Mech 202 Project 2: Autonomous Vehicle

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The Device: “Big Red”

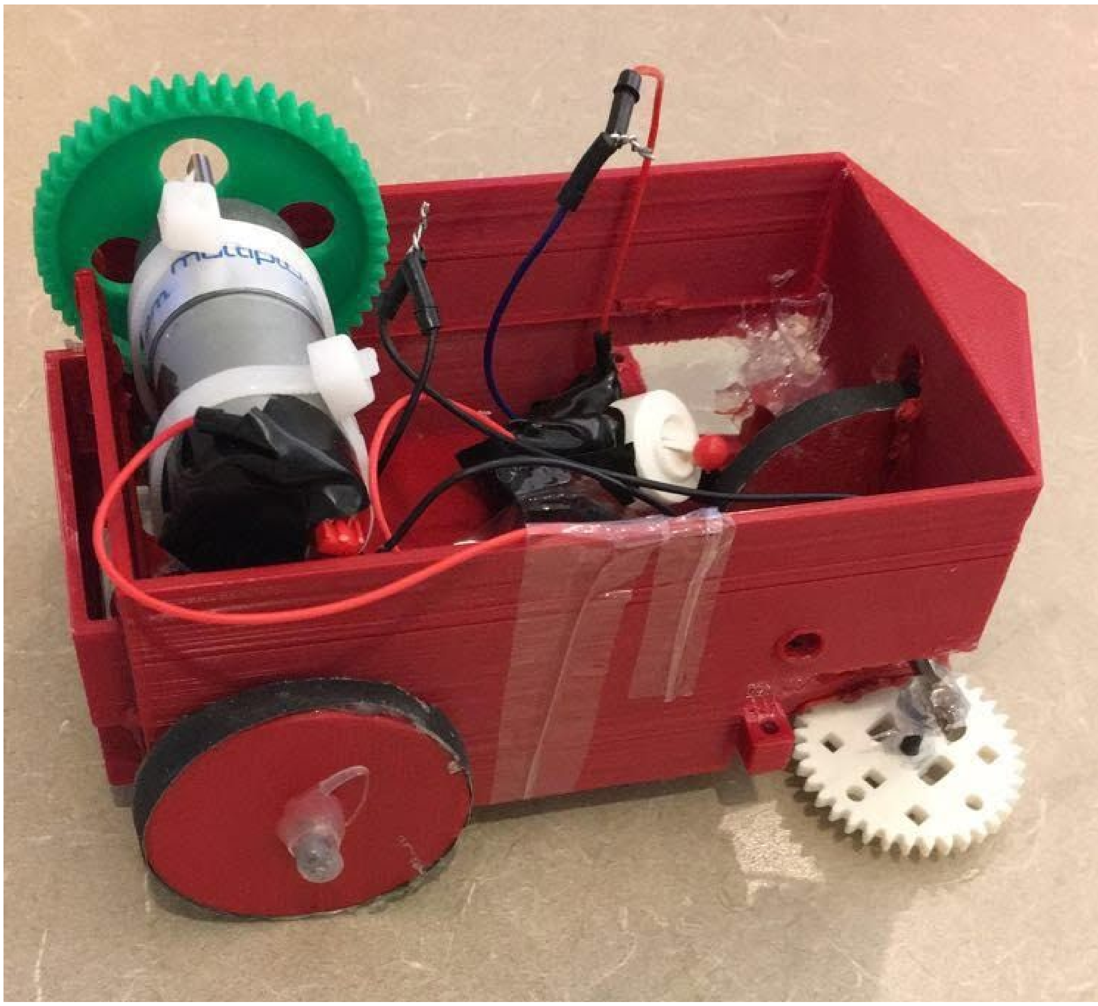

Figure 1

Project Planning

The team began the project by planning out what tasks needed to be completed, and how these tasks related to each other. First, a task list and design structure were created in order to organize project completion. In order to stay on track, Gantt charts were put together detailing which tasks should be completed and when. Weekly snapshots of the Gantt chart were also created. Once the Gantt charts were made, detailed descriptions of the tasks were made in order to ensure that the tasks were sufficiently completed.

The project was broken up into twenty tasks. Each task consisted of a different part of the project. Estimations were made for how long each tasks would take, as well as which group members would be completing the tasks. Each description outlined what the object of the task was in addition to the deliverable produced by the task. The prerequisites as well as the dependencies were included in this outline to ensure that the tasks were completed in the correct order.

Table 1

Task List		
Task Letter	Task	Estimated Duration
A	Project Planning	3 Person, 4 Hours
B	Brainstorming	4 Person, 4 Hours
C	Prototype Design	4 Person, 8 Hours
D	Proof of Concept	2 Person, 3 Hours
E	Prototype Development	4 Person, 24 Hours
F	Test Prototype	4 Person, 2 Hours
G	Engineering Analysis	4 Person, 6 Hours
H	Design Review	2 Person, 3 Hours
I	Final Design and build	4 Person, 12 Hours
J	Final Testing	4 Person, 2 Hours
K	BOM	2 Person, 3 Hours
L	CAD Model Parts	4 Person, 28 Hours
M	Engineering Drawings	4 Person, 5 Hours
N	CAD Assembly	1 Person, 4 Hours
O	CAD Rendering	1 Person, 3 Hours
P	Describe Part Function	4 Person, 4 Hours
Q	Failure Analysis	2 Person, 4 Hours
R	Write Report	4 Person, 18 Hours
S	Edit Report	4 Person, 6 Hours
T	Turn in Report	4 Person, 0.5 Hours
Total Time		142.5 Hours

Design Structure Matrix

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
Project Planning	A	A																			
Brainstorming	B		B																		
Prototype Design	C		X	C																	
Proof of Concept	D			X	D																
Prototype Development	E				X	E															
Test Prototype	F					X	F														
Engineering Analysis	G						X	G													
Design Review	H							X	H												
Final Design and Build	I								X	I											
Final Testing	J									X	J										
BOM	K									X		K									
CAD Model Parts	L									X			L								
Engineering Drawings	M												X	M							
CAD Assembly	N												X		N						
CAD Rendering	O												X		X	O					
Describe Part Function	P									X							P				
Failure Analysis	Q									X	X							Q			
Write Report	R	X									X	X		X	X	X	X	X	R		
Edit Report	S																		X	S	
Turn in Report	T																			X	T

Task Details

Project Planning

Design Organization: Mech 202 Group 4	**Date: 4/26/18**
Proposed Product Name: Vehicle	

Task A	**Name of Task**: Project Planning
	Objective: Plan for project 2
	Deliverables: Have a planned out task list, Gantt chart, and a design structure matrix.
	Decisions needed: Decision 1: Discuss and come up with a task list. Decision 2: Assign a group member to do the Gantt chart, another to do the project planning template, and another to make the task list and design structure matrix. Decision 3: Have all group members agree on the plan.
	Personnel needed: Title: Connor A. Hours:1.33 Title: Gabe B. Hours: 1.33 Title: Kyle V. Hours: 1.33
	Time estimate: Total hours: 4 Lapsed time(include units): 5 hrs
	Sequence: Predecessors: Successors: R Start Date: 2/1/18 Finish Date:2/1/18
	Costs: $0 Disposables: $0

Team member: Husam A.	Prepared by: Kyle V.
Team member: Connor A.	Checked by: Husam A.
Team member: Gabe B.	Approved by: Connor A.
Team member: Kyle V.	

Project Planning

Design Organization: **Mech 202 Group 4**		**Date:** **4/26/18**
Proposed Product Name: Vehicle		
Task B	**Name of Task:** Brainstorming	
	Objective: Come up with ideas for how to approach the project	
	Deliverables: Settle on an idea for a prototype	
	Decisions needed: Decision 1: What ideas do we want to incorporate into our prototype?	
	Personnel needed: Title: Husam A. Hours: 1 Title: Connor A. Hours: 1 Title: Gabe B. Hours: 1 Title: Kyle V. Hours: 1	
	Time estimate: Total hours: 4 Lapsed time(include units): 6 hrs	
	Sequence: Predecessors: Successors: C Start Date:2/20/18 Finish Date:2/20/18	
	Costs: $0 Disposables: $0	
Team member: Husam A.	Prepared by: Husam A.	
Team member: Connor A.	Checked by: Gabe B.	
Team member: Gabe B.	Approved by: Kyle V.	
Team member: Kyle V.		

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Project Planning

Design Organization: Mech 202 Group 4	**Date: 4/26/18**
Proposed Product Name: Vehicle	

Task C	**Name of Task:** Prototype Design
	Objective: Develop a design for the first prototype
	Deliverables: Settle on a design for the prototype
	Decisions needed: Decision 1: What design should we use for the prototype?
	Personnel needed: Title: Husam A. Hours: 2 Title: Connor A. Hours: 2 Title: Gabe B. Hours: 2 Title: Kyle V. Hours: 2
	Time estimate: Total hours: 8 Lapsed time(include units): 10 hrs
	Sequence: Predecessors: B Successors: D Start Date: 3/7/18 Finish Date:3/7/18
	Costs: $0 Disposables: $0

Team member: Husam A.	Prepared by: Husam A.
Team member: Connor A.	Checked by: Connor A.
Team member: Gabe B.	Approved by: Kyle V.
Team member: Kyle V.	

Project Planning

Design Organization: **Mech 202 Group 4**		**Date:** **4/26/18**
Proposed Product Name: Vehicle		
Task D	**Name of Task**: Proof of Concept	
	Objective: Ensure that ideas incorporated in the prototype are feasible.	
	Deliverables: The feasibility of concepts incorporated into the design is proven.	
	Decisions needed: Decision 1: Are there any aspects of the design that are not feasible?	
	Personnel needed: Title: Husam A. Hours: 1.5 Title: Connor A. Hours: 1.5	
	Time estimate: Total hours: 3 Lapsed time(include units): 3 hrs	
	Sequence: Predecessors: C Successors: E Start Date:3/19/18 Finish Date:3/21/18	
	Costs: $0 Disposables: $0	
Team member: Husam A.	Prepared by: Husam A.	
Team member: Connor A.	Checked by: Gabe B.	
Team member: Gabe B.	Approved by: Connor A.	
Team member: Kyle V.		
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Project Planning

Design Organization: Mech 202 Group 4	Date: 4/26/18
Proposed Product Name: Vehicle	

Task E	**Name of Task:** Prototype Development
	Objective: Develop a prototype that will be used for testing
	Deliverables: A prototype is developed that will be used to test feasibility
	Decisions needed: Decision 1: Is the prototype ready for testing?
	Personnel needed: Title: Husam A. Hours: 3 Title: Connor A. Hours: 3 Title: Gabe B. Hours: 3 Title: Kyle V. Hours: 3
	Time estimate: Total hours: 12 Lapsed time(include units): 20 hrs
	Sequence: Predecessors: D Successors: E Start Date:3/19/18 Finish Date: 4/27/18
	Costs: $0 Disposables: $0

Team member: Husam A.	Prepared by: Kyle V.
Team member: Connor A.	Checked by: Connor A.
Team member: Gabe B.	Approved by: Gabe B.
Team member: Kyle V.	

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Project Planning

Design Organization: Mech 202 Group 4	**Date: 4/26/18**

Proposed Product Name: Vehicle

Task F	
	Name of Task: Test Prototype
	Objective: Ensure that the prototype has no major functionality problems
	Deliverables: Results from a test are gathered
	Decisions needed: Decision 1: Is all the necessary data gather from the test?
	Personnel needed: Title: Husam A. Hours: 0.5 Title: Connor A. Hours: 0.5 Title: Gabe B. Hours: 0.5 Title: Kyle V. Hours: 0.5
	Time estimate: Total hours: 2 Lapsed time(include units): 2 hrs
	Sequence: Predecessors: E Successors: G Start Date:3/19/18 Finish Date: 4/27/18
	Costs: $0 Disposables: $0

Team member: Husam A.	Prepared by: Gabe B.
Team member: Connor A.	Checked by: Connor A.
Team member: Gabe B.	Approved by: Husam A.
Team member: Kyle V.	

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Project Planning

Design Organization:	**Mech 202 Group 4**	**Date:** 4/26/18
Proposed Product Name: Vehicle		

Task G	**Name of Task:** Engineering Analysis
	Objective: Use engineering analytical methods to determine design feasibility
	Deliverables: The design is shown to be feasible or infeasible
	Decisions needed: Decision 1: Is the design shown to be feasible by analytical methods?
	Personnel needed: Title: Husam A. Hours: 1.5 Title: Connor A. Hours: 1.5 Title: Gabe B. Hours: 1.5 Title: Kyle V. Hours: 1.5
	Time estimate: Total hours: 6 Lapsed time(include units): 4 hrs
	Sequence: Predecessors: F Successors: H Start Date:4/15/18 Finish Date: 4/22/18
	Costs: $0 Disposables: $0

Team member: Husam A.	Prepared by: Husam A.
Team member: Connor A.	Checked by: Kyle V.
Team member: Gabe B.	Approved by: Gabe B.
Team member: Kyle V.	

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Project Planning

Design Organization: Mech 202 Group 4	Date: 4/26/18
Proposed Product Name: Vehicle	

Task H	
	Name of Task: Design Review
	Objective: Review the design to ensure completeness
	Deliverables: A comprehensive review showing no issues with the design
	Decisions needed: Decision 1: Are there any problems with the design?
	Personnel needed: Title: Connor A. Hours: 1.5 Title: Gabe B. Hours: 1.5
	Time estimate: Total hours: 3 Lapsed time(include units): 5 hrs
	Sequence: Predecessors: G Successors: I Start Date:4/28/18 Finish Date:4/29/18
	Costs: $0 Disposables: $0

Team member: Husam A.	Prepared by: Husam A.
Team member: Connor A.	Checked by: Connor A.
Team member: Gabe B.	Approved by: Gabe B.
Team member: Kyle V.	

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Project Planning

Design Organization: Mech 202 Group 4	**Date: 4/26/18**
Proposed Product Name: Vehicle	

Task I	
	Name of Task: Final Design and Build
	Objective: Agree on a final design for our vehicle and construct it.
	Deliverables: The vehicle works and is ready for the final test.
	Decisions needed: Decision 1: Is the vehicle ready to be tested?
	Personnel needed: Title: Husam A. Hours: 3 Title: Connor A. Hours: 3 Title: Gabe B. Hours: 3 Title: Kyle V. Hours: 3
	Time estimate: Total hours: 12 Lapsed time(include units): 16 hrs
	Sequence: Predecessors: I Successors: J, K, L, P, Q Start Date:4/27/18 Finish Date:4/27/18
	Costs: $0 Disposables: $0

Team member: Husam A.	Prepared by: Husam A.
Team member: Connor A.	Checked by: Connor A.
Team member: Gabe B.	Approved by: Gabe B.
Team member: Kyle V.	
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Project Planning

Design Organization:	**Mech 202 Group 4**	**Date:** 4/26/18

Proposed Product Name: Vehicle

Task J	
	Name of Task: Final Testing
	Objective: Ensure that the vehicle works reliably.
	Deliverables: The vehicle is finished and ready for competition.
	Decisions needed: Decision 1: Are we ready to compete in the demolition derby?
	Personnel needed: Title: Husam A. Hours: 0.5 Title: Connor A. Hours: 0.5 Title: Gabe B. Hours: 0.5 Title: Kyle V. Hours: 0.5
	Time estimate: Total hours: 2 Lapsed time(include units): 3 hrs
	Sequence: Predecessors: I Successors: Q, R Start Date:4/27/18 Finish Date:4/27/18
	Costs: $0 Disposables: $0

Team member: Husam A.	Prepared by: Gabe B.
Team member: Connor A.	Checked by: Connor A.
Team member: Gabe B.	Approved by: Kyle V.
Team member: Kyle V.	

Project Planning

Design Organization: Mech 202 Group 4	**Date: 4/26/18**
Proposed Product Name: Vehicle	

Task K	**Name of Task:** BOM
	Objective: Create a table containing the most important 20 parts and their build martials.
	Deliverables: Have a table with list of materials.
	Decisions needed: Decision 1: Decide the best way to determine the material. Decision 2: Collect all the data and create a table of materials.
	Personnel needed Title: Connor A Hours: 1.5 Title: Gabe B Hours: 1.5
	Time estimate Total hours: 3 Lapsed time(include units): 2 hrs
	Sequence: Predecessors: I Successors: R Start Date:4/7/18 Finish Date:4/7/18
	Costs: $0 Disposables: $0

Team member: Husam A.	Prepared by: Kyle V.
Team member: Connor A.	Checked by: Husam A.
Team member: Gabe B.	Approved by: Gabe B.
Team member: Kyle V.	
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Project Planning

Design Organization: Mech 202 Group 4	**Date: 4/26/18**
Proposed Product Name: Vehicle	

Task L	**Name of Task:** CAD Model Parts
	Objective : Modeling the 20 different parts..
	Deliverables: Have a Cad file for each of the modeled parts.
	Decisions needed: Decision 1: Assign different parts to Different group members for modeling. Decision 2: Discuss the units and templates for the Cad file.
	Personnel needed Title: Husam. A Hours: 7 Title: Connor. A Hours: 7 Title: Gabe. B Hours: 7 Title: Kyle.V Hours: 7
	Time estimate Total hours: 28 Lapsed time(include units): 18 hrs
	Sequence: Predecessors: I Successors: M, N, O Start Date: 29/3/18 Finish Date: 4/19/18
	Costs: $0 Disposables: $0

Team member: Husam A.	Prepared by: Gabe B.
Team member: Connor A.	Checked by: Connor A.
Team member: Gabe B.	Approved by: Husam A.
Team member: Kyle V.	

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Project Planning

Design Organization: **Mech 202 Group 4**

Date: **4/26/18**

Proposed Product Name: Vehicle

Task M

Name of Task: Engineering Drawings

Objective : Use a CAD software to create an engineering drawing.

Deliverables: Have a 2D cad file for the 20 parts of the flashlight dimensioned correctly.

Decisions needed:
Decision 1: Agree on a single drawings size (scale) and template on CAD.

Personnel needed

Title: Husam. A	Hours: 1.25
Title: Connor. A	Hours: 1.25
Title: Gabe. B	Hours: 1.25
Title: Kyle. V	Hours: 1.25

Time estimate Total hours: 5 Lapsed time(include units): 1 hr

Sequence: Predecessors: L Successors: R
Start Date: 30/4/18 Finish Date: 30/4/18

Costs: $0 Disposables: $0

Team member: Husam A.	Prepared by: Husam A.
Team member: Connor A.	Checked by: Connor A.
Team member: Gabe B.	Approved by: Kyle V.
Team member: Kyle V.	

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Design Organization: Mech 202 Group 4		**Date: 4/26/18**
Proposed Product Name: Vehicle		
Task N	**Name of Task:** CAD Assembly	
	Objective: Assemble all the different model parts into one CAD file.	
	Deliverables: Have one Cad file for the assembled flashlight.	
	Decisions needed: Decision 1: Choose a team member to do the assembling through voting.	
	Personnel needed: Title: Kyle V. Hours: 4	
	Time estimate: Total hours: 4 Lapsed time(include units): 1 hr	
	Sequence: Predecessors: L Successors: O, R Start Date: 4/30/18 Finish Date: 4/30/18	
	Costs: $0 Disposables: $0	

Team member: Husam A.	Prepared by: Gabe B.
Team member: Connor A.	Checked by: Connor A.
Team member: Gabe B.	Approved by: Kyle V.
Team member: Kyle V.	
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Project Planning

Design Organization: Mech 202 Group 4	**Date: 4/26/18**
Proposed Product Name: Vehicle	

Task O	**Name of Task:** CAD Rendering
	Objective : Use CAD software to create a rendering for the different parts.
	Deliverables: Completed, realistic-looking flashlight.
	Decisions needed: Decision 1: Agree on the best backgrounds for rendering to make the device look good.
	Personnel needed Title: Gabe B. Hours: 3
	Time estimate Total hours: 3 Lapsed time(include units): 2 hrs
	Sequence: Predecessors: L, N Successors: R Start Date:4/30/18 Finish Date:4/30/18
	Costs: $0 Disposables: $0

Team member: Husam A.	Prepared by: Kyle V.
Team member: Connor A.	Checked by: Husam A.
Team member: Gabe B.	Approved by: Connor A.
Team member: Kyle V.	

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Project Planning

Design Organization: Mech 202 Group 4	**Date: 4/26/18**
Proposed Product Name: Vehicle	

Task P	
	Name of Task: Describe Part Function
	Objective: Explain why each part of the vehicle is necessary and the role that it plays.
	Deliverables: It is clear why each part was used and its importance.
	Decisions needed: Decision 1: Are there any parts used that were not necessary? Decision 2: Make it clear the reason for why each part was used clear.
	Personnel needed: Title: Husam A. Hours: 1 Title: Connor A. Hours: 1 Title: Gabe B. Hours: 1 Title: Kyle V. Hours: 1
	Time estimate: Total hours: 4 Lapsed time(include units): 3 hrs
	Sequence: Predecessors: I Successors: R Start Date: 4/15/18 Finish Date: 4/28/18
	Costs: $0 Disposables: $0

Team member: Husam A.	Prepared by: Connor A.
Team member: Connor A.	Checked by: Kyle V.
Team member: Gabe B.	Approved by: Husam A.
Team member: Kyle V.	

Project Planning

Design Organization: Mech 202 Group 4	**Date: 4/26/18**
Proposed Product Name: Vehicle	

Task Q	**Name of Task:** Failure Analysis
	Objective: Understand what went wrong and why.
	Deliverables: Compile reasons for why the vehicle failed and include improvements that could be implemented in the future.
	Decisions needed: Decision 1: Decide the main causes of the failure.
	Personnel needed: Title: Husam A. Hours: 2 Title: Connor A. Hours: 2
	Time estimate: Total hours: 4 Lapsed time(include units): 3 hrs
	Sequence: Predecessors: I, J Successors: R Start Date: Finish Date:
	Costs: $0 Disposables: $0

Team member: Husam A.	Prepared by: Gabe B.
Team member: Connor A.	Checked by: Kyle V.
Team member: Gabe B.	Approved by: Connor A.
Team member: Kyle V.	

Project Planning

Design Organization: Mech 202 Group 4	**Date: 4/26/18**
Proposed Product Name: Vehicle	

Task R	**Name of Task:** Write Report
	Objective: Finish writing the report.
	Deliverables: The report is ready to be edited.
	Decisions needed: Decision 1: Make sure the report has been finished. Decision 2: Are we all proud of the final product?
	Personnel needed: Title: Husam A. Hours: 4.5 Title: Connor A. Hours: 4.5 Title: Gabe B. Hours: 4.5 Title: Kyle V. Hours: 4.5
	Time estimate: Total hours: 18 Lapsed time(include units): 25 hrs
	Sequence: Predecessors: A, J, K, M, N, O, P, Q Successors: S Start Date:3/21/18 Finish Date: 4/30/18
	Costs: $0 Disposables: $0

Team member: Husam A.	Prepared by: Husam A.
Team member: Connor A.	Checked by: Kyle V.
Team member: Gabe B.	Approved by: Gabe B.
Team member: Kyle V.	

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Project Planning

Design Organization: Mech 202 Group 4	**Date: 4/26/18**
Proposed Product Name: Vehicle	

Task S	**Name of Task**: Edit Report
	Objective: Ensure that the report is formatted appropriately, all grading requirements were followed, and that the spelling and grammar is correct.
	Deliverables: The report is completely finished.
	Decisions needed: Decision 1: Is the report ready to be turned in?
	Personnel needed: Title: Husam A. Hours: 1.5 Title: Connor A. Hours:1.5 Title: Gabe B. Hours: 1.5 Title: Kyle V. Hours: 1.5
	Time estimate: Total hours: 6 Lapsed time(include units): 1 hr
	Sequence: Predecessors: R Successors: Start Date: 4/30/18 Finish Date:4/30/18
	Costs: $0 Disposables: $0

Team member: Husam A.	Prepared by: Gabe B.
Team member: Connor A.	Checked by: Kyle V.
Team member: Gabe B.	Approved by: Husam A.
Team member: Kyle V.	

Project Planning

Design Organization: Mech 202 Group 4	**Date: 4/26/18**
Proposed Product Name: Vehicle	
Task T	**Name of Task:** Turn in Report
	Objective: Turn in report for grading
	Deliverables: A printed and emailed report
	Decisions needed: Decision 1: When in the day report is to be delivered
	Personnel needed: Title: Husam A. Hours: 0.5 Title: Connor A. Hours: 0.5 Title: Gabe B. Hours: 0.5 Title: Kyle V. Hours: 0.5
	Time estimate: Total hours: 0.5 Lapsed time(include units): 0.25 hr
	Sequence: Predecessors: S Successors: Start Date: 5/1/18 Finish Date:5/1/18
	Costs: $0 Disposables: $0
Team member: Husam A.	Prepared by: Connor A.
Team member: Connor A.	Checked by: Husam A.
Team member: Gabe B.	Approved by: Kyle V.
Team member: Kyle V.	

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Gantt Charts

*Due dates were based on canvas dates which were not the actual due dates.
*We didn't realize the drawings, assembly, and rendering were not required. Therefore progress was not included in the Gantt Charts. These were added after the fact.

Table 1: During week one (starting Feb.1), we were working on project 1 along with this project. We had planned to focus on that and keep project 2 on the backburner. Our plan was overly optimistic and we soon saw that this would not be realistic.

Table 2: During week two, we did not make much progress as the due date for project 1 was quickly approaching. Though we had planned to start brainstorming for project 2 towards the end of week 2, this did not come to fruition.

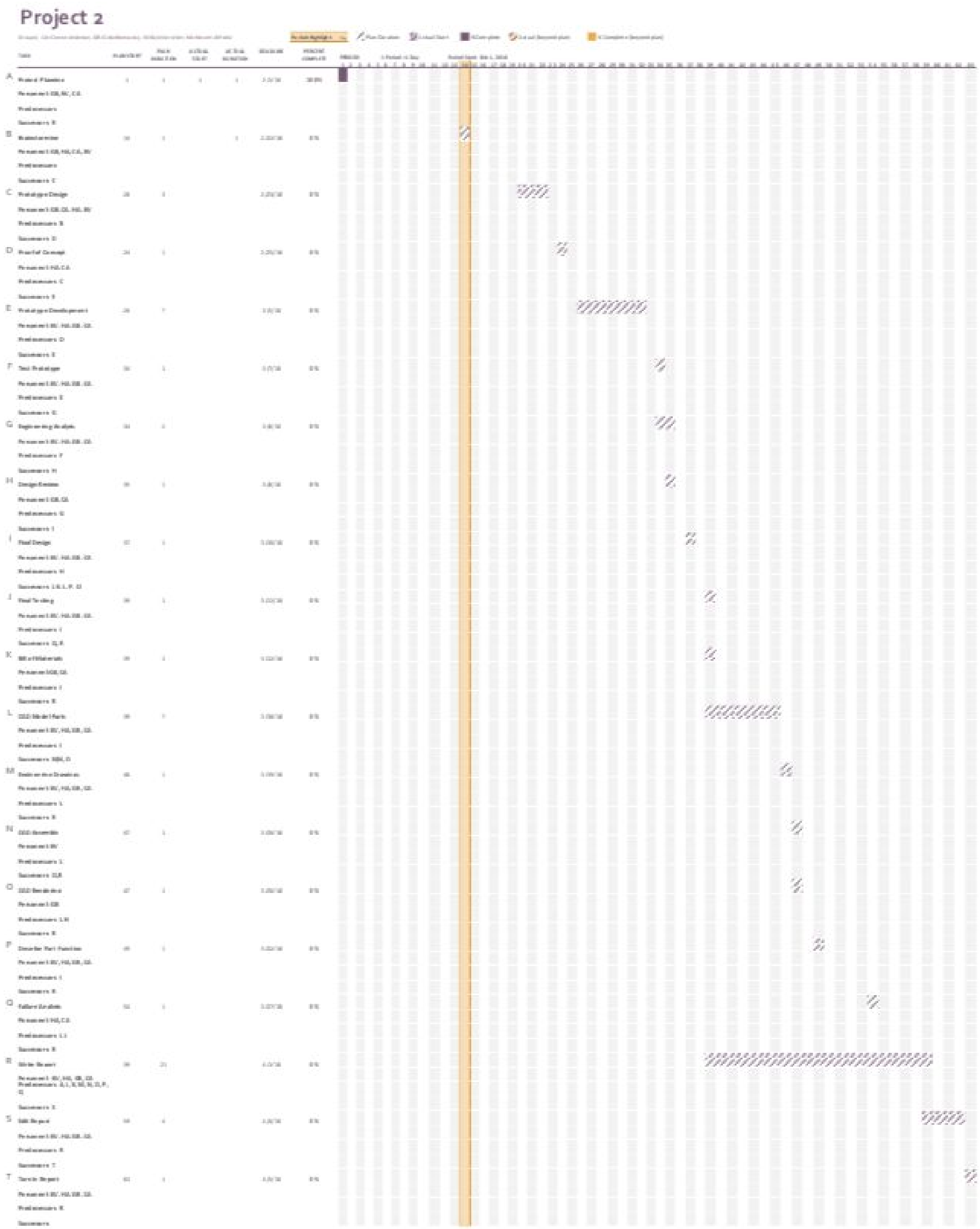


Table 3: On week three, we tried to catch up to our plan. Brainstorming was completed, however, we fell behind on our prototype design.

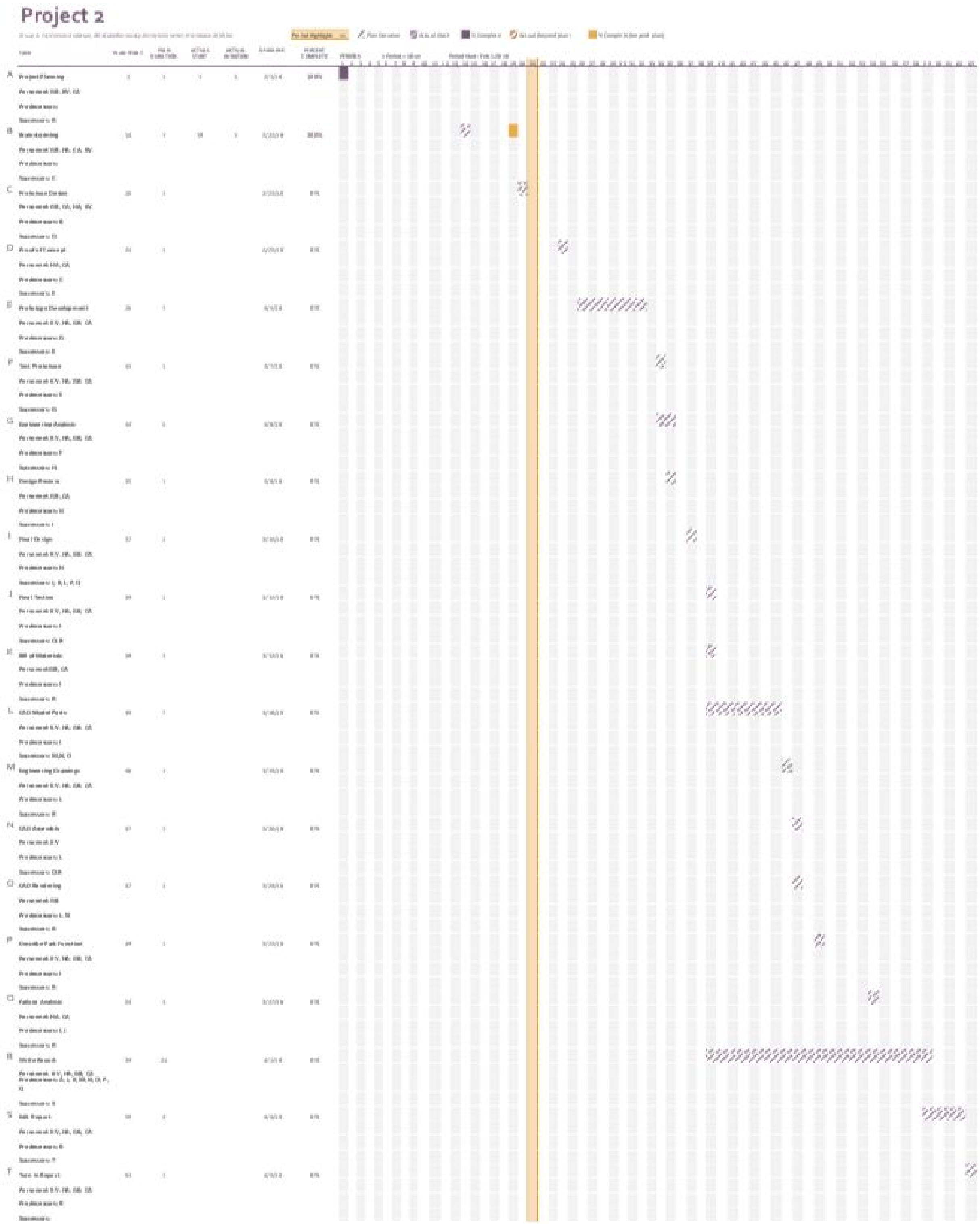


Table 4: It was during week four when we realized our plan was not realistic. It became clear we would have to pick up the pace if we were going to stay on schedule.

Table 5: During week 5, we settled on our line following design. We sketched out original ideas and had a clear path of where we wanted to go with our design.

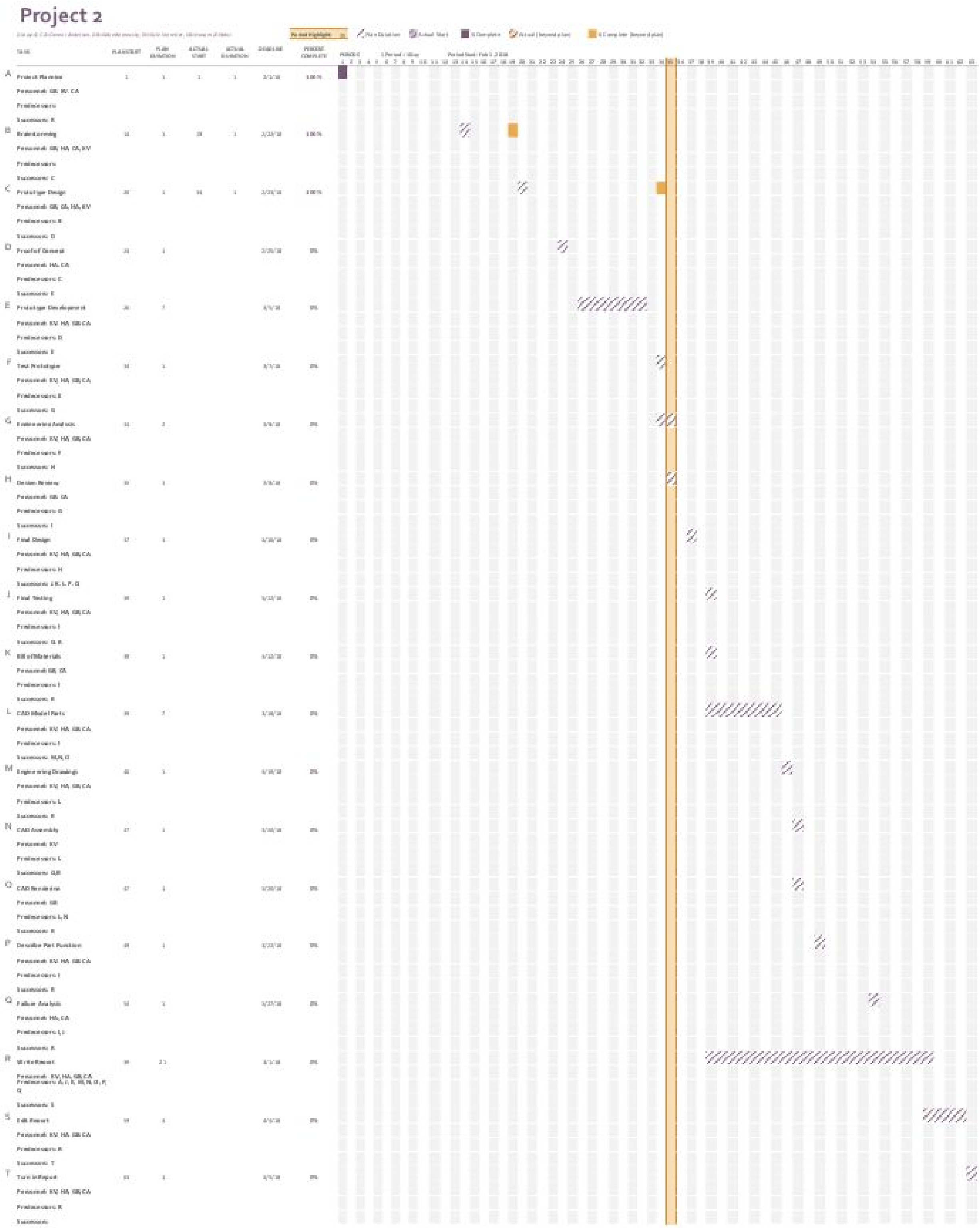


Table 6: During week 6, not much progress was made. We began gathering materials to make our line following car.

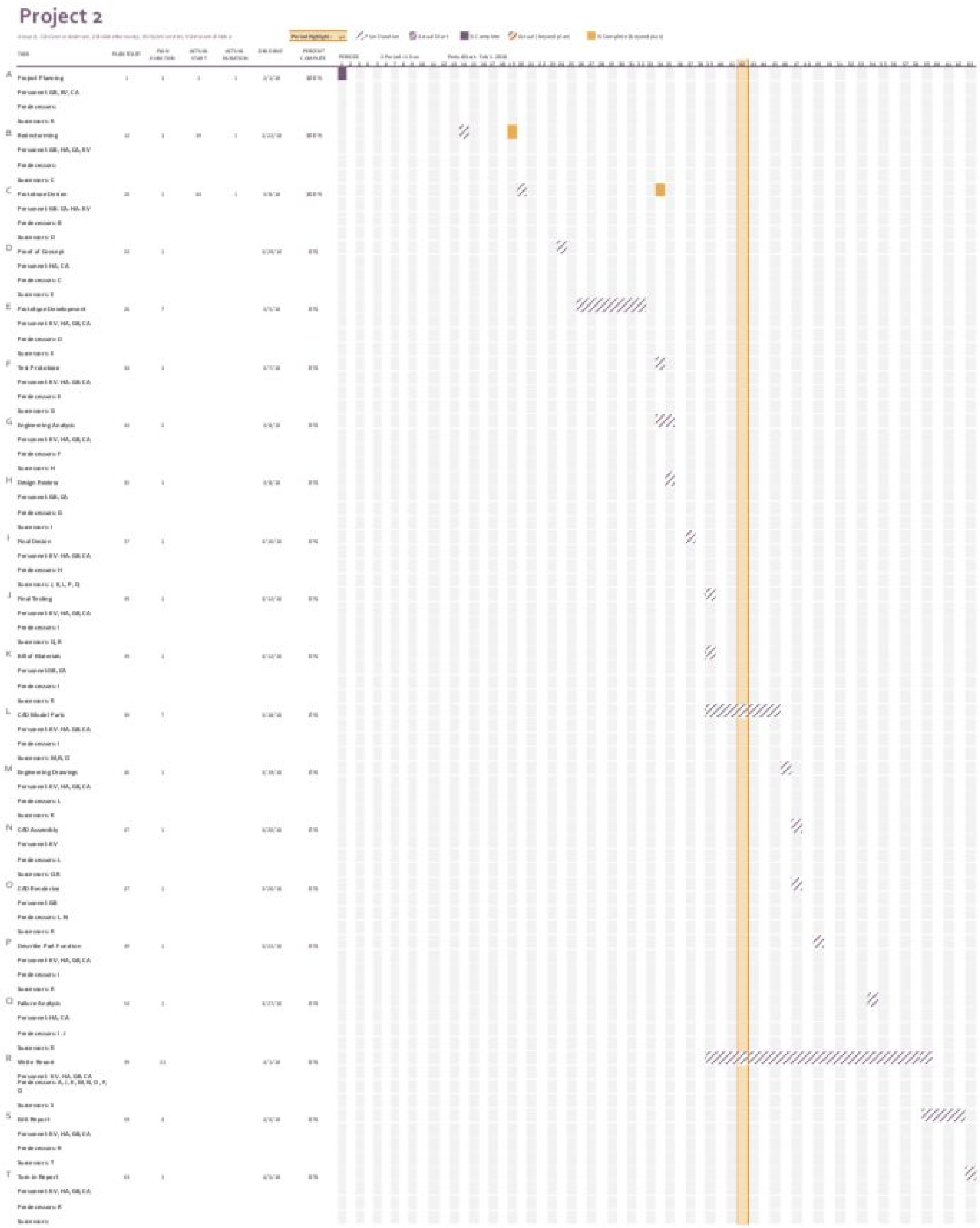


Table 7: During week 7, we began developing our first prototype and proof of concept. The proof of concept, prototype design, and prototype testing were all being completed at the same time.

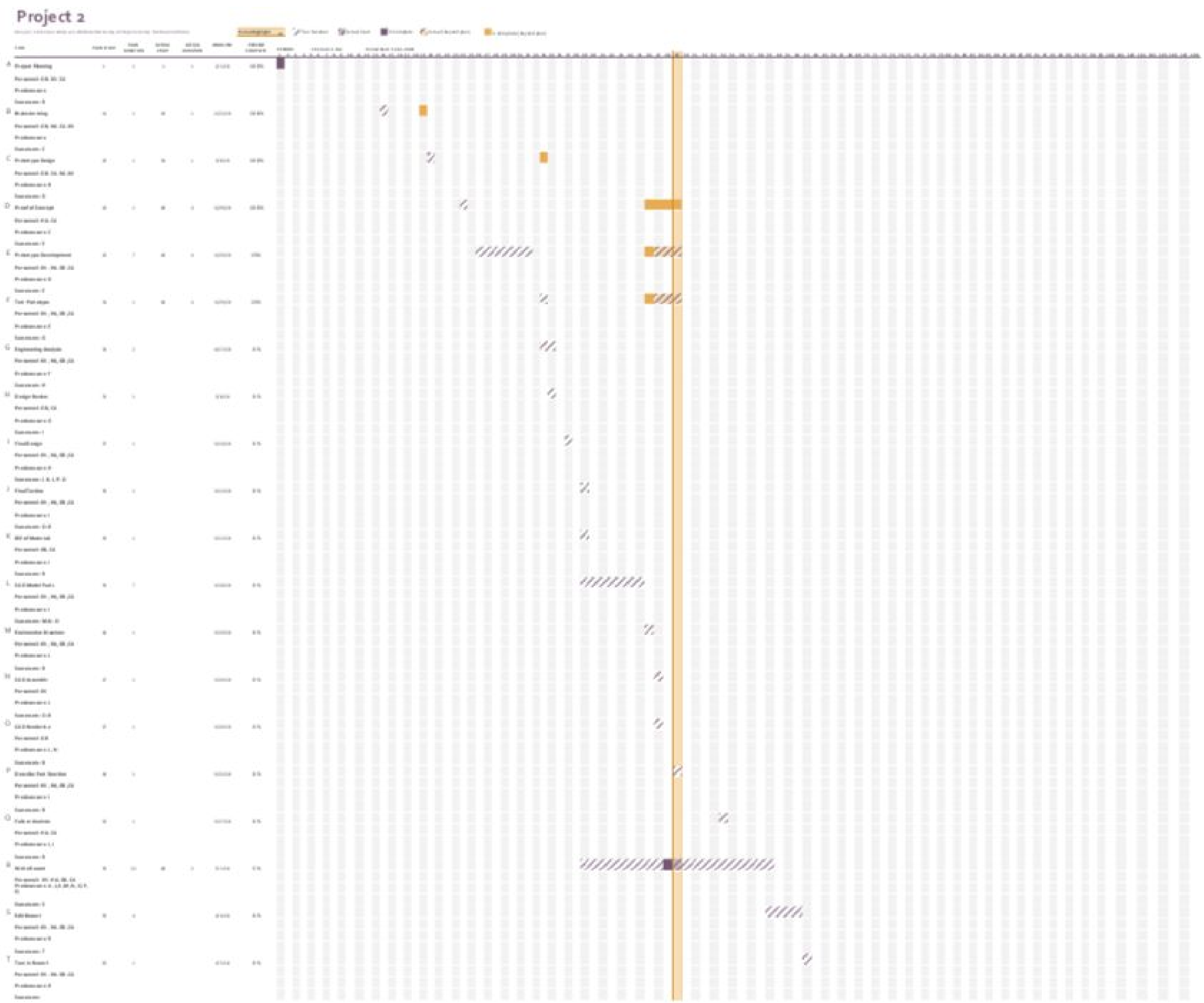


Table 8: During week 8, we improved our original prototype design. We began optimizing our chassis design. We also began writing our report.

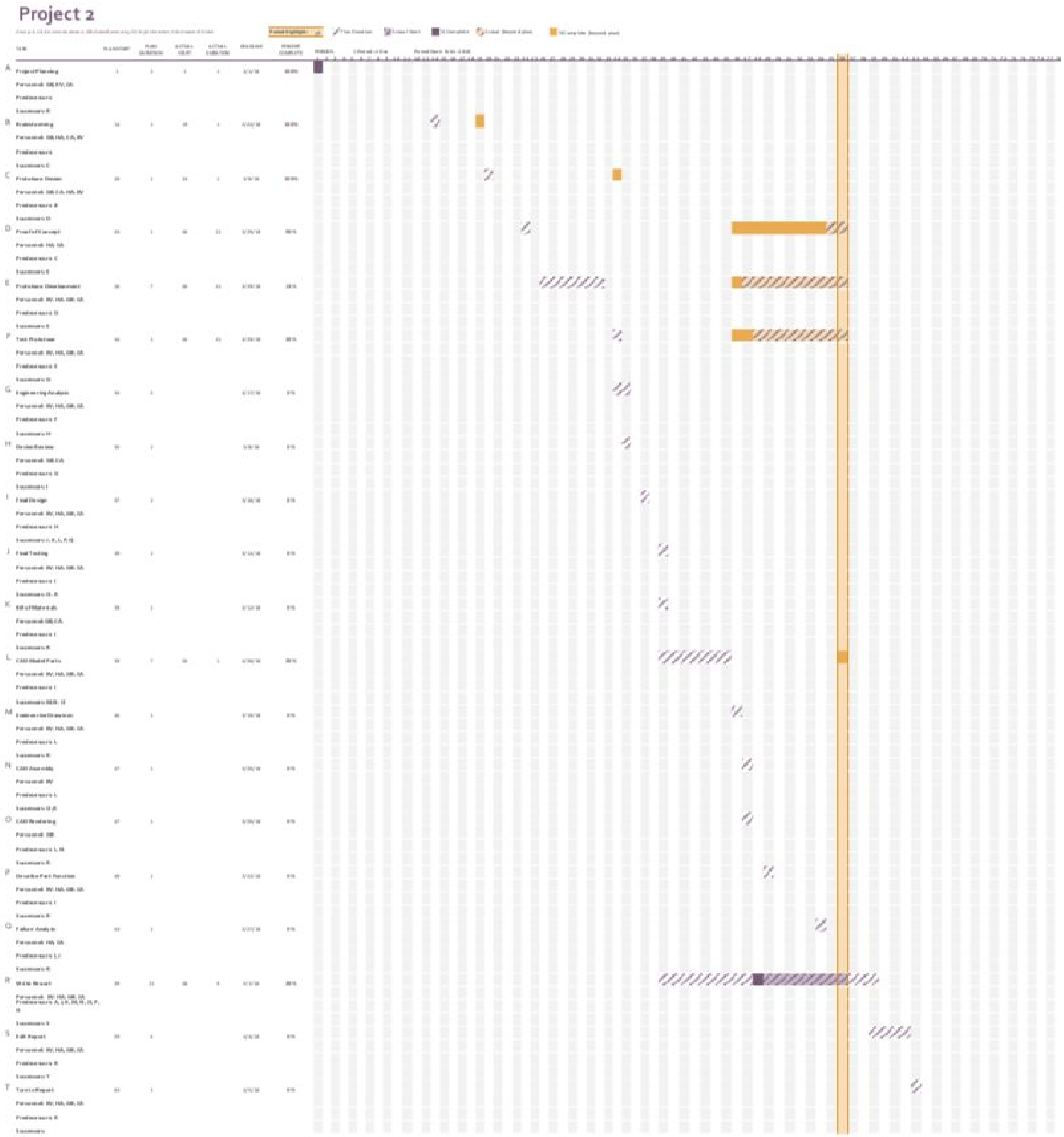


Table 9: During week 9, we continued to improve our chassis and electronics in the steering system. Our proof of concept was complete and we continued to conduct iterative tests throughout prototype development. We also started to model the chassis on Creo.

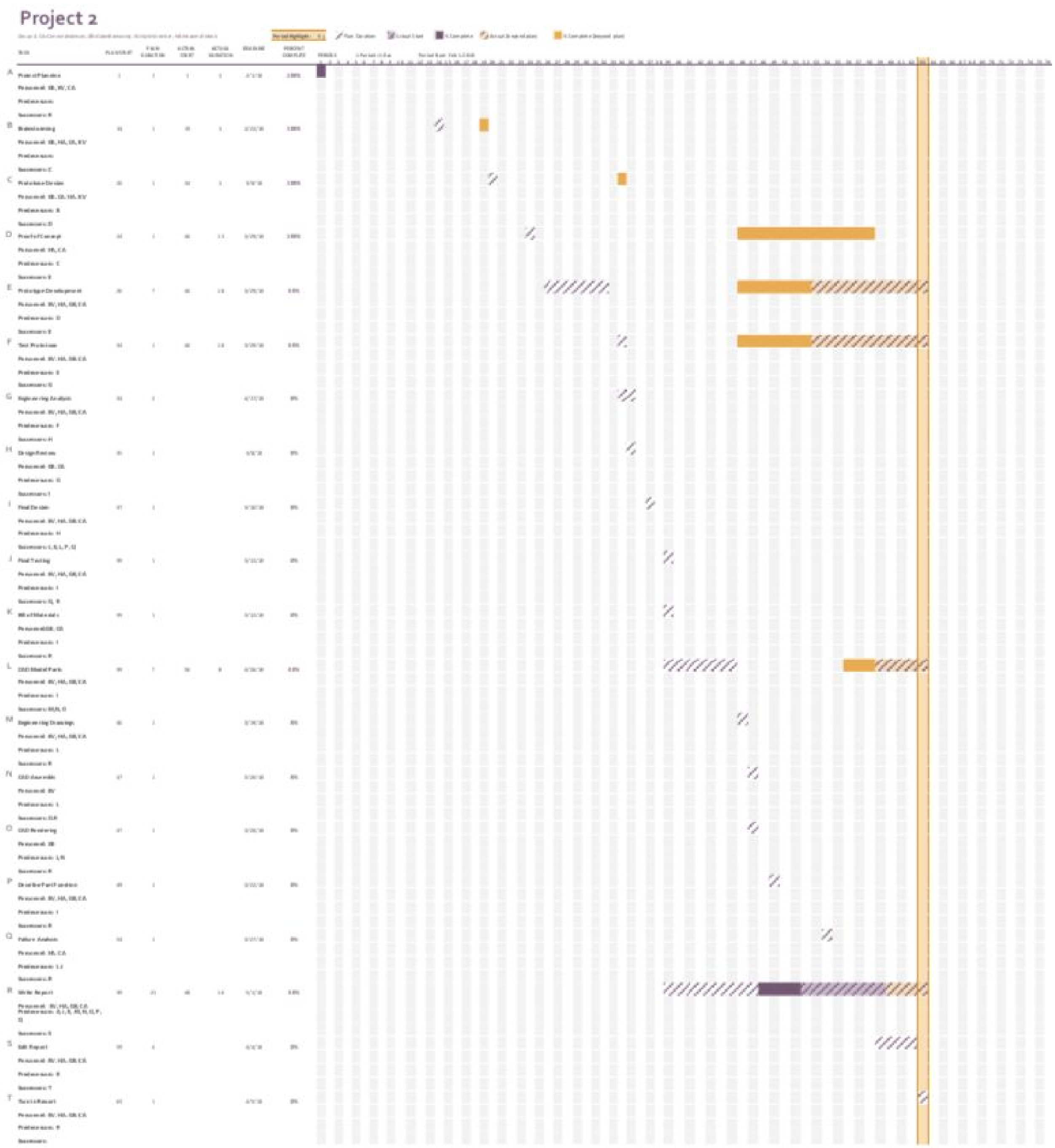


Table 10: During week 10, while still behind our original plan, we kept implementing various improvements to our design. The report was coming along nicely and the bill of materials was complete.

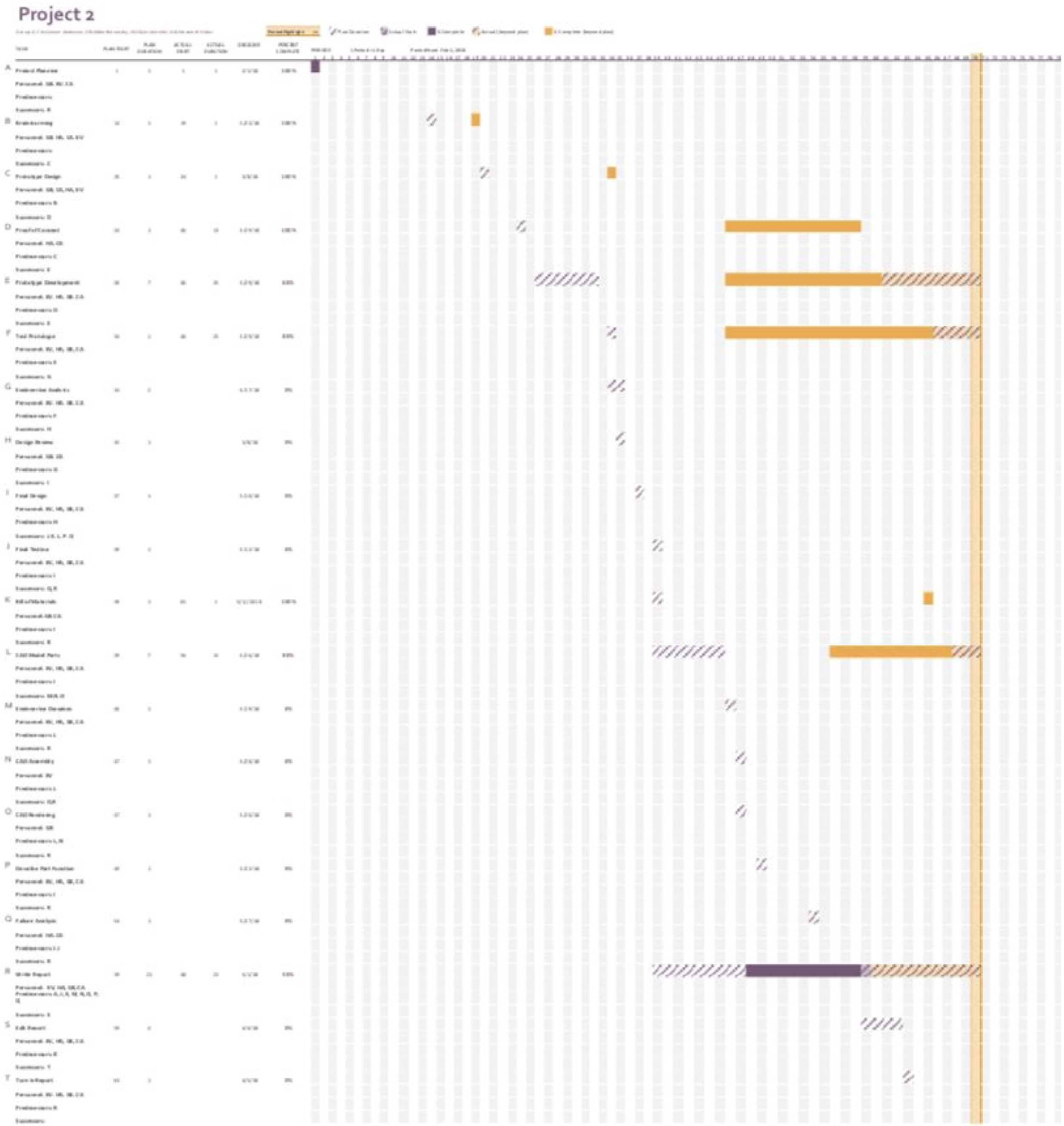


Table 11: During week 11, we were closing in on our final design. We began engineering analysis and describing each part of the design's function.

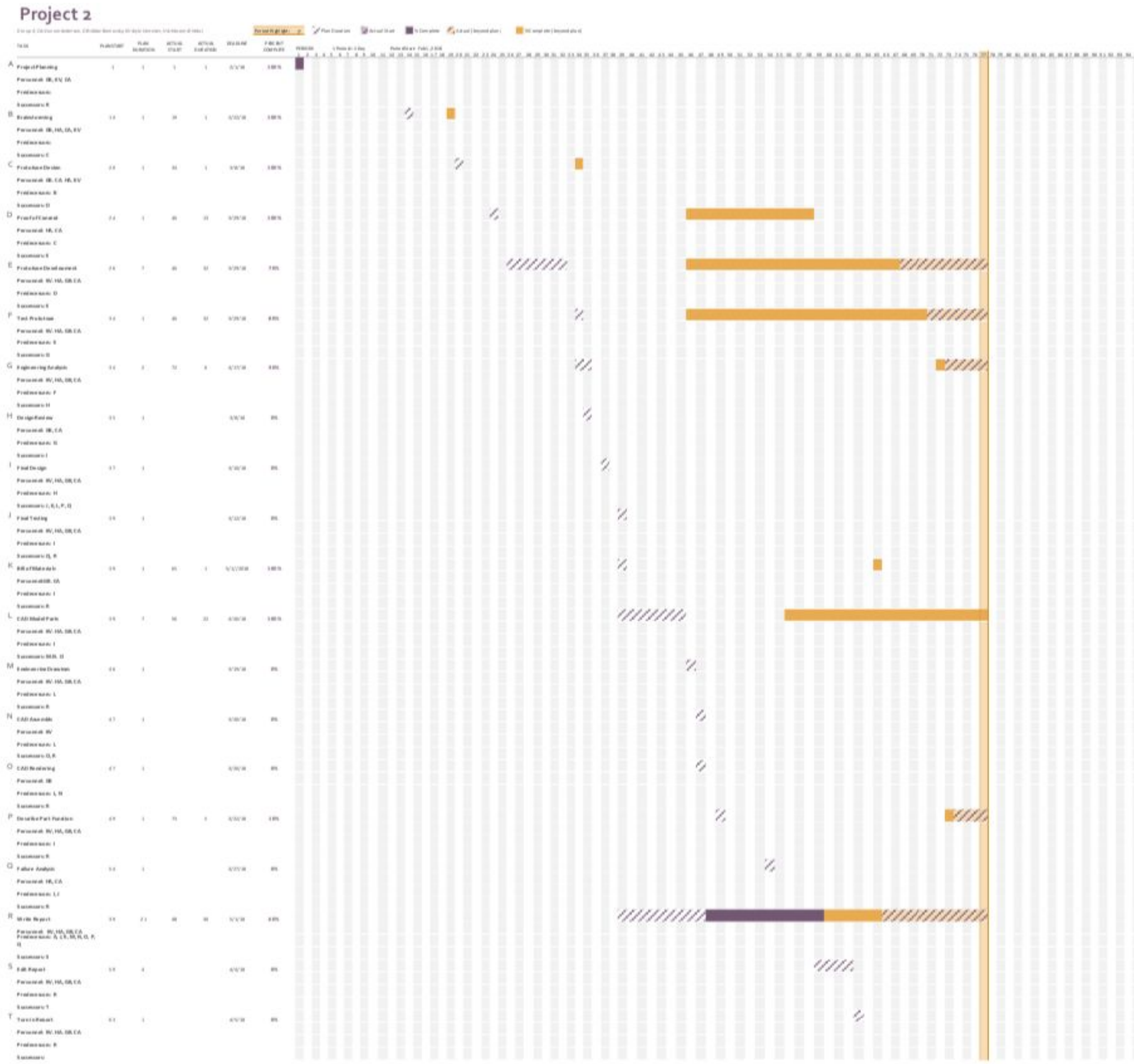


Table 12: During week 12, major design changes were made upon learning of several unavoidable issues, the most egregious being electromagnetic interference. The last half of prototypes were completed during this time.

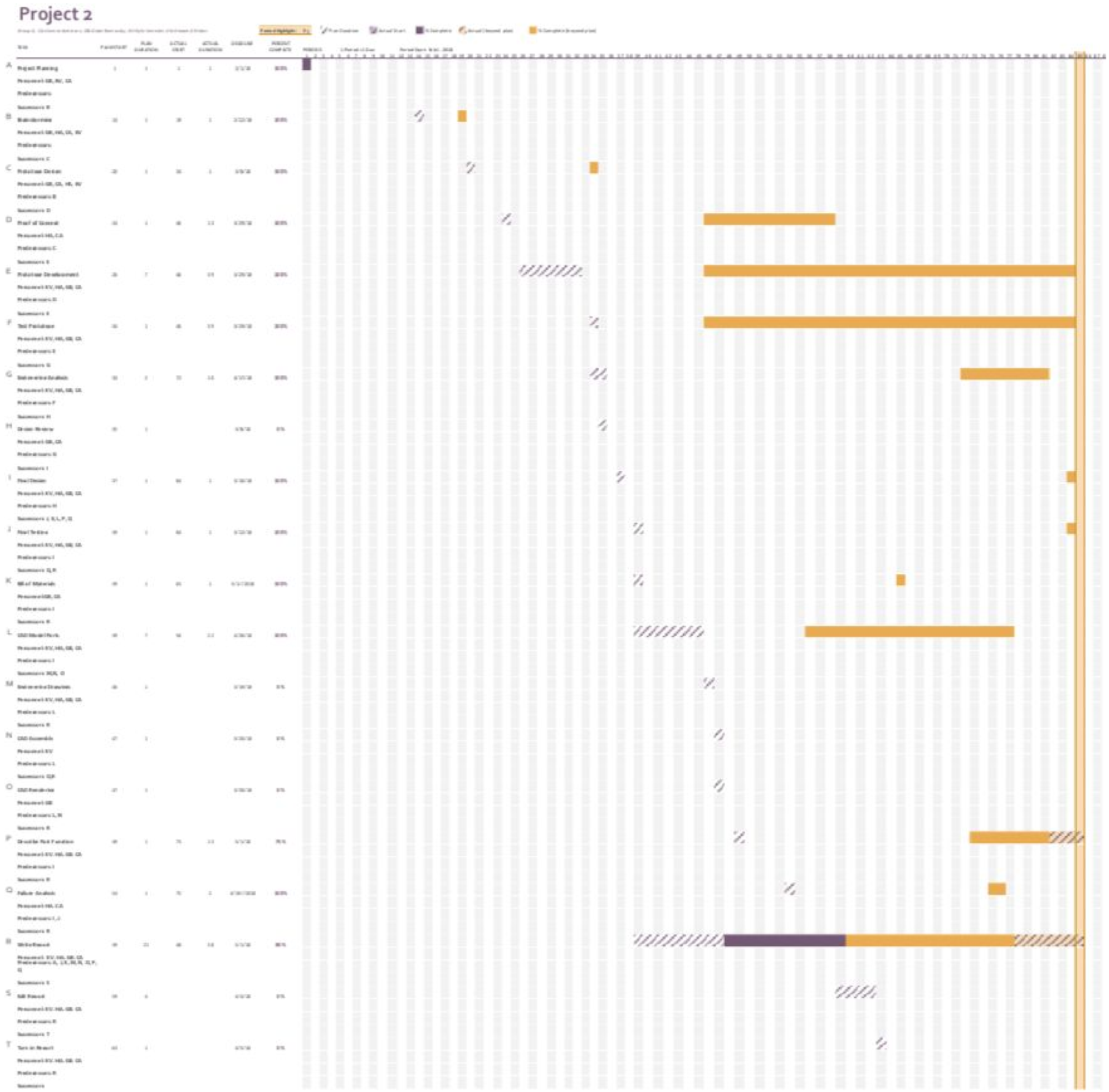
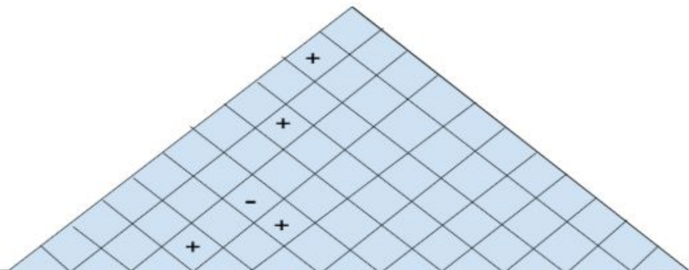


Table 13: During week 13, we were able to shift our focus to the report after the competition. We only had to finalize a few things with the report at this point. Even though we were off schedule, we were still able to complete everything on time.

Specification Development

Quality Function Deployment (QFD)



	Customer				Quality Characteristics (Functional Requirements)											Competitive Analysis (0 = Worst, 5 = Best)							
				Units of Measure	lb	$	ft/sec	V	#	Lb*ft	unitless	#	%	(slug*ft)/sec	#								
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (X)	▲	▼	▲	▲	X	▲	▲	▼	▲	▲	▲								
	Investors	DR. GDOMSKI	Group 4	Demanded Quality (Customer Requirements)	Weight	Total cost	Top speed	Battery voltage	Number of motors	Tourque of motor(s)	The Kinetic friction of wheels	Number of parts	Percentage of successful tests	Withstand impact	Interchangeable parts	Dual motor steering	Slow Destroyer	Wall-Sliding Vehicle (Speed)	1	2	3	4	5
1	45	5	10	Affordable		100										2	3	4		X	$	%	
2	15	0	5	Torque					25			50			25	3	4	2		%	X	$	
3	10	5	5	Easily Replacable								50			50	3	2	4		$	X	%	
4	0	5	15	Speed			75				25					4	1	5	$			X	%
5	10	20	5	Safety				50		25			25			4	2	5		$		%	X
6	5	10	10	Range				50	50							3	4	2		%	X	$	
7	5	15	15	Easily operated								100				3	2	4		$	X	%	
8	0	10	10	Durability	50									50		4	5	3			%	X	$
9	10	30	20	Consistent results									100			5	2	3		$	%		X
10	0	0	5	Programmable		50	25					25				4	2	1	%	$		X	
				Importance Customer 1	0	45	0	15	6.25	2.5	0	17.5	12.5	0	8.75								
				Importance Customer 2	5	5	3.75	15	5	5	1.25	17.5	35	5	2.5								
				Importance Customer 3	5	12.5	12.5	7.5	6.25	1.25	3.75	21.25	21.25	5	3.75								
				Target (Delighted)	2	100	3	12	2	2.5	0.6	50	95%	0.62	15								
				Target (Disgusted)	3	200	1	6	1	1.5	0.3	100	85%	0.36	5								

Quality Function Deployment Reasoning Competitive Analysis

Dual motor steering:

Affordable (2): Having 2 motors and a programmable Arduino will require spending extra money. Also, at least two 9V batteries are required to power the car and will require replacing during competition day.
Torque (3): A dual motor car is essentially a balance between speed and torque. As a result, the vehicle will have an advantage over a solely speed based car.
Easily replicable (3): Due to having two motors and a complex circuit it would be difficult to replace parts if broken or damaged.
Speed (4): Having 2 motors will help in increasing the overall speed of the car. However, due to weight of the car it would be slower than the wall sliding car.
Safety (4): Due to having a complex circuit and two 9V batteries there is a chance of a short happening and that might end up burning the vehicle.
Range (3): As a result of a having two motors and an Arduino most of power will be consumed, and the 9V batteries has a specific capacity and will die after.
Easily operated (3): The Dual motor steering vehicle contains complex circuits which can be easily messed up and it will take serious amount of time and effort to restore them to original position.
Durability (4): The dual motor steering vehicle will have high torque and weight which will help it stay on course.
Consistent results (5): The Dual motor steering car will have consistent results, since each lap it will have the same speed and will take the same route each time (in the middle of the track).
Programmable (5): The core idea of the dual motor steering car is based on having a program that makes each motor run at different speed while turning.

Slow Destroyer:

Affordable (3): The Slow Destroyer contains multiple traps and a strong, torque oriented motor that is powered by two 9V batteries. The components listed above will make the slow destroyer less affordable.
Torque (4): The Slow destroyer mostly depends on a high torque motor. However, this will result in a very slow car and if the opponent's car can dodge the attacks they will win.
Easily replaceable (2): The slow destroyer contains more than one trap and sharp materials sticking from the otter body. As a result, it will be very hard to replace any parts if destroyed or damaged.

Speed (1): Speed and torque are inversely proportional. The slow destroyer is run by a high torque motor, this will result in a slow vehicle.
Safety (2): Safety of a product to the customer is necessary requirement when building it. The slow destroyer is made up from sharp ends and a high torque motor. As a result, the safety of this product is minimal.
Range (4): Range is necessary if considering the car wasn't able to destroy the opponent's car in the time required. As a result, we placed two 9 volt batteries in parallel to maximize voltage to the motors during the three minutes.
Easily operated (2): An easily operable vehicle will be more appealing to the customer due to no previous knowledge or collaboration needed. However, the Slow Destroyer needs maintenance before each run and might not even start some of the time.
Durability (5): Durability is an appealing factor that customers search for in their product. The materials used to build the Slow Destroyer will offer durability to the car. For example, the car chassis is built from Hardened steel and it has a ramp placed on the front and back sides to flip opponents' cars.
Consistent results (2): The sole purpose of the slow destroyer is to destroy the opponent's car. However, if the opposing vehicle managed to move away from the attacks that will result in a complete failure.
Programmable (2): There is no need to attach an Arduino to the Slow Destroyer since it would be hard program it to find the opponent car and destroy it. Also, if it was programmable that will increase the price.

Wall-Sliding Vehicle (Speed):

Affordable (4): The price of a product is what costumer's first look at before going to the other specifications. The Wall Sliding Vehicle is made from light material (plastic ABS) and one DC motor to run it. As a result, it would be the cheapest of the three types of cars listed above.
Torque (2): High torque is a must when trying to push something heavy at low speed. However, the wall sliding vehicle is only speed based and built from light materials. As a result, minimum torque is required.
Easily replaceable (4): Customers tend to worry if something goes wrong with the car and if the dealer offers spare parts that replace the damaged ones. The wall sliding vehicle is made up from simple parts that can be easily exchanged when damaged.
Speed (5): Depending on the costumer, speed might be key factor when competing with other opponents. The wall slider operates solely by a high RPM DC motor and a lightweight chassis. As a result, speed will be maximum.
Safety (5): Safety of a product to the customer is a necessary requirement when building it. The wall sliding has minimal risk due to the low voltage in the circuits and the lightweight chassis.

Range (2): The range of the wall sliding vehicle is minimal due to the low capacity of the batteries (one 9V battery)
Easily operated (4): An easily operable vehicle will be more appealing to the customer since no previous knowledge or collaboration is needed to run it. The wall sliding vehicle can be easily operated through a switch and it doesn't require calibration or maintenance between each run.
Durability (3): Durability is an appealing factor that customers search for in their product. Due to the light weighted material used the Wall Sliding Vehicle won't be able to withstand damage taken from the outside.
Consistent results (3): Consistent results might be most important customer function of all. It can be achieved with testing and remodeling the product. The wall Sliding vehicle can achieve consistent results if it does not suffer from any inflicted damage.
Programmable (1): The Wall sliding vehicle depends only on using the side walls as guidance. As a result, there is no need to have a programmable Arduino attached to it.

Target Values

Maximum weight of vehicle:

Delighted (2lb): We chose this value since having a light car will help meet our customer's requirements.

Disgusted (3 lb): The maximum weight that the car could have is three pounds and if it was more, customers will not be pleased.

Total Cost:

Delighted ($100): Having the total cost less than 100 dollars will help in the sales of the car.

Disgusted ($200): If the total cost is more than 200 dollars the product will not be appealing to our customers.

Top speed:

Delighted (10 ft/sec): Having a fast car will help our customers in achieving the goal they desire.

Disgusted (2 ft/sec): Looking at the QFD all of our customers appreciate having a fast car.

Battery Voltage:

Delighted (12V): Having a high voltage battery will help in delivering optimum power to the DC motor.

Disgusted (6V**):** A six volt battery won't deliver the required power to run the DC motor at full speed.

Number of Motors:

Delighted (2): Having two DC motors will offer the required speed and torque to the vehicle.

Disgusted (1): We choose that having one motor running the vehicle will not meet our customer's basic requirements.

Torque of motor:

Delighted (2.5 lb*ft): Having a (2.5 lb*ft) torque will be able to run the gears and the car smoothly.

Disgusted (1.0 Ib*ft): Having a low torque motor won't be able to run the gears, as a result the car won't be moving.

Kinetic Friction of Wheels:

Delighted (0.6): We chose this number since having high friction will help in moving the car faster and not wasting energy.

Disgusted (0.3): Having a small friction on the wheels will reduce the speed of the car and will waste power.

Number of parts:

Delighted (50): Having fewer parts will decrease the overall weight of the car, and the car can be easily operated by the costumer.

Disgusted (100): We choose this number since most of our customers will find it difficult to operate the car with 100 different parts.

Percentage of successful tests:

Delighted (95%): Having 95 percent of all test run smoothly is our goal.

Disgusted (85%): Our customers will be disgusted if the car only worked 85% of the time.

Withstand Impact:

Delighted (0.62slugs*ft/sec): We chose this value due to the different circumstances that the car might run into.

Disgusted (0.36slugs*ft/sec): We choose this number to be our minimum impact withstanding ability.

Interchangeable parts:

Delighted (15): Having 15 interchangeable parts will help the customers in replacing a damaged part easily.

Disgusted (5): A low number of the interchangeable parts will discourage the customers from buying the product since if any small part gets damaged the whole car needs to be replaced.

Engineering speciation defined:

Battery voltage: The amount of voltage that each battery offers to the motor. More batteries used results in more voltage and current which will affect the RPM of the motor. Also, The type of battery plays a role in the RPM for Motor (e.g.: 1.5 V AA battery vs 9V battery).

Coefficient kinetic friction of wheels: It is basically the value of mu. This is an important function since the coefficient of friction depends only on the type of material that is being used. For example, rubber wheels have a higher coefficient of friction (0.75) compared to wooden wheels (0.5). The friction can be calculated from this formula (F=uN), where N is the normal force and (u) is the coefficient of friction. This function is critical when building the car since it determines how efficiently the wheels are working.

Torque of motor: Torque is basically the amount of force applied on a rotating part. Each motor type has a different torque value and it doesn't depend on the voltage or current supplied, it only depends on how the motor was designed. Knowing the amount of torque required to move the gears and wheels of the car is critical for having a functioning vehicle.

Percentage of successful tests: The amount of tests that are successfully completed in order to have an idea on how reliable the car is. This is the one of the most important functions since it helps in detecting problems that may occur during the actual competition. The car's reliability may be calculated in order to have a better understanding of what parts need to be fixed. The formula is R=(R(function1))*R(function2)….).

Top speed of motor: The top speed of the motor is the number of rotations per minute that the motor completes. Each DC motor has a different RPM, balancing the price of the motor and the RPM is crucial when choosing which motor to pick.

Number of Motors: The number of motors that is required to supply enough torque and power to the car. Calculating how much power the car needs to run at the speed required will help in deciding how many motors are required. More motors doesn't necessarily mean a better car, it will cost more and the car might already be running at full speed with two motors instead of three.

Number of parts: The number of different car parts can play a factor on how easy it is to operate the car.

Withstand impact: The ability of the car to withstand impact when hit by another car. This function is critical when choosing the material of the chassis in order to have maximum impact resistance.

Interchangeable parts: The car with interchangeable parts is more likely to be able to compete easily in the competition, because damage may occur to some parts of the car and having a car built so that parts are easily replaced is essential to win.

Engineering Analysis

For the following calculations, lines in italics denote known values or equations. Lines not in italics show actual calculations.

Battery Life

Battery Charge: $C = 55\ mAh$
Battery Voltage: $V = 11.1V$
Motor Amperage: $I = 1A$
Current Equation: $I = \frac{C}{t}$; $t = \frac{C}{I}$

Scenario 1: One 12V battery
$t = \frac{110mAh}{1A} = .11h = 6.6\ min$
Vehicle can run for approximately 2.2 heats.

Scenario 2: Two 12V batteries in parallel
$t = \frac{220mAh}{1A} = .22h = 13.2\ min$
Vehicle can run for approximately 4.4 heats.

Motor Torque and Power

Battery voltage: V=11.1V
Motor amperage: I=1A
Power equation: $P = V * I$
Torque equation: $P = T * w$; $T = \frac{P}{w}$

Power of motor: $P_{Motor} = (11.1V) * (1A) = 11.1W$
Torque of motor: $T_{Motor} = \frac{11.1w}{2\pi * 200rpm} = 8.833 * 10^{-3}\ N * m * \frac{1.3558\ lb*ft}{1\ N*m} = 0.0198\ lb * ft$

Gear Ratios

Motor rotational speed: $w_M = 200\ rpm$
Large gear radius: $r_l = 1\ in$
Medium gear radius: $r_m = 0.617\ in$
Small gear radius: $r_s = 0.221\ in$
Rear wheel radius: $r_{Wheel} = 0.95\ in$

Angular velocity equation: $w = r_1 v_1 = r_2 v_2$
Rotational speed conversion from rpm to ft/s for rear wheel:
$1\ rpm * \frac{2\pi(.95/12)ft}{1\ rev} * \frac{1\ min}{60\ s} = .00829\ ft/s$
Torque of motor: $T_{Motor} = 0.0198\ lb*ft$

Scenario 1: Maximum Torque - Small Gear to Large Gear

Small gear rotational speed: $w_s = 200\ rpm$
Large gear rotational speed: $w_l = 44.2\ rpm$
Wheel rotational speed: $w_{Wheel} = 44.2\ rpm$
Linear velocity: $v = 0.3664\ ft/s$

Small gear torque: $T_s = 0.0198\ lb*ft$
Large gear torque: $T_l = 0.0896\ lb*ft$
Wheel torque: $T_{Wheel} = 0.0896\ lb*ft$

Scenario 2: Maximum Speed - Large Gear to Small Gear

Large gear rotational speed: $w_l = 200\ rpm$
Small gear rotational speed: $w_s = 905\ rpm$
Wheel rotational speed: $w_s = 905\ rpm$
Linear velocity: $v = 7.502\ ft/s$

Large gear torque: $T_l = 0.0198\ lb*ft$
Small gear torque: $T_s = 0.00438\ lb*ft$
Wheel torque: $T_{Wheel} = 0.00438\ lb*ft$

Scenario 3: Speed Torque Compromise - Large Gear to Medium Gear

Large gear rotational speed: $w_l = 200\ rpm$
Medium gear rotational speed = $w_m = 324\ rpm$
Wheel rotational speed: $w_{Wheel} = 324\ rpm$
Linear velocity: $v = 2.68\ ft/s$

Large gear torque: $T_l = 0.0198\ lb*ft$
Medium gear torque: $T_m = 0.01222\ lb*ft$
Wheel torque: $T_{Wheel} = 0.01222\ lb*ft$

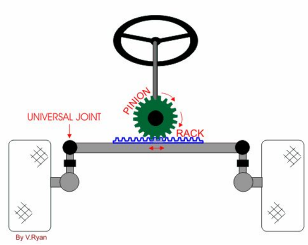
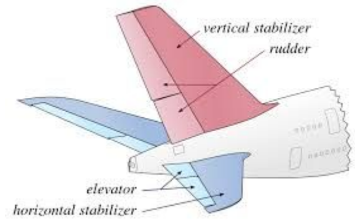
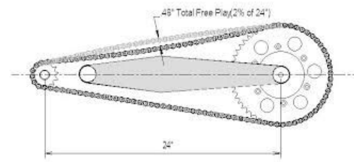
Concept Generation and Selection

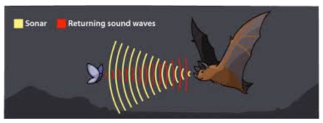
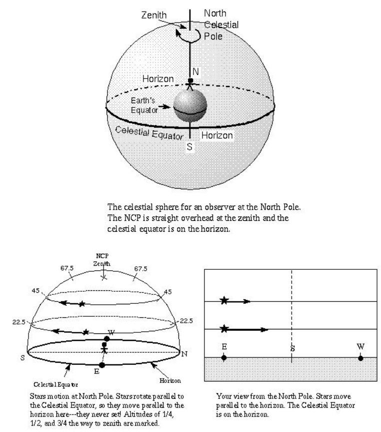
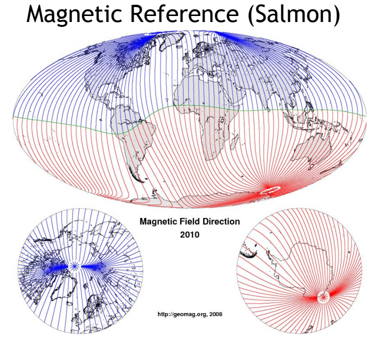
Morphology

Product: Autonomous Vehicle	Organization Name : Vrrrrrrrrrm

Function	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6
Steering	Gear and Bar	Varying speed in wheels	Wall sliding	Air bursts	Stop and rotate with arms	Leaning
Drive	DC motor	Air pressure	Propeller	Wind up	Rubber Bands	Slither
Withstand Collisions	Rubber Bumpers	Hardened steel	Cow catcher	Spears	3D printed shielding	Chicken Wire
Decapacitation	Sticky Trap	Mouse Trap	Spike Strip	Road Block	Wall of shaving cream	Expanding Blockade
Wheels	Honeycomb Wheels	Tank Treads	Lego Wheels	Spikes on wheels	Hamster Ball	Rubber wheels
Guidance	Light Sensors	Slide along wall	Timing	Infrared	Echolocation	GPS
Chassis	3D Print	Aluminium	Wood	Rubber	Honeycomb	Carbon Fiber

Team member: Connor [redacted]	Team member: Gabe Baranovsky	Prepared by: All Members	
Team member: Husam [redacted]	Team member: Kyle [redacted]	Checked by: Gabe Baranovsky	Approved by: Connor [redacted]

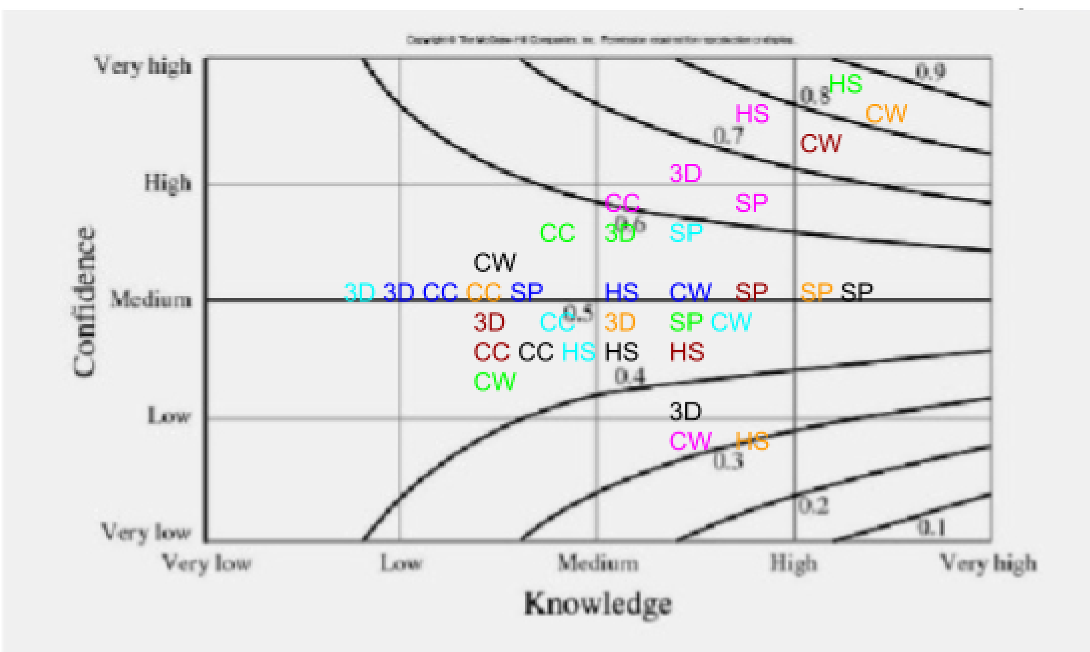
Analogies			
Function	Idea 1	Idea 2	Idea 3
Steering	Car Steering 	Motorcycle Leaning 	Rudder (Airplane or Sail boat) 
Drive	Horse and Buggy 	Military Tanks 	Motorcycle (one wheel driven )
Withstand Collisions	Armadillo Armor 	Cars Crumple on impact (Absorbs Impact) 	Turtle shell 
Decapacitation	Squid Releasing Ink 	Hedgehog 	Mouse Trap 
Wheels	Humvee tires	Four or Two Legged Animals	Hamster Ball

			
Guidance	Bats Echolocation 	External reference (North Star) 	Magnetic Reference (Salmon) 
Chassis	Skeleton 	Building Foundation 	Bike Frame 

Brainwriting				
Function	Husam	Connor	Kyle	Gabe
Steering	Idea 1: four wheel drive Idea 2: different speeds for each wheel Idea 3: air brusts	1: Gears and Bar 2: Vary motor speed 3: Wall guidance	1:Steering wheel 2:Motorized axle connected to guidance system 3:Drive shaft	1: Rack and pinion 2: Slide on walls 3:Solenoid
Drive	Idea 1: use a motor based of RPM Speed Idea 2: add more than one motor Idea 3: air pressure	1: DC Motor 2: Compressed Air 3: Propellers	1:Wind up 2:Motor 3:Magnets	1: DC Motor and battery 2: Compressed air and sail 3: Magnets
Withstand Collisions	Idea 1:flexible material Idea 2: increase the mass Idea 3: make the sides of the car more resistant	1: Bumpers 2: Springs 3: Plating/Shield	1:Snow Plow on front of vehicle 2:Slanted sides 3:Low center of gravity	1:Cowcatcher (all around) 2: Hardened steel outer 3: Cushy ring (around vehicle) to absorb impact
Decapacitation	Idea 1: magnetic pull Idea 2: other car block Idea 3: car flip	1: Sticky drops 2: Roadblock 3: Launching ramp	1:Detachable sticky trap 2:Chassis is shaped like a ramp and when opposing vehicle runs up ramp, platform springs up, launching other vehicle off track 3:Spring loaded pick axe shaped device	1: Rat traps 2: Roadblock 3: Spike strip 4: Thick gel/ shaving cream
Wheels	Idea 1: lego Idea 2: more mm size Idea 3: rubber based	1: Treds 2: Rubber wheels 3: 4 Legs	1:Rubber Wheels 2:Treads (for extra stability) 3:Instead of wheels, entire chassis is hamster ball	1: LEGO 2: Hollow honeycomb 3:rubber 4: Spiked outer (small surface area)
Guidance	Idea 1: light sensors Idea 2: stick on walls Idea 3:	1: Light sensors 2: Timing 3: Wall guide	1:light sensors reading black lines 2:GPS 3:Sensors reading distance to walls on the sides	1: Sonar 2: Teach it the track 3: Light sensor
Chassis	Idea 1: aluminum Idea 2: carbon fibre Idea 3: heat treated steel	1: Wood 2: Aluminum 3: Hamster Ball	1:Aluminum base 2:Hamster ball 3:Chassis in between two big wheels	1: Lego 2: Aluminium 3:

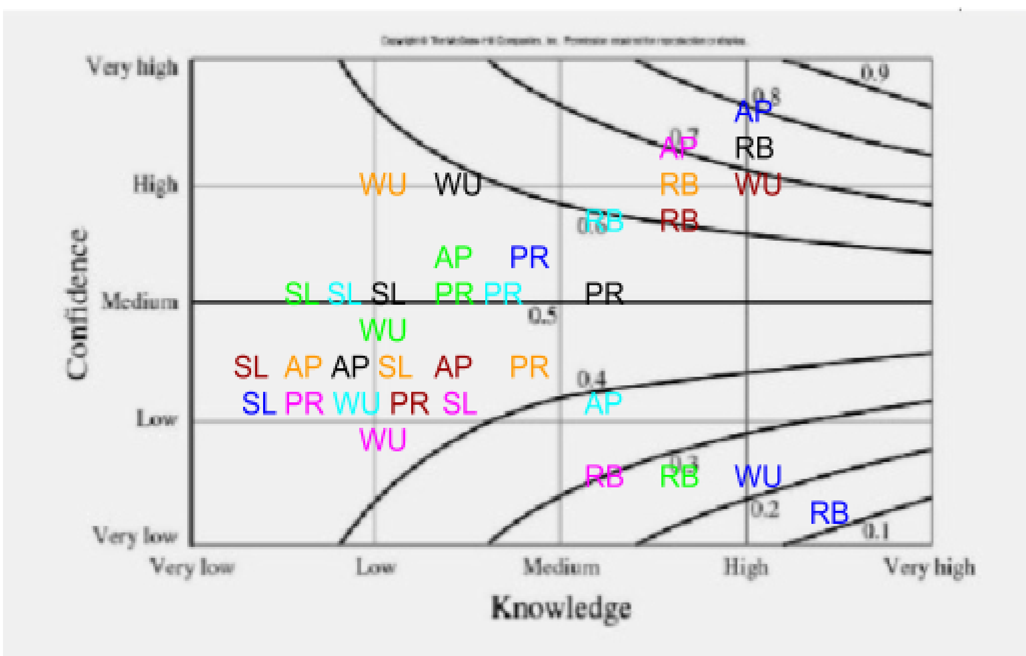
Withstand Collisions

Project Criteria							
Issue: Withstand Collision		Base line Rubber Bumpers	Hardened steel	Cow Catcher	Spears	3D printed shielding	Chicken wire
Manufacturability	25%	0	-1	-1	0	-1	1
Weight	10%	0	-1	0	0	-1	1
Cost	5%	0	-1	-1	0	-1	0
Durability/Longevity	20%	0	1	1	-1	1	-1
Replaceability	10%	0	-1	-1	1	0	0
Increase Speed	5%	0	0	0	0	0	0
Reliability	25%	0	1	1	0	1	-1
Weighted Score			-5	5	-10	5	-10



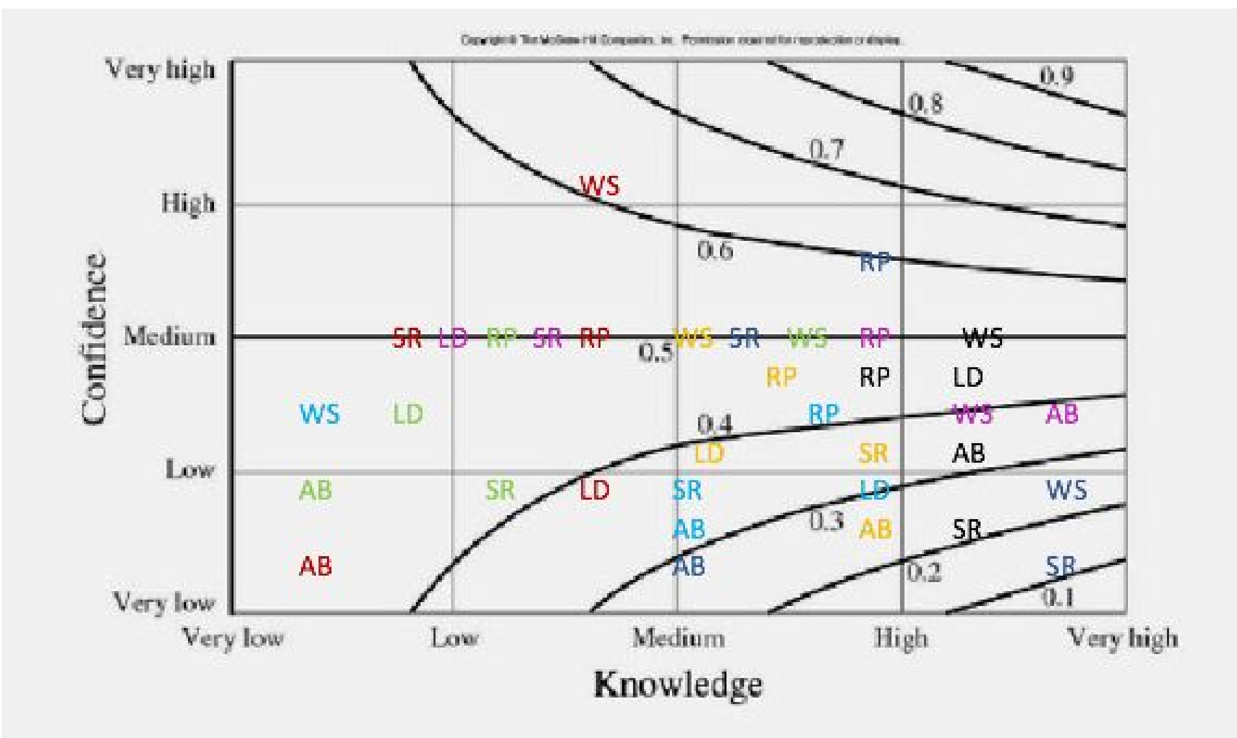
Drive

Project Criteria								
Issue: Drive			Base line DC Motor	Air pressure	Propeller	Wind up	Rubber Bands	Slither
Manufacturability	●	25%	0	-1	-1	1	1	-1
Weight	●	10%	0	-1	-1	1	1	-1
Cost	●	5%	0	-1	0	1	1	0
Durability/Longevity	●	20%	0	1	0	-1	-1	0
Replaceability	●	10%	0	-1	0	-1	1	0
Increase Speed	●	5%	0	1	0	-1	-1	-1
Reliability	●	25%	0	-1	-1	-1	-1	-1
Weighted Score				-50	-60	-20	0	-65



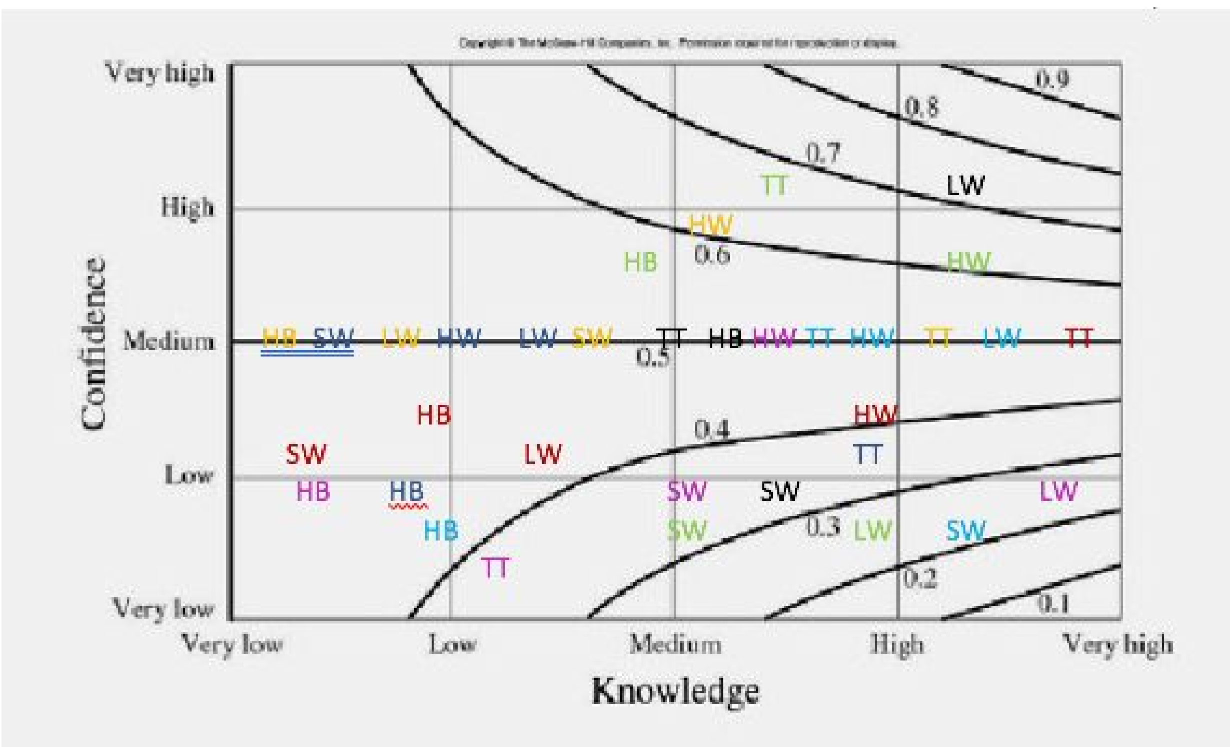
Steering

Project Criteria								
Issue: Steering			Base Line Speed Variability	Rack and Pinion	Wall Sliding	Air Bursts	Stop and Rotate	Leaning Device
Manufacturability	●	25%	0	0	1	-1	0	-1
Weight	●	10%	0	-1	0	-1	-1	-1
Cost	●	5%	0	-1	0	-1	-1	-1
Durability/Longevity	●	20%	0	0	0	-1	-1	-1
Replaceability	●	10%	0	-1	-1	-1	-1	-1
Increase Speed	●	5%	0	1	-1	-1	-1	0
Reliability	●	25%	0	0	-1	-1	0	0
Weighted Score				-20	-25	-100	-50	-75



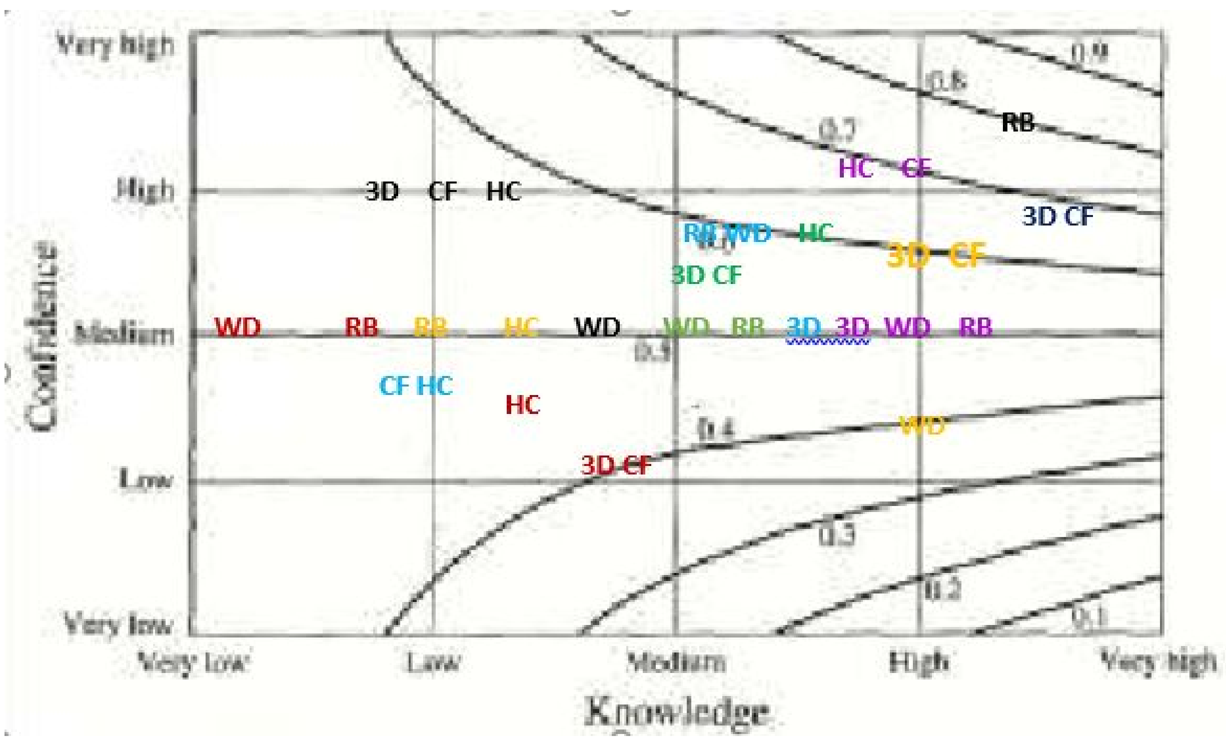
Wheels

Project Criteria								
Issue: Wheels			Base Line Rubber Wheels	Tank Treads	Lego Wheels	Spikes on Wheels	Hamster Ball	Honeycomb Wheels
Manufacturability	●	25%	0	0	-1	-1	-1	-1
Weight	●	10%	0	0	0	0	0	1
Cost	●	5%	0	0	1	-1	0	-1
Durability/Longevity	●	20%	0	1	-1	-1	1	1
Replaceability	●	10%	0	0	0	-1	-1	0
Increase Speed	●	5%	0	-1	0	0	-1	0
Reliability	●	25%	0	-1	-1	-1	-1	0
Weighted Score				-10	-60	-85	-45	0



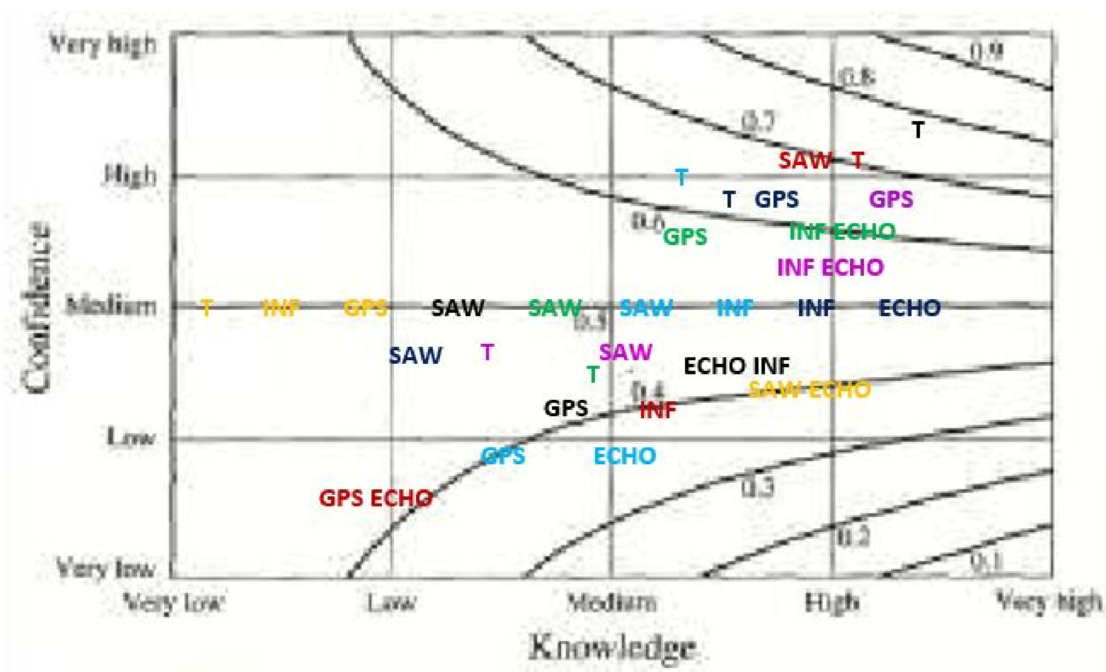
Chassis

Project Criteria							
Issue: Chassis		Base line Aluminium	3D print	Carbon Fiber	Woo d	Rubber	Honeycomb
Manufacturability	25%	0	-1	-1	0	0	-1
Weight	10%	0	1	1	-1	0	0
Cost	5%	0	-1	-1	0	1	-1
Durability/Longevity	20%	0	1	1	0	0	1
Replaceability	10%	0	0	-1	1	1	-1
Increase Speed	5%	0	1	1	0	1	1
Reliability	25%	0	0	1	0	0	1
Weighted Score			5	20	0	20	10



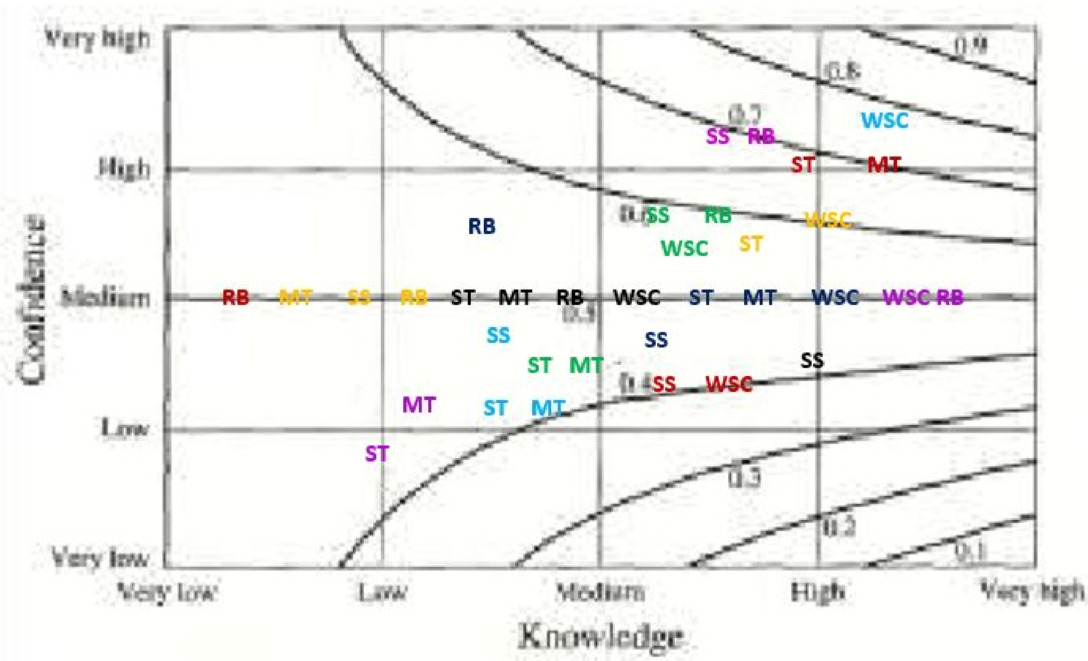
Guidance

Project Criteria							
		Base line					
Issue: Guidance		Light Sensors	Slide Along Wall	Timing	Infrared	Echolocation	GPS
Manufacturability	25%	0	1	1	-1	-1	-1
Weight	10%	0	-1	0	0	-1	0
Cost	5%	0	0	1	-1	-1	-1
Durability/Longevity	20%	0	0	-1	1	1	1
Replaceability	10%	0	0	1	0	-1	-1
Increase Speed	5%	0	-1	1	0	0	1
Reliability	25%	0	-1	-1	1	1	1
Weighted Score			-15	0	15	-5	10



Decapacitation

Project Criteria								
			Base line					
Issue: Decapacitation			Expanding Blockade	Sticky Trap	Mouse Trap	Spike Strip	Road Block	Wall Shaving Cream
Manufacturability		25%	0	1	1	-1	0	-1
Weight		10%	0	1	0	0	0	1
Cost		5%	0	0	0	-1	0	0
Durability/Longevity		20%	0	-1	-1	1	1	1
Replaceability		10%	0	-1	-1	-1	0	1
Increase Speed		5%	0	0	0	-1	-1	0
Reliability		25%	0	-1	-1	1	1	0
Weighted Score				-20	-30	0	40	15



Brainstorming

Each team member was assigned to come up with at least 3 concepts for the car. The way that it was done that for each function of the car (steering, drive, etc.) a concept was generated by each team member in order to have the most ideas. The list below is for six of the most important concepts generated and the pros and cons for each one.

Vary Motor Speed for Steering:

Instead of having a rack and pinion to steer the wheels, each wheel has its own motor that varies speed from wheel to wheel.

Pros:

·Making faster laps since the car will make sharper turns in order to save time.

·Maximizing the speed due to there being four times the output.

Cons:

·Very difficult to code each motor to change speeds based for each curve.

·Will increase the weight and cost of the car.

·Requires significant amount of voltage and current to run.

Magnetic pull for Decapitation:

Using a magnet to destroy other cars or push them off course.

Pros:

·Easily move the other cars out of the way.

·No need to have the car move fast, since the opponent will eventually be disabled.

Cons:

·If the opponent car is made from a non-magnetic material the car will fail to pull them

·Will add serious weight to the car, because in order to pull another car that weighs almost 3 pounds a massive magnet is required.

Light Sensor for Guidance:

The racecourse is marked with black paint down the middle of the track. We can use the black paint as a guidance so that the light sensors in the bottom of the car can identify where it is on the track.

Pros:

·Having constant speed laps.

·Doesn't cost or weight much.

·Even if got hit, the car will automatically go back to course.

Cons:

·Hard to code the car to detect the black light.

·The nature of the course room might play a factor to the light sensor (how is the brightness in the room).

·Will take longer turns since it doesn't use the path to make sharp turns.

Carbon Fiber as Chassis:

Instead of using wood or plastic as the chassis for the car, we could use Carbon Fiber.

Pros:

·Very light and strong material.

·Easily shaped using CNC machine.

·Long term performance.

Cons:

·Expensive.

·Hard to replace.

Sonar Rays For Guidance:

Attach proximity sensors in the front and the back of the car to guide it through the course.

Pros:

·Able to make faster turns.

·The Sensors will be able to detect the other car and stop it from crashing into them.

Cons:

·Will require much time and effort to make it work.

·Other noise can interfere with the sensors.

Cushy Ring for Withstanding Collisions:

Attach a ring of metal spikes around the car to protect the car from Damage.

Pros:

·Offer great protection from potential damage.

·Destroy opponent's car in a short amount of time.

Cons:

·Will add a significant amount of weight.

·The laps will be much slower since the turn radius will be high because of the spikes.

Morphology Chart Defined:

Steering:

Gear and Bar: Use a gear and bar for steering
Varying Speed in Wheels: Having the front and back wheels run in different speeds so that the car rotates.
Wall Sliding: Making the car body contact the nearest wall for steering and saving time.
Air Bursts: Attaching compressed air and using bursts to steer the car.
Leaning: Depend on the walls for steering.

Drive

DC Motor: Using a DC Motor to power the car.
Air Pressure: Using air bursts that will propel the car forwards.
Wind Up: Pulling the car back then it will lunch forward due potential energy.
Rubber Bands: Using the energy stored when stretching rubber bands to run the car.
Slither: Use a snake type of movement.

Withstand Collisions

Rubber Bumpers: Attach rubber Bumpers to the chassis to protect it.
Hardened Steel: Attach a hard steel part to the chassis for extra protection.
Cow Catcher: Remove the other car by throwing them outside the course.
Spears: Attach pointy spears to the chassis for additional protection.
3D Printed Shielding: Print a 3D shield that will offer protection.
Chicken Wire: Wrap the car with chicken wire for more protection.

Decapitation

Sticky Trap: Using a sticky trap to trap opponent's car.
Mouse Trap: Using a mouse trap on opponent's car.
Spike Strip: Making a spike strip on the car body to damage opponents car.
Road Block: Using the car to provide road blockage for opponent's car.
Wall of Shaving Cream: Using wall of shaving to make opponent's car slippery.
Expanding Blockade: Making the car in way that the body expands after the start to block the opponent's car.

Wheels

Honeycomb Wheels: Making the wheels in a honeycomb way for extra protection.
Tank Treads: Using tank treads instead of regular wheels.
Lego Wheels: Using Lego wheels for the vehicle since they are light.

Spikes on Wheels: Attaching spikes to the wheels for and extra layer of protection.
Hamster Ball: Using a Hamster ball instead of normal wheels.
Rubber Wheels: Having rubber wheels since they are light and provide more friction.

Guidance:

Light Sensors: Attaching light sensors that will detect if the car is off path.
Slide Along the Wall: Make the vehicle slide along the wall for guidance (distance sensor).
Timing: Timing the vehicle so that it makes turns in the based on predetermined timing.
Infrared: Using infrared light to guide the car.
Echolocation: Using an Echolocation mechanism to guide the car.
GPS: Attaching an antenna to the car that will provide exact location coordinates for guidance.

Chassis:

3D Print: Modeled and 3D printed a Chassis.
Aluminum: Use Aluminum as chassis for the car since it light, hard, easily modified.
Wood: Use wood as a chassis for the vehicle since it is cheap and easy to modify.
Rubber: A rubber based Chassis will help in absorbing the impact of collisions.
Honeycomb: A Honeycomb chassis that will be able to withstand collisions.
Carbon Fiber: Expensive, but will provide protection and very light.

Device Description

Design Goal

This was our goal for the final design.

Steering

Overview: Our device steers using a rack and pinion. A pinion gear is mounted on the servo, and a rack is mounted on the front axle. When the servo turns, the pinion gear pushes the front axle to the side which angles the tie rods. This angles the wheels, turning the car.

Front Wheels (4): The front wheels control the steering of the car. The wheels are controlled using a servo and a rack and pinion steering mechanism. These work to rotate the front wheels left and right which turns the car. They rotate freely around the individual wheel axles.

Servo (10): The servo is mounted vertically in the center of the chassis. Since the servo can turn between 0° and 180°, the front wheels being pointed straight is defined as 90°, or neutral. When the servo receives a left turn signal from the guidance system, the servo turns to 50°, with a right turn signal resulting in a turn to 130°.

Medium Pinion Gear (11): A medium pinion gear is mounted to the servo output. The gear is meshed with a rack that is fastened to the front axle.

Rack (12): The rack is mounted on the front axle and has teeth that interlock with the teeth of the medium pinion gear. When the servo rotates, it rotates the medium pinion gear. The rack slides horizontally when the medium pinion gear rotates.

Front Axle (13): The front rack is glued onto the front axle, so when the rack slides left and right, the axle does as well. The ends of the axle are connected to the front of the tie rods.

Tie Rod (15): The tie rod is attached to the tie rod support and the front axle and connects to the individual wheel axle. It pivots about the tie rod support when the front axle slides back and forth which changes the angle of the individual wheel axles.

Individual Wheel Axle (16): The individual wheel axle is connected to the front wheel and tie rod. Since the individual wheel axle is rigidly attached to the tie rod, when the tie rod rotates, the individual wheel axle does as well. This causes the wheel attached to the tie rod axle to rotate.

9V Battery (23): Two 9V batteries connected in parallel power the servo.

Electrical Tape (25): The electrical tape is used to secure the connection between wires and batteries and to fasten the arduino and breadboard to the chassis.

Hot Glue (26): Hot glue is used to connect the front axle to the screw at the front of the tie rod, stop the front wheels from falling off of the individual wheel axles, and secure the servo to the servo stand.

Screw (27): There is a screw in the front and back of the tie rod to help secure it to the tie rod support and front axle.

Metal Washer (28): The metal washer is placed between the hot glue and the front wheel so the wheel does not get caught on the glue and has a smooth rotation.

Plastic Washer (29): The plastic washer goes between the tie rod and front wheel on the individual front axle to keep the wheel in place and ensure a smooth rotation.

Metal Nut (31): Metal nuts are used to secure the two screws to each tie rod.

Guidance

Overview: The vehicle is guided by a line follower. The line follower consists of two light sensors mounted to the underside of the chassis. The light sensors on the underside of the chassis detect dimming when the vehicle crosses over the black line. The vehicle then course corrects by steering toward the side of the sensor that detected the dimming.

Arduino (19): The arduino is the interface between the steering and guidance.

Light Sensors (20): The light sensors read the amount of light hitting them and communicate that with the arduino which then gives a command to the servo. The light sensors are positioned on the bottom of the chassis on either side of the servo.

LEDs (21): The LEDs were placed underneath the chassis to provide more light for the light sensors. This helped mitigate the effect that outside lights, such as shadows had on the light sensors. It also increases the contrast between the track and the black line, making it easier for the light sensors to distinguish the difference.

Breadboard (22): The breadboard organizes the wires that connects the arduino, servo, and 9V batteries.

Drive

Overview: The vehicle is driven by a 12V motor. A large drivetrain gear is mounted to the motor and meshed with a medium drivetrain gear that is attached to the rear axle. When driving, the motor runs which turns the gears and spins the rear wheels.

Drivetrain Large Gear (2): The drivetrain large gear is fixed to the motor and its gears are locked with the drivetrain medium gear. When the motor spins, the large drivetrain gear does as well, which also rotates the drivetrain medium gear.

Drivetrain Medium Gear (3): The drivetrain medium gear is glued to the rear axle so that when the drivetrain medium gear rotates, the rear axle also rotates.

Rear Wheels (5): The rear wheels are glued to the rear axle and provide the power to drive the car forward.

Rear Axle (6): The rear axle is spun by the drivetrain medium gears. The rear wheels are locked to it, so that they spin with the rear axle.

12V Motor (7): The 12V motor rotates which spins the drivetrain large gear that is connected to it. This leads to the rear wheels rotating which provides the propulsion for the car.

Sandpaper (18): Sandpaper is wrapped around the rear wheels to increase friction and decrease slipping. This will minimize the power lost due to poor grip.

12V Battery (24): Two 12V batteries are connecting in parallel to power the 12V motor. This is to provide the necessary voltage to run the motor as well as an increased amount of current. Also, this doubles the run time vehicle.

Electrical Tape (25): The electrical tape connects is used to secure the connection between wires and batteries.

Hot Glue (26): Hot glue is used to secure the drivetrain medium gear to the rear axle and the rear wheels to the rear axle to prevent them from rotating freely.

Chassis

Chassis (1): The body of the vehicle that houses the majority of the components.

Motor Stand (8): The motor stand holds the motor in place at the appropriate height so that there is space for both drivetrain gears to fit between the motor and the rear axle.

Zip Ties (9): Zip ties are used to secure the motor to the motor stand and the servo to the servo stand.

Tie Rod Support (14): The tie rod support acts as an axis of rotation about which the tie rod can rotate.

Servo Stand (17): The servo stand holds the servo in place at the appropriate height so that there is space for the pinion gear and rack to mesh above the front axle.

Front Axle Support (31): The front axle support keeps the front axle in the same position while allowing it to rotate freely.

Prototypes

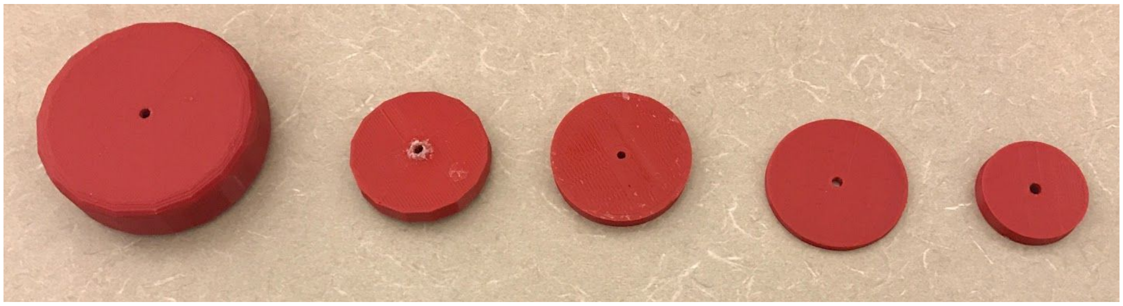


Figure 2: Iterations of 3D printed wheels. The the wheels are lined up from left to right with the left wheel as the oldest design and the right wheel as the newest design. Names from left to right: Big wheel, Polygon wheel, Ideal wheel, Skinny wheel, Small wheel.

Prototype 0: Proof of Concept

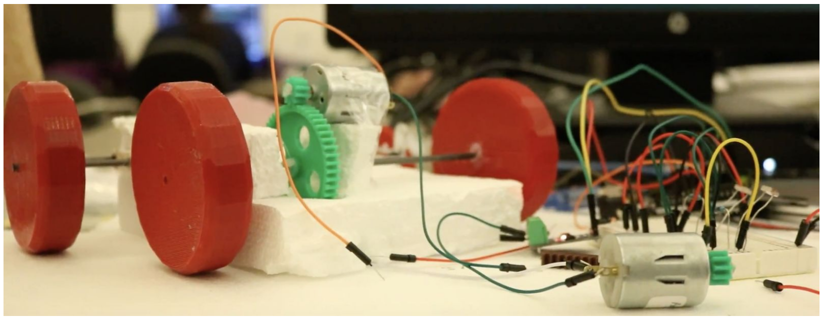


Figure 3: Proof of Concept

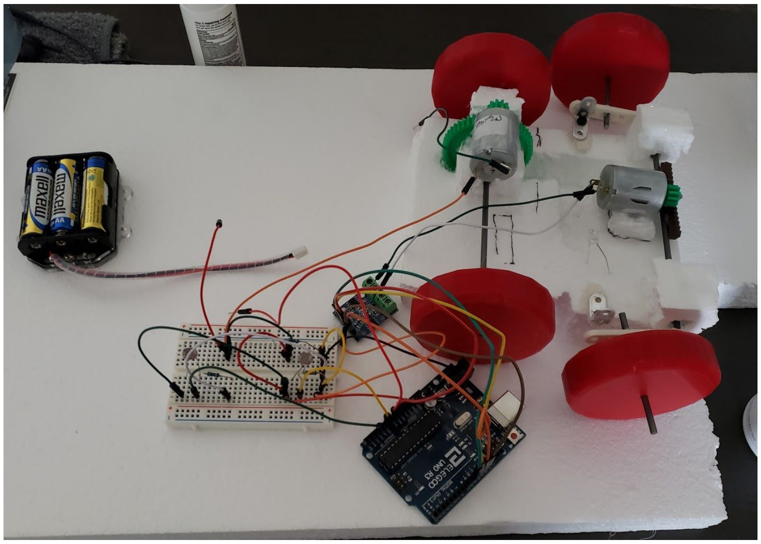


Figure 4: Proof of Concept Top View

The first prototype that we made was a proof of concept that was crudely constructed using styrofoam. The primary goal of this concept was to show that single motor rear wheel drive was an effective method of propulsion and that rack and pinion steering was a realistic way of steering the car. Another goal of our proof of concept was to set up a basic arduino code and wiring that could control the steering. We did not connect the light sensors at this stage, however, we considered the prototype successful since it moved forward when the motor was turned on and the steering could be controlled when the arduino was connected to a computer.

After building the prototype and talking with Josh and Marco at the proof of concept meeting, we decided on making two changes when we constructed our next prototype. First, it was obvious that the large wheels that we 3D printed were much bigger than we needed them to be. They had a diameter of 2.8 inches and a thickness of 0.75 inches. We also noticed that the wheels were not perfectly round, but we thought that this would be an easy fix and that we could solve both problems at once. Since the wheels were too big, we decided to redesign them so they were smaller, and to print the smaller wheels. We also (incorrectly) hypothesized that printing smaller wheels would make it easier for the 3D printer to make them perfectly round.

Marco and Josh suggested the second change, which was to use a servo rather than a motor to control the steering because a servo can rotate a predetermined number of degrees, which would give us more accurate and consistent steering. Kyle had a robotics kit that had two servos in it, so we decided to use one of them. This gave us a good starting point that we could build off of in future iterations.

This prototype was useful in testing and developing an original code. We used a dual H bridge motor controller for two reasons. One is for the ability to run two motors from the arduino and the second reason is that we were able to power both motors externally. The arduino can only supply 5V and a low amount of current, nowhere near what was need to power both batteries. The arduino code operates on the premise of “if this then that”. If the sensors detected a certain light gradient from the track to the black line (if the car was coming away from the black line), it would signal the steering motor through PWM (Pulse Width Modulation) to rotate the rack and pinion to compensate. The code is pictured below **(figure 5).** This code accomplished what it was supposed to but as mentioned above, the small motor did not do a good enough job of bringing the rack and pinion to its neutral position consistently.

```
void setup() {
  // put your setup code here, to run once:
Serial.begin(9600);
pinMode(dir1PinA,OUTPUT);
pinMode(dir2PinA,OUTPUT);

}

void loop() {
  // put your main code here, to run repeatedly:
  photocellReading = analogRead(photocellPin);
  photocellReading2 = analogRead(photocellPin1);
  Serial.print("Analog reading = ");
  Serial.print(photocellReading);     // the raw analog reading
  Serial.print("Analog 2 reading = ");
  Serial.print(photocellReading2);     // the raw analog reading


  if (photocellReading2 > 400 && photocellReading2 < 500) {
    Serial.println(" PC2 Active");
        digitalWrite(dir1PinA, HIGH); // direction = right
        digitalWrite(dir2PinA, LOW);
        delay(750); //delay
        digitalWrite(dir1PinA, LOW); // direction = right
        digitalWrite(dir2PinA, LOW);
        delay(500);
  } else if (photocellReading > 400 && photocellReading < 500) {
    Serial.println("PC1 Active");
        digitalWrite(dir1PinA, LOW); // direction = right
        digitalWrite(dir2PinA, HIGH);
        delay(750);
        digitalWrite(dir1PinA, LOW); // direction = right
        digitalWrite(dir2PinA, LOW);
        delay(500);
  } else {
    Serial.println("Nothing ");
       digitalWrite(dir1PinA, LOW); // direction = right
        digitalWrite(dir2PinA, LOW);
  }
  delay(1000);
```

Figure 5: Arduino Motor Control Code. This is the code that was written when we were planning to use a DC motor to control steering.

Prototype 1: 3D Printed Chassis

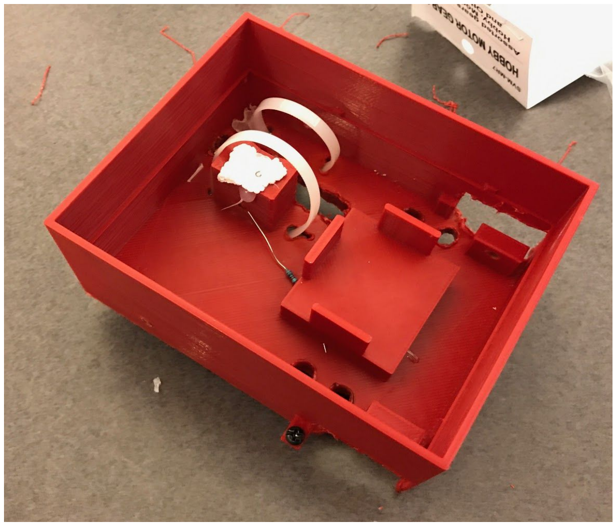


Figure 6: 3D Printed Chassis

We treated protype 1 almost as a second proof of concept. We were not concerned with staying within the 6 inches x 5 inches dimensions. Our main goal for this prototype was to construct a realistic representation of our vehicle and hopefully test the propulsion and steering at the same time. This car was 5 inches x 4 inches and it quickly became apparent that it was going to be far too wide due to the rack and pinion steering system. This chassis was designed for a small to large drivetrain gear in order to maximize torque. We also felt that a wider wheel base would make our vehicle more stable. Another problem we ran into was that when the wheels were turned towards the chassis, the tie rod would hit the car so we decided to integrate wheel wells for the next design.

The next iteration of the wheels we printed was the polygon wheels. They were designed to be circular with a diameter of 1.8 inches and 0.25 inches thick, but printed as 32-sided cylinders. We asked the staff in the Idea2Product Lab and they said we needed to adjust the resolution of the .stl file in Creo.

When fully assembled, it was clear that the 6V motor we had planned on using doesn't provide nearly enough torque. The motor was easily able to turn the wheels through the drive train, however, when the wheels came in contact with the ground the motor instantly stopped. Fortunately, Kyle also had two motors 12V in his robot kit, so we decided to replace the smaller motor with Kyle's motor for the next prototype. Kyle's motor was significantly slower, but had much more torque.

The code was not changed in this iteration since we had to see how it ran when implemented into a chassis. The servo was seated in a servo holder we designed which was intended to be a place where the servo could be secured to the chassis.

This concept worked well and was implemented into further iterations. We currently had no specific place to set our arduino and breadboard, but this was not at the forefront of our concerns.

Prototype 2: Improved 3D Printed Chassis

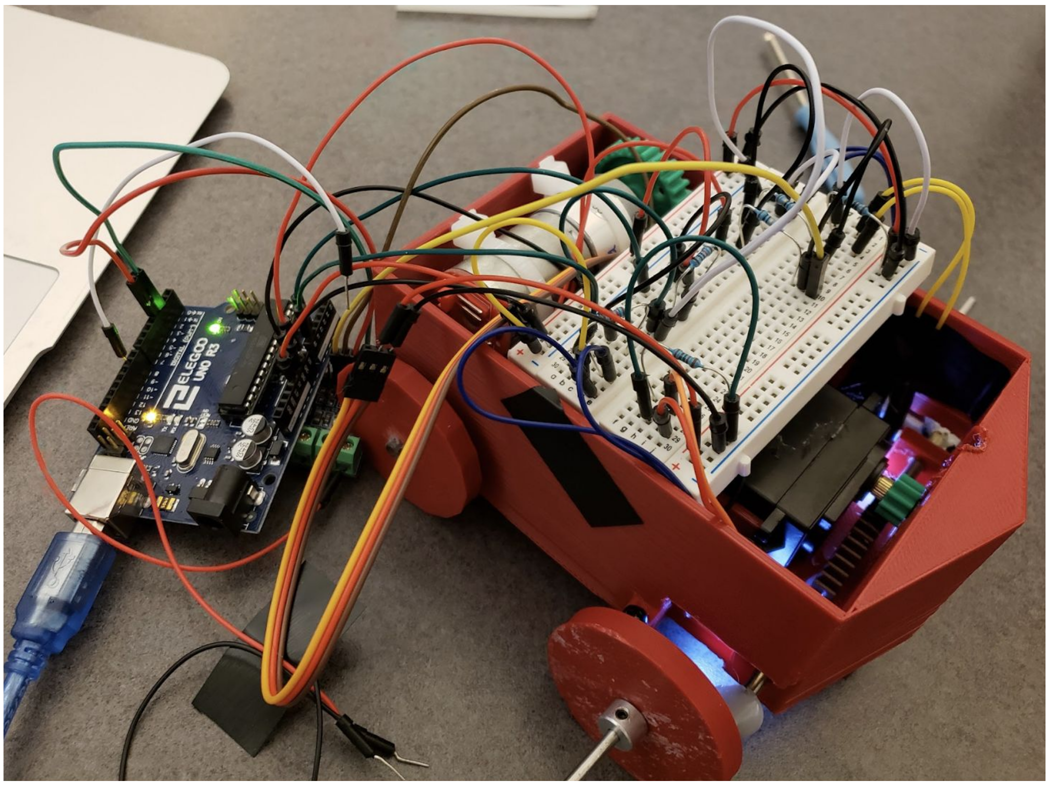


Figure 7: Improved 3D Printed Chassis

Our goal for prototype 2 was to have a functioning vehicle, that was would only require minor changes for our final design. Unfortunately, there were too many problems with this iteration, so we did very little testing before making the appropriate changes and moving onto the next prototype.

This prototype was 5.5 inches x 3.5 inches and included a pointed front to help deflect anything we crashed into to the side of our car. We decided that the motor had plenty of torque, but was slow, so the chassis was designed to fit a medium to medium drivetrain gear. After testing, we decided that this setup was still too slow and to increase the gear ratio on the next prototype. The biggest issue with this design was moving the front axle forward in an attempt to lengthen the wheelbase. The front axle was so close to the front of the car that the screw that holds in the pinion gear and extends outwards would have had to been sticking out of the front of or chassis in order to fit and allow the pinion gear to mesh with the rack. For this prototype we were using a small pinion gear, but thought that it would be better to use a medium pinion gear to ensure that the rack could slide have a full range of motion in both directions to ensure it could steer left and right equally.

We tried printing the wheels again after adjusting the resolution in Creo and printed the Ideal wheels which are the wheels we ended up using on our final design. The Ideal wheels had the same dimensions as the Polygon wheels, but this time they were round.

The basic outline of the code stayed the same as we saw no reason to change its basic function. We did however incorporate code to control the servo rather than the smaller, 6V motor. The servo we used ran at an optimal 4.5V and had high torque, a valuable characteristic. Our servo holder was now built into the printed chassis and again worked well. On this iteration, we started to test the function of our car on the track. The wires, arduino, and breadboard were a mess and there was no place to put them on the car. We ended up resting them on the top of the car while it ran, but it was clear this was a problem that needed to solved.

Prototype 3: Ideal Light Sensor Prototype

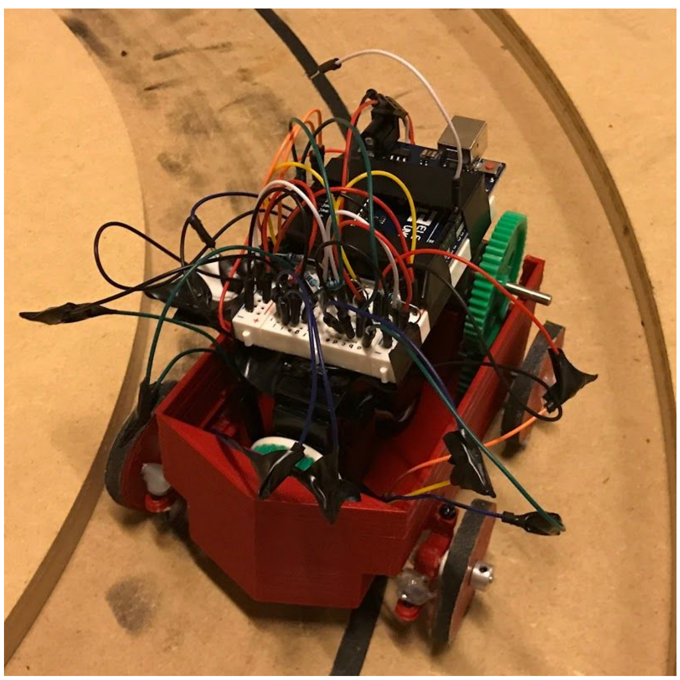


Figure 8: Ideal Light Sensor Prototype

We knew when designing this that we would need significant amount of time to test the electronic components and calibrate them correctly, so when we printed this we hoped it would be our final chassis, which it was. We were happy with the length of prototype 2, but it was still going to be too wide because of the rack and pinion steering system, so this chassis, was 3.25 inches wide.

We changed our gear ratio to have large to medium drivetrain gears in order to increase speed. This meant raising the motor pedestal, so that the gears would fit with the drivetrain.

We wanted to keep our wheelbase long, so we decided to glue our pinion gear to our servo, so we could keep our front axle in the same position. However, we wanted to have our light sensors closer together, so they could be tighter on either side of the black line of the track which we deemed the optimal way to read the line. The servo stand got in the way of this, so we decided to mount it vertically which meant designing a new servo stand.

We were happy with the Ideal wheels, but wanted to ensure we had the best possible design, so we printed two other wheel designs to test as the front wheels. We printed the Skinny wheels, which also had a diameter of 1.8 inches but were only 0.13 inches thick. We designed them to be skinny since we were worried that the car might be out of spec and we knew that having skinny wheels would help. We then realized that we could use thicker wheels and still be in spec, so we designed the Small wheel, so the front of the car would be lower to give the car a lower center of gravity and put the light sensors closer to the track. The Small wheels had a diameter of 1.35 inches and were 0.225 inches thick. We decided that they did not provide any significant benefits and thought it would be best to use the same size wheels for the front and back of the car, so we decided to stick with the Ideal wheels. We wanted to increase the grip of the wheels since we felt that the PLA did not provide enough grip and we knew that having good traction would prevent slipping which would improve speed and turning radius. First we tried wrapping the wheels in electrical tape, but did not feel that it would provide enough grip. Then we tried using the roughest sandpaper we could find since that sandpaper would have the highest coefficient of friction. We bought 220 grit sandpaper and after cutting it into strips, used hot glue to adhere it to all four Ideal wheels. This addition increased the wheels' diameter to 1.9 inches. After feeling the sandpaper and running the car a few times, we were pleased with the amount of grip the sandpaper provided and opted to stick with it.

We were pleased with the way this prototype turned out and the competition was less than one week away, so we hooked up the batteries, arduino, and breadboard and took the car down to the track. After calibrating the light sensors (done by recording readings from when the sensor is on the black line and when its on plain track), we started testing with the hope optimizing the light intensity calibration and tick rate (the rate at which the code checks for light differentials) through trial and error. Unfortunately, sometimes the light sensor would output several outlier values. When a 10kΩ resistor was placed in series with the light sensors and circuit, the light sensors would read a value around 100 when over the track and around 150 when above the black line. However, sometimes it would read a values of about 20 above and below what the value should be. We discussed this problem with

Marco and he said that this was not an uncommon problem and this noise is just an intrinsic property of sensors. He said that using a higher resistance or using a moving average component in our code could reduce noise. As this noise was nowhere near consistent, we figured the moving average equations may be less helpful and not to mention time consuming. We tried using resistances that ranged from 100Ω to 1MΩ to try to pinpoint a optimum resistance for minimizing noise while making the threshold for light and dark readings as far from each other as possible. A 10kΩ resistor seemed to be the right amount of resistance we needed. In order to easily test this noise reducing method, the the light sensors were not secured in the car. When we did eventually secure them, the noise was significantly worse and again became unworkable. The proximity of the servo and the fact that there was a spike in noise when the servo was activated led us to believe that there was electromagnetic interference coming from the servo. We tried researching ways to block or reduce electromagnetic interference, but could not find any realistic solutions to our predicament. Moving the light sensors was not an option either as we were running low on time and it would require a reprint of the chassis. At this point, we decided to abandon using light sensors and instead use timing to drive around the track.

```
#include <Servo.h>
Servo myservo;
int photocellPin = 0;
int photocellReading;
int photocellPin1 = 1;
int photocellReading2;
int dir1PinA = 2;
int dir2PinA = 3;


void setup() {

Serial.begin(19200);
myservo.attach(6);
myservo.write(90);
pinMode(dir1PinA,OUTPUT);
pinMode(dir2PinA,OUTPUT);

}

void loop() {

 delay(010);
        digitalWrite(dir1PinA, HIGH);
        digitalWrite(dir2PinA, LOW);


   photocellReading = analogRead(photocellPin);
  photocellReading2 = analogRead(photocellPin1);
  Serial.print("Analog reading = ");
  Serial.print(photocellReading);
  Serial.print("Analog 2 reading = ");
  Serial.print(photocellReading2);


  if (photocellReading2 > 780 && photocellReading2 < 830) {
    Serial.println(" PC2 Active");
  myservo.write(150);
  delay(800);
  myservo.write(90);
  delay(800);
} else if (photocellReading > 100 && photocellReading < 130) {
  Serial.println("PC1 Active");
   myservo.write(30);
  delay(800);
  myservo.write(100);
}else if (photocellReading > 200 && photocellReading < 250 && photocellReading2 > 550 && photocellReading2 < 700) {
  Serial.println("PC1 Active");
  myservo.write(180);
  delay(500);
  myservo.write(90);
} else {
  Serial.println("Nothing ");

}
delay(10);
```

Figue 9: Arduino Line Following Code

Prototype 4: Timing

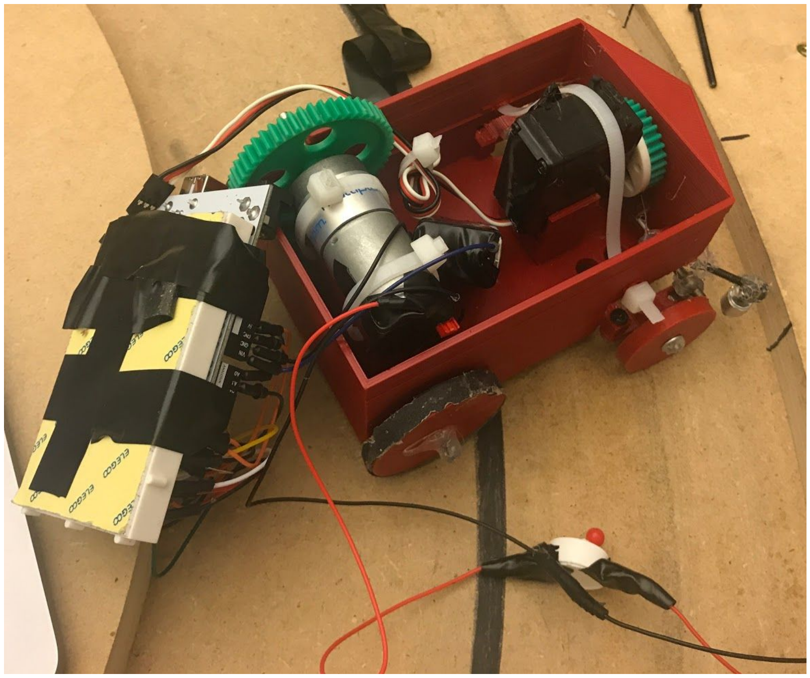


Figure 10: Timing

The transition from using light sensors to timing was fairly simple. The only physical change we originally made was removing the LEDs and light sensors. Connor wrote a new code, but it was very simple, and, after some research on Arduino forums, it took less than an hour to write. Our plan was to have the code say to turn left, then straight, and then right all for a set amount of time and then loop. We could then have two different, but mirrored codes, and flip a different switch to indicate which one to run which would account for our starting direction (the code is shown below in figure ?). Our plan was to use trial and error to adjust the code until it was perfect. However, we struggled to receive consistent results because our battery was small, so it could run out of power quickly. We found that as the battery started to run low, the car got slower, and surprisingly, its minimum turning radius increased. We realized that a three minute race was too long for the battery to run while outputting consistent power, which meant that it would be difficult to time the car precisely enough to stay on course. Another issue with timing is that if there was a collision it would either change the speed or direction which could throw off the timing enough to crash the car and ruin the race. We realized that we should attach rollers to the front of the car in order to widen our margin of error to account for power loss or a collision. As we continued testing we started relying on wall sliding more and more. We realized that timing would be faster than wall sliding because we could have the car take turns on the inside which shortens the distance travelled, but that it would not make a significant difference and the lost time was unlikely to cost us a race. We also started thinking more seriously about the downsides of timing (short battery life led to inconsistent speed and turning radius and a collision could lead to timing causing us to crash and lose the race) that we had previously discussed. After weighing the pros and cons we decided against using timing and to fully commit to wall sliding.

```
#include <Servo.h>
Servo myservo;
int photocellPin = 0;
int photocellReading;
int photocellPin1 = 1;
int photocellReading2;
int dir1PinA = 2;
int dir2PinA = 3;


void setup() {

Serial.begin(19200);
myservo.attach(6);
myservo.write(90);
pinMode(dir1PinA,OUTPUT);
pinMode(dir2PinA,OUTPUT);
delay(3000);
}

void loop() {




    myservo.write(60);
    delay(2800);
     myservo.write(150);
    delay(6000);
     myservo.write(90);
    delay(2500);
     myservo.write(40);
    delay(5000);
}
```

Figue 11: Arduino Timing Code

Prototype 5: Wall Sliding

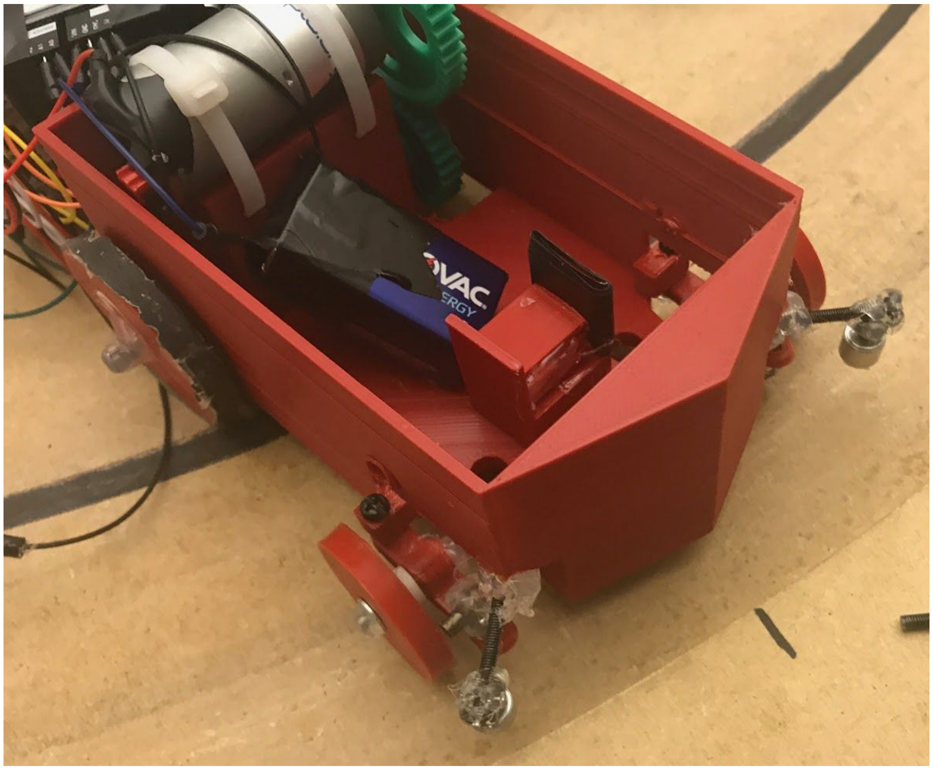


Figure 12: Wall Sliding

We decided to keep the servo attached with the pinion gear meshed to the rack in order to lock the wheels in the forwards position. When we started testing with this setup we realized that there was a problem. During right turns, when the left side of the car was sliding against the left wall, it would drift left when it came out of the turn and crash into the corner at the intersection. This was not an issue on left turns so we tested to see if the car had a tendency to drift left. It seemed to, after setting it down and turning it on a few times, drive pretty straight every time. We concluded that there was an issue with the left side of the car. We noticed that the right side of the rear axle cleared the wall, but the hot glue on the left side of the rear axle would catch on the wall and rotate the car to collide with the intersection. We removed the glue and glued the left wheel back on the rear axle without using any glue on the outside of the wheel. After testing again it was clear that our solution was unsuccessful.

The next theory we came up with was that the sliders were at different angles and that having the left slider as far out from the side of the car as possible would change the angle at which the car contacted the wall, reducing drag between the wall and rear wheel which would stop the car from drifting left. The problem with this solution was that the car was approximately 4.9 inches wide with the current setup and making the left slider perpendicular to the side of the car would make the car out of specifications. We decided to try to diagnose the problem and bring the car back within the acceptable dimensions after we figured out the solution to the problem. It seemed to help, but the car could only make it through the intersection about 20% of the time which was nowhere near good enough for the fast-approaching competition. We thought that we could solve two problems at once by bringing the wheels closer to the body. The hope was that this would reduce drag between the rear wheels and side wall and allow us to bring the rollers closer to the body, which would give the additional benefit of bringing the car within spec. We moved the rear wheels much closer to the chassis. However, we could not move the front wheels any closer because they would hit the rollers. We asked why we needed four wheels and a steering system if we were not going to use steering, so we gutted the steering system. We removed the servo along with the pinion, servo stand, rack, and tie rod. We then needed to place a wheel in the middle of the chassis, to turn the car into a three-wheeler.

Prototype 6: One Wheel in Front

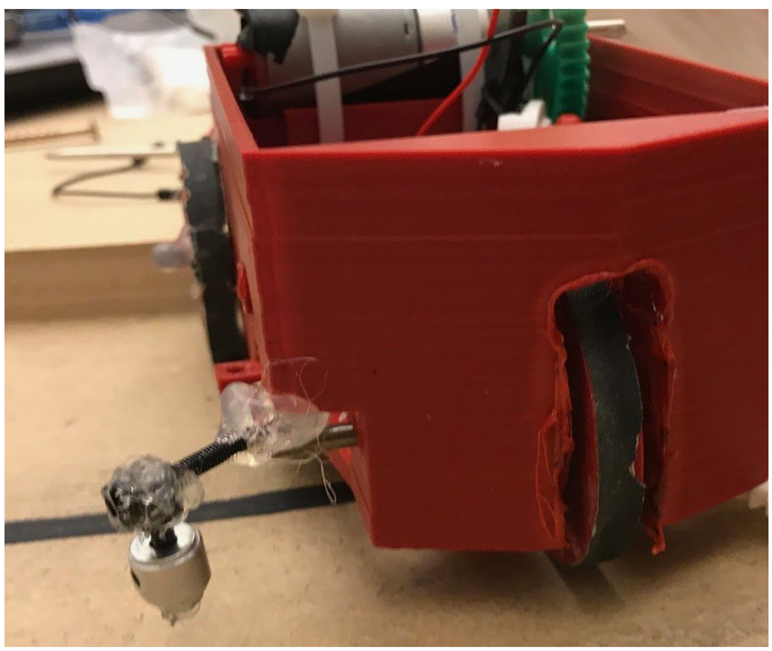


Figure 13: 3D Printed Chassis

For the lone front wheel to fit, we had to make a cutout in the bottom and front of the chassis. Unfortunately the front wheel stuck out of the front of the chassis, which we knew was not ideal, but we quickly realized was unlikely to be a major problem. We came to the realisation that the motor we were using was optimized for torque, and not speed, our car was so slow that there was almost very little chance that we would catch a competitor, let alone rear end it with enough force to cause an issue with our car. This helped tremendously since the rollers were now much wider than the rear wheels, but the car was also comfortably less than 5 inches wide. The car was able to complete three laps 60% of the time now, but it needed to be better. Kyle then had the breakthrough idea. He explained that we should use replace our current rollers which only had a diameter of 0.36 inches with something that had a larger diameter because it would have a larger surface area which would more effectively roll us through our glancing collision with the intersection wall.

Final Design: Gears on Undercarriage

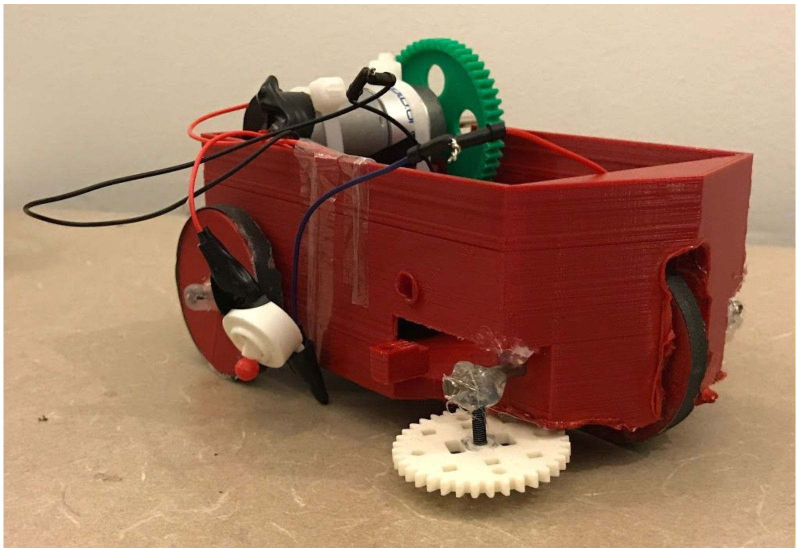


Figure 14: Gears on Undercarriage

We found 1.48 inches diameter gears and mounted them to the front axle using a screw and hot glue. The larger roller worked like a charm and after testing we were able to complete three laps 80% of the time. With the competition the next day, we decided that we were happy with our success rate and none of us could think of ways to improve the design. This test taught us an important lesson. It showed us that just because we cannot fix a problem (the car would still drift left coming out of right turns), does not mean we cannot find a solution.

Bill of Materials

We used Kyle's robotics kit at no cost to the group. Materials used from the kit are denoted as (robotics kit).

Bill of Material

Product: Vehicle (total material used) | Date: 4/25/2018

Assembly: Vehicle Components

Item #	Qty.	Name	Description	Material	Manufacturing Process	Cost
1	4	Chassis	Holds, Protects, and Connects the Parts of the Vehicle	PLA	3D Printing	$10.00
2	1	Drivetrain Large Gear	Uses Motors Rotation to Rotate Drivetrain Medium Gear	Plastic	Injection Molding	$2.00
3	1	Drivetrain Medium Gear	Rotated by Drivetrain Large Gear. Spins Drive Shaft.	Plastic	Injection Molding	$2.00
4	2	Front Wheels	Steer the Vehicle	PLA	3D Printing	$1.00
5	2	Rear Wheels	Provides the Propulsion	PLA	3D Printing	$1.00
6	1	Drive Shaft	Rotated Through Connection to Drivetrain Medium Gear. Rotates Rear Wheels.	Steel	Cold Rolled	$0.50
7	1	12V Motor	Rotates Large Drivetrain Gear.	Steel	Assembly Line	$0.00 (Robotics Kit)
8	2	Motor Stand	Raises Motor Off the Base of the Chassis.	PLA	3D Printing	$1.00
9	4	Zip Ties	Holds Motor in Place	Plastic	Injection Molding	$3.00
10	1	Servo	Rotates Medium Pinion Gear.	Plastic, Steel	Assembly Line	$0.00 (Robotics Kit)

11	1	Medium Pinion Gear	Rotated By Servo. Meshes with Rack to Slide Rack.	Plastic	Injection Molded	$2.00
12	2	Rack	Slides due to Connection to Medium Pinion Gear. Mounted to Front Axle.	Plastic	Extrusion	$2.00
13	1	Front Axle	Connects power to LED	Steel	Cold Rolled	$0.50
14	2	Tie Rod Support	Holds Tie Rod	PLA	3D Printing	$0.50
15	4	Tie Rod	Connected to Front Axle and Tie Rod Support. Rotates about the Tie Rod Support	PLA	3D Printing	$0.50
16	2	Individual Wheel Axle	Connects Front Wheel to Tie Rod	Steel	Cold Rolled	$0.00 (Robotics Kit)
17	2	Servo Stand	Holds Servo at Appropriate Height for the Medium Pinion Gear to Mesh with the Rack.	PLA	3D Printing	$1.00
18	4	Sand Paper	Strips were placed on outside of all four wheels to provide better traction.	Paper, Adhesive, Abrasive	Adhesive Glued to Paper	$2.00
19	1	Arduino	Powers LEDs, Light Sensors, and Servo. Uses Input from Light Sensors to Control Servo.	Silicon, Steel	Automated Assembly Line	Provided
20	2	Light Sensors	Senses Amount of Light Reaching it and Sends that Information to the Arduino.	Silicon	Automated Assembly line	$5.00
21	2	LEDs	Illuminate below the Chassis to Increase Performance of Light Sensors.	Silicon	Automated Assembly line	$2.00

22	1	Breadboard	Organizes wires connected between the Arduino and Various electrical devices.	Plastic, Copper	Automated Assembly line	Provided
23	4	9V Battery	Powers the Arduino.	Nickel-cadmium	Automated Assembly line, progressive forming	$10.00
24	10	12V Battery	Powers the Motor	Nickel-cadmium	Automated Assembly line, Progressive Forming	$40.00
25	N/A	Electrical Tape	Used to Secure Arduino and Breadboard and Wrapped Around Wire Connections to Prevent Shorts.	Vinyl	Automated Assembly, tension adjusters	$2.75
26	N/A	Hot Glue	Secures Servo Stand to Chassis and Servo to Servo Stand. Keeps Front Wheels From Sliding Off Front Individual Wheel Axle and Rear Wheels From Sliding Off Drive Shaft.	Ethylene vinyl acetate	Chemical mixture, Extruded	$10.50
27	4	Screw	Connects Tie Rod to Individual Wheel Axle and Front Axle	Steel	Casting	$0.00 (Robotics Kit)
28	4	Metal Washer	Allows Front Wheels to Rotate Freely Without Catching on Hot Glue.	Steel	Punching	$0.00 (Robotics Kit)
29	2	Plastic Washer	Allows Front Wheels to Rotate Freely Without Catching on Tie Rod or Front Axle.	Plastic	Punching	$0.00 (Robotics Kit)
30	1	Switch	Closes the circuit connecting the 12V batteries to the 12V motor.	Plastic	Assembly line	$2.00

31	2	Front Axle Support	Supports the front axle while allowing it to rotate freely.	PLA	3D Printing	$2.00
32	4	Metal Nut	Used to Secure the Screws.	Steel	Cold Forming	$0.00 (Robotics Kit)
33	2	Small Drivetrain and Pinion Gear	Small gears were used in iterative prototypes to transfer power to the rack and pinion and motor	Plastic	Injection molded	$4.00
34	50	Arduino Jumper Wires	Wires were used to connect components together and complete circuits	Copper, Plastic	Extrusion	Provided
Total cost:						$104.00

Testing

Prototype 3

Light Sensor Noise Testing

The guidance system was experiencing an issue in which values read by the light sensors would be precise when the servo was disconnected from the arduino but would fluctuate severely when the servo was connected. The noise could not be caused by a current problem, since the problem persisted when the sensors were connected to their own personal power source. Upon discussing the problem with the class TA's and conducting research online, one possible reason for the observed noise was electromagnetic interference from the servo. The hope was to mitigate the noise from the interference by increasing the sensitivity of the sensors . One way of achieving this is changing the current flow through the light sensors. Different resistors were connected in series with the light sensors to achieve this. The following tests were completed when the sensors were removed from the chassis in order to isolate the single variable tested.

Resistor [Ω]	Light-Dark Gradient	Noise
100	20	20-30
10 k	50	20-30
1 M	5	20-30

The noise from electromagnetic interference was the same in every trial. However, the difference in light sensor readings was the greatest when the 10 kΩ resistor was connected in series. This provides more accurate readings since the noise is a smaller factor in terms of the light-dark gradient.

Another method of increasing the sensitivity is to have the light sensors and LEDs closer to the ground so the light-dark gradient is increased. This test included manually holding the LEDs and sensor above the track at different heights. The test showed that there was a greater difference when the sensors were held less than .1" from the track as opposed to being secured to the underside of the chassis. Additionally, as the sensor and LEDs were position closer to the track, the LEDs became more dominant of a light source. This had the added benefit of reducing randomness due to shadows and lighting in the testing room. This proved to be an important solution since the lighting from race to race on competition day varied greatly.

These tests were conducted when the sensors were removed from the chassis. Due to the physical distance between the sensors and the servo, the noise during the tests was smaller than it would be when the car is properly mounted and running. The purpose of these tests was to investigate methods of reducing the effect of interference from the servo. However, our optimizations were not enough to mitigate the interference. The noise when the servo was operating right next to the sensor was much larger than when the sensors were removed from the chassis. At this point we came to the decision to abandon the concept of light sensors entirely.

Prototype 4

Timing Testing
Due to the new design being based on timing, a substantial amount of testing needed to be done. The code had to include values for how far to turn the servo in order to make it around the curved section. Additionally, the code had to include how long the servo must stay at that orientation before returning to its neutral position for the straight sections. Several trials were conducted to determine turning radius as well as length of turn. The vehicle had to start every trial in the same exact position since any slight deviation would send it off course. However, the main issue with our testing is that the batteries would die after a few trials. Once the batteries stopped delivering maximum power, testing became pointless since even a slight drop in speed would change our values.

Prototype 5

Operational Testing (one lap)
Preliminary testing for prototype 6 was conducted in order to determine how consistently the vehicle could complete a lap as well as the point of failure if the lap could not be completed.

Trial	Completion of lap	Point of failure
1	yes	none
2	no	Hit corner in intersection
3	no	Hit corner in intersection
4	no	Hit corner in intersection
5	no	Hit corner in intersection

6	no	Stuck on wall on the right side
7	yes	none
8	no	Hit corner in intersection
9	no	Hit corner in intersection
10	no	Hit corner in intersection

This iteration had a 20% success rate for completing a lap. The most common point of failure occurred when the vehicle passed through the intersection.The vehicle drifted slightly towards the left when it disengaged from the wall. Because of this, the vehicle would drift towards the middle of the track when it left contact with the wall from its right side, however it would drive towards the intersection corner when leaving contact from its left side.

Prototype 6

Operational Testing (three laps)

Operational testing of the new design was conducted with three consecutive laps being the requirement for a successful test.

Trial	3 laps completed?	Point of Failure
1	no	Hit corner in intersection
2	yes	none
3	yes	none
4	no	Hit corner in intersection
5	yes	none

The vehicle had a success rate of 60%, which is a dramatic increase in reliability from the last iteration. This design change decreased overall bias for the vehicle to drift one way or the other. However, the point of failure remained the same from the last iteration.

Final Design

Operational Testing (three laps)

Operational testing was conducted for the final design to determine its reliability. The test required the vehicle to complete three consecutive laps. Five trials were conducted.

Trial	3 laps completed?
1	yes
2	yes
3	yes
4	no
5	yes

The vehicle completed three laps in four out of five trials, or 80%.

Speed Testing

Speed testing was done in order to assess the speed of the vehicle. This testing consisted of running the vehicle and recording the time it takes to complete each lap for three laps. For trials 1-3, the motor was powered by a single 12v battery.

Trial 1: Facing Left 1

Lap number	Time [s]
1	16.3
2	16.9
3	17.5
Average	16.9

Trial 2: Facing Right 1

Lap number	Time [s]
1	16.6
2	17.7
3	18.8
Average	17.7

Trial 3: Facing Left 2

Lap number	Time [s]
1	17.1
2	19.3
3	20.8
Average	19.1

Due to the slowing of the car over the three trials, the assumption was made that the battery was dying. Since the car had only completed nine laps using one battery, it became clear that battery life would be a problem. To solve this, two 12V batteries were connected in series in order to extend battery life for trial 4. The fourth trial measured five laps instead of three in order to determine if there was any significant drop off in speed over time.

Trial 4: Facing Right 2 (2 fresh batteries in parallel)

Lap number	Time [s]
1	11.2
2	13.4
3	12.6
4	11.9
5	11.8
Average	12.2

There was no discernable decrease in speed over the trial. This trial also showed that using two batteries in parallel supplied more power to the motor, since the speed of the car increased so drastically. The average speed with the batteries in parallel was 12.2 seconds as opposed to 17.9 seconds for the single battery. This shows that two batteries in parallel is better than a single battery. Three batteries in parallel was not tested due to fears that this would burn up electrical components in the motor due to too much current being supplied.

Reliability Analysis

FMEA (Failure Modes and Effects Analysis)

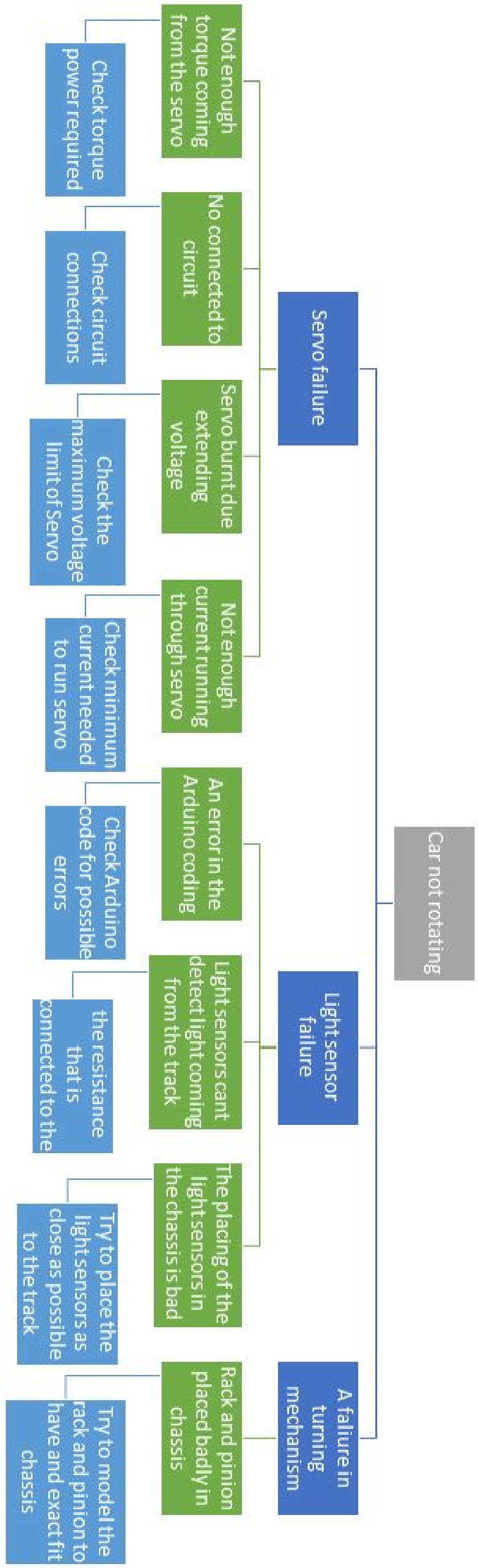
Product:The Big Red

Organization Name : Group 4

#	Function	Potential Failure Modes	Potential Failure Effects	Potential Causes of Failure	Current Process Controls	Recommend Actions	Responsible Person	Taken Actions
1	Guidance	No torque to rotate wheels.	The car isn't able to make turns.	1-Servo burnt out. 2-Not enough current running through the servo.	Servo attached to Arduino (5V).	Find the optimal current vs voltage required to run the servo at full power.	Husam. A	Rewire and add power depending on the servo.
2	Drive	Power not enough to spin the wheels.	1-Not enough speed. 2-Car not moving.	1-Low current running through the DC motor. 2-DC motor burnt out. 3- Low torque from the DC Motor.	One 12V battery supporting the motor.	1-Find the optimal current vs voltage required to run the DC motor at full power. 2- Estimate the torque required to run the gears smoothly.	Gabe. B	Attach two 12V batteries in parallel for more current.
3	Guidance	Light sensors not working.	The car can't make turns.	1-The light sensor is not close to the black tape. 2- An error in the coding of the light sensor. 3- The brightness of the room.	Light sensors placed far up in the chassis.	1- Close the distance between the light sensor and black tape. 2- Ensure the code is running correctly.	Conner. A	Redesign the chassis to make the light sensor closer to the black tape.
4	Chassis	Car components don't fit exactly inside the chassis.	1-Increased car weight. 2-More power need to run the car.	Error in measuring the optimal dimensions of the car in order to fit the components exactly.	Dimensions are wrong.	Measure each component of the car then try to design the chassis based on that.	Kyle. V	In the process of making the third chassis that holds the components in exact fit.
5	Guidance	Small turning radius.	1-The car makes wide turns. 2-More time to complete laps.	1-The position of the rack and pinion doesn't allow the wheels to turn freely. 2-Having big wheels which require more turning radius.	The Rack and pinion current position doesn't allow maximum turn.	1- Decrease the radius of wheels. 2- Position the rack and pinion in a place that allows maximum turning radius for the wheels.	Kyle. V	Redesign the chassis in order to place the rack and pinion allowing maximum turning radius.

6	Wheels	Wheels spin freely	The car doesn't move.	No friction between the wheels and the track.	3D printed wheels.	Try to find the best material for the wheels to have maximum friction when in contact with the track.	Husam. A	In the process of trying small rubber wheels.
7	Steering	9V Battery dies.	No power delivered to the servo.	Over estimating the Capacity of 9V battery	One 9V battery.	Attach two 9V batteries in parallel to support the servo.	Husam. A	Design the chassis in order to support two 9V Batteries.
8	Drive	The gears connecting the DC motor and the wheels are not meshing together.	1-Wheels not turning.	Not having an exact fit between the gears. Gear teeth break.	Low quality gears.	Find gears that attach ideally. Higher quality gears.	Husam.A	Testing couple of gears to find the most efficient one.
9	Steering	The hot glue connecting the rack and pinion to the wheels wares off.	1- Car not able to make turns.	The hot glue doesn't have enough strength to glue the two parts.	Hot glue.	1-Use super glue and dry it for 12 hours. 2- Try to 3D print the rack and pinion in one piece.	Kyle. V	Testing the glued rack and pinion under extreme conditions to see if reliable.
10	Chassis	A breakage in the chassis attachments during competition.	1-All of the car components come loose (Servo, Motor…). 2- No movement.	1-The material used for 3D printing (PLA) isn't strong enough. 2-Underestimating force that is required to hold the components in place.	Thin chassis attachments.	1-Use different materials for the chassis attachment for more strength. 2- Try to 3D print thicker chassis attachments.	Gabe. B	Redesign the chassis attachments and make it thicker.

Fault Tree Analysis (FTA)



Reliability Calculations	
Task	Success Rate
1- Device turned on	100%
2- Device moved at least 1in	100%
3- Made it through the first intersection	70%
4- completed one full lap	85%
5- completed 3 laps	80%
6- completed three minutes mark	70%
Reliability=R1*R2*R3*R4*R5*R6	33.32%

In engineering its important that the product meets a high reliability level so that the customer is pleased. It is up to the engineer to remodel and optimize his device to meet high reliability levels. Through testing and analyzing the car under different circumstances we were able to calculate the reliability for our car. As it is clear from the table above, the reliability of our car is almost 33.32%. The group wasn't very pleased with that value. In order to improve the reliability of our car more testing and improving should be made. For example, 70% of the time we ran the car it hit the intersection. In order to solve that issue, the steering mechanism should be optimized.

Safety Analysis

Safety concern	Description	Preventative Measure	Concern Level
Electrical shock	• An exposed wire may shock the user while touching it.	• Turn power off if not using. • Don't touch an exposed wire.	Moderate
Burns to user body and surrounding place.	• A short in a circuit may cause some components to catch fire. • The battery exploding or catching fire.	• Make sure same types of batteries are used. • If motor, servo, batteries heat up, close device immediately. • Never touch the vehicle with wet hands. • Don't use rechargeable batteries • Seek immediate help.	Moderate
Laceration	• The user may cut themselves while touching sharp edges on the vehicle.	• Try to prevent touching any sharp edge of the device. • Use protective gloves while touching sharp edge.	Low

Service and Support Plan

From the first day of working on the car until competition day, the group encountered many unexpected problems. As a result, the team came up with a service plan so that the customer can deal with the problems if they arise. Below is a table for all the parts that will be in the service kit.

The issue that the group ran into most of the time is running out of battery. As a result, on competition day the group brought four 12 volt batteries and one 9 volt to support the DC motor. During testing, we figured out that the 12 volt battery lasts almost for 5 min while running at full power, so its beneficial having spare batteries because one race might last up to 3 minutes.

In addition, the fourth race for our group on competition day helped us find an issue that we thought was not there. To further explain, the opponent's car was made from metal and ours is 3D printed. While racing, we took significant damage which resulted in destroying our front guidance rollers. After brainstorming for ideas to deal with this problem. The group came up with 4 more guidance rollers that can be easily replaced in the car if they were damaged.

Moreover, the group discovered that the tool kit should include basic tools that help in attaching the components to the car. For example, on competition day the hot glue that was used wared off and we needed to hot glue certain parts again. Also, after racing the nuts that held the tires in place were a bit lose so a small wrench was needed. In the table below we listed all the tools that will be provided if the costumer ran to the same problem.

Furthermore, the group realized that during the process of making the car that the housing of the DC motor comes off after impact. So the group planned to provide extra 3D printed housing parts for the costumer to change when in need.

The chassis that holds everything together isn't likely going to break easily, however, providing a file for the 3D printed model and the physical frame in the support kit is very beneficial to have. Different customers might run into different problems depending on how they use the car.

The gears that transform power from the DC motor to the wheel might sometimes not mesh together due to any sort of damage taken or even if they run for too long. In order to solve that issue, the group added couple of spare gears that can be easily replaced if the same issue occurred.

Finally, having a support kit that comes with detailed instructions on how to deal with some of the problems that the customer might run into is a necessary thing to include. Also, having an email and phone number that is only made to deal with customer issues on the product will help in improving the product in the future.

Device service and support kit		
Replacement Part	**Quantity**	**Description**
Left Guidance Roller	2	A guidance roller is placed in the front of the vehicle near the wheels (left side)
Right Guidance Roller	2	A guidance roller is placed in the front of the vehicle near the wheels (right side)
3D printed Chassis	1	A 3D printed frame in case if original frame damaged
DC motor housing	2	Housing for the DC motor if damage happens
12V batteries	4	If batteries need replacing/dead
3D printed Wheels	4	If wheels lose friction/damaged
Gears	4	If gears damaged or don't mesh together
Replacement hardware		
3mm nuts	50	Nuts will need to frequently changed
3mm bolts	50	Bolts will need to frequently changed
Additional items		
Super glue	1	An easy fix if parts not in place
Electric tape	1	Connects wires to battery
Zip ties	15	Holds the DC motor in place
Wires	15	In case damaged or burnet
Hot glue	1	A 5 minute fix in any of the car components came loose.
Tools		
Screw driver	1	To screw in and out the screws
Wire cutters	1	If wires need to be cut
Hex keys	1	To tighten bolts
Small wrench	1	To tighten bolts

Teamwork Analysis

Individual Reflections and Lessons Learned:

Husam [redacted]

In the second project me and my teammates did the best to we can do to win this competition. In any engineering project it is critical for the group members to have good communication skills in order to get ideas from each team member. Another feature that every engineer must have is to be responsible for every single thing and not expect others to do it for him. Finally, being able to manage time effectively is one of the most critical features than an engineer needs to have since every project has a particular deadline. After each project it's necessary to write a reflection that sums up the problems you faced and how you dealt with them, because if faced in future it would be easy to deal with.

I gained significant amount of experience from project 2. The first thing that was different from project one and two is that in the second project you need to convert your calculations and drawings to a physical thing. During that process learned that sometimes in paper it seems legit and easy to work with, however when converting it we faced many of problems that we thought didn't exist. I think that happens because the in our calculations we assumed that the world runs perfectly and there is no power loose. Furthermore, the other difference that this project had is that we need to estimate and manage our own financial situation. In any project it's critical to minimize cost in order to gain maximum profit. Finally, the most important lesson I learned is how to manage your time in the most effective way, because after having half of the time left we realized that the car needs major fixing and time was ticking fast.

From my perspective I feel that I did a good effort in the second project, however there were some mistakes that I needed to change. First of all, I missed 3 group meetings and I feel bad that I made my teammates carry some of work instead of me doing it. Moreover, I once came late to meeting for half an hour. Even though my teammates didn't object that, when working for major corporations it will be considered as a big deal and I will get a plenty for it.

I was responsible for completing some parts of the report while the other three group members: Kyle, Connor, Gabe worked on the car. The QFD, engineering reasoning, Safety and support plan, FMEA and FTA, delighted and disgusted features and the quality function were the task assigned for me to complete.

Finally, I'm thankful for the experiences I gained during my time in Mech 202 class. It would certainly help in my future design classes and defiantly in my career life. Also, I learned a bunch from my teammates since we spent almost 4 months together.

Kyle [redacted]

The second project presented more challenges than the first. Whereas the first project was analyzing an already developed design, the second project required inventing our our design. The autonomous vehicle project was much more open ended. This project required developing concepts as a group and implementing those concepts into one design. The difficulty from this project stemmed from the lack of a specific design to begin with.

However, using the techniques we learned in this class, our group was able to approach the project systematically. Using tools such as tasks lists, we were able to develop our own set of instructions for completing the project. Concept generation tools such as brainwriting and morphology helped us come up with ideas and filter out bad ones. Some of the project requirements helped our group think about the project in different ways. For example, having to include a service and support plan helped us thoroughly consider what extra parts we would have to prepare for competition day. Additionally, completing the engineering analysis showed which gear ratios would yield the best balance of torque and speed.

The autonomous vehicle has been one of the most fun projects I have done thus far in college. It has been the first project where I feel like a real engineer. Developing a design to meet specific requirements is what engineers do. Having the long term focus to work on a project of this magnitude is a skill I have developed in this class.

I am proud of my groups performance on this project. Even though our original plan of using light sensors did not pan out, we put much effort into this project. Besides the engineering experience I gained from this project, my biggest take away has been how to work as part of a team. This has been the most in depth group project I have ever completed. Our team worked well together. We were able to divide up the work in a way to play to each individual's strengths as well as make changes to our design all at the same time. This project was not taken over by a single individual: it was a collaborative effort.

Connor [redacted]

This project offered several distinct learning opportunities that allowed the group to grow. We went into this project knowing next to nothing about coding with Arduino but through persistence and hard work we were able to figure it out with no instruction. This demonstrates the group's collective desire to learn and our ability to adapt to certain situations. As with project 1, the group worked well with each other and there were no real conflicts. Each of our personalities led us to fill certain roles to use each of our talents. Gabe gravitated to Creo modeling and designing the chassis iterations, Kyle worked primarily on building the mechanisms of the car, I wrote code and wired all the electronics, and Hussam helped with miscellaneous tasks as well as made sure the report was coming along. This group dynamic of using everyone's talents worked well for us and made sure everyone was doing equal work.

I found the topics covered in class helped us greatly in our design process and execution. We were able to see the general flow of design first hand. One thing I found especially applicable to our project was the assertion that the first design or idea is almost guaranteed to fail. We went through several iterations of chassis', each solving a problem put forth by the previous iteration. We even went through three ideas of navigation. All of these trials helped us to narrow our design into the most efficient final design. I found it useful that there were many smaller due dates for parts of our project. This helped us stay on track and not find ourselves too bogged down with any one issue. The QFD charts that were introduced in project 1 were even more applicable in this project. We designed for the specifications that we wanted to meet rather than those of some third party. This allowed us to narrow a very daunting task into smaller more manageable ones.

I am grateful to have had this opportunity to work with a team to accomplish such a broad design project. Not only have I learned much about the design process, I also learned how to better work in a group to accomplish a task. This is easily the most fun project I've had in my school career. One of the biggest themes of this projects was overcoming adversity. There were a seemingly never ending flow of problems that we had to solve one at a time. These problems even occurred the night before the competition. Unforeseeable issues such as electromagnetic interference forced us to change our design and we had to quickly figure out a different approach . Though it was also probably one of the more stressful projects I've undertaken, there are many skills that I learned that I will be able to use in my continued education and career.

Gabe Baranovsky:

I feel like I contributed my fair share of time, effort and work over the course of the project. On average we have met between two and three times each week since Spring Break and I think I only missed one or two meeting. However, on a couple occasions, I had to leave early because I had a few exams on Tuesdays and Thursdays during the semester, so I would leave early to study more before the exam. Other than these rare occasions, I was at every team meeting for the entirety of the meeting. I did the majority of the 3D modeling for the parts that we printed. I also did all of the 3D printing. Going into the semester I had no 3D printing experience and now I feel comfortable printing. One of my goals coming into the semester was to learn how to use a 3D printer and I had signed up for the 3D printing class before Dr. Gadomski told us that we should learn to 3D print. However, if it was not for this class

I would not be anywhere near as comfortable with a 3D printer as I am today. I enjoy the process of 3D printing and look forward to printing more in the future, both for future classes and individually.

I also felt that even though my role on the team was not Team Leader, that I helped in organizing the team. I made sure that everyone had something to work on for each meeting, so that we would be as productive as possible as a team. I think that one of my asset as a team member is being able to recognize others' strengths and organize tasks for them that optimize the productivity of the entire team. It was gratifying to me when team members turned to me when they needed something to do and were not sure what they should work on.

I thoroughly enjoyed learning about the rack and pinion steering system as we were building it. Kyle and Connor took the lead on integrating the rack and pinion system into our design, so they were the resident experts on the team. I knew that all modern cars use a rack and pinion for steering, but beyond that, I did not know anything about this steering system and wanted to know more. Fortunately for me, Connor and Kyle were patient, explained the mechanics to me, and answered any questions I had. All cars use a rack and pinion, so I am confident that having a basic understanding of this universally used mechanism will come in handy at some point in my future.

We wanted to make a car that used a rack and pinion and line follower for two reasons. The first reason was we thought it would work better than the alternatives and the second is we thought it would make for a more interesting project and that we would learn more. I do not regret attempting to make the car this way since even though it did not work out, I still feel that I learned throughout this process. If we had gone with the wall sliding strategy originally, our car would have probably turned out better while spending about a third of the time that we did trying to get our more complex, original design to work. This project did teach me an important lesson, that I believe will be valuable in my future mechanical engineering classes and after I graduate. The lesson I learned is that sometimes the simple way is the best way. If I had known this going into the project, we could have gone with wall sliding from the start and dedicated more of our time to optimizing the speed, the body, and the rollers. I do not regret the path we took on this project since I think it made it more interesting and I feel that I learned more over the course of the project.

Team Contract

Design Organization: Vrrrrrrrrrrrrrrrrm	Date: 3/8/18

Team Member	Roles	Signature
Kyle Vorreiter	Chief Modeler	Kyle Vorreiter
Connor Anderson	Project Management	[illegible]
Gabe Baranovsky	President of Editing	Gabe B[illegible]
Husam Al Habsi	Chief Tech Engineer	H H

Team Goals	Responsible Member
1. Earn an A grade by working hard, holding each other accountable, and exceeding the minimum requirements in the syllabus.	Kyle
2. Complete project in a timely manner. Break up the work throughout the 7 weeks, so that we do not have to work too much in the last week and can focus on editing the report.	Gabe
3. Open and honest communications. It is everyone's responsibility to speak their mind and let others know if they have a problem with a decision or quality of work.	Hussam
4. Gain useful experience. Everyone should be involved (could be as little as making sure the work is up to their standards) in every step of the process and understand how and why it was done. This way they have a good enough understanding to provide well-informed ideas and feedback.	Kyle, Connor, Gabe, Hussam
5. Delegate jobs fairly by involving everyone in the process of breaking up the work, so we can speak out if we are unhappy with the way the work was distributed.	Connor

Team Performance Expectations	Initial			
• Bi-weekly meeting immediately after class on Tuesdays and Thursdays. Everyone should be prepared for meetings to last around 90 minutes. Everyone should recognize that some meetings will last longer than others. Meetings will often be used to complete the homework assignments.	K.V.	G.B.	H.H.	C.A.
• If someone is unable to attend a meeting, they should inform everyone before the start of class on the day of the meeting. This can be done in person, or through the group chat.	K.V.	G.B.	H.H.	C.A.
• The primary method of communication when we are not together should be in the group chat so that everyone in the group can stay informed on what is happening (even if it doesn't directly pertain to them). Even if someone is not involved in a specific aspect of the project, they might still be able to offer valuable insight.	K.V.	G.B.	H.H.	C.A.
• Group members should be producing a high quality of work, so that we can achieve our goal of earning an A. If people are not happy with someone's work, they should share their thoughts on how it can be improved and then the group can decide if they agree.	K.V.	G.B.	H.H.	C.A.

Strategies for Conflict Resolution:

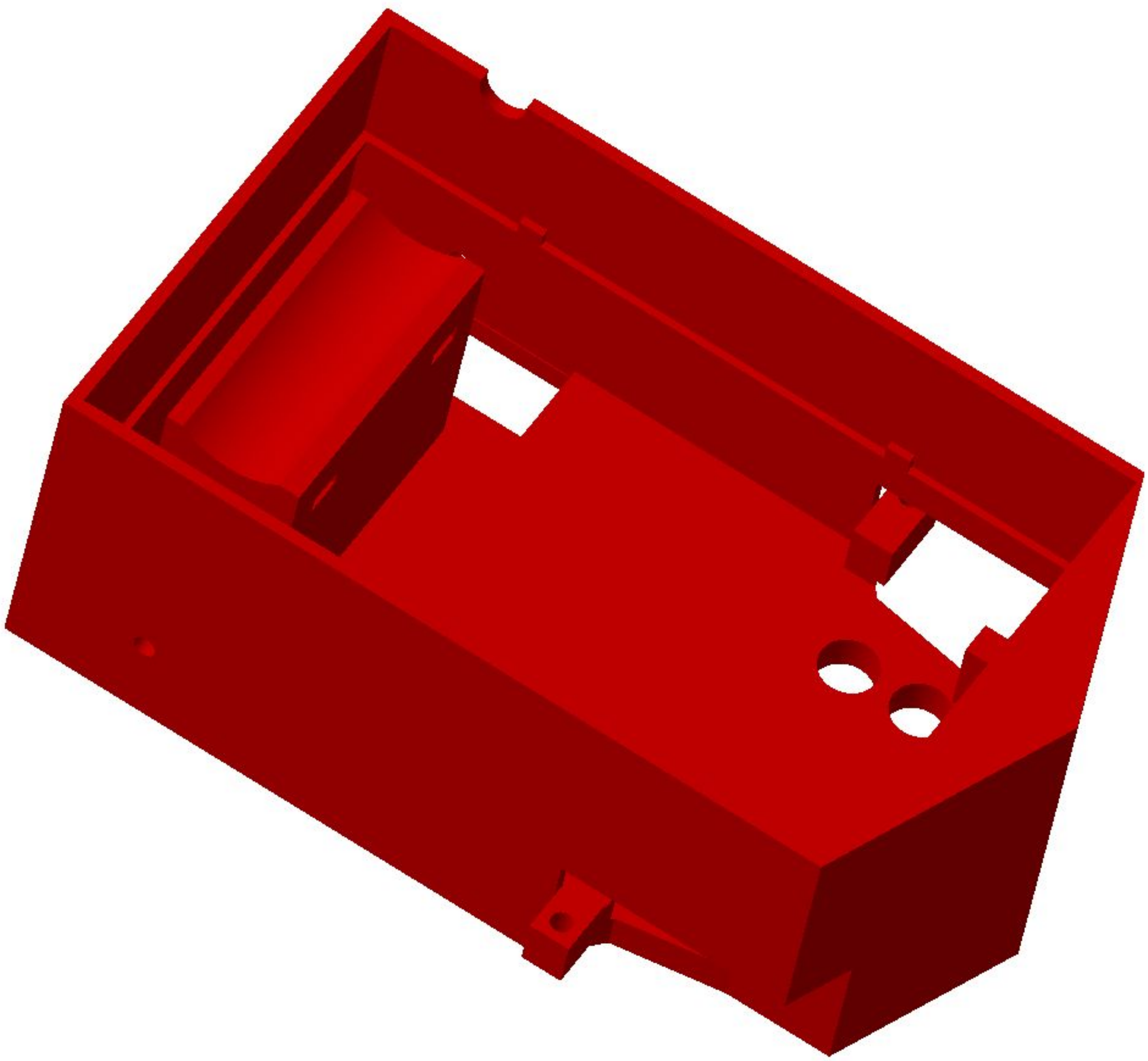
- Talk between individuals
- Have a meeting with the entire group to try to find a fair compromise to resolve the conflict. If a compromise cannot be reached, we will create a pro/con list to decide whose idea is better.
- If conflict is between two people, have a third party mediate.
- Trial by combat

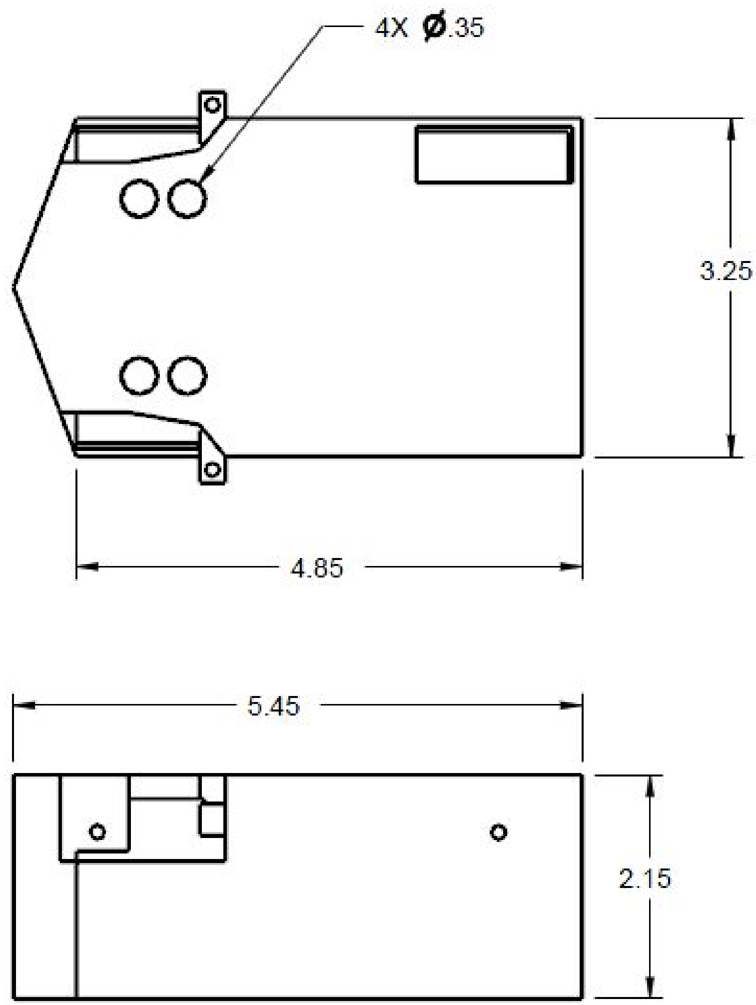
The Mechanical Design Process Designed by Professor David G. Ullman
 Form # 2.0

Appendix

Renderings and Drawings:

Chassis

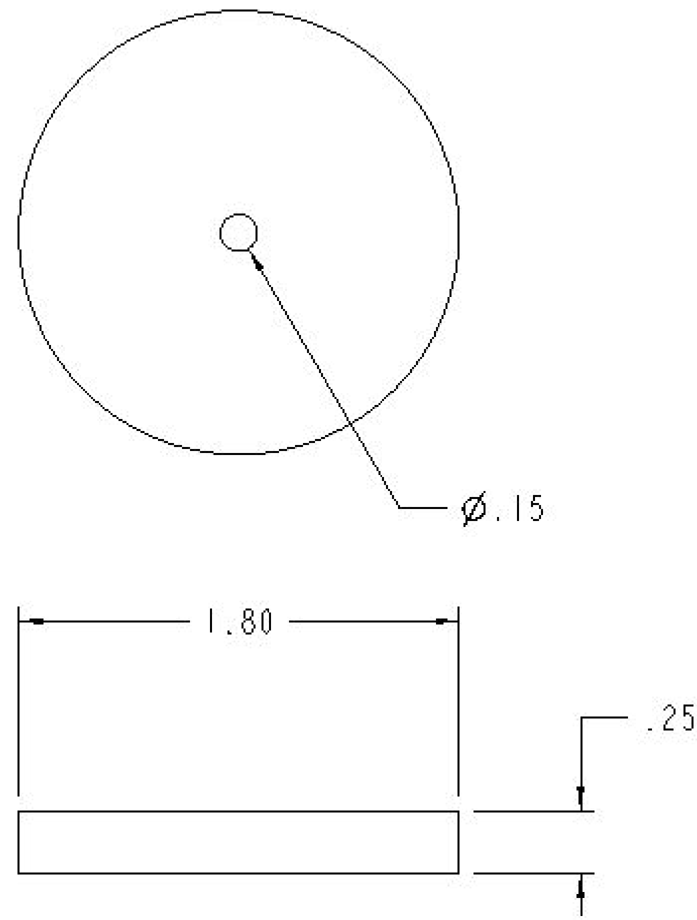




PART NO:	1	PART NAME:	Chassis
QTY:	1		
Colorado State University Mechanical Engr. Dept. Fort Collins, CO 80523 (970) 491-6558		UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE: FRACTIONS: ± 1/32 DECIMALS: ± .02 ANGLES: ± .5°	
SCALE:	0.500	DRAWN BY:	Kyle Vorreiter
MATERIAL:	PLA	FINISH:	
DATE:	May-01-18		

The final chassis was designed and printed with the intent of using it as part of a line following car that uses a rack a pinion steering system. As the iterations of our design changed, we cut holes in the chassis to accommodate the new design.

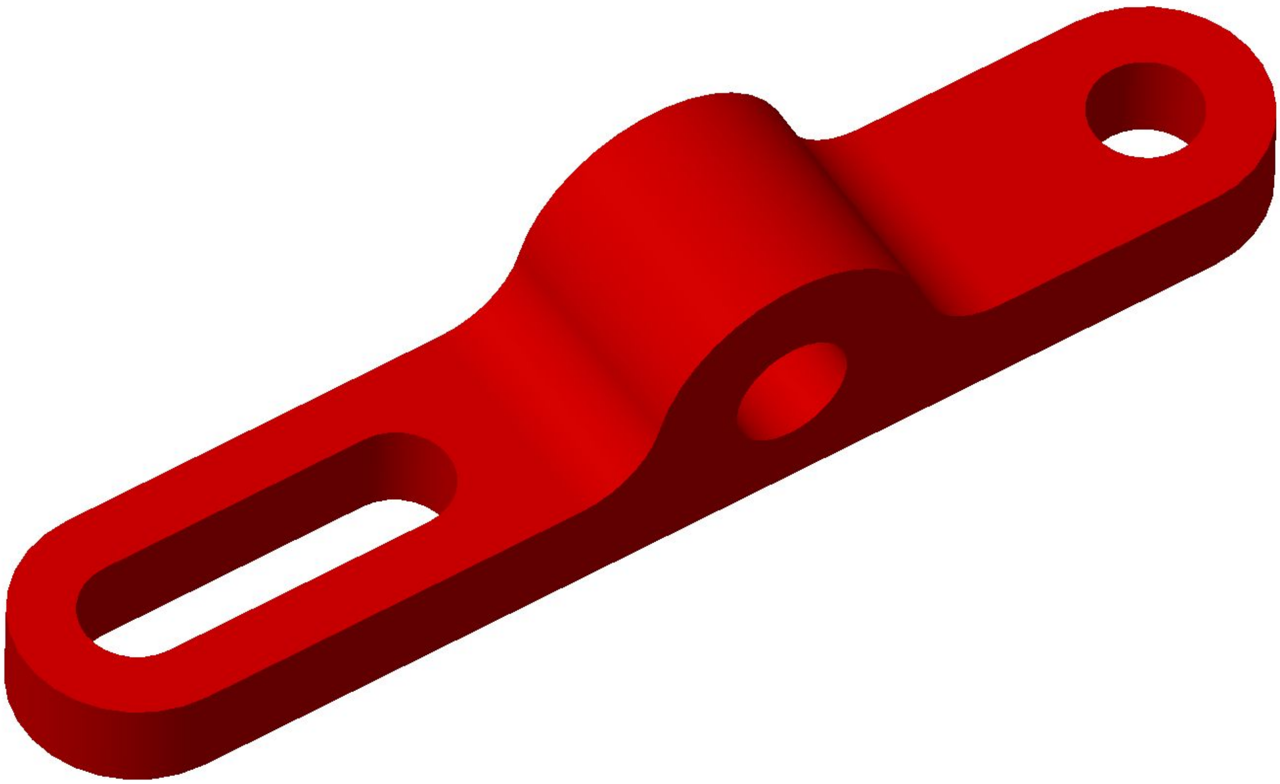
Ideal Wheel

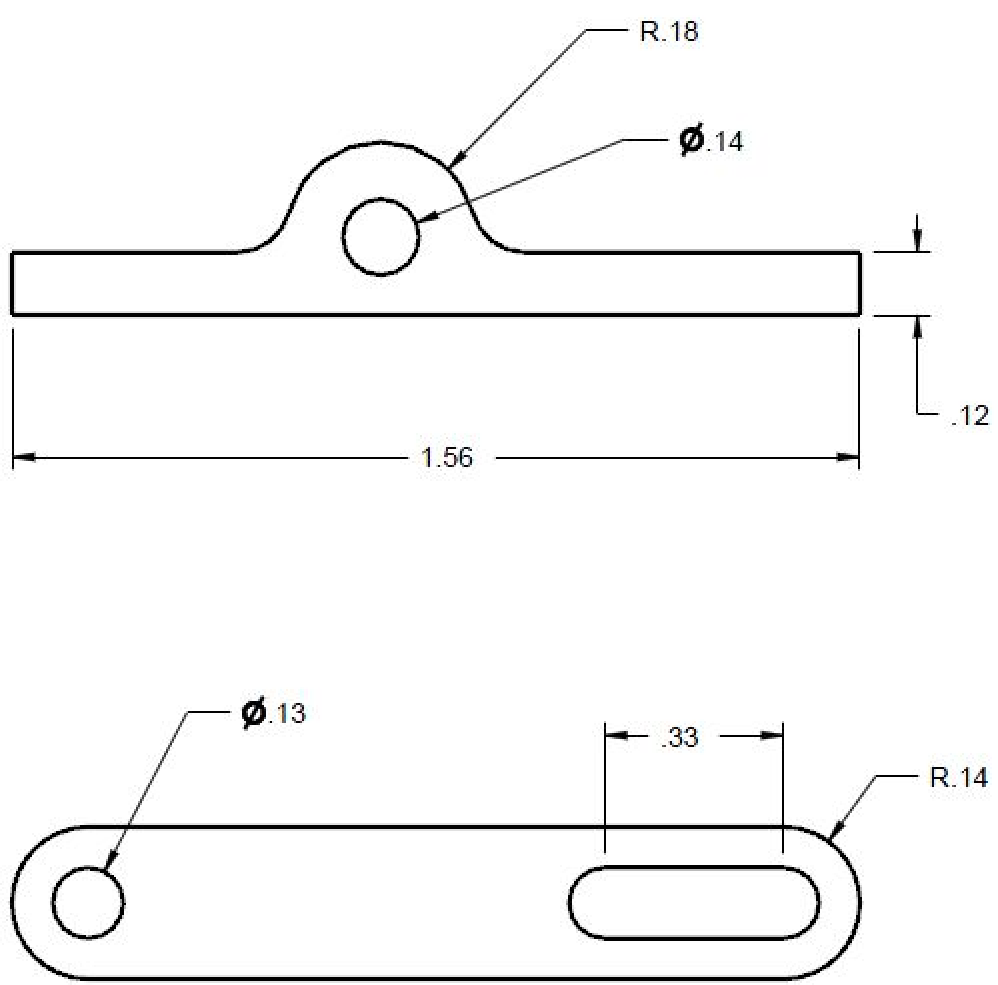


PART NO.	4 and 5	PART NAME:	Front and Rear Wheels	QTY:	3
		Colorado State University Mechanical Engr. Dept. Fort Collins, CO 80523 (970) 491-6558		UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE: FRACTIONS: ± 1/32 DECIMALS: ± .02 ANGLES: ± .5	
SCALE:	1.000	DRAWN BY:	Kyle Vorreiter	MATERIAL:	PLA
DATE:	May-01-18			FINISH:	

Originally, 8 wheels were printed. The plan was to use four on the car and have four spares, but then we redesigned the car to have three wheels which meant we ended up with five spare tires.

Tie Rod

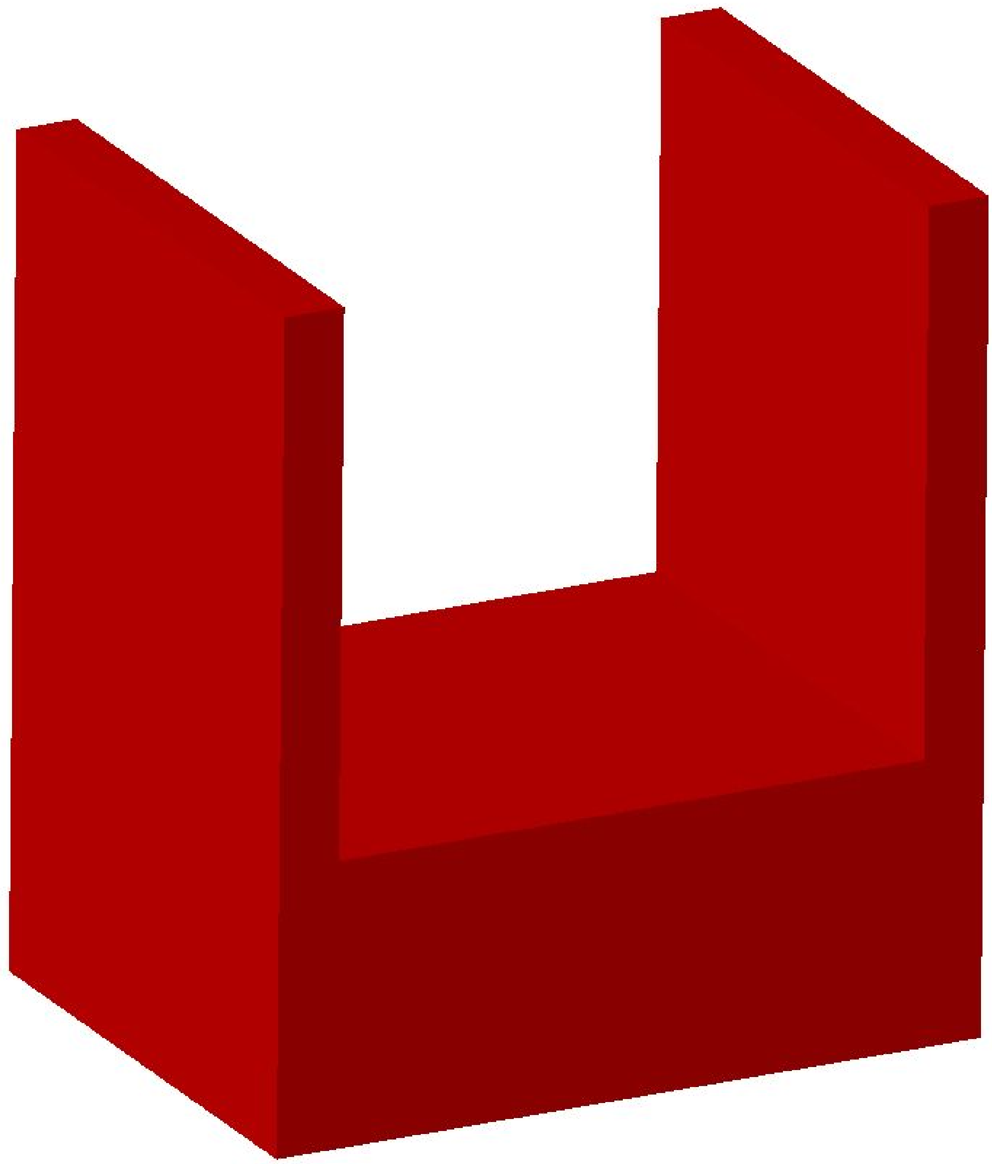


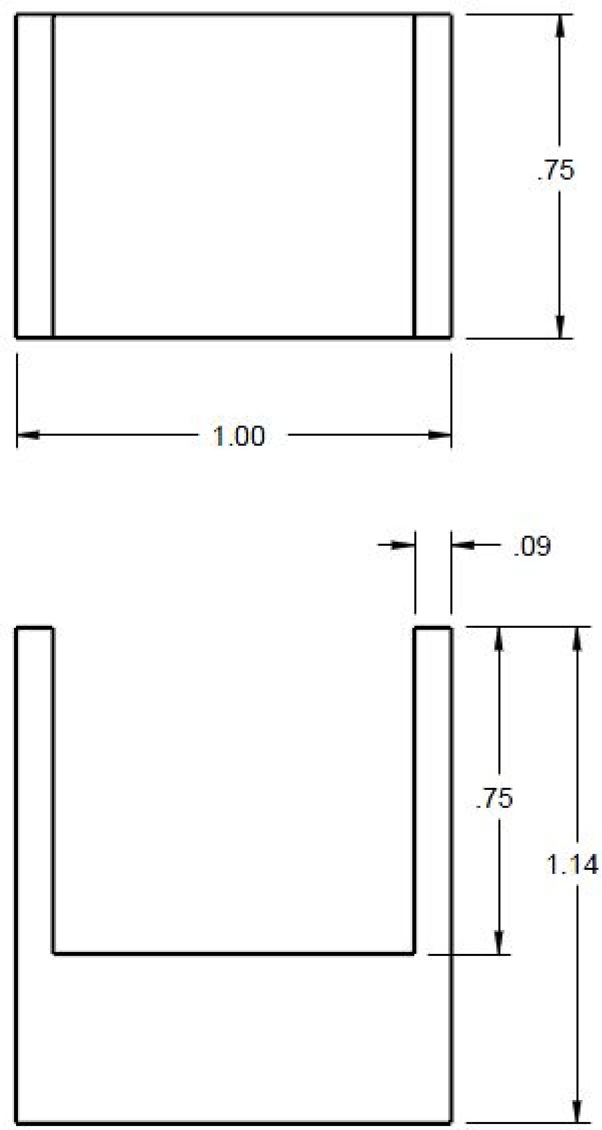


PART NO.	15	PART NAME:	Tie Rod	QTY:	2
		Colorado State University Mechanical Engr. Dept. Fort Collins, CO 80523 (970) 491-6558		UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE: FRACTIONS: ± 1/32 DECIMALS: ± .02 ANGLES: ± .5°	
SCALE:	2.500	DRAWN BY:	Kyle Vorreiter	MATERIAL:	PLA
DATE:	May-01-18			FINISH:	

We designed and 3D printed two tie rods to use during the race since they are important components of rack and pinion steering. Since they are on the outside of the car, we thought there was a good chance they could be damaged, so we printed two spares. However, after abandoning the rack and pinion steering system, we did not need the tie rods, so they were not used on the final.

Vertical Servo Stand





PART NO.	17	PART NAME:	Servo Stand	QTY:	1
		Colorado State University Mechanical Engr. Dept. Fort Collins, CO 80523 (970) 491-6558		UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE: FRACTIONS: ± 1/32 DECIMALS: ± .02 ANGLES: ± .5°	
SCALE:	2.000	DRAWN BY:	Kyle Vorreiter	MATERIAL:	PLA
DATE:	May-01-18			FINISH:	

We 3D printed the servo stand separately from the chassis and then glued it to the chassis with hot glue to ensure it was positioned correctly. Like the tie rod, once we decided to use fixed steering, we realized that the servo stand would only be in the way, so we removed it.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