FRC Drive Trains

Strategy & Success

Jesse Knight

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Introduction

- Jesse Knight, Lockheed Martin
- 8th Season in FIRST FRC
- 5th Season in FIRST FTC
- 157 matches coached

Which really just means I have first-hand accounts of my team's many mistakes…

JesseK
Chaotic Itinerancy
AKA: Jesse
FRC #1885 (iLITE)
Team Role: Mentor

Presentation Structure

- Strategy of a FRC Drivetrain
  20 mins
- Concepts within a FRC Drivetrain
  20 mins
- Designing a FRC Drivetrain for specific strategies; Best Practices
  20 mins
- Total time:
  1hr, 15 mins

Some Inspiration

- *Any intelligent fool can make things bigger and more complex... It takes a touch of genius - and a lot of courage to move in the opposite direction.*
  -Albert Einstein

- *It is not enough to do your best; you must know what to do, and **then** do your best.*
  -W. Edwards Deming

What's Important?

- What's the most important thing for a robot to do on the field?

MOVE

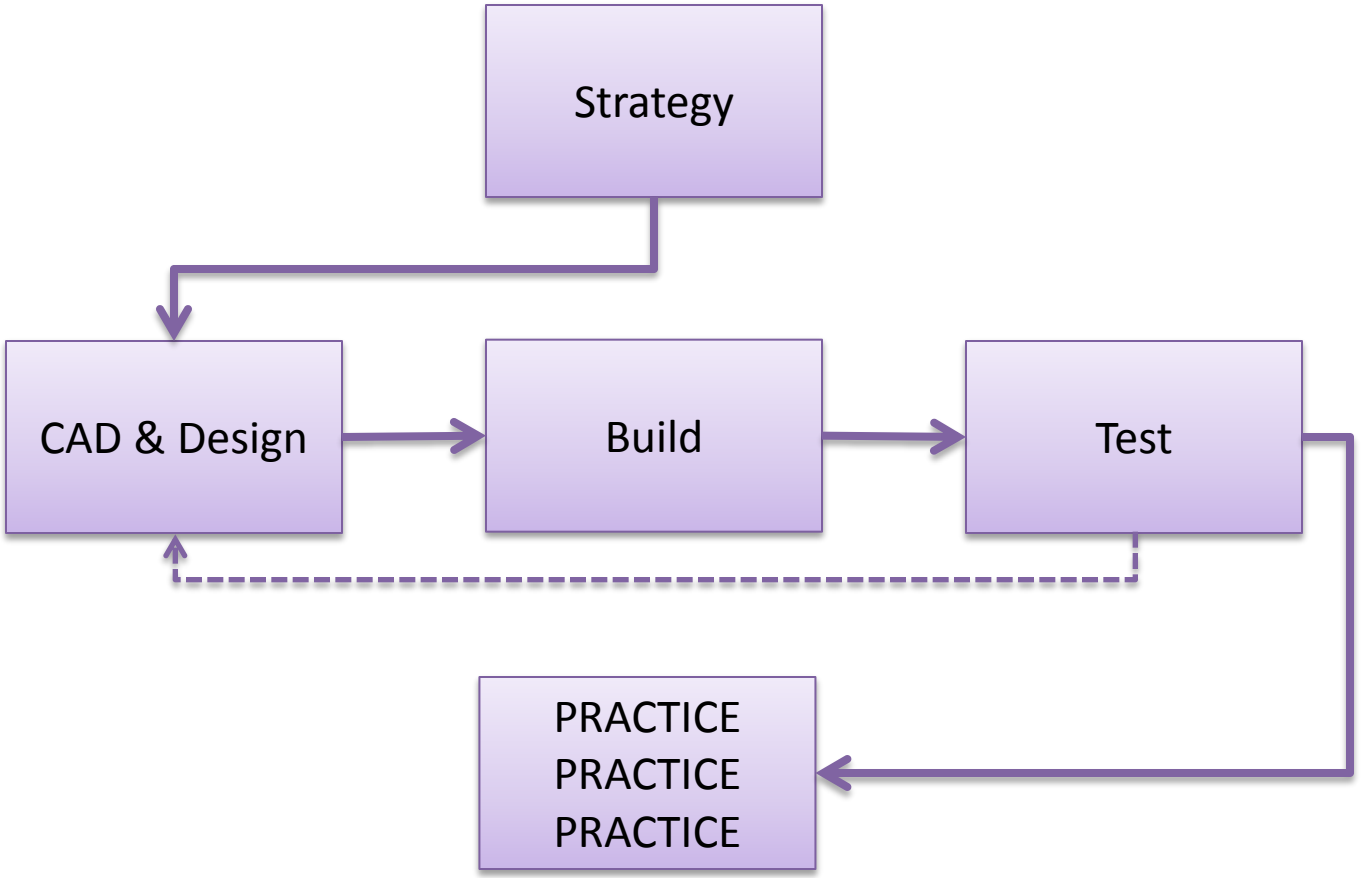
- What's the second most important thing?

ACQUIRE GAME PIECE

- And then?

SCORE

Where to Start?



What Do Drivetrains DO?

- MOVE!
  - Go in a direction
  - Turn

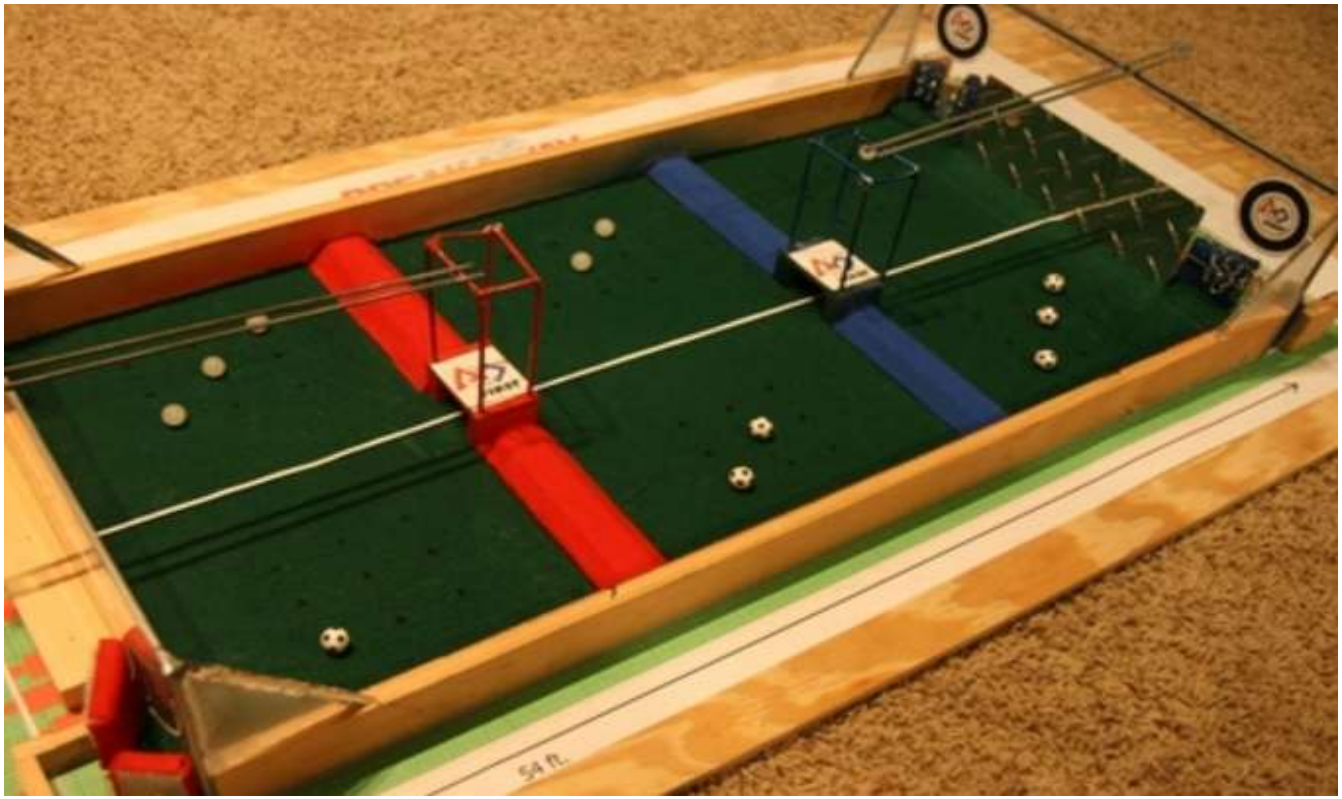
- SUPPORT!
  - The rest of the robot attaches to it
  - Drive train absorbs most of a robot-robot impact
  - Bumper rules change every year too

Drive Train Strategies

- Move Yourself
- Move Others
  - Get them out of the way so you can score
  - Prevent them from scoring
- Don't *BE* Moved

Game Strategy – Move Yourself

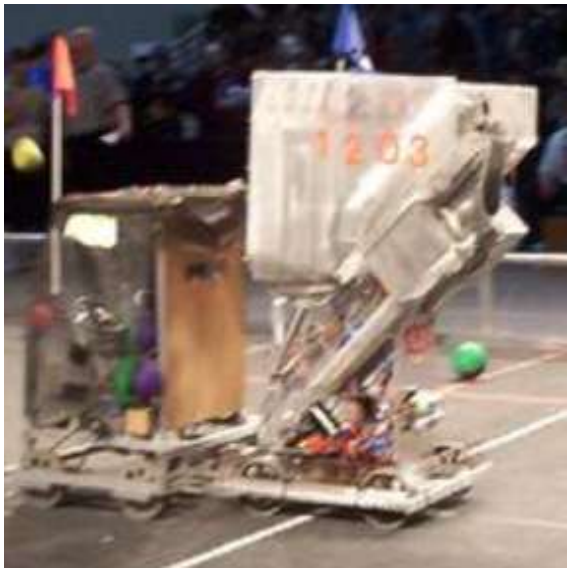
- Key Factors: Speed & Agility
- How far will you actually move?



Game Strategy – Move Others

- Key factors: Torque & Traction
- Also need max weight & low c.g.

Game Strategy – Don't *Be* Moved



Dashed Hopes

If you can score really well while not under defense, ***many*** robots will play defense on you!

Game Strategy -- Corollaries

- If any of these three things don't happen…
  - Leave enough battery juice for other systems
  - Work every match, for the whole match
  - Prevent tip over

- … your effectiveness and usefulness diminishes

The Big Picture -- Schedule

- Get it done EARLY
- "Kitbot on Steroids", by FRC 1114

The Big Picture -- Cost

- Shifting transmissions cost ~$800 shipped
- Complex custom drive trains
  - Omni is ~$800
  - Mecanum is ~$1,000
  - Shifting Swerve is $2,000+

The Big Picture -- Practice

- Good drivers with a simple drive train are MORE VALUABLE than a fancy drive train with drivers who haven't had practice

- A robot with a working drive train can always play defense

- Doing a complex drive train that your team has *never* successfully done before will take away from your practice time!

The Big Picture -- Reliability

- Risk vs. Impact: If it breaks, you can't score ANY points
- Fancy drive trains have a much higher risk of breaking
- Often it is more beneficial to iteratively improve a simple drive train to be more reliable from year to year
- Don't let this stop you from experimenting ***IN THE OFFSEASON***

Quick Break

- Questions?
- Resources:
  - Kit-Bot on Steroids
    http://www.simbotics.org/media/videos/2011/presentations/kitbot-presentation-kitbot-steroids
  - Primary Source of Pictures
    http://www.chiefdelphi.com
- When we return:

  Motors, Gearing, Wheels, & Transmissions

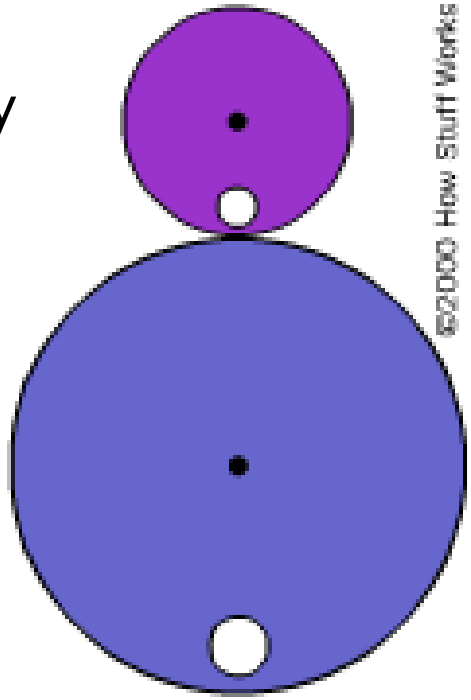
Drive Train Design

Let's assume you have the Kit Of Parts drive train, completely stock. What tweaks & changes could you make without a full redesign?

- Different Gearing for more or less speed
  - Change internal gears
  - Change sprockets
- More Motors
- Different Wheels
  - Size
  - Tread
- Different Transmissions (add shifting)

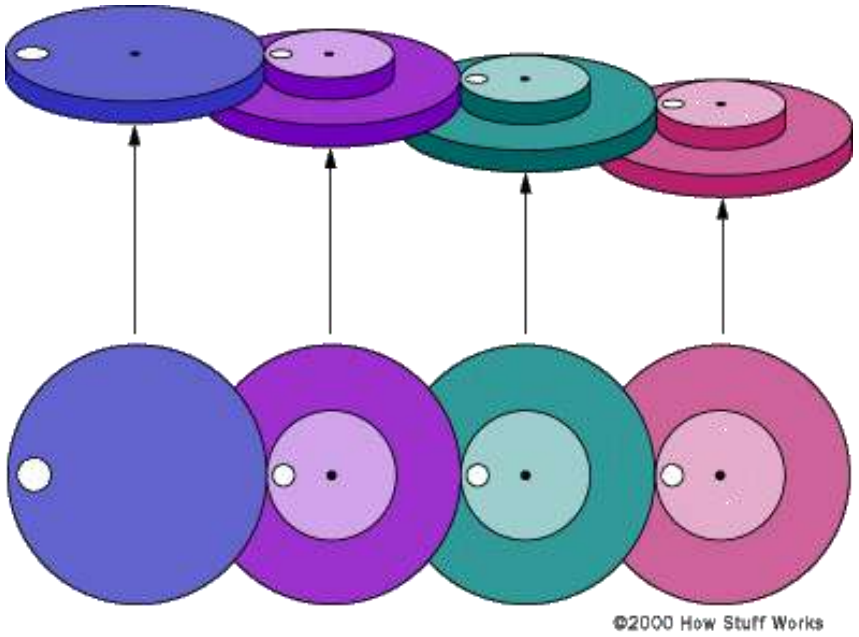
Different Gearing

- Increase 'driven' gear/sprocket
  - Goes slower, is more controllable
  - Has more pushing torque
  - Draws less current from the battery
- Increase 'driving' gear/sprocket
  - Goes faster, is more maneuverable
  - Can win a race to a game piece
- Choose based upon team strategy for the game!



Compound Gearing

- 1:2 & 1:2 & 1:2 = 1:(2x2x2) = 1:8 ratio
  - Purple spins 2x faster than Blue
  - Green spins 2x faster than Purple, 4x Blue
  - Red spins 2x faster than Green, 8x Blue

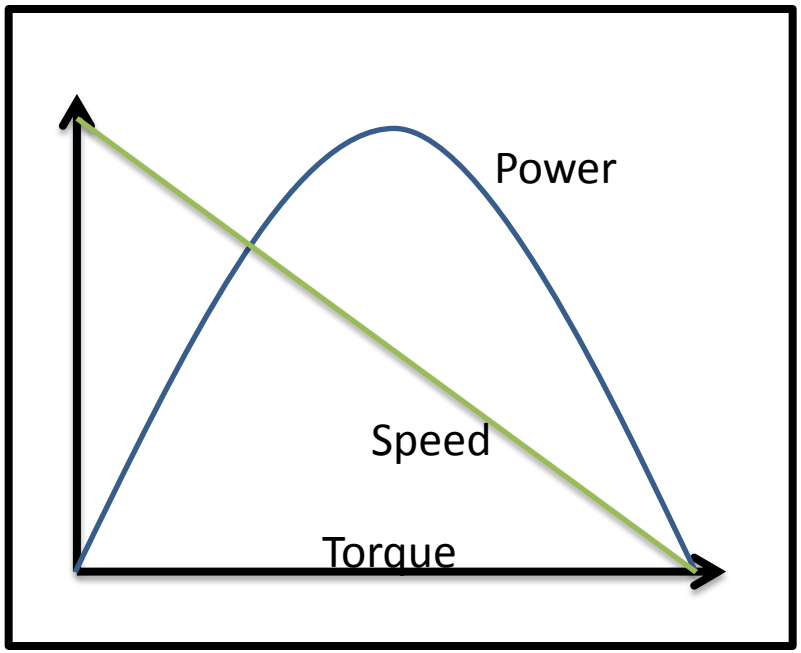


Gearing Example

- Motor speed = 150 rpm
- Motor Torque = 300 oz-in = 18.75 in-lb
- Gearbox: 40-tooth on motor, 80-tooth on wheel = 2:1
- Wheel Speed = 150/2 = 75 rpm = 1.25 rot/sec
- Resulting torque = 18.75*2 = 37.5 in-lb
  - Bot speed/pushing power depends on wheel size

Effects of Changes – More Motors

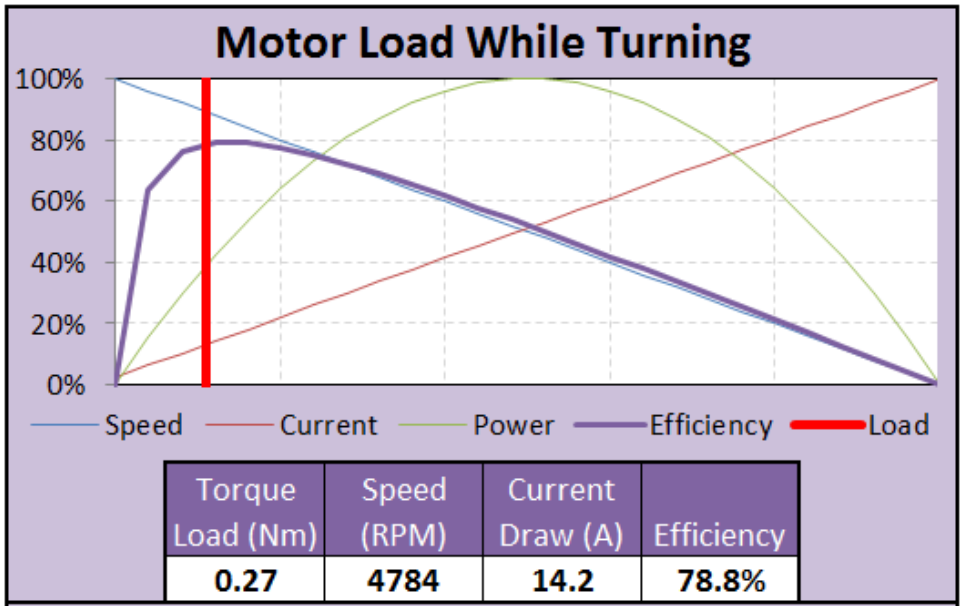
- Motors have limited power
- Gears tradeoff speed for torque (or vice versa)
- The only way to get more speed AND more torque is to add more motors



Motor Characteristics

Motor			CIM	
Spec Voltage (V)	Free Speed (RPM)	Stall Torque (Nm)	Stall Current (A)	Free Current (A)
12	5380	2.43	107	2.7
		Applied Voltage (V)		12
		Total # of Motors		4

These are the #'s most people will talk about when doing calculations



Torque Load (Nm)	Speed (RPM)	Current Draw (A)	Efficiency
0.27	**4784**	**14.2**	**78.8%**

Motor Bias

- Motor Bias: a motor might appear to turn faster/stronger in one direction than the other
- Why?
  - Difference in internal windings of the motor
    - This is negligible with CIM Motors
  - Appearance of bias due to unbalanced friction forces throughout the drive train
  - Improper calibration of Victor 884 Speed Controllers
- Affects autonomous “drive straight” routines

Effects of Changes – Wheels

- Changing the size of a wheel is effectively like changing the 'driven' gear in a gearbox
- Large wheels = faster, less torque
- Smaller wheels = slower, more torque

- Width of a wheel may effect traction
  - FRC surfaces are carpet, a fine fibrous material
  - FRC Wheels are flexible rubber with perpendicular surfaces
  - Therefore standard 'smooth' assumptions may not apply
  - The debate never ends, so YMMV

More About Wheels

- Have 2 coefficients of friction that translate torque to traction or resistive force
- Lateral (sideways) friction is a force that resists turning
  - A.k.a. skidding
- Tread also affects traction – types & patterns

Wheels – Final Note

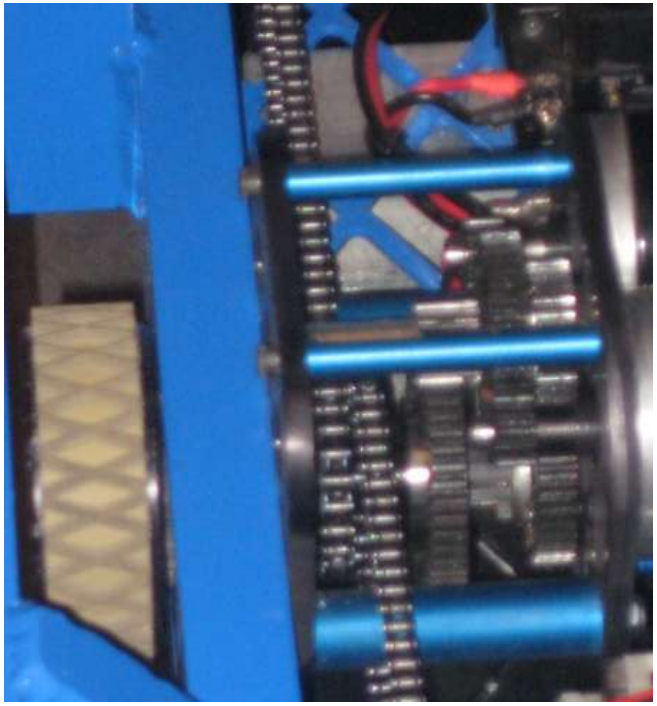
- Of course, for every anecdote that states "you MUST have high traction"…

Team 111, Wildstang
2011 Champions

COTS Transmissions

- There are very few COTS shifters available

- Building your own requires machining and good engineering



Transmissions

- Always know how to re-calculate your ratios if you do change your transmissions

Super Shifter Gearbox

	Driving	Driven	Efficiency	0
Stage 1	12	40	97%	0.30
Stage 2	28	35	97%	0.80
Stage 3	20	45	97%	0.44
Stage 4				1.00
Diff. between High/Low Gear			2.56	
High Gear:	**9.38 : 1**		91%	0.107

- For COTS transmissions, it may be easier to adjust the sprockets between the transmission and wheel

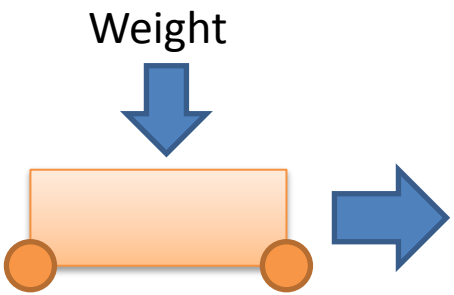
Quick Break

- Questions?
- All COTS parts shown are from
  - www.andymark.com
  - www.vexrobotics.com → VEXPro
- When we return:

  Designing to Push
  Designing for Speed
  General Best Practices

Designing to Push – Concepts

- Coefficient of Friction
  - Translates weight to pushing force
  - KOP wheels are typically 0.7-0.8
  - 'Roughtop' treads are typically 1.2



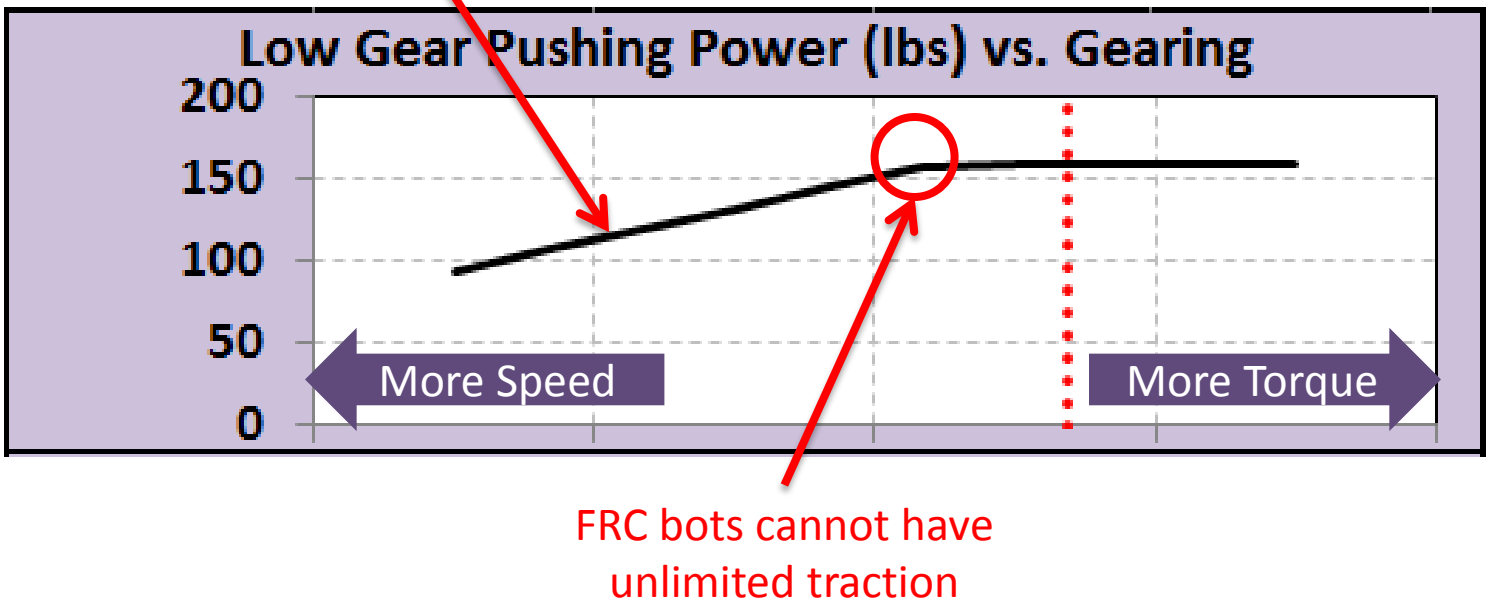
- Inertia
  - Low c.g. ensures your opponent's momentum isn't lower than yours
  - Lower momentum vectors causes rear wheels on the other robot to momentarily lose *some* traction

- You have to catch the other robot first!
  - Shifting transmissions
  - Smart driving!

Designing to Push – Tradeoffs

Unless they shift, FRC bots cannot go fast and push

Stock Super Shifters, 6” Wheels



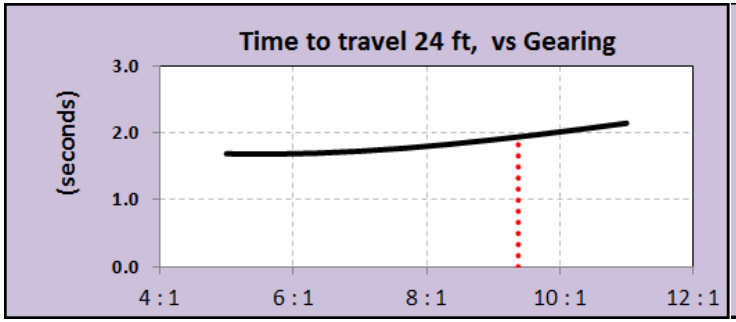
FRC bots cannot have unlimited traction

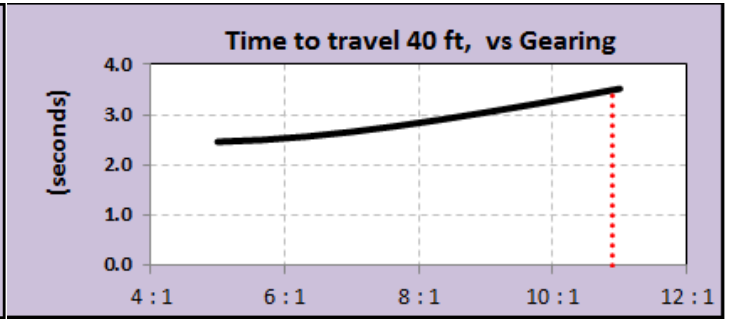
Designing to Push – Best Practices

- To push the heaviest robots, your robot must also be heavy
- "Low gear" is typically best between 5-6 ft/s
  - YMMV
- Make contact in high gear at speed, shift to low gear to follow through
- If you can push other robots, most importantly you can ***push through defense***

Designing for Speed – Concepts

- It's easy to go fast, but there's a balance
  - Still need to control the robot
  - Still need to be able to turn easily.
- There's little benefit in high speed if the max sprint distance is short





Turning

- Properly tension your chains
- Make sure your robot can turn:
  - http://www.chiefdelphi.com/media/papers/1917
  - http://www.chiefdelphi.com/media/papers/1443

2) If you don't like math, use the following rules of thumb:
   - Make the track width greater than the wheel base ($L_{TW} > L_{WB}$)
   - If possible, reduce the lateral friction coefficient while keeping the longitudinal friction high (i.e., use holonomic wheels or choose a good wheel tread pattern).
   - Try to move the center of mass slightly away from the center of the robot. Use caution to not move the COM far enough so that the robot becomes unstable.

3) Once you satisfy the equation in step 1), you should have values for the important dimensions (L_{TW}, L_{WB}, and L_{CY}). Plug these numbers into the following equation to determine the force necessary at each wheel to make the robot turn:

$$F_{LR} > \frac{\mu_y W}{L_{TW}} \left(\frac{L_{WB}}{4} - \frac{L_{CY}^2}{L_{WB}} \right)$$

4) Using the force calculated in step 3), a minimum gearing can be determined such that the motors can produce the necessary force at the wheel.

Turning

- Example of different lateral coefficients of friction that help turn

Prototyping

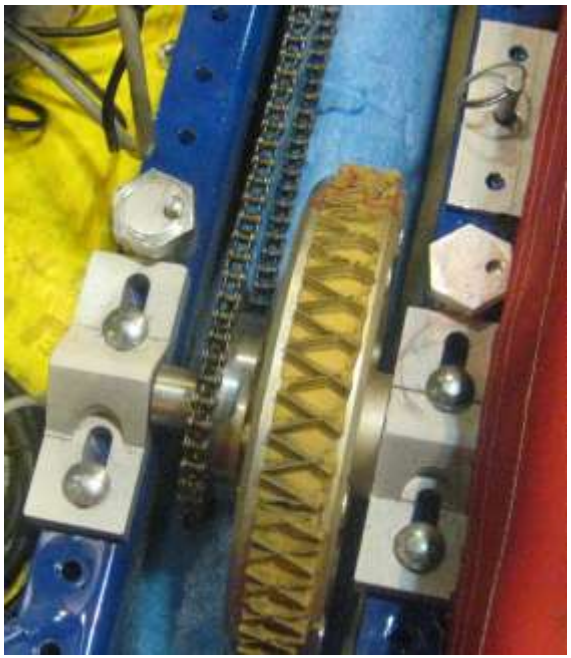
- If you need to make a major change, prototype it as quickly as possible!

- Built in 3 hours:

Tensioning Chain

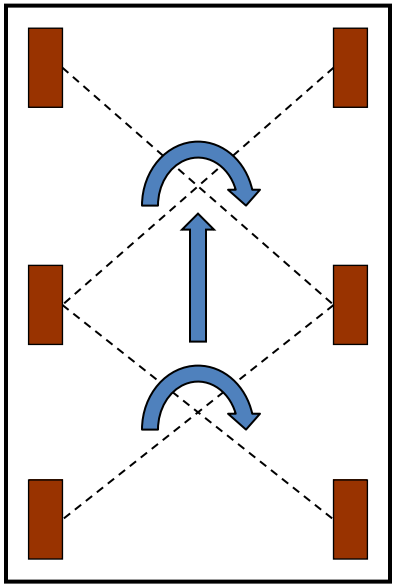
- Chain must always be under proper tension
- Chain also stretches under load

- Thus, make your chain tensioners adjustable



Center of Gravity

- You know it should be low, but…
  - Reference the "Turning" Slide
- KOP is setup so that only 4 wheels touch the ground at any one time

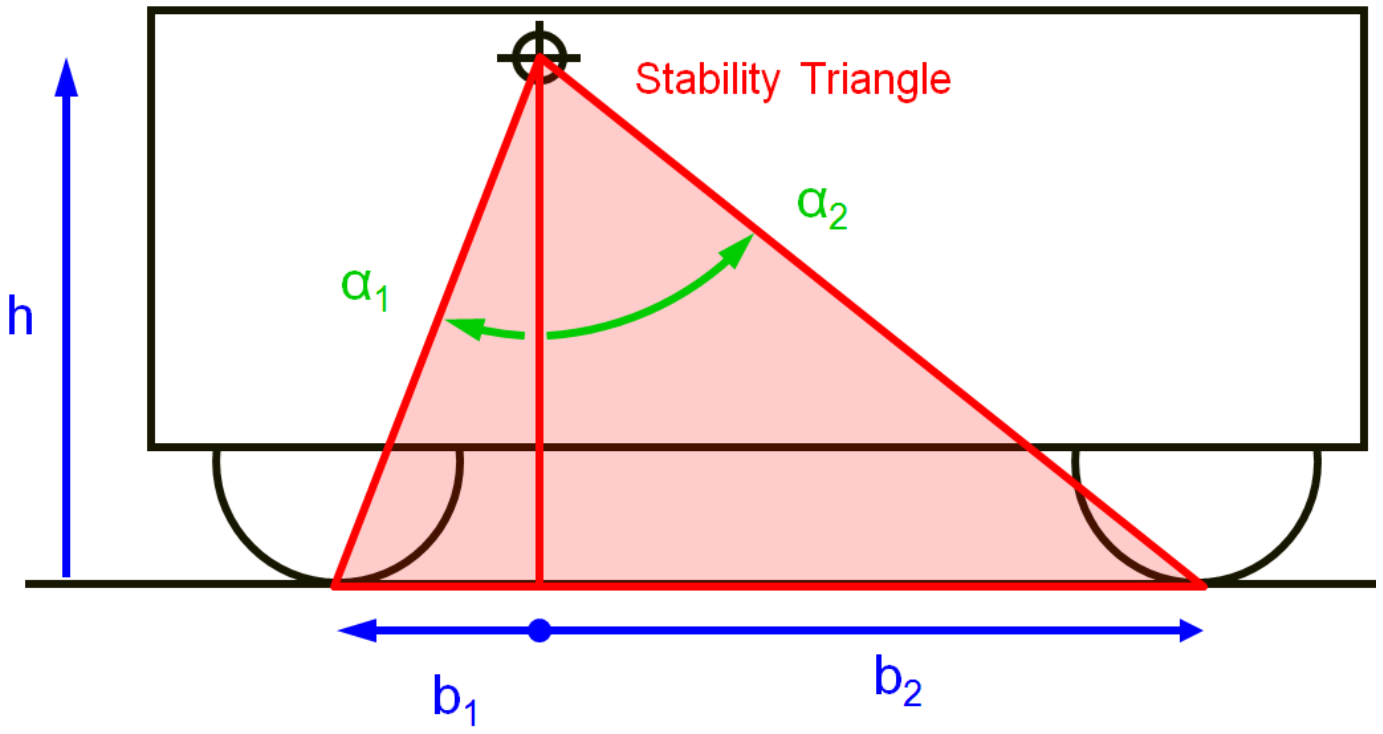


- The only way to move c.g. away from each center of area AND maintain robot stability is to …
- Move the heavy components to adjust where the c.g. is located

Center of Gravity

How to calculate …

- Tilt the robot on all 4 sides until the tipping point
- Where the planes intersect is the c.g.



Courtesy of Andrew Keisic, Team 294

Center of Gravity

1 reason swerve drives do not behave as the driver expects

Motor Burn-In

- Motor + Gearbox burn-in
  - Removes manufacturing imperfections on the gears that cause inefficiency
  - To perform:
    - Mount the motor on the gearbox
    - Apply LOTS of grease to the gears
    - Run the motor on a battery for 10 minutes
    - Take gearbox apart, clean the gears, rebuild gearbox
- Mount everything securely
- Use Loctite on bolts, grease in the gearbox

At the Competition

- Clean wheel tread or Mecanum Rollers
- Maintain proper tension on the chains
- Check for misalignments
  - Sprockets
  - Wheel direction
  - Can be caused by bearings that pop out
- Check for loosened bolts

Final Thoughts

2011's Top 25 offensive robots
Courtesy of John V-Neun

254 - Skid Steer
111 - Skid Steer
1114 - Skid Steer
2016 - Skid Steer
217 - Skid Steer
987 - Skid Steer
148 - Skid Steer
1503 - Skid Steer
2056 - Skid Steer
233 - Skid Steer
67 - Skid Steer
33 - Skid Steer

1717 - Swerve
469 - Skid Steer
177 - Skid Steer
71 - Swerve
40 - Swerve
2054 - ???
118 - Skid Steer
330 - Skid Steer
16 - Swerve
51 - Slide Drive
27 - Skid Steer
2826 - ???
1538 - Skid Steer

Questions & Tool Walkthrough

- More resources:

WPI Archive: http://first.wpi.edu/Workshops/index.html

- Graphs in this presentation were generated using this tool: www.chiefdelphi.com/media/papers/2469