Breakdown, Brainstorm, Plan, and Prototype: Laying the Foundation for a Successful Robot

Bryan Culver

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Who am I?

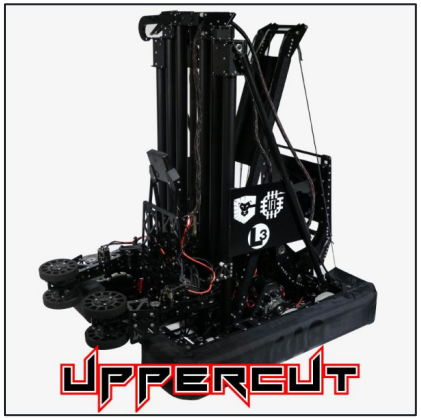
Bryan Culver

- 10 Years of FRC Experience (2009 – Present)
- Technical Mentor – Strategic Design, Detailed Design, Match Strategy & Scouting
- 5 Years of Robot Game Design Experience (VEX GDC 2015-2019)
- Currently a Mechanical Design Engineer at Auris Health

frc33 2017

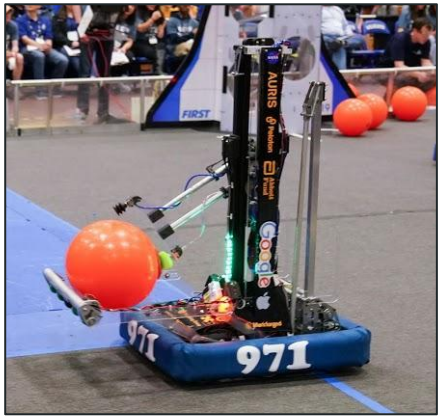
- Southfield District
- MSC Dow District
- MSC District Championship

frc148 2018



- Dallas Regional
- Hopper Division
- Houston Championship

frc971 2019



- San Francisco Regional
- Utah Regional
- Houston Galileo Division

Other Resources – The FRC Brain Trust

Recommended Viewing

- Karthik Kanagasabapathy – Effective FIRST Strategies for Design and Competition
  https://www.youtube.com/watch?v=smWy7FQ8jLE
- Mike Corsetto – Strategic Design
  https://www.youtube.com/watch?time_continue=577&v=dSXDV-UhhxU
- Adam Heard – Simple Robots that Win
  https://www.youtube.com/watch?v=vkLuooWkKic

Additional Resources

- 971 Spartan Series Workshop
  http://frc971.org/workshops
- The Compass Alliance
  https://www.thecompassalliance.org/
- Chief Delphi Robot Forum
  https://www.chiefdelphi.com/

Other Resources – The Golden Rules

Karthik's Golden Rules

1. Build within your limits
2. Focus on doing a few things as well as possible

Mike's Golden Rules

1. Keep it simple
2. Leverage historically successful mechanisms
3. Use a proven / battle-tested drivetrain
4. Touch it, own it (continuous, wide intake)
5. When possible, mechanically align robot scoring
6. Fail in the shop, not on the field

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The Overarching Functional Goal

Process Oriented Goal

- Compete with a robot that maximally contributes to winning each match.

Results Oriented Goal

- Seed within the top 8 alliances at an event
- Win a District / Regional event
- Win a World Championship

The Triangle of Robot Performance and the Robot Performance Curve

Strategic Design

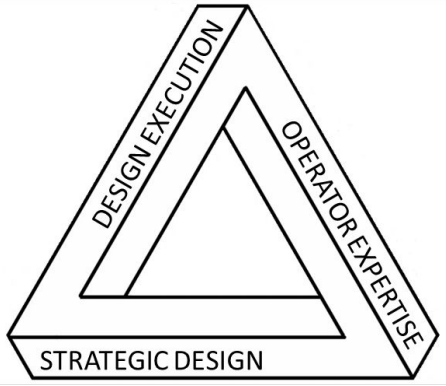
- What actions the robot performs in-match

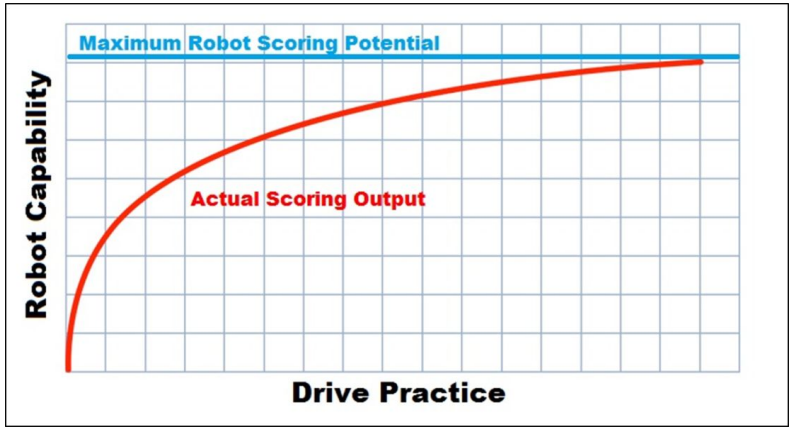
Design Execution

- How consistently and / or quickly the robot performs those actions

Operator Expertise

- What percentage of the robot's functionality is being utilized in-match





Strategic Design Overview

Breakdown

- Rules
- Actions
- Cycles

Brainstorm

- Ideation
- Architecture

Plan

- Assessing Risk
- Allocating Resources

Prototype

- Feasibility Prototyping
- Optimization Prototyping

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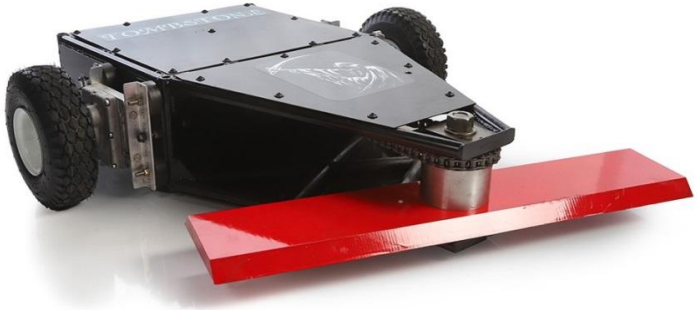
Kickoff

Breakdown – Understanding the Rules

The Rules form the bounds of the game within which your Robot will compete.

Understand the Rules!!!

- If you don't understand the bounds of a problem, you are unlikely to find the optimal solution.
- Create a 'Unclear Rules' List



Common Rule Points of Interest

- Match Points
- Game Object and Field Element Size / Placement
- Competition Ranking Points
- Robot / Match Play Restrictions

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Breakdown – Identifying All Robot Actions

A robot Action is anything that a robot can do within the Rules.

Create a ‘Robot Action’ List

Platforms	Hatch	Driving
Drive off of Level 1 (Auto)	Pickup Hatch from HP station	Drive around flat field
Drive off of Level 2 (Auto)	Pickup Hatch from floor	Drive over wire harness
Fit with partner on Level 2 (Auto)	Pickup Hatch from floor on opponents' side	Drive over Corral
Climb onto Level 1 straight	Pickup Hatch from leaning against wall	Drive over Level 1 platform
Climb onto Level 1 diagonally	Pickup Hatch from another robot	Drive on opponents' side (no protrusions)
Climb from Level 1 onto Level 2	Place Hatch on Cargo Ship	
Climb from Corral onto Level 2	Place Hatch on level 1 rocket	**Defense**
Climb from Level 1 onto Level 3	Place Hatch on level 2 rocket	Intake oppoent's ball on ground
Climb from Level 2 onto Level 3	Place Hatch on level 3 rocket	Intake opponent's disk on ground
Drive from Level 2 onto Level 3	Place Hatch on floor	Drive into and scatter opponent Corral Balls
Fit with partner on Level 2	Place Hatch against wall	Hit opponent while scoring on rocket
Fit with 2 partners on Level 2	Place Hatch into partner robot	Hit opponent while scoring on cargo ship
Fit with partner on Level 3	Launch Hatch (less than 2 ft)	Block opponent from rocket
Fit with 2 partners on Level 3		Block opponent from cargo ship
Attach/hold Partner for Lifting	**Balls**	Block opponent from their Platform zone
Lift partner from Level 1 to Level 2	Pickup ball from HP station	Block opponent from their HP station
Lift partner from Level 2 to Level 3	Pickup ball from Corral	Block opponent defense from our offensive robots
Lift partner from Level 1 to Level 3	Pickup non-bouncing ball from floor	Shoot opponent Ball out of the air
Lift self and partner from Level 1 to Level 2	Pickup bouncing ball from floor	
Lift self and partner from Level 2 to Level 3	Pickup ball from floor on opponents' side	
Lift self and partner from Level 1 to Level 3	Pickup ball from Cargo Ship (Auto)	
Lift 2 partners from Level 1 to Level 2	Place ball in Cargo Ship	
Lift 2 partners from Level 2 to Level 3	Place ball in Cargo Ship from opposite side	
Lift 2 partners from Level 1 to Level 3	Place ball in level 1 rocket	
Lift self and 2 partners from Level 1 to Level 2	Place ball in level 2 rocket	
Lift self and 2 partners from Level 2 to Level 3	Place ball in level 3 rocket	
Lift self and 2 partners from Level 1 to Level 3	Place ball in level 1 rocket through opposite opening	
	Place ball in level 2 rocket through opposite opening	
	Place ball in level 3 rocket through opposite opening	
	Place ball in partner	
	Shoot Ball	
	Roll Ball	

For Best Results…

- ‘Robot Ideas’ => ‘Robot Actions’
- Keep it engaging
- Get detailed
- Continue adding

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Breakdown – Identifying All Scoring Cycles

A robot Scoring Cycle is any series of Actions that results in a change of match points.

Create a ‘Scoring Cycle’ List (points / cycle)

	Hatch Starting Location			Hatch Ending Position	
24	HP station	-> Drive to Scoring Location ->	0-6	Cargo Ship (L1)	-> Drive to Pickup Location ->
0 start	Ground		4	Rocket (L1)	
0 start	another robot		4	Rocket (L2)	
0 start	against wall		4	Rocket (L3)	
	Ball Starting Location			**Ball Ending Position**	
12	HP station	-> Drive to Scoring Location ->	2-8	Cargo Ship (L1)	-> Drive to Pickup Location ->
12	In Corral		4	Rocket (L1)	
0-6	In Cargo Ship		4	Rocket (L2)	
0 start	Ground		4	Rocket (L3)	
0 start	another robot				

For Best Results...

- Work backwards
- Be systematic

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Breakdown – Scoring Cycles Types

By Match Period

- Autonomous / Sandstorm(2019) Cycles
- Driver Control Cycles
- Endgame Cycles

By Opportunity for Repetition

- Repeatable Cycles
- Finite Cycles
- Single-Instance Cycles

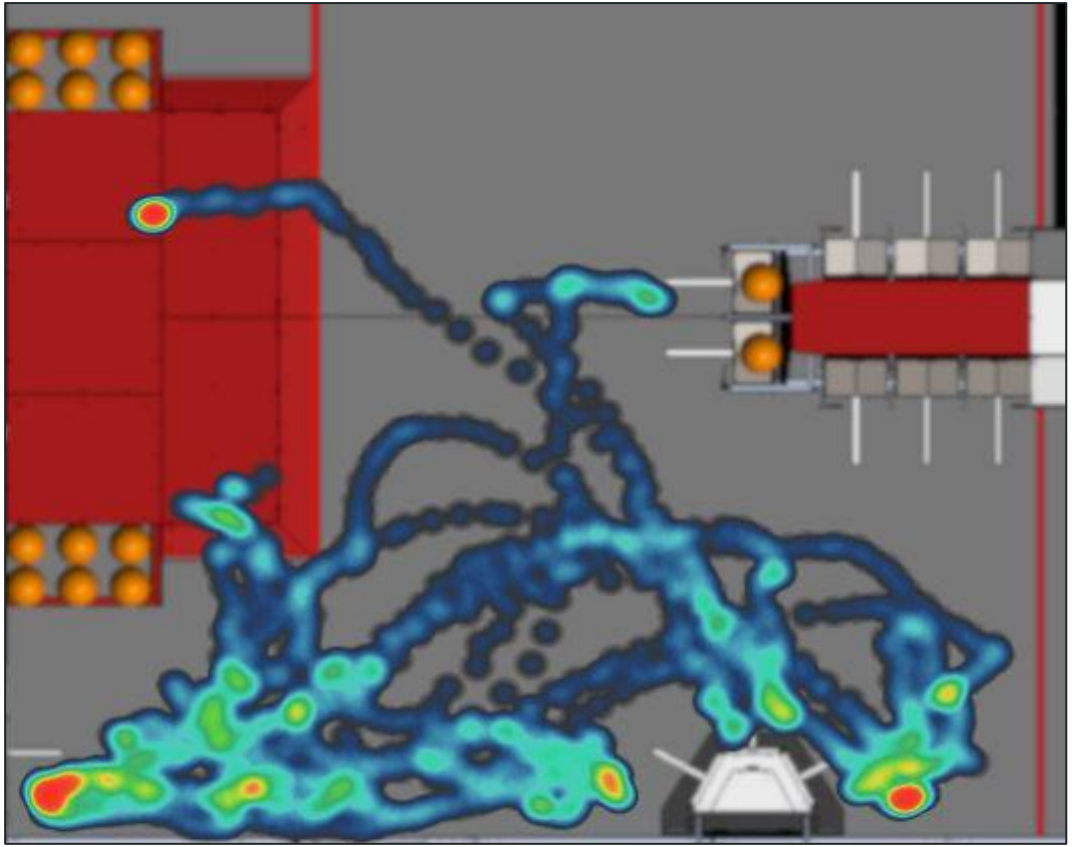

Image Credit: Matt Boehm

Example: Solo Rocket RP, HP Station Cycles - 2019

1X	**Hatch - HP Station to Close Rocket NL1**		1X	**Hatch - HP Station to Close Rocket NL2**		1X	**Hatch - HP Station to Close Rocket NL3**	
	Pickup Hatch from HP station			Pickup Hatch from HP station			Pickup Hatch from HP station	
	Drive around flat field			Drive around flat field			Drive around flat field	
2 pts	Place Hatch on near rocket NL1		2 pts	Place Hatch on level 1 rocket close		2 pts	Place Hatch on level 1 rocket close	
	Drive around flat field			Drive around flat field			Drive around flat field	
1X	**Hatch - HP Station to Close Rocket FL1**		1X	**Hatch - HP Station to Near Rocket FL2**		1X	**Hatch - HP Station to Near Rocket FL3**	
	Pickup Hatch from HP station			Pickup Hatch from HP station			Pickup Hatch from HP station	
	Drive around flat field			Drive around flat field			Drive around flat field	
2 pts	Place Hatch on near rocket FL1		2 pts	Place Hatch on near rocket FL2		2 pts	Place Hatch on near rocket FL3	
	Drive around flat field			Drive around flat field			Drive around flat field	
2X	**Ball - HP Station to Close Rocket L1**		2X	**Ball - HP Station to Close Rocket L2**		2X	**Ball - HP Station to Close Rocket L3**	
	Pickup Ball from HP station			Pickup Ball from HP station			Pickup Ball from HP station	
	Drive around flat field			Drive around flat field			Drive around flat field	
3 pts	Place Ball in near rocket L1		3 pts	Place Ball in near rocket L2		3 pts	Place Ball in near rocket L3	
	Drive around flat field			Drive around flat field			Drive around flat field	

Action Count

- 12 – Cycles Total
- 48 – Actions Total
- 6 – Pickup Hatch from HP station
- 2 – Place Hatch on L1
- 2 – Place Hatch on L2
- 2 – Place Hatch on L3
- 6 – Pickup Ball from HP station
- 2 – Place Ball in L1
- 2 – Place Ball in L2
- 2 – Place Ball in L3

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Breakdown – Accessing Scoring Cycles with Time

Cycle Time is the sum time of each component Action within the Cycle.

Assessing Cycle Time (points / second)

Points / Sec Evaluations	Points	Time	Pts/sec
Leaving Level2 in 0.5sec	6	0.5	12.00
Leaving Level1 in 0.5sec	3	0.5	6.00
Scoring Disk on CB in 8 sec	5	8	0.63
Scoring Disk on CB in 10 sec	5	10	0.50
Scoring Disk on CB in 15 sec	5	15	0.33
Climbing Level 1 in 0.5sec	3	0.5	6.00
Climbing Level 2 in 1sec	6	1	6.00
Climbing Level 2 in 3sec	6	3	2.00
Climbing Level 2 in 5sec	6	5	1.20
Climbing Level 2 in 8sec	6	8	0.75
Climbing Level 2 in 10sec	6	10	0.60
Climbing Level 3 in 1sec	12	1	12.00
Climbing Level 3 in 3sec	12	3	4.00
Climbing Level 3 in 5sec	12	5	2.40
Climbing Level 3 in 8sec	12	8	1.50
Climbing Level 3 in 10sec	12	10	1.20
Climbing Level 3 in 16sec	12	16	0.75
Climbing Level 3 in 20sec	12	20	0.60
Suspending 2 robots in 30 sec	36	90	0.40
Suspending 2 robots in 20 sec	36	80	0.45
Suspending 1 robot in 10 sec	24	15	1.60

Points / Sec Evaluation	Points	Time	Pts/sec
Scoring Disk in 8sec	2	8	0.25
Scoring Disk in 10sec	2	10	0.20
Scoring Disk in 12sec	2	12	0.17
Scoring Disk in 14sec	2	14	0.14
Scoring Disk in 16sec	2	16	0.13
Scoring Disk in 18sec	2	18	0.11
Scoring Disk in 20sec	2	20	0.10
Scoring Ball in 8sec	3	8	0.38
Scoring Ball in 10sec	3	10	0.30
Scoring Ball in 12sec	3	12	0.25
Scoring Ball in 14sec	3	14	0.21
Scoring Ball in 16sec	3	16	0.19
Scoring Ball in 18sec	3	18	0.17
Scoring Ball in 20sec	3	20	0.15

Historical Reference Material		
2016 Stronghold Einstein points	16	balls/match
Teleop Time	135	sec
Points/robot	8.4375	sec/ball
# Robots	2	#
Robot Time per ball	16.875	sec
148Bolt Steamworks points	9	gear/match
Teleop Time	135	sec
gears/match	15	sec/gear
Best Average Steamworks points	4	gear/match
Teleop Time	135	sec
gears / match	33.75	sec/gear

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Example: Assessing Peak Performance Hyper-Competent Robot Cycles/Match

Einstein Level_Hyper Competent Robot_Elimination Match

Remaining Time	Time/action	Action	Point/action	Total Points
150	8	Place Disk on CS	11	11
142	8	Place Disk on CS	5	16
134	9	Place Disk on L1	2	18
125	9	Place Disk on L1	2	20
116	9	Place Ball on L1	3	23
107	9	Place Ball on L1	3	26
98	9	Place Disk on L2	2	28
89	9	Place Disk on L2	2	30
80	9	Place Ball on L2	3	33
71	9	Place Ball on L2	3	36
62	10	Place Disk on L3	2	38
52	10	Place Disk on L3	2	40
42	9	Place Ball on L3	3	43
33	9	Place Ball on L3	3	46
24	9	Ball on CS	3	49
15	8	Climb to Level 3	12	61
7		Time left in Match		

Einstein Level_Hyper Competent Robot_Qualification Match

Remaining Time	Time/action	Action	Point/action	Total Points
150	9	Place Disk on L1	8	8
141	9	Place Disk on L1	2	10
132	9	Place Ball on L1	3	13
123	9	Place Ball on L1	3	16
114	9	Place Disk on L2	2	18
105	9	Place Disk on L2	2	20
96	9	Place Ball on L2	3	23
87	9	Place Ball on L2	3	26
78	10	Place Disk on L3	2	28
68	10	Place Disk on L3	2	30
58	10	Place Ball on L3	3	33
48	10	Place Ball on L3	3	36
38	12	Disk on CS	2	38
26	12	Ball on CS	3	41
14	8	Climb to Level 3	12	53
6		Time left in Match		

Example: Assessing Variable Functionality
L1 Ball-Only Robot Cycles/Match

A) Ball Only Robot_Elimination Match

Remaining Time	Time/action	Action	Point/action	Total Points
150	15	Place Ball on CS	9	9
135	15	Place Ball on CS	3	12
120	15	Place Ball on CS	3	15
105	15	Place Ball on CS	3	18
90	15	Place Ball on CS	3	21
75	15	Place Ball on CS	3	24
60	15	Place Ball on L1	3	27
45	15	Place Ball on L1	3	30
30	15	Place Ball on L1	3	33
15	10	Climb to Level 2	6	39
5		Time left in Match		

B) Ball Only Robot_Elimination Match

Remaining Time	Time/action	Action	Point/action	Total Points
150	20	Place Ball on CS	9	9
130	20	Place Ball on CS	3	12
110	20	Place Ball on CS	3	15
90	20	Place Ball on CS	3	18
70	20	Place Ball on CS	3	21
50	20	Place Ball on CS	3	24
30	20	Place Ball on L1	3	27
10	15	Climb to Level 2	6	33
-5		Time left in Match		

C) Ball Only Robot_Elimination Match

Remaining Time	Time/action	Action	Point/action	Total Points
150	25	Place Ball on CS	9	9
125	25	Place Ball on CS	3	12
100	25	Place Ball on CS	3	15
75	25	Place Ball on CS	3	18
50	25	Place Ball on CS	3	21
25	15	Climb to Level 2	6	27
10		Time left in Match		

D) Ball Only Robot_Elimination Match

Remaining Time	Time/action	Action	Point/action	Total Points
150	30	Place Ball on CS	9	9
120	30	Place Ball on CS	3	12
90	30	Place Ball on CS	3	15
60	30	Place Ball on CS	3	18
30	15	Climb to Level 2	6	24
15		Time left in Match		

Breakdown – Finding the Critical Point

2019 - Lifting two robots with L3 climb less valuable than fast single L3 climb facilitating others.

2018 – Capturing and holding the Scale was basically the only thing that mattered.

2017 – Shooting fuel is way less valuable than gears. Fuel only valuable if performed at a very high level.

2016 – High consequence for missing shot, accuracy needs to be prioritized.

2015 – Winning the contested Containers is basically the only thing that mattered.

Breakdown – Exploring Questions and Functional Goals

Quantitative Questions to Explore

- What will the optimal ranking point robot do in match?
- What will the optimal point scoring robot do in a match?
- What will the optimal 2nd Pick robot do in a match?
- What will the Einstein Winning alliance do during the match?
- What will the most effective defense look like?
- What is the most/least efficient method(s) of scoring points?

Assessing Functional Requirements

- Understand how quickly you need to perform scoring cycles to achieve your match objectives.
- This can inform prototyping goals.

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Brainstorming – Ideation

How the robot performs an Action(s).

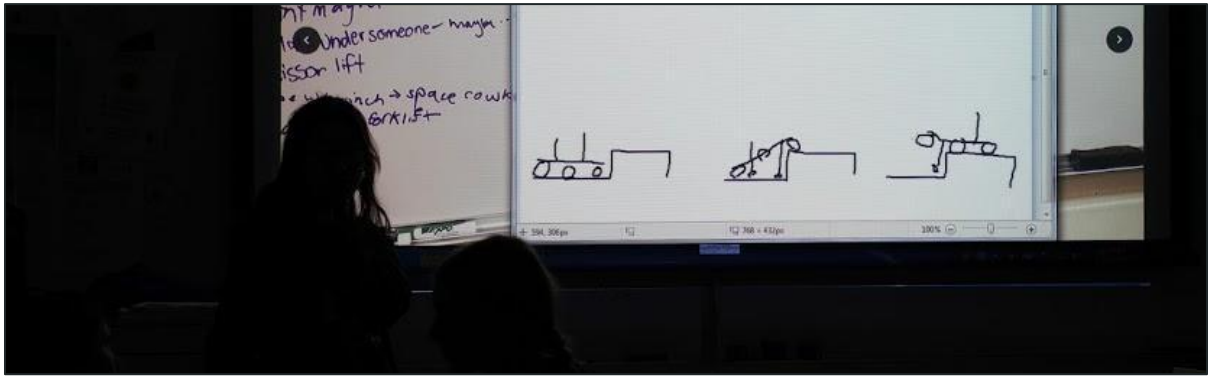
Gathering All Ideas

- Acquire as many ideas as possible, irrespective of quality
- Group participation = More Ideas
- No dismissing ideas

Brainstorming – Question Prompts

To Spark more ideas!

- How can we use wheels/rollers to handle game objects?
- How can we mechanically align to the field?
- How can we have a full width intake?
- How can we minimize game object handling within the robot?
- How can we keep the robot Center of Gravity low?
- How can we accomplish multiple actions with one mechanism?



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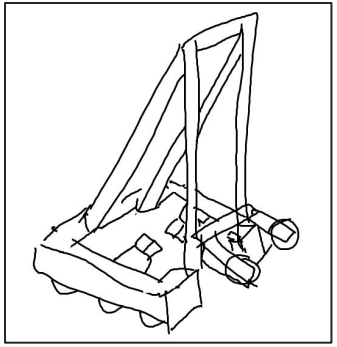
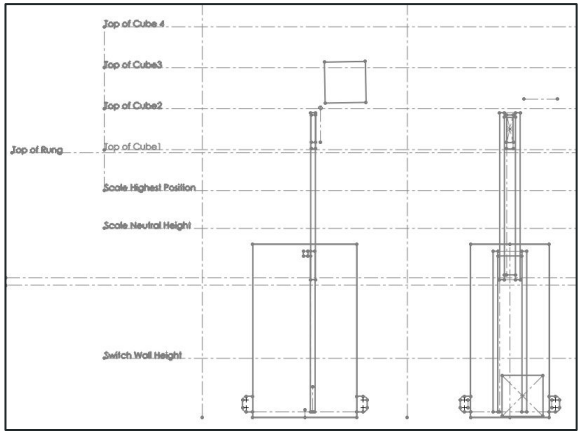
Brainstorming – Robot Architecture

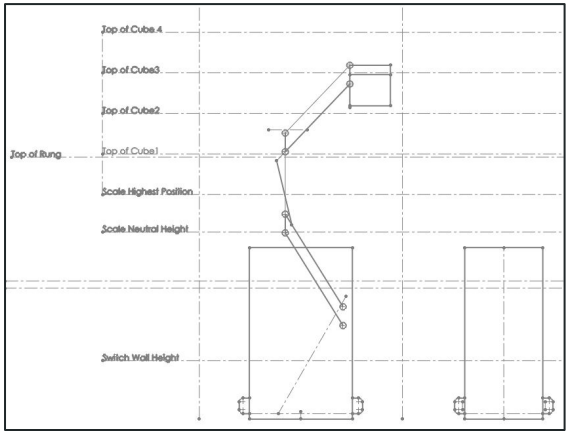
How all of the robot mechanisms combine into the robot functionally and volumetrically.

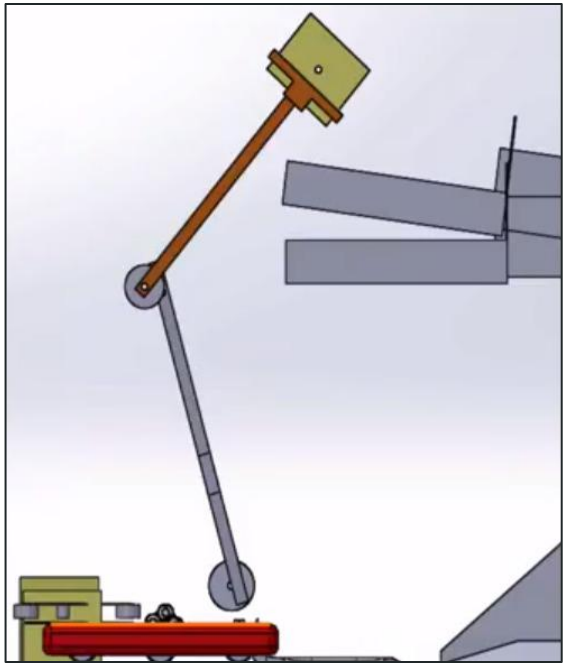
Architecting Robots

- Whiteboard sketches
- 2D CAD sketches
- 3D CAD block robots

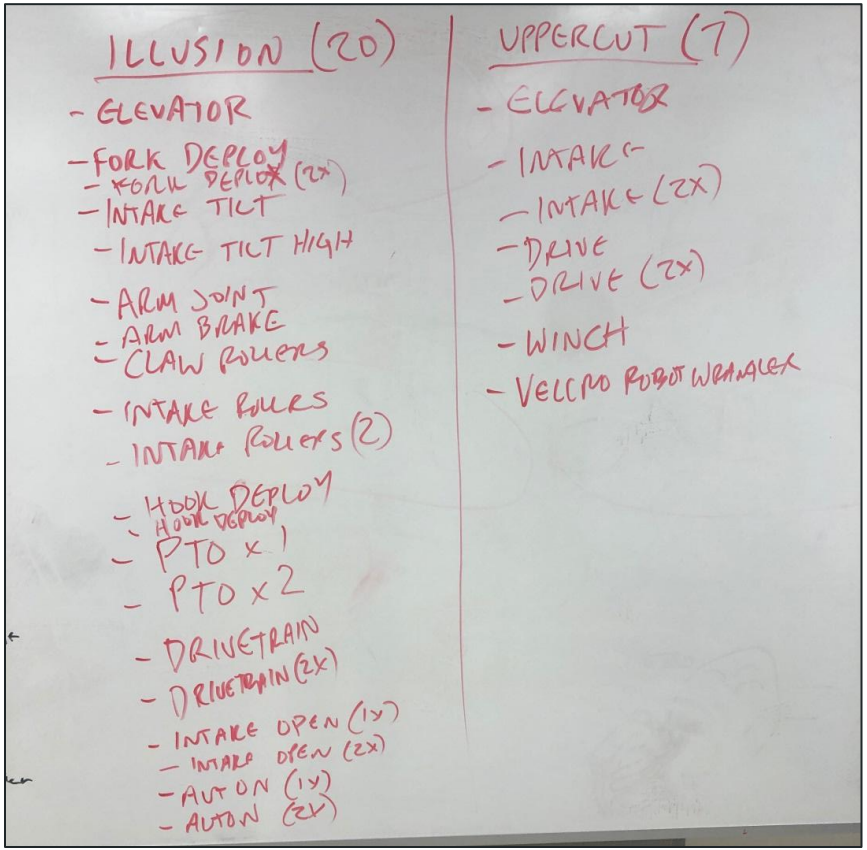








Brainstorming – Minimizing Degrees of Freedom



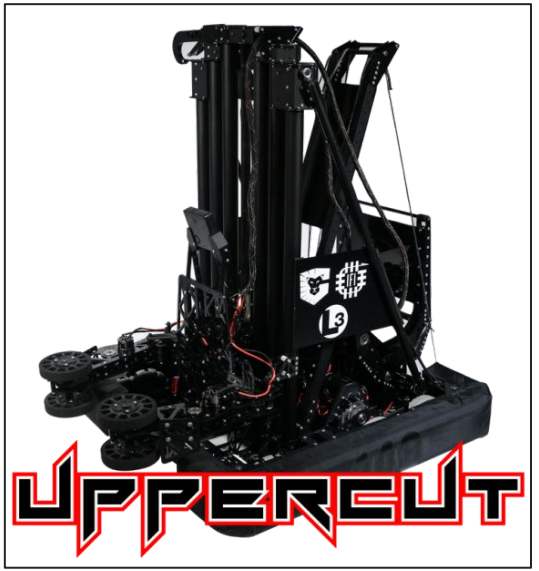


Image Credit: John V-Neun

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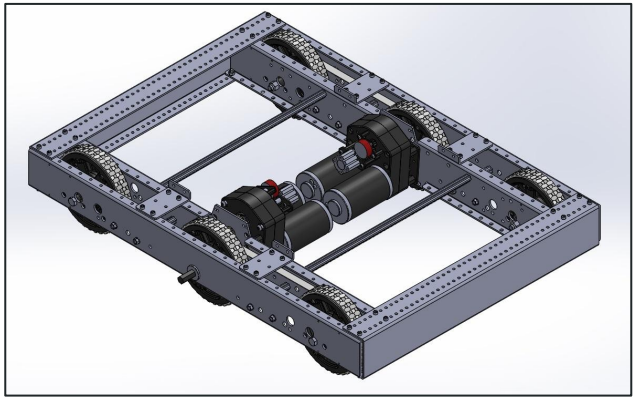
Plan – The Two Paths Forward

Path 1 – Upfront Architecture

- Decide on a architecture before prototyping.
- Narrow prototyping – prototype only mechanisms that fit into the decided robot architecture.

Path 2 – Prototype Driven Architecture

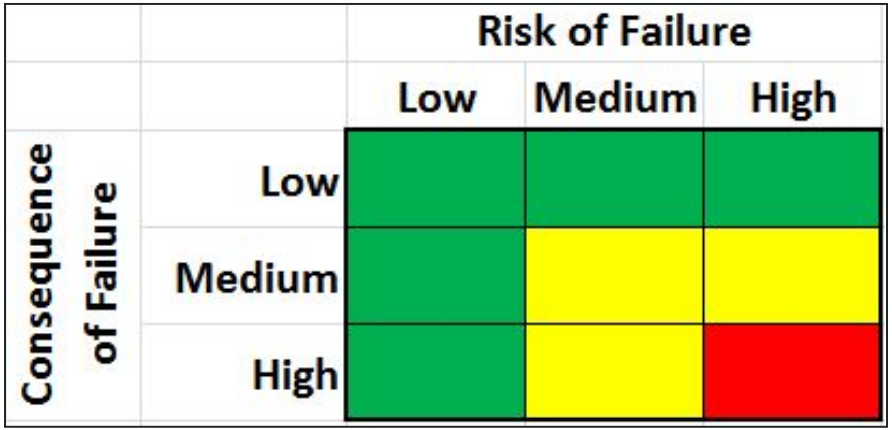
- Delay finalizing the robot architecture.
- Wide Prototyping – prototype a wide variety of mechanisms (some high risk/high reward).
- Use the varied prototyping results to inform the final robot architecture.



Plan – Assessing and Mitigating Risk

Assessing Risk – The Risk List

- Updating this list frequently keeps everyone on the same page.



Mitigating Risk and Allocating Resources

- High Risk items require a lot of resources and backup plans.
- Low Risk items free up resources to be used elsewhere.

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Example: 971's Suction Cup Risk Management

- Initial success with feasibility prototype on disks, not balls.
- Robot architecture designed around the suction cup intake.
- Immense effort went into prototyping through the end of build season.

Prototyping –Documentation

Documenting Prototyping Progress

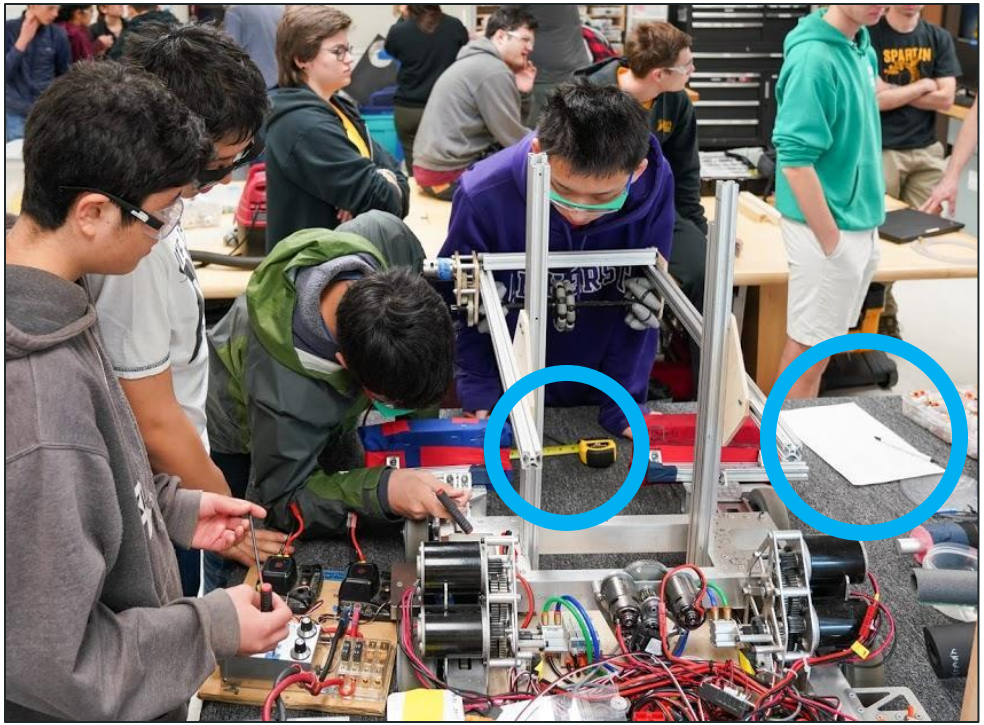
- Google Sheets
- Assign prototype names
- Track revision numbers, dates, and video.

Pre-Prototype

- Record the goals, constraints, and variables.

Post-Prototype

- Record results, optimal variables, problem constraints.



Prototyping – Feasibility vs Optimization

Feasibility Prototyping

- “Does this work?”
- Success / Failure

Optimization Prototyping

- “How well can this work?”
- “Can we achieve functionality with additional constraints on this mechanism?”

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Prototyping – You Need Stuff to Make Things

- Wheels / Game object interaction
- Hex shaft / Bearings / Shaft Collars
- Drills / Motors / Versaplanetaries
- ¼” Plywood / PC / 2x1 box tube
- Drivetrain

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Summary- Some Key Takeaways

- Plan your season with the triangle of robot performance in mind.
- Use time-based analysis to understand the game.
- Assess mechanism risk and allocate resources appropriately.
- Prototype with intent.

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Thank You!

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