Drive System Fundamentals

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FIRST Kickoff Workshops
Novi, MI

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Agenda

1. Introduction (why we are here)

2. Robot Drive Systems (important things to know about drive systems for OCCRA robots)

3. Questions & Answers

Introduction – Who am I?

Ken Patton

Engineering Group Manager, GM Powertrain
Advanced Engine Design and Development (17 years)

Bachelor of Science, Mechanical Engineering
Michigan Technological University (Houghton, MI)

Master of Science, Mechanical Engineering
Massachusetts Institute of Technology (Cambridge, MA)

7th year of participation in FIRST, Team #65

Introduction

<u>Why you are here:</u>

To learn about drive systems for FIRST robots
- what to do
- what not to do

To gain confidence as you go into the 2003 season
- know more about the process to follow
- more fun, less work, more exciting robots!

Highly recommended: Paul Copioli's presentation this afternoon

Introduction, Cont'd

<u>What this session will NOT do:</u>

It will not tell you which drivetrain design is the best one

It will not tell you anything about the 2003 FIRST game

It will not get into details on other robot systems (arms, etc.)

Robot Drive Systems

1. Drive System Requirements

2. Traction Fundamentals

3. Gearing Fundamentals

4. Reliability

Drive System Requirements
(Know what you want it to do!)

Before you start designing your machine, you must know what you want it to do

The game rules and your team's chosen strategy will help you decide what you want it to do

By spending some time and deciding for sure what you want it to do, you will be able to make good decisions about what design to choose

This needs to be a **team** effort

What Attributes Are Required?

Attribute
high top speed
acceleration
pushing/pulling ability
maneuverability
accuracy
obstacle handling
climbing ability
reliability/durability
ease of control

Attribute Descriptions

Attribute	Comments
high top speed	able to cover a lot of ground in a short period of time ("high velocity")
acceleration	able to get up to top speed in a short period of time ("high acceleration")
pushing/pulling ability	able to exert a lot of drive force ("tractive effort") on other objects
maneuverability	able to change directions quickly and accurately ("directional control")
accuracy	able to move to the desired location without a lot of error ("positional control")
obstacle handling	able to quickly and smoothly move over objects in the playing field
climbing ability	able to climb or descend ramps/hills/steps quickly and smoothly
reliability/durability	doesn't break down; doesn't require a lot of maintenance to keep running in top condition ("QRD")
ease of control	easy to drive ("user-friendly"), and easy to learn to drive ("steep learning curve")

Decide "Musts" and "Wants"

Attribute	Comments	Must Have	Want to Have
high top speed	able to cover a lot of ground in a short period of time ("high velocity")		
acceleration	able to get up to top speed in a short period of time ("high acceleration")		
pushing/pulling ability	able to exert a lot of drive force ("tractive effort") on other objects		
maneuverability	able to change directions quickly and accurately ("directional control")		
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What to Do Once You Know What the Requirements Are

Look at designs of existing machines (robots, cars, ATV's, heavy equipment, forklifts, Dean's latest inventions, etc.)

Brainstorm: Identify design features that help meet the requirements (write them down, draw sketches)

Think of new or modified designs that use the "good" design features

Choose sets of design features ("concept designs") that meet the requirements

Pick ~3 concept designs to go forward with….

Do a Trade-off Study

Attribute	Must Have	Want to Have	Weighting	Score
high top speed		X	2	
acceleration		X	2	
pushing/pulling ability	X		4	
maneuverability	X		4	
accuracy	X		5	
obstacle handling		X	1	
climbing ability		X	2	
reliability/durability	X		5	
ease of control		X	3	

EXAMPLE ONLY

Involve **whole** team

Decide must haves and want to haves

Decide on weighting for each attribute

Make one sheet for each concept design

Score each concept design for all attributes

Multiply score by weighting to get weighted score

Add up weighted scores

Compare scores for each concept design

Use Requirements to Make a Decision

Attribute	Comments	Must Have	Want to Have
high top speed	able to cover a lot of ground in a short period of time ("high velocity")		
acceleration	able to get up to top speed in a short period of time ("high acceleration")		
pushing/pulling ability	able to exert a lot of drive force ("tractive effort") on other objects		
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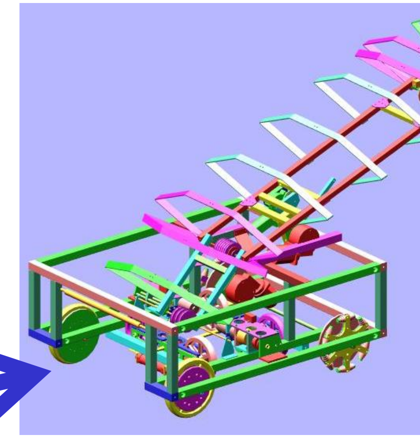
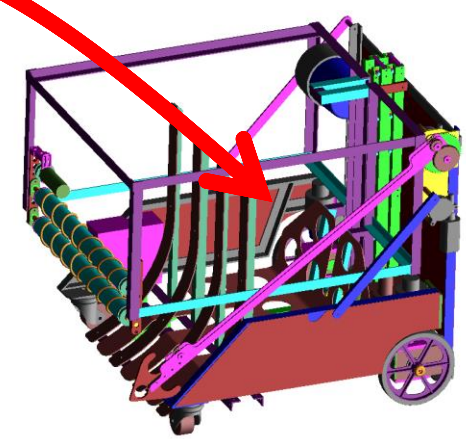
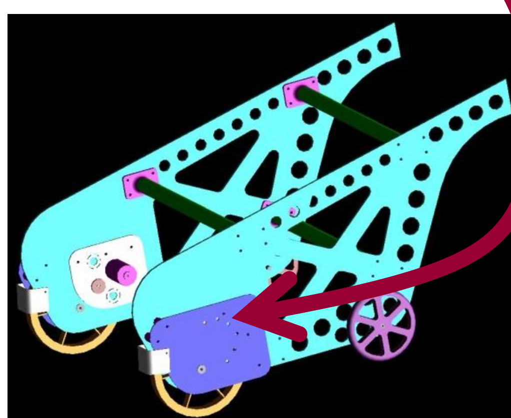




- **Trade-off Study**
- **Strengths**
- **Weaknesses**
- **Strategy**



Some Features That Help Provide Good Drive System Attributes

Attribute	Good Features to Have
high top speed	high power, low losses, the right gear ratio
acceleration	high power, low inertia, low mass, the right gear ratio
pushing/pulling ability	high power, high traction, the right gear ratio, low losses
maneuverability	good turning method
accuracy	good control calibration, the right gear ratio
obstacle handling	ground clearance, obstacle "protection," drive wheels on floor
climbing ability	high traction, the right gear ratio, ground clearance
reliability/durability	simple, robust designs, good fastening systems
ease of control	intuitive control method, high reliability

Some Features That Help Provide Good Drive System Attributes

TRACTION

Attribute	Good Features to Have
high top speed	high power, low losses, the right gear ratio
acceleration	high power, low inertia, low mass, the right gear ratio
pushing/pulling ability	high power, high traction, the right gear ratio, low losses
maneuverability	good turning method
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obstacle handling	ground clearance, obstacle "protection," drive wheels on floor
climbing ability	high traction, the right gear ratio, ground clearance
reliability/durability	simple, robust designs, good fastening systems
ease of control	intuitive control method, high reliability

Some Features That Help Provide Good Drive System Attributes

GEARING

Attribute	Good Features to Have
high top speed	high power, low losses, the right gear ratio
acceleration	high power, low inertia, low mass, the right gear ratio
pushing/pulling ability	high power, high traction, the right gear ratio, low losses
maneuverability	good turning method
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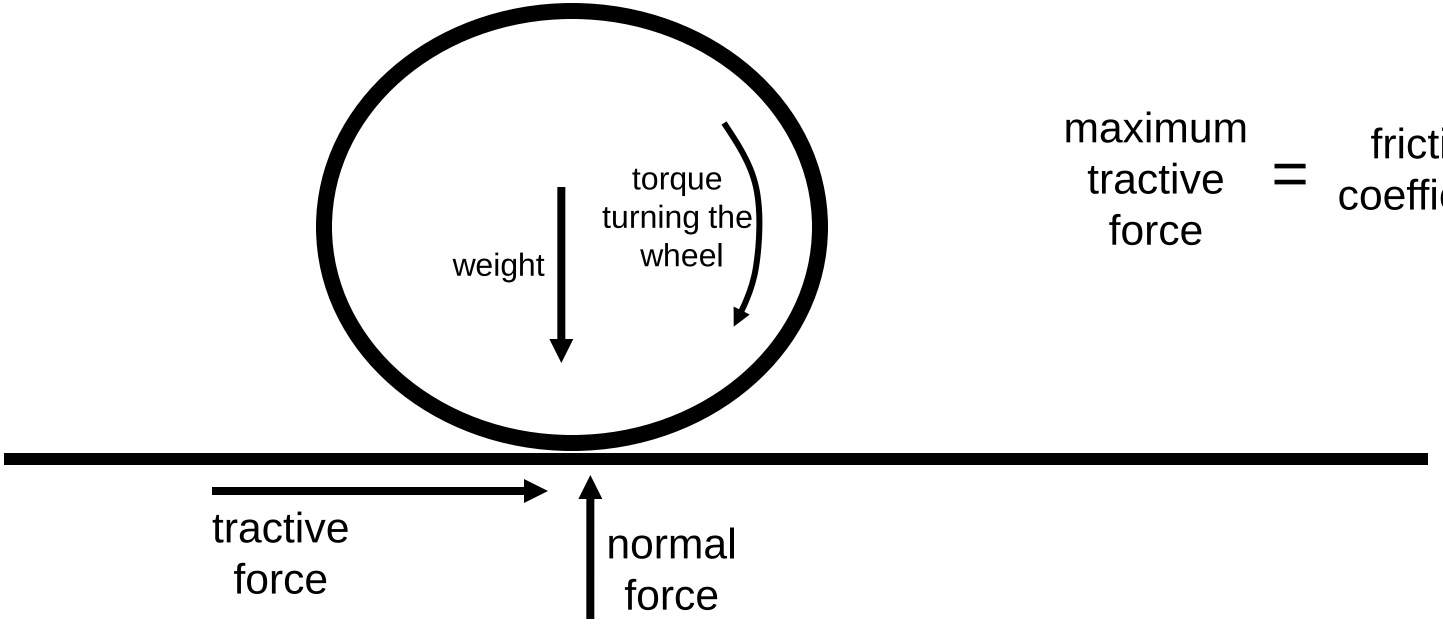
Robot Drive Systems

1. Drive System Requirements
2. Traction Fundamentals
3. Gearing Fundamentals
4. Reliability

Traction Fundamentals Terminology



maximum tractive force = friction coefficient x normal force

The friction coefficient for any given contact with the floor, multiplied by the normal force, equals the maximum tractive force can be applied at the contact area.

Tractive force is important! It's what moves the robot.

Traction Fundamentals
"Friction Coefficient"

Friction coefficient is dependent on:

- Materials of the robot wheels (or belts)
- Shape of the robot wheels (or belts)
- Material of the floor surface
- Surface conditions

Traction Fundamentals
Wheel Materials

Friction coefficient is dependent on:

Materials of the robot wheels (or belts)

Shape of the robot wheels (or belts)

Material of the floor surface

Surface conditions

Good:
soft materials
"spongy" materials
"sticky" materials

Bad:
hard materials
smooth materials
shiny materials

It is often the case that "good" materials wear out much faster than "bad" materials - don't pick a material that is TOO good!

Advice: make sure you have tried & true LEGAL material

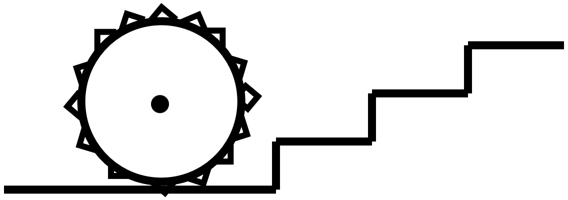
Traction Fundamentals
Shape of Wheels (or Belts)

Friction coefficient is dependent on:

- Materials of the robot wheels (or belts)
- **Shape of the robot wheels (or belts)**
- Material of the floor surface
- Surface conditions

Want the wheel (or belt) surface to "interlock" with the floor surface

On a large scale:



And on a small scale:

(see previous slide)

Traction Fundamentals
Material of Floor Surface

Friction coefficient is dependent on:

- Materials of the robot wheels (or belts)
- Shape of the robot wheels (or belts)
- **Material of the floor surface** →
- Surface conditions

This is not up to you!

Know what surfaces (all of them) that you will be running on.

Traction Fundamentals
Surface Conditions

Friction coefficient is dependent on:

Materials of the robot wheels (or belts)

Shape of the robot wheels (or belts)

Material of the floor surface

Surface conditions

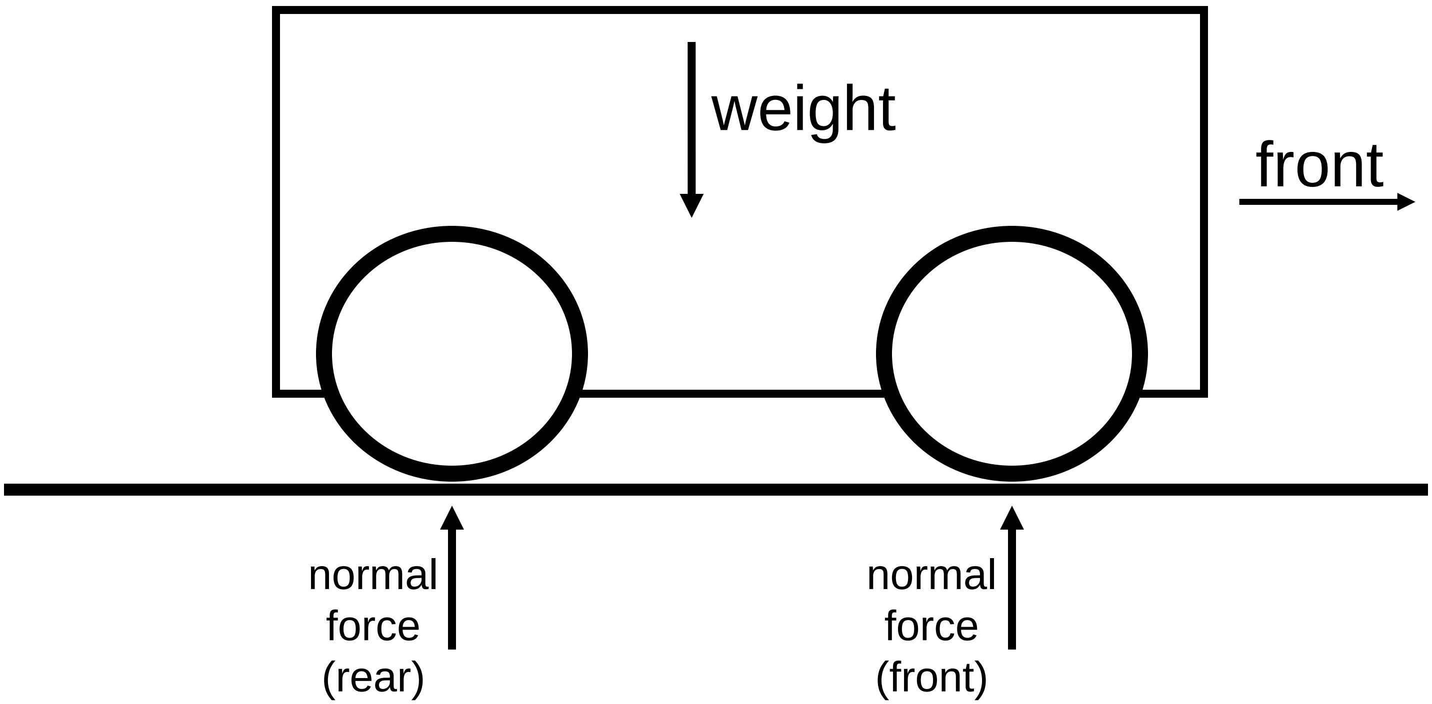
In some cases this will be up to you.

Good:
clean surfaces
“tacky” surfaces

Bad:
dirty surfaces
oily surfaces

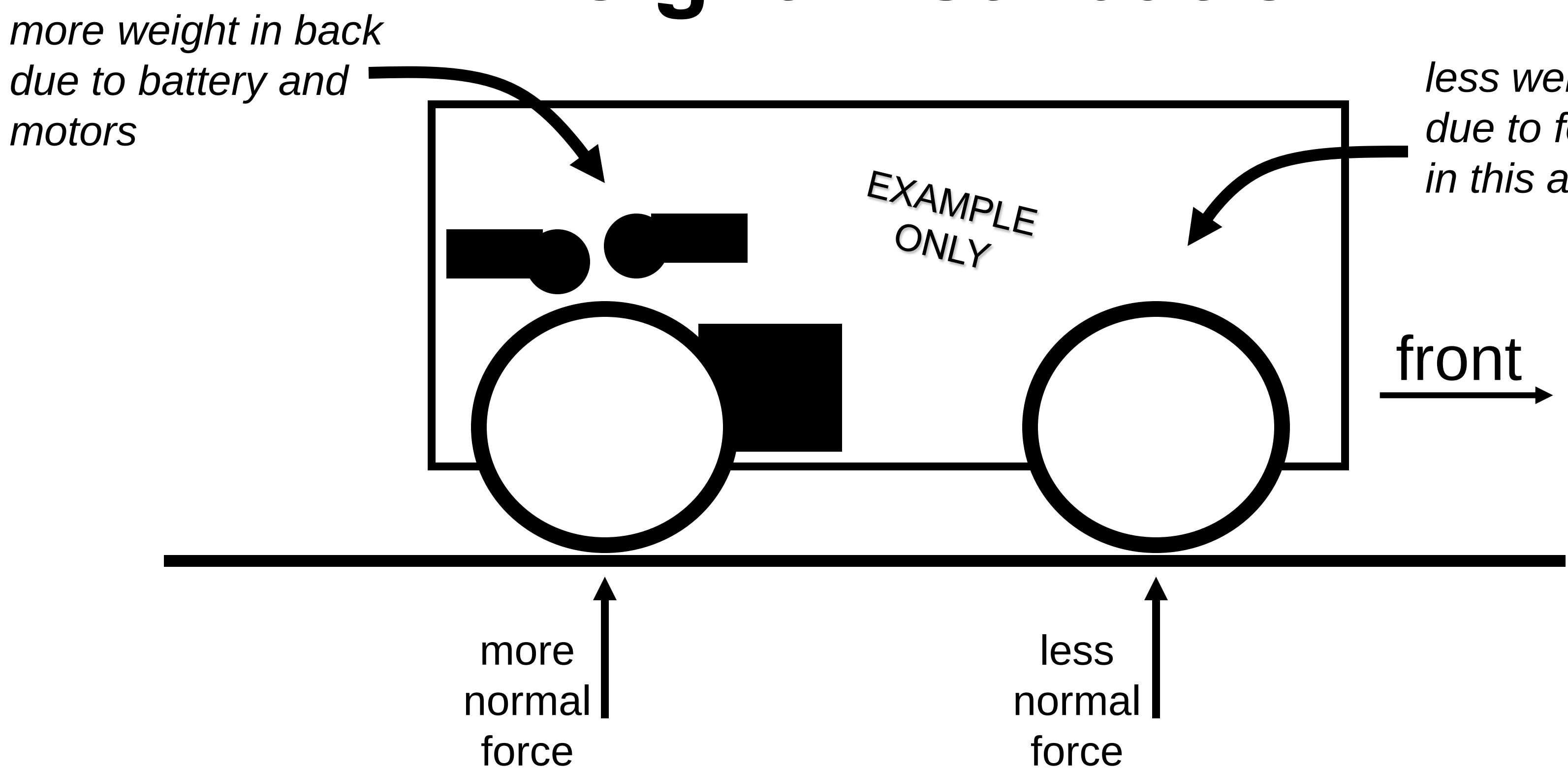
Don’t be too dependent on the surface condition, since you cannot always control it. But … don’t forget to clean your wheels.

Traction Fundamentals
"Normal Force"



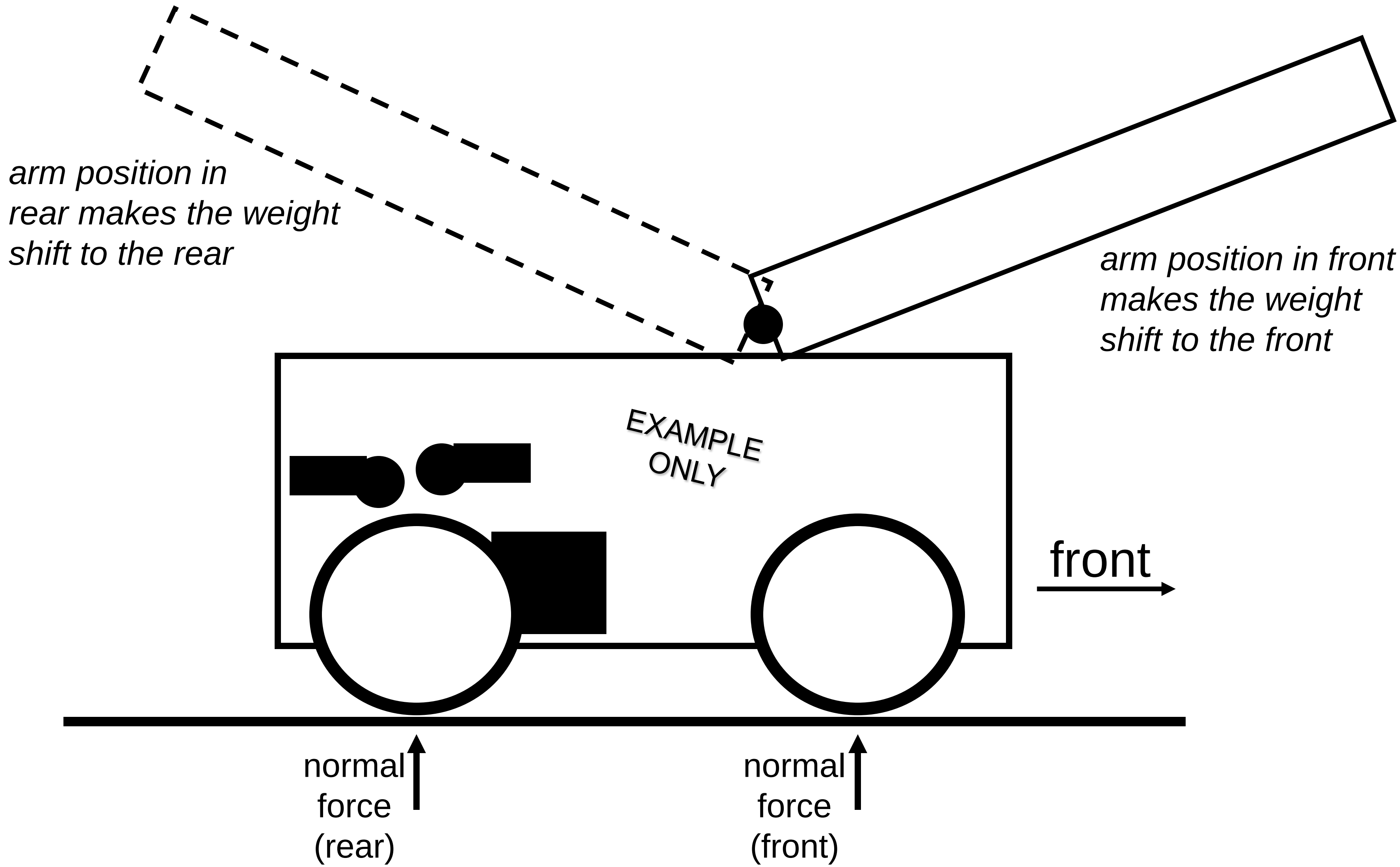
The <u>normal force</u> is the force that the wheels exert on the floor, and is equal and opposite to the force the floor exerts on the wheels. In the simplest case, this is dependent on the weight of the robot. The normal force is divided among the robot features in contact with the ground.

Traction Fundamentals
"Weight Distribution"



The weight of the robot is **<u>not</u>** equally distributed among all the contacts with the floor. <u>Weight distribution</u> is dependent on where the parts are in the robot. This affects the normal force at each wheel.

Traction Fundamentals
Weight Distribution is Not Constant



Traction Fundamentals
Weight Distribution is Not Constant

Where the weight is in the robot is only part of the story!

When the robot accelerates (changes speed), inertial forces tend to change the weight distribution.

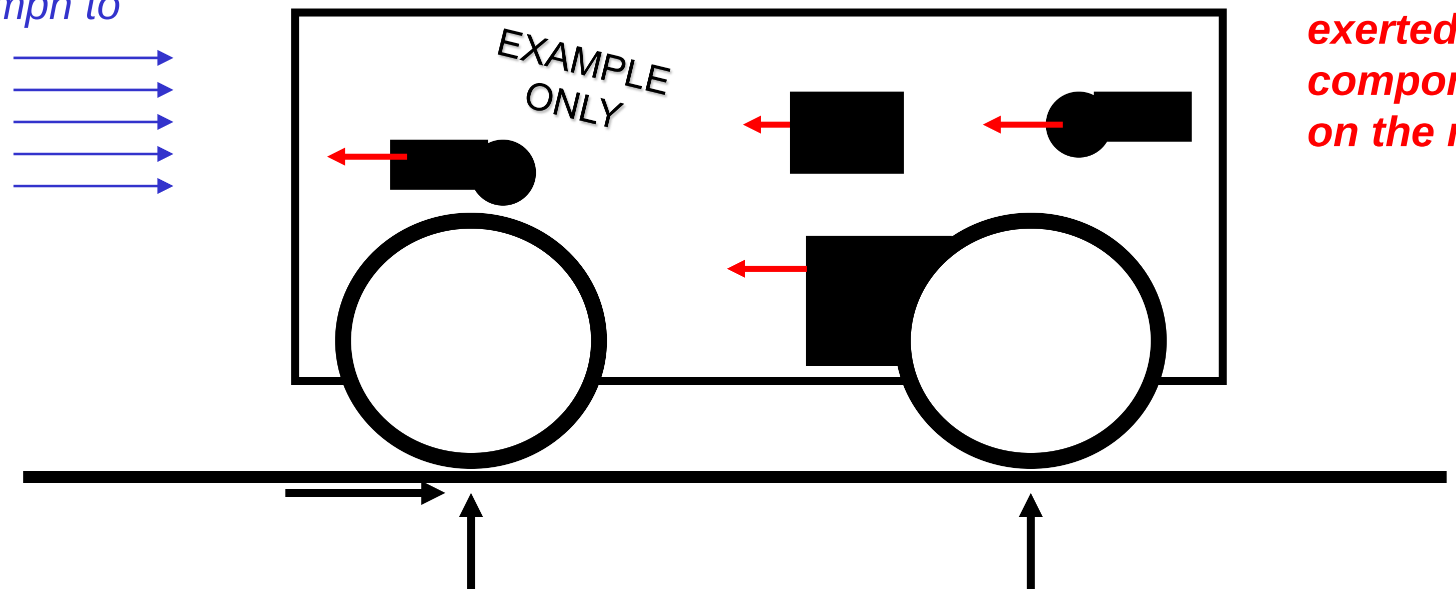
(Example of inertial force: the force exerted by the seat on your back in a Z06 Corvette as it accelerates.)

So, it is important to consider how the weight distribution changes when the robot changes speed.

Traction Fundamentals
“Weight Transfer”

robot accelerating from 0 mph to 6 mph

inertial forces exerted by components on the robot



more normal force *is exerted on the rear wheels because inertial forces tend to rotate the robot toward the rear*

less normal force *is exerted on the front wheels because inertial forces tend to rotate the robot away from the front*

In an extreme case (with rear wheel drive), you pull a wheelie
In a really extreme case (with rear wheel drive), you tip over!

Traction Fundamentals
Consider "Transient" Conditions

transient = changing with time

What happens when the robot bumps into something?

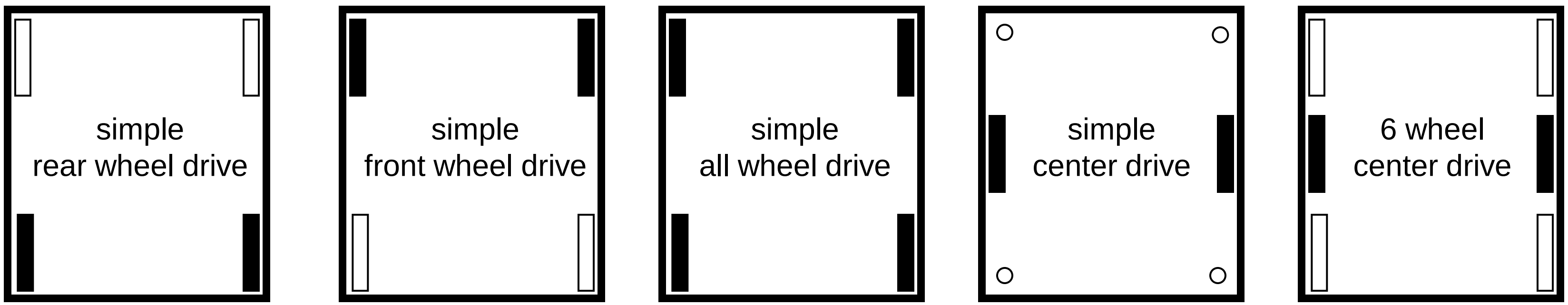
What happens when the robot picks up an object?

What happens when the robot accelerates hard?

What things can cause the robot to lose traction?

Traction Fundamentals
Number & Location of Drive Wheels

many variations, and there is no "right" answer



Drive elements can:
- steer (to enable turning or "crabbing")
- move up and down (to engage/disengage, or to enable climbing)

***** Can combine some of these features together *****

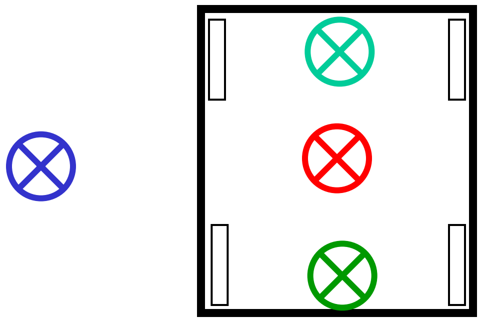
Advice: Don't make it more complex than it has to be!
Advice: Make sure it complements your other systems!

Traction Fundamentals
Number & Location of Drive Wheels

Review your system requirements - what do you need?

Consider the moves (all of them) that your robot will be making

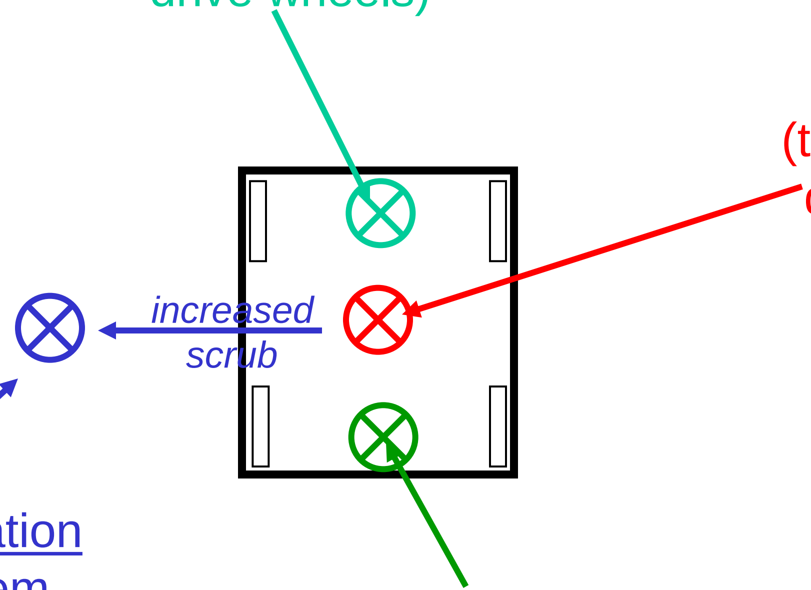
Answer the question:
What center point do you
want the robot to turn about?



Traction Fundamentals
Number & Location of Drive Wheels

Rotate @ Front End
(this favors front end drive wheels)

Spin In Place
(this favors center drive wheels, or 4 wheel drive)



Offset Center of Rotation
(4 wheel drive system with scrub)

Rotate @ Rear End
(this favors rear end drive wheels)

Robot Drive Systems

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4. Reliability

Gearing Fundamentals
"Torque" and "Power"

(some oversimplified definitions)

Torque is the ability to exert a rotational effort. In this case, the ability to make a wheel turn.

Torque determines whether or not you can get the job done.

Power is the rate at which energy is delivered. In this case, the rate at which wheel torque is being transferred to the floor.

Power determines how fast you can get the job done.

Gearing Fundamentals
Motor Choices

In FIRST, you are given a limited set of motors to choose from. Choose the motors for each job based on their available power and torque AND your available gearing.

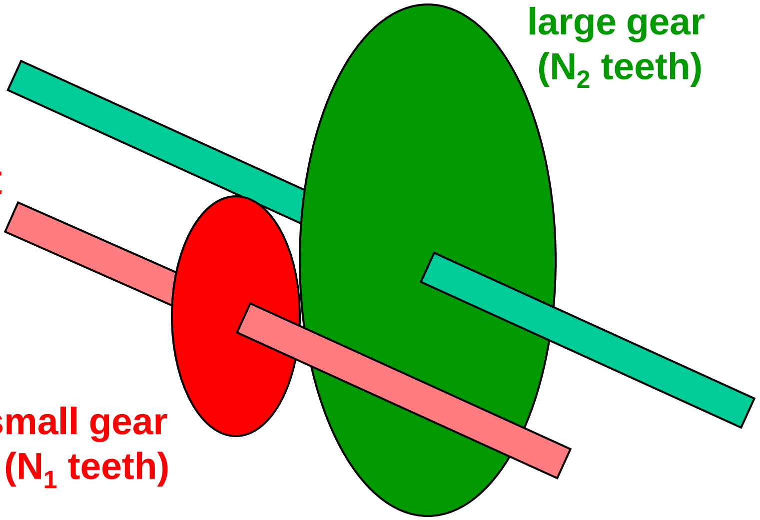
In general, the bigger the job, the more power you need.

In general, the faster you want something done, the more power you need.

Remember that you can use <u>gear ratios</u> to match the motor to the job (see Paul Copioli's presentation this afternoon).

Gearing Fundamentals
Gear Ratios

Gearing is used to convert (low torque + high speed) into (high torque + low speed), or vice versa.



$\omega \equiv$ rotational speed
"omega"

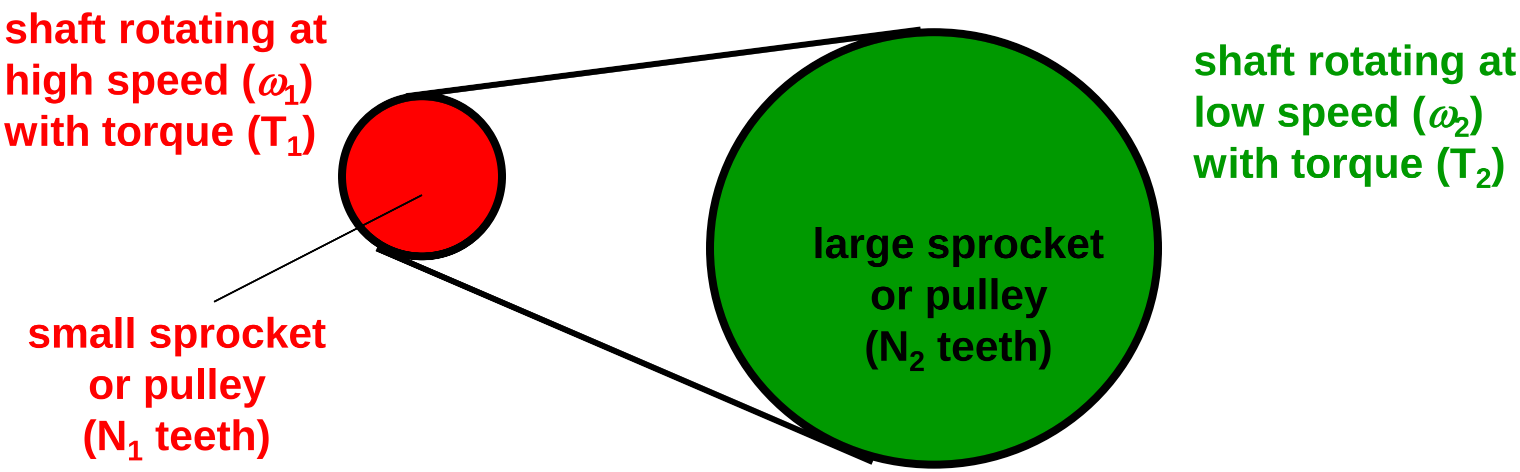
$$\omega_1 \times N_1 = \omega_2 \times N_2$$

(speed formula)

$$\frac{T_1}{N_1} = \frac{T_2}{N_2}$$

(torque formula)

Gearing Fundamentals
Formulas Also Work for Belts, Chains



$$\omega_1 \times N_1 = \omega_2 \times N_2$$

(speed formula)

$$\frac{T_1}{N_1} = \frac{T_2}{N_2}$$

(torque formula)

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Reliability

Keep it simple!
- makes it easier to design and build
- makes it easier to fix when it breaks

Get it running quickly
- find out what you did wrong sooner
- allow drivers some practice (the most important thing)
- make sure to replicate actual robot weight
- chance to fine-tune

Use reliable fasteners
- often this is where things break, come loose, etc.

Drive System Fundamantals

QUESTIONS?

Gearing Fundamentals Using Simulation Results