ME 250 Fall 2019
Design and Manufacturing I

Final Report: Team 71 “The UnicHorn”

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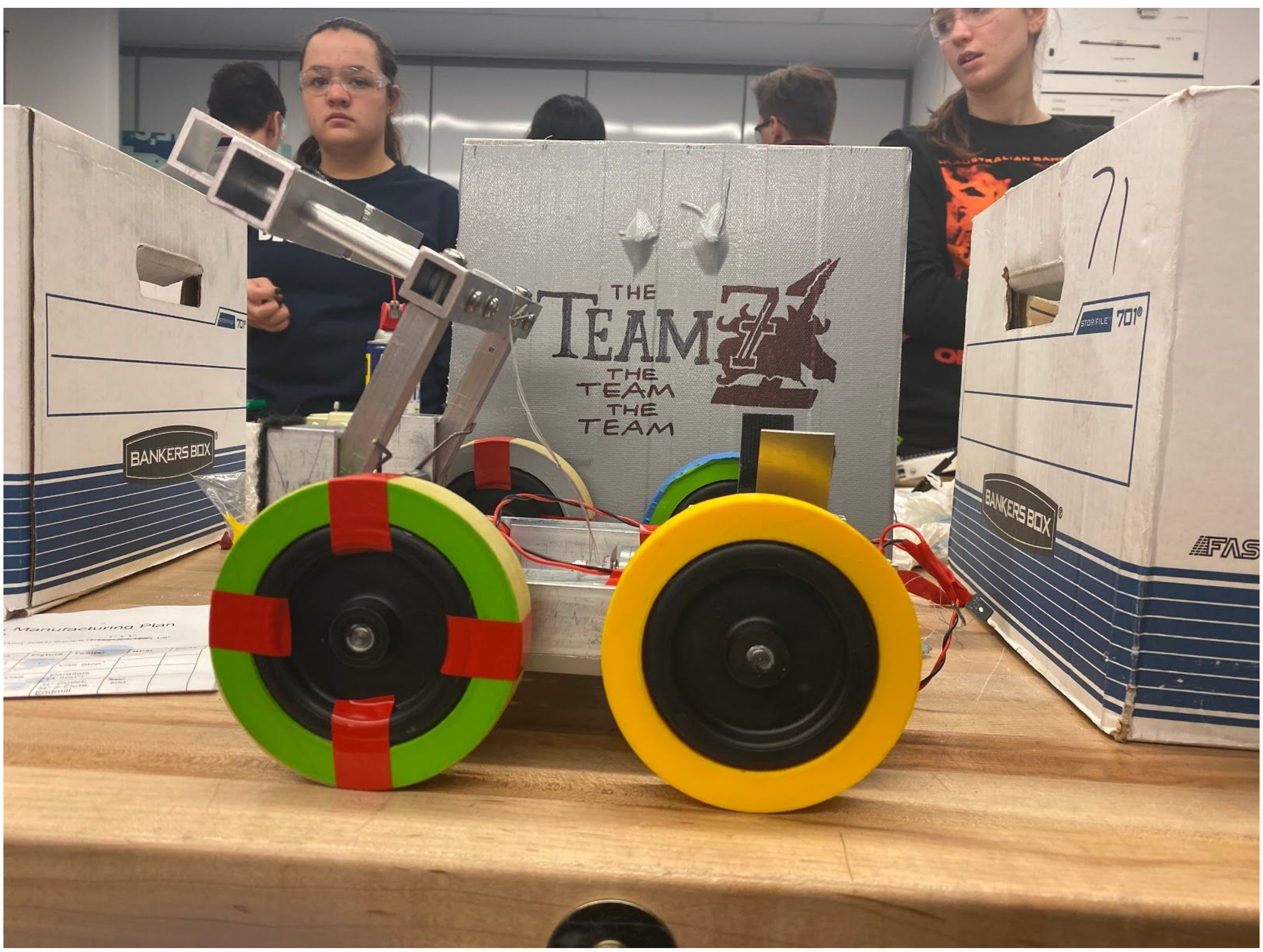
David Wells



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1. INTRODUCTION (1 POINT)

This project pertains to the final two parts of the learning objectives that are: communicate design and analysis, and work professionally in a team. For this report we are working as a team to communicate our design, such as the reason as to why we used three motors. Also, we had to work professionally as a team so as to improve our communication skills in the workplace. Game of zones is a test of our RMP, and we are writing this project to analyze that test.

2. RMP DESIGN (37 POINTS)

2.1. Strategy and RMP Strategy (2 points)

RMP 1 (our team's RMP) started in zone 3 and was required to cross the gravel field 2, knock down the drawbridge, return across the gravel field to the maze, travel the maze, and push the heavy block out of the way. RMP 2 set out from zone 2 with the goal of retrieving the 6 corner cubes, traversing the seesaw, pyramid, and drawbridge, and delivering the corner cubes to the high goal. Then, RMP 2 would return across the drawbridge to zone 1 and wait for RMP 4. RMP 3 started in zone 1, with the objective of collecting the replenishing yellow cubes, crossing the pyramid and drawbridge, and depositing them in the high goal. RMP 4 started in zone 2 with the purpose of dislodging the red cubes from the tower, collecting them, and depositing them over the wall between zones 1 and 2 for RMP 2 to collect. RMP 2 would then cross the drawbridge and score these blocks in the high goal.

RMP 1's tasks were chosen because they seemed to have similar requirements in terms of design (robust frame, high torque drivetrain, maneuverability and ability to cross obstacles). The order of execution was chosen so that RMP 1 could clear a pathway to the high goal as quickly as possible.

2.2. Functional Requirements (7 points)

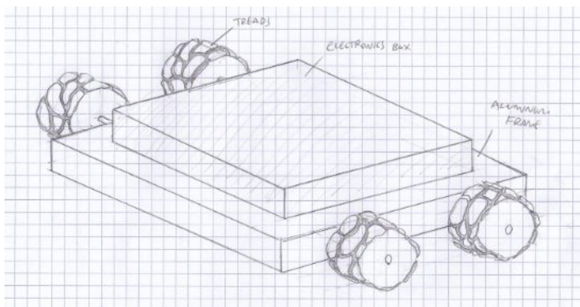
A safety factor of 1.5 for time has been applied. RMP 1's final functional requirements were to:

- <u>Cross gravel field 2 in no more than 45 seconds</u> : We chose to put a very small limit on time for crossing gravel field 2 of 45 seconds because other teams in our squad were dependant on the success of our team lowering the drawbridge in a short amount of time. Since the gravel field is a barrier between our RMP and the drawbridge, we needed to cross it quickly.
- <u>Lower the drawbridge in zone 4 in no more than 52.5 seconds:</u> We put a fairly large time constraint on lowering the drawbridge because we knew it was one of the most integral components of our squad strategy (RMPs 3 and 4) scoring heavy blocks in the high goal) and we needed the lowering to be flawless.
- <u>Displace the heavy block by 10" in no more than 60 seconds:</u> We put the largest time constraint on displacing the heavy block because we knew that it would take many impacts to result in any substantial movement from the heavy block.

2.3. Design Concepts and Subsystems (10 points)

Our team went through many design concepts, all with the purpose of achieving our RMP's specific tasks. We were able to narrow down our options to three design concepts.

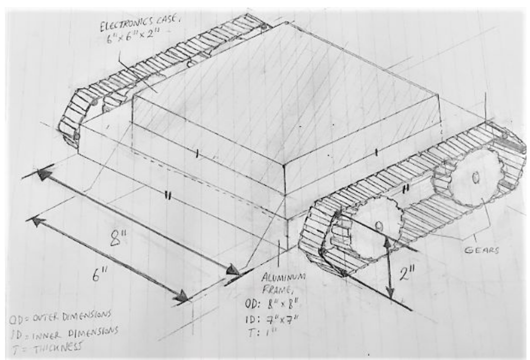
The General Design Concept:



Our first design concept was the general design concept. This design utilized a four-wheel drive with a sturdy frame and treading on each wheel to provide friction for traversing gravel field 2 and pushing the heavy block. This design also incorporated 4 motors for massive torque to lower the drawbridge.

Figure 1: sketch of RMP 1's general design concept

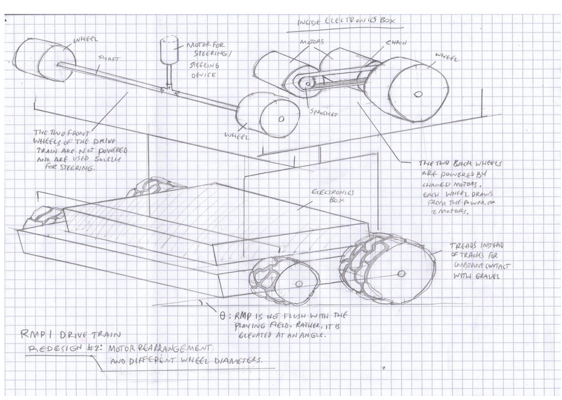
Design Concept #1:



Our second design concept (design concept #1) was very similar to the general design concept but with more focus on the task of traversing gravel field 2. This design utilizes treads for increased surface area contact between the playing field and the RMP. This design still utilizes 4 motors to provide enough torque to lower the drawbridge and push the heavy block.

Figure 2: sketch of design concept #1 for RMP 1

Design Concept #2:



Our third design was one that utilized a rear-wheel drive and a motor for steering of the two front wheels of the RMP. This design also had smaller diameter wheels in the front of the RMP compared to the back for improved steering. The improved steering paired with the rear-driven wheels was justified to make navigating the maze and pushing the heavy block manageable. These same qualities made lowering the drawbridge and traversing gravel field 2 less efficient but still manageable.

Figure 3: sketch of design concept #2 for RMP 1

Using a pugh chart, we were able to pit the qualities of each of our design concepts against one another and move forward with a design to build off of. Our chart and our reasoning for values allocated are both below:

Functional Requirement	Weight	General D.C.	D.C. 1	D.C.2
Traveling gravel field 2	3	0	1	-1
Lowering the drawbridge	3	1	0	1
Pushing the heavy block	1	0	-1	-1
Manufacturability	2	1	-1	0
Creativity	1	0	1	1
Reasoning				
Traveling gravel field 2		Less grip than D.C. 1	Tracks w/ Grip	Smaller Front wheels
Lowering the drawbridge		high-speed impact	Slower (Tracks)	high-speed impact
Pushing the heavy block		neutral	More weight	More weight
Manufacturability		Same wheel diam.	complex tracks	differing wheel diam.
Creativity		neutral	Tracks	Race Car
Totals		5	1	0
*D.C. = Design Concept				

Figure 4: pugh chart comparing design aspects of each design concept

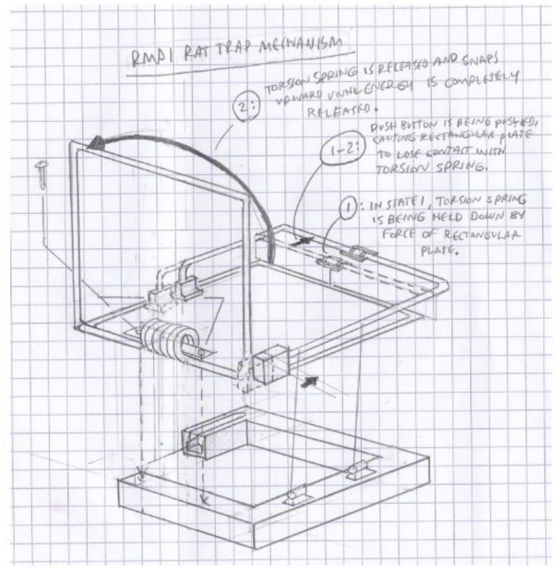


Figure 5: sketch of rat trap mechanism.

As a result of the pugh chart analysis, the general design concept was the design that our team moved forward with for RMP 1. This is due to the neutrality of the design: it was a blank slate for more mechanisms to be built on top of to achieve RMP 1's functional requirements, one of such being our rat trap mechanism showcased in figure 5.

After doing more performance testing, our RMP design was altered to repurpose the rat trap mechanism to be reloadable for precision positioning of the rat trap's contact bar and a ramp was added to the RMP to be deployed on gravel field 2, ultimately assisting in two of RMP 1's functional requirements. The CAD for our new RMP can be found in section 2.5.

2.4. Analysis (14 points)

List the critical decision variables for your RMP, and what analysis you performed to determine the optimal value for each. Justify your choice of critical decision variables, and choice of analysis. The critical decision variables for RMP 1 were:

The height of the rat trap mechanism when fully relaxed: We chose to analyze the maximum height that comes from the rat trap being fully relaxed because we need to know at what height along the drawbridge's surface would be best to impart a force on to lower it. we chose to do a **first principle model** to find this optimal height region because at the time our rat trap was not fully operable.

$$F1 : (c.c.w.\ +)\ \Sigma Mo = 0 : \ -mgL(\tfrac{3}{4}) + F1 sin\theta h + F1 cos\theta(\tfrac{h}{tan\theta}) = 0;\ F1 = \frac{(mgL(\frac{3}{4}))}{h(sin\theta + \frac{cos^2\theta}{sin\theta})}$$

$$F2:(c.c.w.\ +)\,\Sigma Mo = 0:\ -mgL(\tfrac{3}{4}) - F2h = 0;\ F2 = \frac{-mgL(\frac{3}{4})}{h}$$

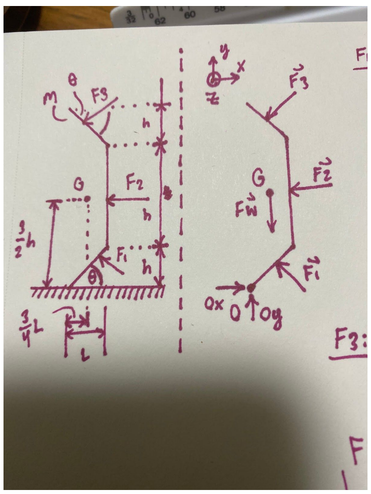
$$F3:(c.c.w.+)\,\Sigma Mo = 0:\ F3sin\theta h - F3cos\theta(h-0.2)sin(90-\theta) - mgL(\tfrac{3}{4}) = 0;\ F3 = \frac{mg\frac{3}{4}L}{sin\theta[h - sin\theta(h-0.2)]}$$

$$*\,m = 2.25\,kg,\ g = 9.81\,\tfrac{m}{s^2},\ L = 0.1m,\ \theta = 45^{O} >> A = mgL(\tfrac{3}{4})$$

$$|F1| = \tfrac{A}{h}\left(\frac{1}{sin\theta + \frac{cos^2\theta}{sin\theta}}\right) >> F1 = (\tfrac{\sqrt{2}}{2}A)(\tfrac{1}{h})\ \{0 \le h \le 0.1\}$$

$$|F2| = \tfrac{A}{h}\{0.1 \le h \le 0.2\}$$

$$|F3| = \tfrac{A}{sin\theta}\left(\frac{1}{h - sin\theta(h-0.2)}\right) >> F1 = (\tfrac{2}{\sqrt{2}}A)\left(\frac{1}{h - \frac{\sqrt{2}}{2}(h-0.2)}\right)\ \{0.2 \le h \le 0.3\}$$



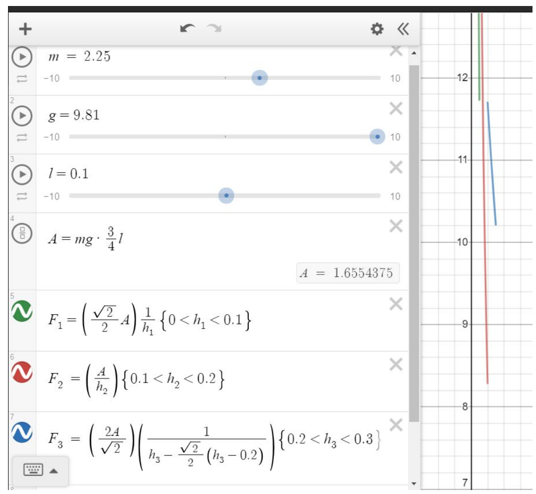
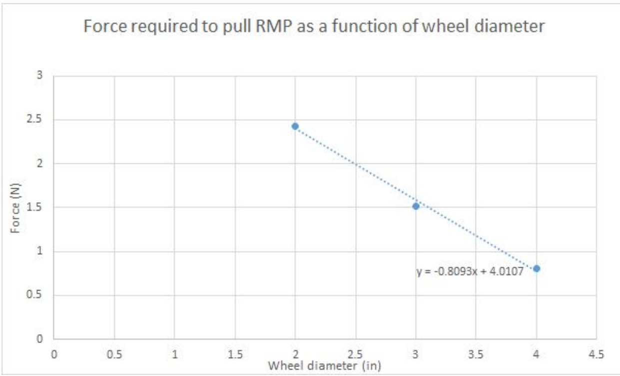


Figure 6: FBD of drawbridge. Figure 7: equations and graphs derived from free-body diagram analysis.

We made an approximate free body diagram and derived calculations based on the placement of forces in this static model. As a result of our calculations, we found that attacking the drawbridge in the region where the impact force would be horizontal would take the least amount of force. This can be interpreted as the red curve in figure 7 having the lowest possible value for force under the assumed constant values.

The overall diameter of the RMPs wheels: we empirically tested the effect of wheel diameter on the amount of force necessary to scale the lip to access Zone 4. We chose an empirical test because as a result of our first principle model, we found that there were too many variables to gain any tangible data to persuade our decision variables. The results from this experiment showed that as the diameter of the wheel increased, the required force decreased.



Diameter(in)	Weight(N)			
	Trial			
	1	2	3	Average
2	2.551	2.403	2.305	2.420
3	1.815	1.717	1.030	1.521
4	0.589	1.030	0.785	0.801
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Figure 9 (above): data points for figure 8

Figure 8 (left): graph showing the effect of wheel diameter on the force required to pull RMP over lip to Zone 4

<u>The type of traction material on our 3D printed wheel extenders:</u> We tested multiple traction materials through performance testing mockup to understand which would result in the best traction. This testing method was chosen because we had good engineering intuition as to what would happen in service of the RMP and it would be a quick test to run. In these tests, we essentially swapped out the traction material on our wheels and drove around our RMP to get a visual and physical feel for how the RMP operated given the differing materials. The best material combination turned out to be masking tape and rubber bands.

<u>The type of infill pattern for our 3D printed wheel extenders:</u> We performed a first principle model to understand how much mass we should dedicate to our 3D printed wheel extenders for the purpose of friction. Our first principal analysis was hard to interpret, so we ended up relying on empirical results from our 3D printing assignment and our wheel diameter test (shown a bit below) to sway our decision on settings for our 3D printed wheel extenders. 95% infill and triangle infill pattern were best for this application because the geometry would be load-bearing and the infill would make for a sturdy structure. The first principal model for mass calculations of the 3D printed wheel extenders can be found below:

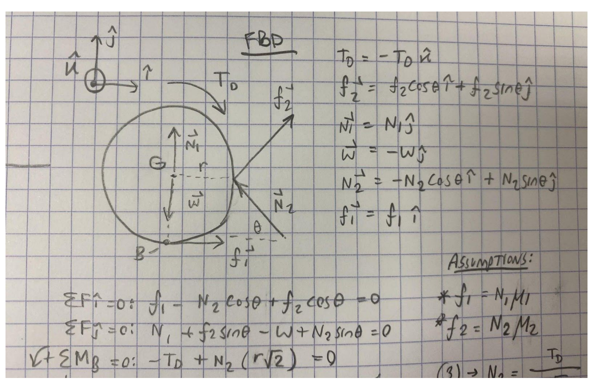


Figure 10: FBD for wheel when in contact with lip in zone 4

$(c.c.w.\ +)\ \Sigma Mo = 0:\ -T + N2(r\sqrt{2}) = 0;\ N2 = \frac{T}{r\sqrt{2}}$

$\Sigma Fi = 0:\ f1 - N2cos\theta + f2cos\theta = 0;\ N1\mu1 + N2cos\theta(\mu2 - 1) = 0;\ N1 = -(\frac{T}{r\sqrt{2}})\frac{cos\theta(\mu2-1)}{\mu1}$

$\Sigma Fj = 0:\ N1 + f2sin\theta - w + N2sin\theta = 0;\ m = N1 + (1+\mu2)N2sin\theta = ((\frac{T}{r\sqrt{2}})((1+\mu2) - \frac{cos\theta(\mu2-1)}{\mu1}))/g$

$*\ T = 210\ oz-in,\ *\ r = 2\ in,\ *\ \mu1 = 0.95\ (silicon-wood),\ *\ \mu2 = 0.5(silicon - metal),\ *\ g = 386.6\ \frac{in}{s^2}$

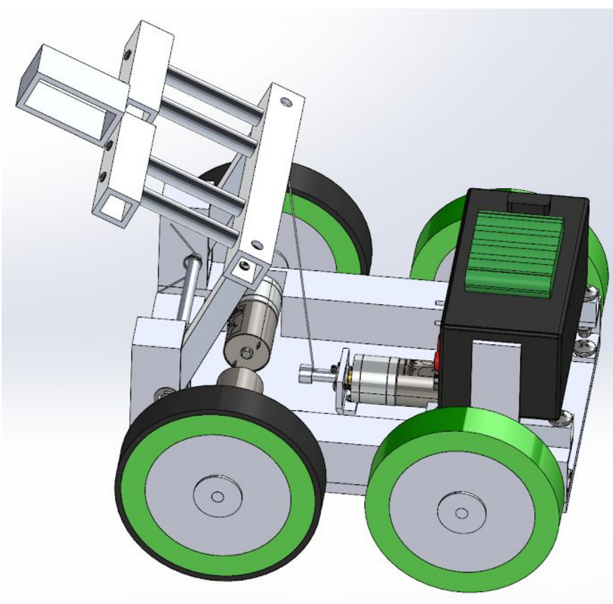
$* \mathit{Assumptions}: \; * f1 = N1\mu 1 \; * f2 = N2\mu 2$

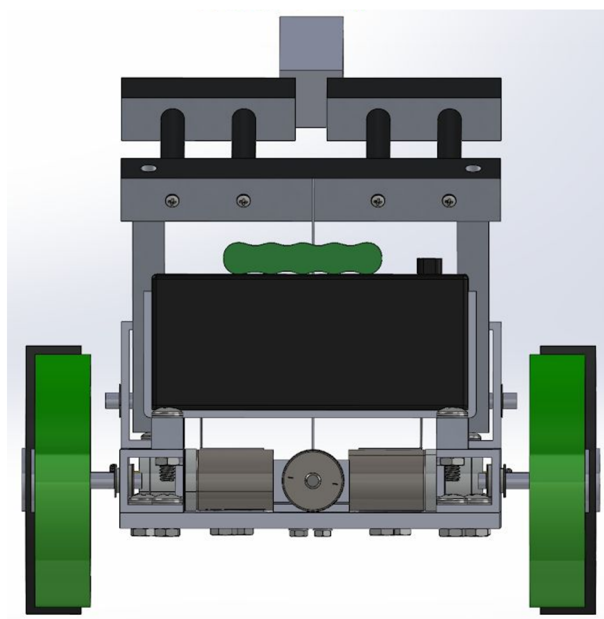
$m = 0.29\, oz = 8.19\, g$ << *This value corresponds to the minimal mass or each wheel necessary.*

<u>The amount of attach force for the velcro on our gravel drawbridge:</u> Through performance testing mockup, we varied the amount of velcro used to attach our gravel drawbridge ramp to our RMP to figure out what the threshold would be for our drawbridge lowering mechanism's success. This testing method was chosen because we had good engineering intuition as to what would happen in service of the RMP and it would be a quick test to run. Conclusions from this testing pointed to the barest amount of contact to allow for less force to knock the drawbridge from the RMP onto the gravel field.

<u>The angle of our gravel drawbridge:</u> We performed performance testing mockup and varied the placement of the tube stock under the gravel drawbridge ramp to understand what angle would provide the best seating of the drawbridge ramp in the gravel field and would provide the RMP with the best means to overcome the ramp in Zone 4. results swayed the positioning of the square tube stock to be near almost the maximum height of the ramp.

2.5. Final Design and CAD Model (4 points)





An isometric and rear view of the final RMP.

The model is designed with front wheel drive, with friction material on the front wheels, to allow for maximum maneuverability. A third motor is used in conjunction with a high strength string wound to a special driveshaft to control the height of rat trap, allowing it to be electronically fired and reloaded. The 2" extender block on the contact bars (the UnicHorn) was added to ensure that the custom bridge would be pushed fully off the velcro when released. This design allows us to carry our own bridge to cross the gravel field, place it down, and then reload the rat trap and re-use it to knock down the drawbridge.

We stripped out the mechanical release assembly for firing the rat trap, and pulled the two motors off the rear wheels. We fabricated a mount for one of the motors from the angle stock and attached it to the base plate using holes drilled for the mechanical firing assembly. Finally, we fabricated a special driveshaft from ⅜" aluminum rod. Then, we assembled our electronically controlled rat trap release mechanism, using high strength string wound by the motor to control the height of the rat trap. We added sheet metal tabs and velcro on the front of the RMP to mount our bridge to. Then, we attached the bridge. The bridge is not shown in the CAD, as it was a large sheet of metal velcroed to the front of the RMP and would obscure the images of the mechanical systems if included. For the full explanation of the design changes made during testing and manufacturing, please see Section 4.1 below.

3. RMP MANUFACTURING (10 POINTS)

3.1. Bill of Materials (3 points)

ME 250 Team 71 - Bill Of Materials

Part Title	Material	Dimension(s)	Supplier	Quantity	Price	Notes	Design/CAD
Square_Tubing	Aluminum Square Tube Stock - 1"x1", 1/8" Wall	9" Long	Kit	2	---	Plunge milling slots for motors	Pranav
Base_Sheet	Aluminum plate, 1/4" thick	6" x9"	Kit	1	---	Using waterjet for holes	Stephen
10-24 thread nuts	18-8 Stainless Steel	1/8" height, 10-24 threading, 3/8" width	Crib	20	---	---	---
10-24 thread 1/2in screws	Passivated 18-8 Stainless Steel	1/2" length, 10-24 threading	Crib	20	---	---	---
Rat Trap Torsion Spring	---		Purchase	2	4	---	---
4-40 thread nuts	18-8 Stainless Steel	1/8" height, 4-40 threading	Crib	2	---	---	---
10-24 thread 1in screws	Passivated 18-8 Stainless Steel	1" length, 10-24 thread	Crib	2	---	---	---
1/4in e-clip	Zinc Yellow-Chromate-Plated Spring Steel	1/4" inner diameter	Crib	8	---	---	---
4-40 flat washers	18-8 Stainless Steel	0.125" ID, 0.312" OD, 0.025"-0.040" Thickness	Crib	2	---	---	---
10-24 flat washers	18-8 Stainless Steel	0.203" ID, 0.438" OD, 0.025"-0.040" Thickness	Crib	6	---	---	
16mm M3 Metal Gearmotor Mounting Screws	Passivated 18-8 Stainless Steel	16mm Length, M3 threading	Crib	6	---	---	---
1/4in Length 3/8in Oil Embedded Sleeve Bearing for 1/4in Shaft	SAE 841 Bronze	3/8in OD, 1/4in ID, 1/4in Length	Crib	4	---	---	---
3/16in Length 4-40 thread Cup Point Set Screw	18-8 Stainless Steel	3/16" Length, 4-40 Thread	Crib	3	---	---	---
Pololu 1576 99:1 Metal Gearmotor 25D x 54L mm HP	---	25D x 54L mm	Crib	3	---	Trading w/ squad for last two motors, or buying them	---
Masking Tape	---	---	Crib	1	---	---	
Sheet_Metal_Bracket_Mill	Aluminum plate, 1/16' thick	9.25" x 1"	Kit	1	---	---	David
Wheel_Extender	PLA Plastic	4" O.D., 3" I.D., 0.875" Thickness	3D Printing Lab - Duderstadt	4	---	Printing one spare wheel extender per wheel	Stephen
Drive_Shaft	Aluminum rod, 3/8" diameter	1.75" Long, 0.250" Diameter	Kit	4	---	---	Stephen
Control_Box_Mounter	Stock: 1/2 " x 1/2 " Aluminum Square Stock	3.00" x 0.50" x 0.50"	Kit	2	---	---	Pranav
Stop_Block	Architectural Aluminum Tube (Alloy 6063) Square, 1/8" wall	2" x 1"	Kit	2	---	---	David
Spring_Support_Block	Architectural Aluminum Tube (Alloy 6063) Square, 1/8" wall	1" x 1"	Kit	2	---	---	David
Rat_Trap_Spring_Bar	Tight-Tolerance 12L14 Carbon Steel Rod Ultra-Machinable, 1/4" Diameter	6.5" length	Kit	1	---	---	David
Rat_Trap_Extending_Rod	Aluminum rod, 3/8" diameter	3.5"	Kit	2	---	---	David
Rat_Trap_Contact_Bar	Architectural Aluminum Tube (Alloy 6063) Square, 1/8" wall	2.75" x 0.75" x 0.75"	Kit	2	---	---	Stephen
Rat_Trap_Base_Bar	Architectural Aluminum Tube (Alloy 6063) Square, 1/8" wall	6.00" x 0.75" x 0.75"	Kit	1	---	---	Stephen
Rat_Trap_Base_Rod	Stock: 1/2 " x 1/2 " Aluminum Square Stock	3.75" x 0.5" x 0.5"	Kit	2	---	---	Stephen
Rat_Trap_Motor_Mount	1/8' 90 degree angle stock 1x1	1x1x1	Kit	1	---	---	Pranav
UnicHorn	Architectural Aluminum Tube (Alloy 6063) Square, 1/8" wall	2x1x1	Kit	1	---	---	Stephen
Rat_Trap_DriveShaft	Aluminum rod, 3/8" diameter	1" Long, 3/8" Diameter	Kit	1	---	---	David
Rubber bands	---	---	---	1	9.99	---	Stephen
Super Glue	---	---	---	1	6.49	---	Pranav
Rubber Traction	---	---	---	1	17.95	---	David
				TOTAL BUDGET:	38.43		

A larger detail of the BoM is available in Appendix 8.2.

Presented here is our BoM. Important to note was our total team budget of $38.43.

3.2. Materials and Manufacturing Process (7 points)

The most critical parts of our RMP were our drive system, gravel drawbridge ramp and gravel drawbridge ramp lowering mechanism. The components of our most critical parts are listed below:

<u>Drive System:</u>

- *Aluminum plate, 1/4" thick*: We chose to use the ¼" Aluminum plate for our base plate because it provided a sound and robust base for the rest of our dynamic mechanisms to be built on.
- *x2 Machined Aluminum Square Tube Stock - 1"x1", 1/8" Wall:* chosen for its stability and symmetry to create mounters for drive motors and non-driven rear wheel drive shafts. This material was best for the job because it provided ample stability with its ⅛" wall thickness and its shape was not complex, making for ease of assembly. The holes and pockets on these parts were machined using a Mill because the motor holes needed to be reamed precisely for bearings on the drive motors and the pockets needed to be precise for fasteners later in assembly.
- *x4 M3 x 8mm Fastener*: 8mm chosen to prevent damage to metal motor gearbox.

- *x2 Pololu 1576 99:1 Metal Gearmotor 25D x 54L mm HP*: Metal Gearmotors chosen to provide enough torque to over gravel field 2 and push the heavy block in Zone 3.
- *Tight-Tolerance 12L14 Carbon Steel Rod Ultra-Machinable, 1/4" Diameter, 1ft long*: Used to make our drive shafts. Chosen for its stiffness/ resistance to deflection given the wheels would be 0.5" from the frame of the RMP.
- *x4 #4-40 set screw*: Used to secure our drive shafts to the motor shafts.
- *x4 Polypropylene wheels, 3" diameter, 1/4" bore*: high rigidity and diameter.
- *x4 3D Printed Wheel Extenders*: Increase the diameter of the drive wheels to 4" to cross lip
- *x2 #84 Rubber Bands 3.5" x 1/2" wide*: Increase friction between the playing field and the RMP.
- *Masking Tape*: Reduce slip between the 3D printed wheel extenders and the playing field surface.
- *x6 E-Clip retaining rings - 1/4" Dia.*: Secure the drive shafts within the gearmotor mounters

<u>Gravel Drawbridge Ramp:</u>

- *Aluminum plate, 1/16" thick*: Light-weight with enough surface area and strength to support the full weight of the RMP without yielding or failing. Hole patterns were drilled into the plate using a drill press to vary the total height/angle of the ramp.
- *Aluminum Square Tube Stock - 1"x1", 1/8" Wall*: Stiff enough to support the full weight of the RMP and modular to change the angle of the ramp.
- *x2 #10-24 x 3/4" Fastener, Nuts*: Used to secure the aluminum square tube to the 1/16" Aluminum plate to complete the drawbridge assembly.

<u>Gravel Drawbridge Ramp Lowering Mechanism</u>

- *x1 Pololu 1576 99:1 Metal Gearmotor 25D x 54L mm HP*
- *Aluminum rod, 3/8" diameter*
- *Coarse tensile string*
- *x4 M3 x 8mm Fastener*
- *Aluminum 90 Degree Angle Stock - 1"x1", 1/8" thick*
- *x2 #4-40 x 3/4" Fasteners, Washers and Nuts*

4. RMP TESTING (10 POINTS)

4.1. Preliminary Test (7 points)

Upon completing the assembly of the RMP, we ran several tests to determine the functionality of our design. First, we positioned the RMP near the drawbridge and fired the rat trap, which knocked down the drawbridge with a great degree of violence. We decided this was due to the high strength of the two torsion springs, which we had pulled from an actual Victor rat trap. This led us to remove a spring from the rat trap. Re-testing showed the rat trap still perfectly capable of knocking down the drawbridge, with much less violence.

Next, we locked the rat trap down and drove the RMP into the drawbridge. We found that the RMP had enough torque to knock down the drawbridge without using the rat trap, which gave us a back up plan.

Then, we attempted to cross the gravel field. At this point we were using our original design (4 wheel drive). Our RMP powered through the gravel, but proved utterly incapable of ascending the lip as our frame kept catching on it. We realized that our RMP was designed to ascend the lip from the surface of the gravel, but was designed to cross the gravel by digging through it to the playing table surface. This 1" difference in height rendered our design useless. To address this, we went back to the drawing board completely. We decided to use the rat trap to release a drawbridge of our own, which we fabricated from sheet metal. We used a motor to control the drawbridge, and the one spring we had attached tot he rat trap initially. The rat trap was found to lack the power necessary to detach the velcro, so we added the second spring back in. This generated enough power, but the rat trap didn't push the bridge far enough away from the front of the RMP to fully detach the velcro. Thus, we added the "unicorn horn" made from the 2x1" architectural stock to the contact bars on the rat trap, and finally we could electronically control the release of our bridge. We took the RMP back to the playing field, and attempted to use the subsystem. The bridge was released flawlessly, providing an easy pathway over the gravel field! However, even with rubber bands on the wheels, our RMP continually slid off the bridge. Thus, we added duct tape to our bridge, and planned on crossing the gravel field backwards to increase friction. Finally, we had a working method of crossing the gravel field!

Next, we tested the maneuverability through the maze. We found that the removal of the rear motors we had done to enable the electronic control of the rat trap actually increased the maneuverability of the RMP dramatically, but it was struggling because of the rubber bands used as friction material on the rear wheels, left over from the old 4wd design. We thus removed these rubber bands, and our RMP was ready to roll!

Finally, we attempted to move the block. Our initial attempt used two rubber bands on each front tire for friction, but this failed as the wheels were not uniform. We thus swapped the rubber bands for a high friction vinyl material, which worked considerably better. We then took the RMP back across the gravel field, finding to our dismay that the vinyl did not get good traction on the duct tape. At this point, we tried several configurations of rubber bands, and ultimately found that putting masking tape around the wheel then gluing a single rubber band to it worked best for both tasks. This allowed us to move the block successfully.

4.2. Discussion of Competition Results (3 points)

Overall, our squad scored 10 points. These points were scored by our team, in which we had to alter our strategy. The points were scored from crossing the gravel pit, pushing the block and going over the seesaw. This is because during pre-competition testing, we changed our strategy so that our team would have to push another RMP to pick up yellow cubes. However, other RMPs were blocking our way as we tried to pass the pyramid, and the rest of the course.

In general, we could have gone over several other strategies before competition. Since there was one of the RMPs blocking our way, we should have had a discussion about what to do in that situation. As for our RMP, we could have made it lighter by removing some excess material. This would have made the RMP faster, which would have let us navigate through the course faster.

5. DISCUSSION AND RECOMMENDATIONS (12 POINTS)

5.1. Recommendation for RMP Design and Analysis (7 points)

As a result of our testing and experience in the competition, we developed several recommendations for future RMP designs. First, keep the circuitry as simple as possible. Our initial 4wd model was abandoned in part because it was extremely difficult to drive using the provided control box, which was incapable of providing enough current to drive all four motors concurrently at the same speed. In addition, it required the use of Mixed Mode, which was largely unsuccessful. Second, design for manufacturability. We designed with an emphasis on functionality and ease of assembly, but found that the machining process took significantly more time than the assembly. Third, simplify the overall design. Several of our subsystems (in particular, the control box mounter subsystem) were unnecessarily complex, and ultimately we abandoned them. After testing and adapting our design prior to the competition, we feel that our final RMP design was adequate. In terms of testing, our main focus was ensuring that our RMP drove with full contact with the surfaces of the playing field and that we had control when steering. During the competition, Our RMP almost flawlessly moved in coordination with the driver and no surface posed an issue to its operation. Though our testing did not result in quantitative data, it did result in stronger engineering intuition when designing drive systems.

5.2. Recommendation for Mass Production (5 points)

If our RMP were to be under consideration for mass production, we recommend that:

- <u>Add more access holes to parts for assembly:</u> maintenance of certain components of the RMP under dire times was arduous.
- <u>Invest resources into single-body wheels instead of the composite wheels present on RMP 1:</u> having a single-body wheel will make assembly more efficient and decrease human error.
- <u>Stabilize seating of torsion springs:</u> on the current RMP, the torsion springs used on the rat trap mechanism are seated without restriction along the rod they are mounted on. We recommend e-clips be used to ensure that while the spring is relaxed, the springs do not slide off of their mount.
- <u>Make the mount for the control box one part:</u> the assembly of the control box mount ended up being more complex than it needed to be. We recommend that this part be either bent out of one piece of sheet metal or 3D printed with an acceptable wall thickness.
- <u>Invest in a stronger spring:</u> currently, the string used in the gravel drawbridge lowering system had to be wrapped about itself four times to operate in service without breaking. We recommend procuring a stronger string so that less of it can be used and the gravel drawbridge lowering mechanism can operate under more cycles of operation.

  *All these methods should be feasible for a single prototype because they marginally alter the processes used on RMP 1.

The following sections are NOT INCLUDED in the total page count.

6. REFERENCES (2 POINTS)

6.1. Future Project Idea (1 point)

It would be interesting to have a glue that would allow for metal-metal bonding, which would save time for placing in set screws. It would perhaps be beneficial to use this glue only when the students have used a certain amount of set screws, since it is an important topic in the lectures.

Also, in our RMP playing field table, the lip for the push block was not removed. It may be beneficial to change that so that the block can be pushed from passing through the maze.

6.2. Resources (1 point)

The resources used for our team were the internet, and lecture slides. We used the internet and the lecture slides for first principles analysis. The CAD labs were used for design, along with the internet.

7. ACKNOWLEDGEMENTS (1 POINT)

We would like to acknowledge Dory for helping us through the process, even though there were certain moments when we freaked out about the deadlines! Also, we would like to thank Professor Austin-Brenneman for believing in our idea and Professor Umbriac for his constant support, pushing us to complete it even when we thought it was impossible!

Then, we would like to acknowledge the other GSI's for helping us with testing, and the machine shop advisors: Don, Charlie, and John, for teaching us the right way to manufacture.

8. APPENDIX (2 POINTS)

8.1. Approval Packets (2 points)

These will be printed and brought to the lab.

8.2. Extra calculations, images, graphs

See next page for BoM.

ME 250 Team 71 - Bill Of Materials

Part Title	Material	Dimension(s)
Square_Tubing	Aluminum Square Tube Stock - 1"x1", 1/8" Wall	9" Long
Base_Sheet	Aluminum plate, 1/4" thick	6" x9"
10-24 thread nuts	18-8 Stainless Steel	1/8" height, 10-24 threading, 3/8" width
10-24 thread 1/2in screws	Passivated 18-8 Stainless Steel	1/2" length, 10-24 threading
Rat Trap Torsion Spring	---	
4-40 thread nuts	18-8 Stainless Steel	1/8" height, 4-40 threading
10-24 thread 1in screws	Passivated 18-8 Stainless Steel	1" length, 10-24 thread
1/4in e-clip	Zinc Yellow-Chromate-Plated Spring Steel	1/4" inner diameter
4-40 flat washers	18-8 Stainless Steel	0.125" ID, 0.312" OD, 0.025"-0.040" Thickness
10-24 flat washers	18-8 Stainless Steel	0.203" ID, 0.438" OD, 0.025"-0.040" Thickness
16mm M3 Metal Gearmotor Mounting Screws	Passivated 18-8 Stainless Steel	16mm Length, M3 threading
1/4in Length 3/8in Oil Embedded Sleeve Bearing for 1/4in Shaft	SAE 841 Bronze	3/8in OD, 1/4in ID, 1/4in Length
3/16in Length 4-40 thread Cup Point Set Screw	18-8 Stainless Steel	3/16" Length, 4-40 Thread
Pololu 1576 99:1 Metal Gearmotor 25D x 54L mm HP	---	25D x 54L mm
Masking Tape	---	---
Sheet_Metal_Bracket_Mill	Aluminum plate, 1/16' thick	9.25" x 1"
Wheel_Extender	PLA Plastic	4" O.D., 3" I.D., 0.875" Thickness
Drive_Shaft	Aluminum rod, 3/8" diameter	1.75" Long, 0.250" Diameter
Control_Box_Mounter	Stock: 1/2 " x 1/2 " Aluminum Square Stock	3.00" x 0.50" x 0.50"
Stop_Block	Architectural Aluminum Tube (Alloy 6063) Square, 1/8" wall	2" x 1"
Spring_Support_Block	Architectural Aluminum Tube (Alloy 6063) Square, 1/8" wall	1" x 1"
Rat_Trap_Spring_Bar	Tight-Tolerance 12L14 Carbon Steel Rod Ultra-Machinable, 1/4" Diameter	6.5" length
Rat_Trap_Extending_Rod	Aluminum rod, 3/8" diameter	3.5"
Rat_Trap_Contact_Bar	Architectural Aluminum Tube (Alloy 6063) Square, 1/8" wall	2.75" x 0.75" x 0.75"
Rat_Trap_Base_Bar	Architectural Aluminum Tube (Alloy 6063) Square, 1/8" wall	6.00" x 0.75" x 0.75"
Rat_Trap_Base_Rod	Stock: 1/2 " x 1/2 " Aluminum Square Stock	3.75" x 0.5" x 0.5"
Rat_Trap_Motor_Mount	1/8' 90 degree angle stock 1x1	1x1x1
UnicHorn	Architectural Aluminum Tube (Alloy 6063) Square, 1/8" wall	2x1x1
Rat_Trap_DriveShaft	Aluminum rod, 3/8" diameter	1" Long, 3/8" Diameter
Rubber bands	---	---
Super Glue	---	---
Rubber Traction	---	---

[redacted]

Supplier	Quantity	Price	Notes	Design/CAD
Kit	2	---	Plunge milling slots for motors	Pranav
Kit	1	---	Using waterjet for holes	Stephen
Crib	20	---	---	---
Crib	20	---	---	---
Purchase	2	4	---	---
Crib	2	---	---	---
Crib	2	---	---	---
Crib	8	---	---	---
Crib	2	---	---	---
Crib	6	---	---	
Crib	6	---	---	---
Crib	4	---	---	---
Crib	3	---	---	---
Crib	3	---	Trading w/ squad for last two motors, or buying them	---
Crib	1	---	---	
Kit	1	---	---	David
3D Printing Lab - Duderstadt	4	---	Printing one spare wheel extender per wheel	Stephen
Kit	4	---	---	Stephen
Kit	2	---	---	Pranav
Kit	2	---	---	David
Kit	2	---	---	David
Kit	1	---	---	David
Kit	2	---	---	David
Kit	2	---	---	Stephen
Kit	1	---	---	Stephen
Kit	2	---	---	Stephen
Kit	1	---	---	Pranav
Kit	1	---	---	Stephen
Kit	1	---	---	David
---	1	9.99	---	Stephen
---	1	6.49	---	Pranav
---	1	17.95	---	David
	TOTAL BUDGET:	38.43		