by using the *Material Price List* in *Appendix A.* Each item that was not provided by the lab or any excess 80/20 extrusion above 6' that was used had its price per unit calculated and totaled. The total material cost for each designs ball hopper was recorded in the tables.

	Total
Design 1	$8.00
Design 2	$1.18
Design 3	$9.32
Design 4	$8.00

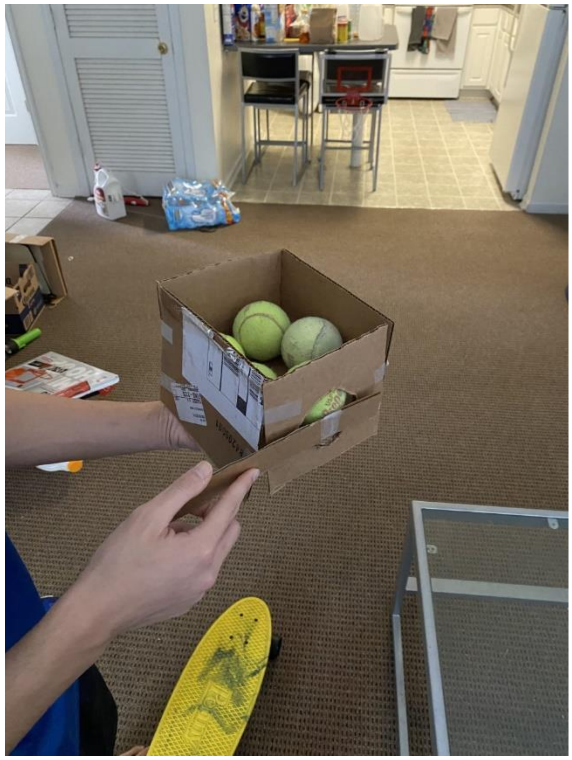
Ball Release Testing Data

Ball Release Speed

Ball Release Speed was tested using the representative models that were built. Five balls were placed in the release mechanism, and it was measured as too how long it would take for the balls to exit the release. Each design was tested 10 times with the average speed being compared to the rest. These measurements are found in the Ball Release Speed table in *Appendix A.*

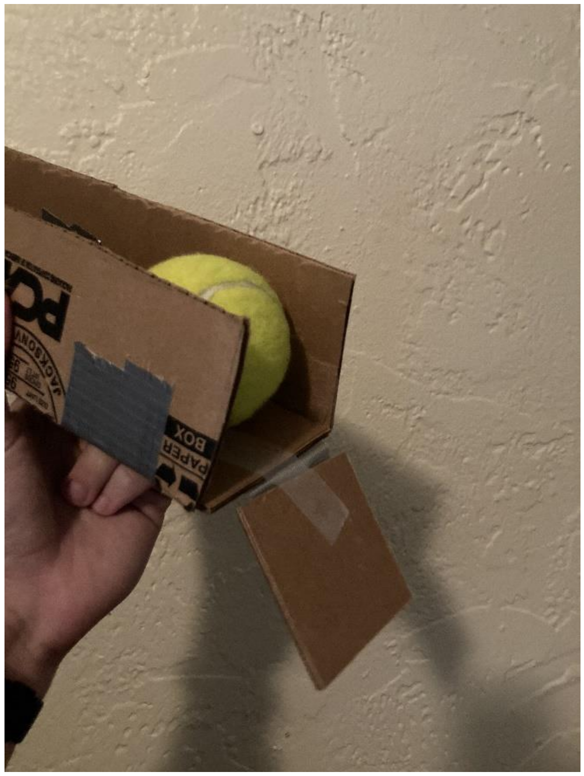
	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Avg
Design 1	9s	11s	10s	13s	18s	15s	9s	10s	19s	12s	12.6s
Design 2	60s	54s	55s	63s	62s	60s	58s	57s	59s	59s	58.7s
Design 3	13s	12s	13s	14s	12s	11s	12s	12s	13s	14s	12.6s

Design 4	15s	13s	13s	14s	17s	16s	14s	14s	16s	17s	14.9s



Design 1

Design 2



Design 3

Design 4 - Open to show multiple balls

Ball Release Efficiency

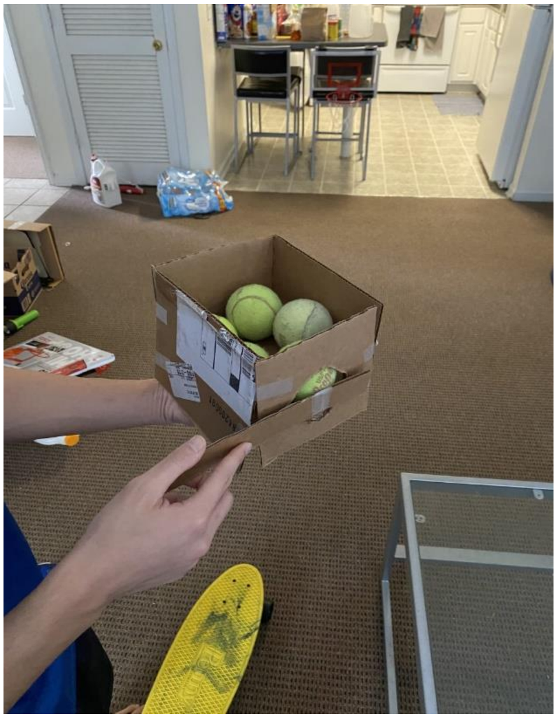
Ball Release Efficiency was estimated by determining the height at which the balls would be released. Since balls can be inflated differently and floor material impacts bounce, it was determined that the best way to test this category is height. Smaller height would mean a smaller bounce if each ball was dropped onto the same material. The height measurements can be found in the Ball Release Efficiency in *Appendix A*.

	Height
Design 1	8 inches
Design 2	8 inches
Design 3	8.5 inches
Design 4	13 inches

Ball Release Controllability

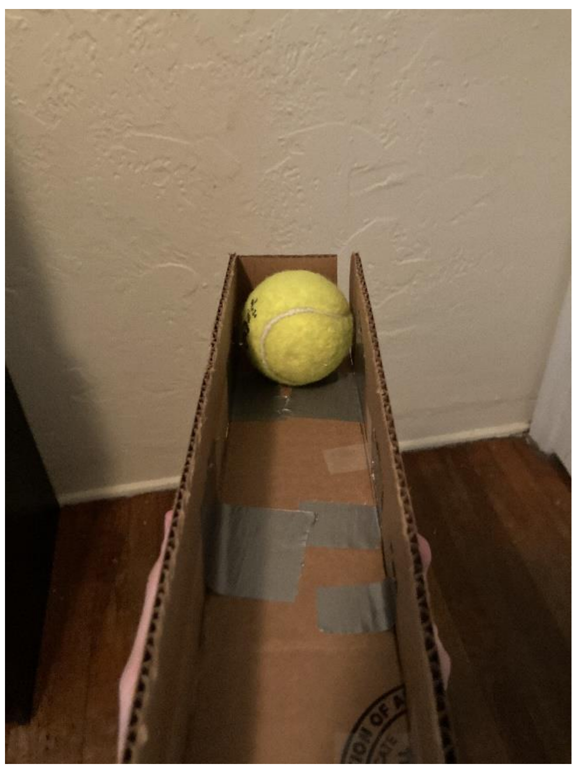
Ball Release Controllability was tested with the representative models created to see how long it would take to position the release in the proper spot after coming within a certain distance of the bucket. This process was repeated 10 times for each design and the average time is what was put into the decision matrix. The results of these trials can be found in the Ball Release Controllability table in *Appendix A*.

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Avg
Design 1	10s	7s	14s	12s	8s	9s	12s	10s	9s	9s	10s
Design 2	11s	13s	15s	14s	10s	12s	13s	14s	11s	12s	12.5s
Design 3	13s	12s	14s	14s	15s	13s	12s	12s	12s	13s	13s
Design 4	12s	14s	12s	11s	12s	13s	10s	12s	13s	12s	12.1s



Design 1

Design 2



Design 3

Design 4 – Bottom tape serves as sheet metal that blocks ball from falling

Ball Release Manufacturing Time

Ball Release Manufacturing Time was estimated using the EML2322L Time Estimation for Parts provided to us. These designs all used different materials and parts, so the estimations were made based off prior knowledge or careful thought. A breakdown of the time estimates for each design is listed under the table Ball Release Manufacturing Time in *Appendix A*.

	Time
Design 1	1 hour
Design 2	4.3 hours
Design 3	2.3 hours
Design 4	2 hours

Ball Release Material Cost

Ball Release Material Cost was calculated based off the Material Price List. We measured the length, area or diameter needed to perform the release and then measured this up to the price of the material needed. Each design piece price was added up and can be seen in the Ball Release Material Cost table in *Appendix A*.

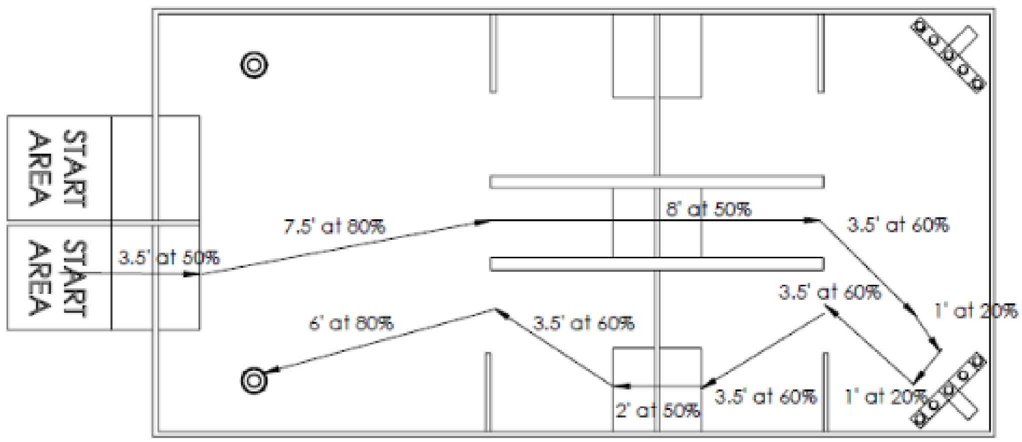
	Total
Design 1	$5.00
Design 2	$17.15
Design 3	$6.91
Design 4	$8.68

Appendix B: Robot Path Illustrations, Speed & Time Calculations

<u>Robot Path Illustrations</u>

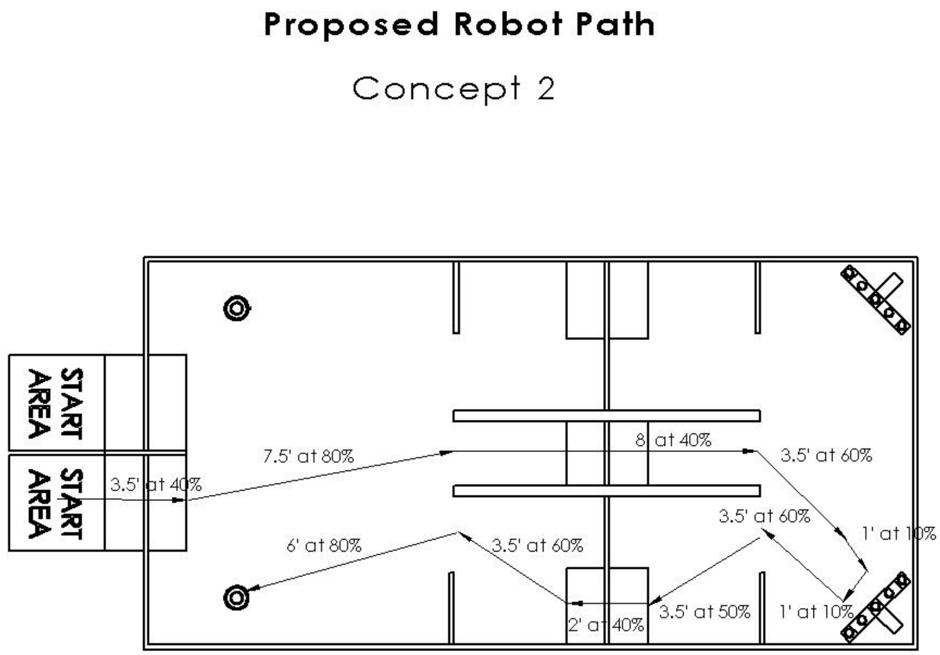
Proposed Robot Path

Concept Design 1



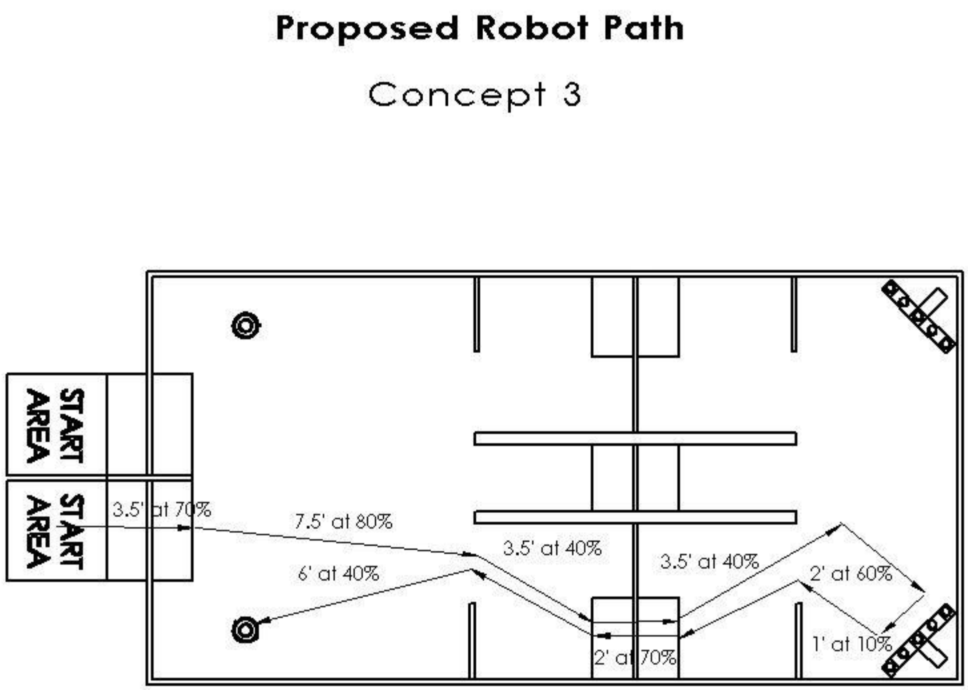
Robot Path for Concept 1

For Concept 1 Robot Path, the path is similar to the original template because the design one model is small enough to fit through the center ramp. The two sections where the robot is operating at 80% of max speed is because those sections are far from walls and do not require much maneuvering. The ramps are crossed at 50% of the robot's max speed to ensure that there are no problems going up and down the ramps. The sections at 60% require maneuvering around walls so it is slower than the 80% sections and the 20% sections are where the robot must position the manipulator over the source tree so it will be a lot slower than the robot's max speed.



Robot Path for Concept 2

The proposed robot path of Concept 2 is like the original template because it is small enough to barely fit through the center of the arena. Going over the ramps it needs to go slower because it needs to maintain traction on the angled wood ramps. For this reason, it moves at 40% of its max speed. For the long section right out of the starting area it can move much faster on the flat terrain and it moves at 80% of its max speed. Around the smaller sections between ramps of 3.5 feet it moves at 60% of its max speed. For the smallest sections it is more fine movements, so it moves at 10% of its max speed. Right after the second 3.5’ section of flat terrain it moves at 50% instead of 60% of its max speed because it needs to do more turning and will move a little slower, but should move close to the normal speed.

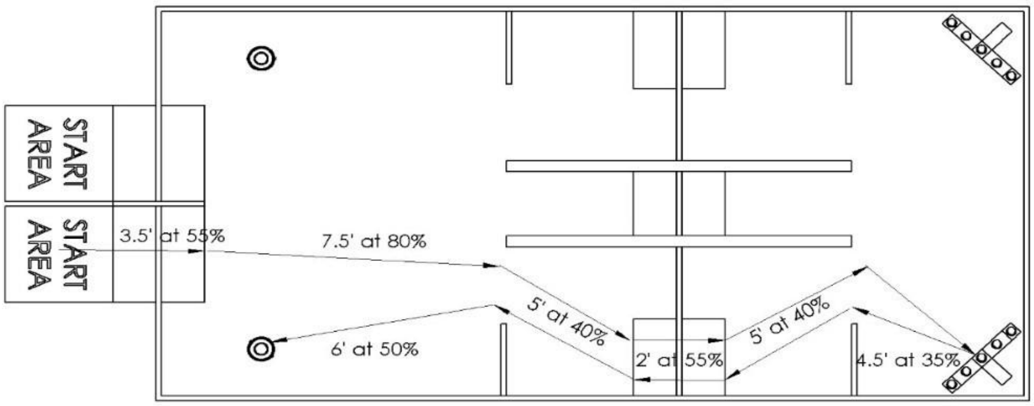


Robot Path for Concept 3

The proposed robot path of Concept 3 takes a different approach to the template provided. This is because the robot is too wide to fit through the middle section and must use the lower or upper ramps instead. The robot cannot go fast over the ramps which is why its speed is set to 70% over the two ramps. In longer straight lines the robot can travel faster which is why the initial and final straight sections are at 80% speed. Maneuvering through the bottom opening and over the ramp will take a certain amount of precision which will require the robot to travel at lower speeds, hence why the straight-line speed is 40% in that section. When making its way towards the ball tree it can travel at 60% speed since it is straight and medium distance. Once at the tree the motion needs to be very precise, so the speed will only be 10% of the max.

Proposed Robot Path

Concept 4



Robot Path for Concept 4

The proposed robot path for concept design differs from the original template provided. The width of this concept was too large for to maneuver through the middle ramp, causing it to travel through the side ramps there and back. The wooden ramps get a speed of 55% even though it is a straight line to prevent any bounces or mishaps that the incline may give. The section at the beginning of the course is 80% of max speed because it is flat, straight and far away from any walls or ramps. When maneuvering around the middle section of the course, I designated the robot to move at 40% the max to prevent any sharp turns or collisions with the walls. Near the tree, the robot must move slow to prevent the balls from falling to the ground, which is why the slowest speed percentage is given here. At the very end of the path, it is a straight line to the bucket, but the precision and carefulness needed around the bucket lowers the percentage to 50.

Speed & Time Calculations

The average robot velocity parameter measures what percentage the robot travels on average throughout the course. The distance is divided by the time, giving the average robot velocity. This value is then divided by the max velocity, which in turns gives the average velocity percentage.

Concept 1 Driving Parameters							
Concept 1 Vmax [ft/s]:	2.9	-					
	Portion or Segment of Robot Trajectory						Total
	1	**2**	**3**	**4**	**5**	**6**	
Percent of Max Velocity [%]:	100	70	50	25	10	0	-
Travel Distance [ft]:	12	5	2	3	2	0	24
Velocity [ft/s]:	2.9	2.0	1.5	0.7	0.3	0.0	-
Time [s]:	4.1	2.5	1.4	4.1	6.9	0.0	19.0
Average Robot Velocity [ft/s]:	-						1.3
Average Robot Velocity [%]:	-						43.5

Concept 2 Driving Parameters							
Concept 2 Vmax [ft/s]:	2.9	-					
	Portion or Segment of Robot Trajectory						Total
	1	**2**	**3**	**4**	**5**	**6**	
Percent of Max Velocity [%]:	80	60	50	40	10	0	-
Travel Distance [ft]:	13.5	10.5	3.5	13.5	2	0	43
Velocity [ft/s]:	2.3	1.7	1.5	1.2	0.3	0.0	-
Time [s]:	5.8	6.0	2.4	11.6	6.9	0.0	32.8
Average Robot Velocity [ft/s]:	-						1.3
Average Robot Velocity [%]:	-						45.2

Concept 3 Driving Parameters							
Concept 3 Vmax [ft/s]:	1.4	-					
	Portion or Segment of Robot Trajectory						Total
	1	**2**	**3**	**4**	**5**	**6**	
Percent of Max Velocity [%]:	80	70	60	40	10	0	-
Travel Distance [ft]:	13.5	7.5	4	14	2	0	41
Velocity [ft/s]:	1.1	1.0	0.8	0.6	0.1	0.0	-
Time [s]:	12.1	7.7	4.8	25.0	14.3	0.0	63.8
Average Robot Velocity [ft/s]:	-						0.6
Average Robot Velocity [%]:	-						45.9

Concept 4 Driving Parameters							
Concept 4 Vmax [ft/s]:	1.4	-					
	Portion or Segment of Robot Trajectory						Total
	1	**2**	**3**	**4**	**5**	**6**	
Percent of Max Velocity [%]:	80	55	50	40	35	0	-
Travel Distance [ft]:	7.5	7.5	6	20	9	0	50
Velocity [ft/s]:	1.1	0.8	0.7	0.6	0.5	0.0	-
Time [s]:	6.7	9.7	8.6	35.7	18.4	0.0	79.1
Average Robot Velocity [ft/s]:	-						0.6
Average Robot Velocity [%]:	-						45.2

Tables for each concept's driving parameters

Concept - -	Motor Description - -	Nominal Speed [rpm]	Wheel Diameter [in]	Distance Traveled [ft]	Average Robot Velocity [%]	Driving Time - [sec]	 [min]
Concept 1	Denso Gearmotor	150.0	6.0	24	44	19	0.3
Concept 2	Denso Gearmotor	150.0	6.0	43	45	32	0.5
Concept 3	Entstort Gearmotor	44.0	10.0	41	46	62	1.0
Concept 4	Entstort Gearmotor	44.0	10.0	50	45	77	1.3

Table for Driving Times for each design

Source Bucket Manuevering Time [sec]	Source Bucket Dispensing Time [sec]	Target Bucket Manuevering Time [sec]	Ball Release Time [sec]	Miscellaneous Time [sec]	Est. Competition Time [sec]	 [min]
10	102.3	10	7	30	178	3.0
15	89.2	12.5	60	30	239	4.0
10	101.5	13	12.6	30	229	3.8
15	109.3	12.1	14.9	30	258	4.3

Table for Speed Calculations for each design

Source Tree Maneuvering Time- Estimate of how long it takes to set the robot into position for ball manipulator to pick up balls on source tree.

Source Tree Gathering Time- Estimate of how long it takes to gather 5 balls on the source tree and move them to the hopper on the robot.

Target Bucket Maneuvering Time- Estimate of time to move robot into position over the target bucket.

Ball Release Time- Estimate of time for release mechanism to open and drop all 5 balls into target bucket. We have not tested this yet, so our completion time will be more accurate in the next report.

Miscellaneous Time- Estimate of extra time spent maneuvering the course. Same for each design to account for user mistakes in maneuvering or other time needed.

Appendix C: Wheel and Lifting Motor Torque Calculations

Drive Wheel Motor Torque Calculations

Concept 3 Mobile Platform Drive Wheel Parameters

Gross vehicle weight (W_{GV}, lb)	35 lb
Weight on each drive wheel (W_W, lb)	12 lb
Radius of wheel/tire (R_w, in)	10 in
Desired top speed (V_{max}, ft/sec)	1.5 ft/sec
Desired acceleration time (t_a, sec)	1.5 sec
Maximum incline angle (α, deg)	16.3
Worst surface friction coeff. (C_{sf}, -)	.01
Static friction coeff. (μ_s, -)	0.6

To choose motors capable of producing enough torque to propel the example vehicle, it is necessary to determine the total tractive effort (TTE) requirement for the vehicle:

TTE [lb] = RR [lb] + GR [lb] + F_a [lb]

where:
TTE = total tractive effort [lb]
RR = force necessary to overcome rolling resistance [lb]
GR = force required to climb a grade [lb]
F_a = force required to accelerate to final velocity [lb]

The components of this equation will be determined in the following steps.

Step One: Determine Rolling Resistance

Rolling Resistance (RR) is the force necessary to propel a vehicle over a particular surface. The worst possible surface type to be encountered by the vehicle should be factored into the equation.

RR [lb] = W_{GV} [lb] × C_{sf} [-] = 35 lb × 0.01 = **.35 lbs**

where:
RR = rolling resistance [lb]
W_{GV} = gross vehicle weight [lb]
C_{sf} = surface friction coefficient [-] (value obtained from Table 1 in *EML2322L Drive Wheel Motor Torque Calculations* document)

Step Two: Determine Grade Resistance

Grade Resistance (GR) is the amount of force necessary to move a vehicle up a slope or grade. This calculation must be made using the maximum grade the vehicle must climb in normal operation.

To convert incline angle, α, to grade resistance:

GR [lb] = W_{GV} [lb] × sin(α) = 35 lb × sin(16.3°) = ***9.82 lbs***

where:
GR = grade resistance [lb]
W_{GV} = gross vehicle weight [lb]
α = maximum incline angle [degrees]

Step Three: Determine Acceleration Force

Acceleration Force (F_a) is the force necessary to accelerate from a stop to maximum speed in a desired time.

F_a [lb] = W_{GV} [lb] × V_{max} [ft/s] / (32.2 [ft/s^2] × t_a [s]) = 35 lb × 1.5 ft/s / (32.2 ft/s^2 x 1.5 s) = ***1.09 lbs***

where:
F_a = acceleration force [lb]
W_{GV} = gross vehicle weight [lb]
V_{max} = maximum speed [ft/s]
t_a = time required to achieve maximum speed [s]

Step Four: Determine Total Tractive Effort

The Total Tractive Effort (TTE) is the sum of the forces calculated in steps 1, 2, and 3. (On higher speed vehicles friction in drive components may warrant the addition of 10%-15% to the total tractive effort to ensure acceptable vehicle performance.)

TTE [lb] = RR [lb] + GR [lb] + F_a [lb] = 0.35 lb + 9.82 lb + 1.09 lb = ***11.26 lbs***

Step Five: Determine Wheel Motor Torque

To verify the vehicle will perform as designed in regards to tractive effort and acceleration, it is necessary to calculate the required wheel torque (T_w) based on the tractive effort.

T_w [lb-in] = TTE [lb] × R_w [in] × RF [-] = 11.26 lb × 10 in × 1.1 = ***123.86 lb-in***

where:
T_w = wheel torque [lb-in]
TTE = total tractive effort [lb]
R_w = radius of the wheel/tire [in]
RF = resistance factor [-]

The resistance factor accounts for the frictional losses between the caster wheels and their axles and the drag on the motor bearings. Typical values range between 1.1 and 1.15 (or 10 to 15%).

Step Six: Reality Check

The final step is to verify the vehicle can transmit the required torque from the drive wheel(s) to the ground. The maximum tractive torque (MTT) a wheel can transmit is equal to the normal load times the friction coefficient between the wheel and the ground times the radius of the drive wheel.

MTT = W_w [lb] × μ_s [-]× R_w [in] = 12 lb × 0.6 × 10 in = ***72 lb-in***

where:
W_w = weight (normal load) on drive wheel [lb]
μ_s = friction coefficient between the wheel and the ground (~0.4 for plastic on dry wood) [-]
R_w = radius of drive wheel/tire [in]

Interpreting Results

Total Tractive Effort is the net horizontal force applied by the drive wheels to the ground. If the design has two drive wheels, the force applied per drive wheel (for straight travel) is half of the calculated TTE.

The Wheel Torque calculated in Step Five is the total wheel torque. This quantity does not change with the number of drive wheels. The sum of the individual drive motor torques must be greater than or equal to the computed required Wheel Torque.

The Maximum Tractive Torque represents the maximum amount of torque that can be applied before slipping occurs for each drive wheel. ***The total wheel torque calculated in Step Five must be less than the sum of the Maximum Tractive Torques for all drive wheels or slipping will occur.***

Parameter	**Concept 3**
Gross Vehicle Weight (W_{GV}, lb)	35
Weight on each Drive Wheel (W_W, lb)	12
Radius of Wheel/Tire (R_w, in):	10
Desired Top Speed (V_{max}, ft/sec):	1.5
Desired Acceleration Time (t_a, sec):	1.5
Maximum Incline Angle (α, deg):	16.3
(Worst) Surface Friction Coeff. (C_{sf}, -):	0.01
(Worst) Static Friction Coeff. (μ_s, -):	0.6
Rolling Resistance (RR, -):	0.35
Grade Resistance (GR, -):	9.82
Acceleration Force (F_a, lb):	1.09
Total Tractive Effort (TTE, lb):	11.26
Resistance Factor (RF, -):	1.1
Wheel Motor Torque (T_w, lb-in):	123.86
Maximum Tractive Torque (MTT, lb-in):	72

The total tractive effort for this design is 11.26 lbs divided into 2 drive wheels, giving each wheel a TTE of 5.63 lbs.

The total wheel torque is 123.86 lb-in divided into 2 drive wheels, giving each wheel a torque of 61.93 lb-in. Each of the 44 RPM Entstort motors gives 120 lb-in of torque. This is more than enough of the required torque for each wheel.

The maximum tractive torque is 72 lb-in which gives a total for 2 drive wheels of 144 lb-in. The total wheel torque (123.86 lb-in) is less than the total maximum tractive torque (144 lb-in) so the wheels will not slip.

Lifting Motor Torque Calculations

Step One: Determine Component Weights

Weight can always be determined from a material's density and volume, but for components with complex cross-sectional areas (such as 80/20), using the material's linear mass density (i.e. weight per unit length) can simplify the calculation.

For 80/20 arm = 0.8lbs
For Linear Actuator = 4.5lbs
For PVC ring = 0.11lbs
For Steel Sheet = 0.3lbs
Total = 5.71lbs

Step Two: Calculate Center of Mass

The center of mass and centroid of an object are similar but the center of mass applies when you have components of different materials. Use symmetry to find individual centroids, Xc, but remember the distances should be measured from the rotating axis.

$Xcom[in] = \sum(Xc[in] \times W[lb]) \sum(W[lb])$

$Xcom = ((4.48*0.8) + (3.2*4.5) + (14.25*0.11) + (9.6*0.3)) / 5.71 = 3.93$ in

Where:
Xcom = center of mass in x-direction [in]
Xc = centroid of each component [in]
W = weight of each component [lb]
Center of rotation is 1.395in from start of bar same as center of globe motor.

Step Three: Calculate Gate / Lifting Arm Torque

$Tgate/arm [lb\text{-}in] = Xcom [in] \times Wtotal [lb]$

Where: Tgate/arm = required torque to operate gate/arm [lb-in]
Xcom = center of mass in x-direction [in]
Wtotal = total weight [lb]

This problem:
$Tgate/arm = 3.93 \text{ in} \times (5.71) = 22.44$ lb.-in

Step Four: Calculate Required Motor Torque

The final step is to verify the selected motor can produce the required torque. To account for the acceleration of the moving components and typical manufacturing and assembly tolerances in brushedtype electric motors, use an efficiency factor of approximately 60%.

$TM, REQ'D = Tgate/arm [lb\text{-}in] / \eta$
where:
TM, REQ'D [lb-in] = required motor torque [lb-in]
Tgate/arm [lb-in] = required gate/arm torque [lb-in]
η [%] = efficiency factor ≈ 60%

This problem
TM, REQ’D = 22.44 lb-in / 0.60 = 37.4 lb-in

Interpreting Results

This design requires a motor that can produce 37.4 lb-in of torque. The motor choice used for the design is the 4.5 RPM globe gear motor that can produce 125 lb-in of torque, so the design does not need to be redesigned.

Parameter	Concept 1
Weight of 80/20 arm	0.8 lb.
Weight of Linear Actuator	4.5 lb.
Weight of PVC ring	0.11 lb.
Weight of Steel Sheet	0.3 lb.
Weight total	5.71 lb.
Xc 80/20 arm	4.48 in
Xc Linear Actuator	3.2 in
Xc PVC ring	14.25 in
Xc Steel Sheet	9.6 in
Xc rotation	0 in
Xcom	3.93 in
Tgate/arm	22.44 lb.-in
TM, REQ’D	37.4 lb.-in
Torque of globe motor	125 lb.-in