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2011 FRC Virtual Training Session 2

Drive Train Design

November 11 2011

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Overview

- Importance
- Fundamental Considerations
- Types of Drive Systems
- Traction
- Power and Power Transmission
- Practical & Realistic Considerations

Presentation Contents Derived From

- **Drive Systems Presentation on Kansas City FIRST Web Site**
  - *Ben Heaivilin – Lead Advisor: Team 1764 (5 years)*
  - *Jon Nelson – Mentor; Industrial Engineer - Honeywell*
  - *Rachel Lindsay – Student Team 1764*
- **Bernie McBryan 2010 BEMRC Presentation**

Importance

- **The best drive train…**
  - *is more important than anything else on the robot*
  - *meets your strategy goals*
  - *can be built with your resources*
  - *rarely needs maintenance*
  - *can be fixed within 4 minutes*
  - *is more important than anything else on the robot*

Fundamental Considerations

- **Know your resources**
  - *Cost, Machining Availability, Parts, Expertise, etc*
- **Keep it simple (KISS)**
  - *Easy to design and build*
  - *Gets it up and running quicker*
  - *Easier to fix*
- **Get it Running**
  - *Find out what is wrong*
  - *Practice for Driving*
  - *Time for Fine-Tuning*
- **Give software team TIME to work**

Types of Drive Train

- **Drive Train Decision Depends on:**
  - *Team Strategy*
  - *Attributes needed*
    - *Speed, Power, Pushing, Climbing, Maneuverability, Acceleration, Accuracy, Obstacle Handling, Reliability, Durability, Ease of Control*
  - *Resources available*
- **Must sacrifice some attributes for others. No one system will perform all the above functions**

Good Features to have to attain proper attributes

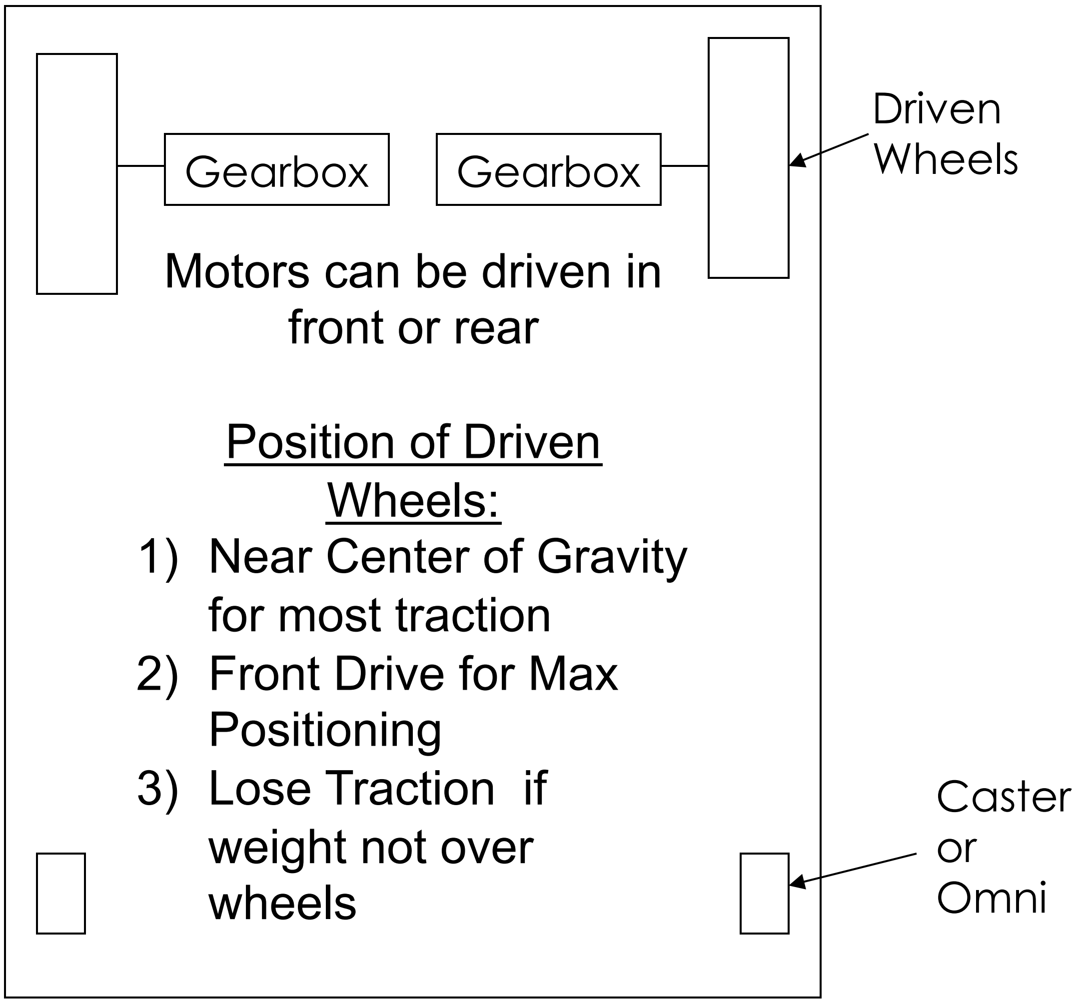
- ***High Top Speed***
  - *High Power*
  - *High Efficiency/Low Losses*
  - *Correct Gear Ratio*
- ***Acceleration***
  - *High Power*
  - *Low Inertia*
  - *Low Mass*
  - *Correct Gear Ratio*
- ***Pushing/Pulling***
  - *High Power*
  - *High Traction*
  - *High Efficiency/Low Losses*
  - *Correct Gear Ratio*
- ***Obstacle Handling***
  - *Ground Clearance*
  - *Obstacle "Protection"*
  - *Drive Wheels on Floor*
- ***Accuracy***
  - *Good Control Calibration*
  - *Correct Gear Ratio*
- ***Climbing Ability***
  - *High Traction*
  - *Ground Clearance*
  - *Correct Gear Ratio*
- ***Reliability/ Durability***
  - *Simple*
  - *Robust*
  - *Good Fastening Systems*
- ***Ease of Control***
  - *Intuitive Control*
  - *High Reliability*
- ***Maneuverability***
  - *Good Turning Method*

What types of Drives are Available?

- **2 Wheel Drive**
- **4 Wheel Drive with 2 Gearboxes**
- **4 Wheel Drive with 4 Gearboxes**
- **6 Wheel Drive with 2 Gearboxes**
- **Tank Drive and Treads**
- **Omni-directional Drive Systems**
  - *Mecanum*
  - *Holonomic / Killough*
  - *Crab/Swerve*
- **Other**

DRIVE SYSTEMS

2 Wheel Drive



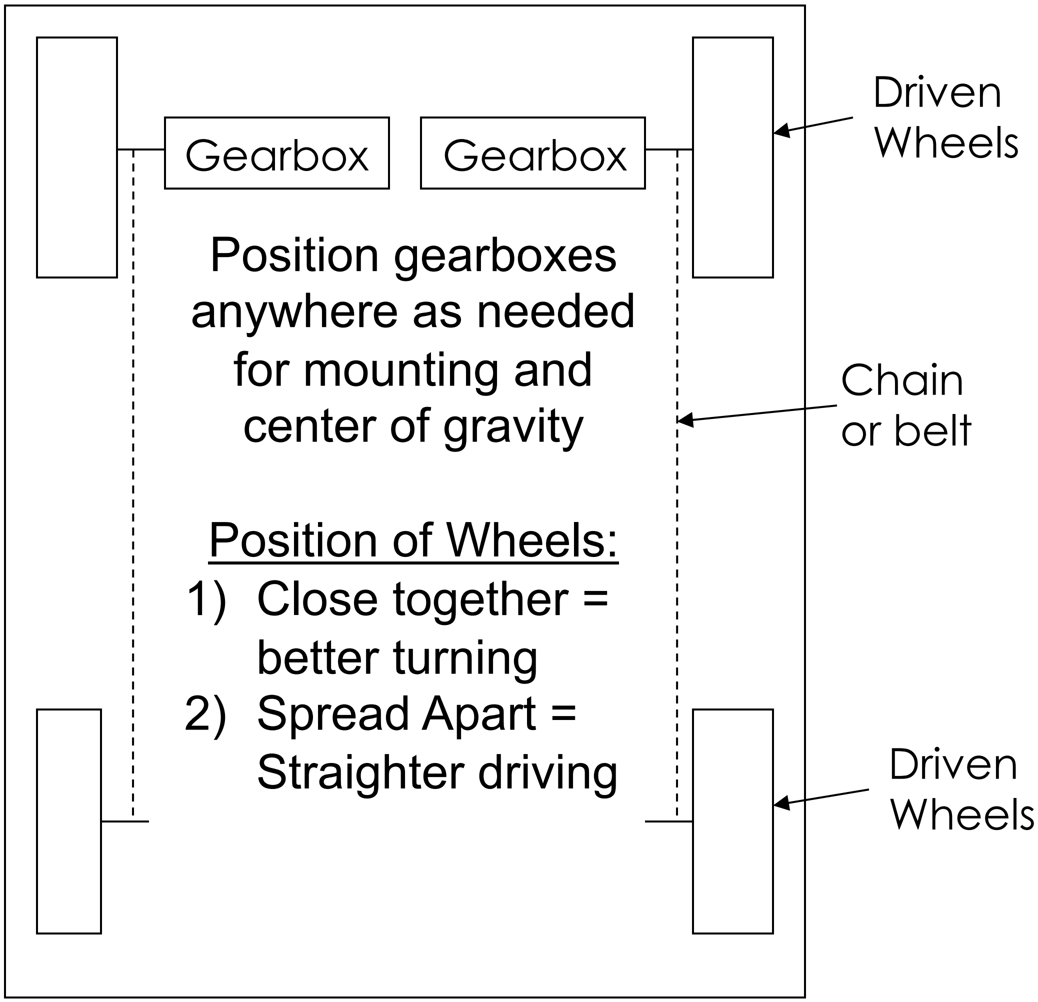
Motors can be driven in front or rear

<u>Position of Driven Wheels:</u>

1) Near Center of Gravity for most traction
2) Front Drive for Max Positioning
3) Lose Traction if weight not over wheels

- **Pros (+)**
  - *Easy to Design*
  - *Easy to Build*
  - *Light Weight*
  - *Inexpensive*
  - *Agile*
  - *Easy Turning*
  - *Fast*
  - *COTS Parts*
- **Cons (-)**
  - *Not Much Power*
  - *Does not do well on ramps*
  - *Poor Pushing*
  - *Susceptible to spin outs.*
  - *Able to be pushed from the side*

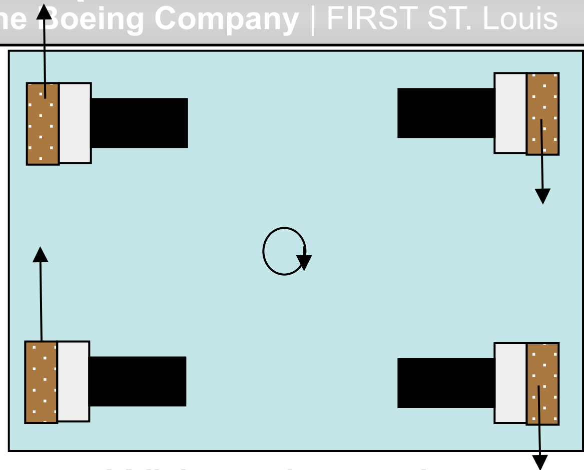
4 Wheel Drive – 2 Gearboxes (AKA Tank Drive – no treads)



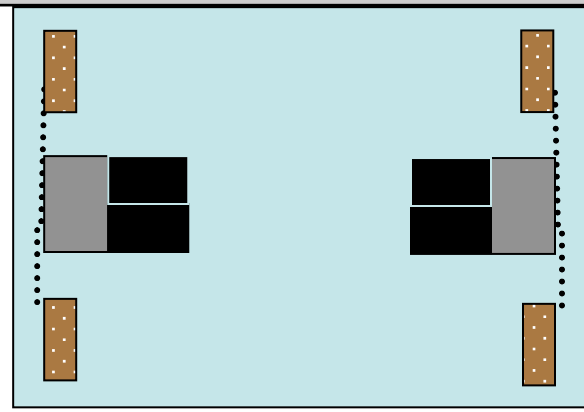
- **Pros (+)**
  - *Easy to Design*
  - *Easy to Build*
  - *More Powerful*
  - *Sturdy and stable*
  - *Wheel Options*
    - *Omni, Traction, Other*
  - *COTS Parts*
- **Cons (-)**
  - *Not Agile*
    - *Turning can be difficult*
    - *Adjustment Needed*
  - *Slightly Slower*

Tank Drive: Four Wheels

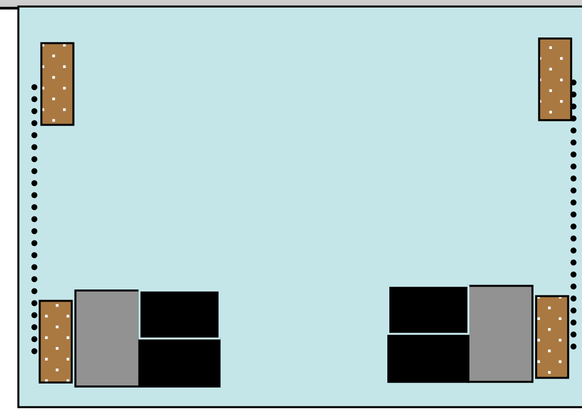
(can use v-belts or cog belts instead of chains)



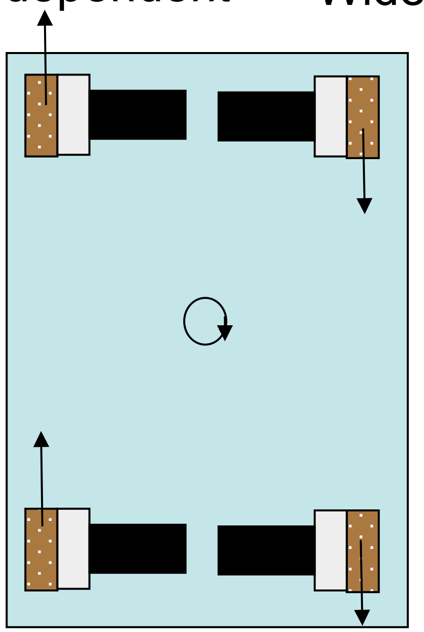
Wide Independent



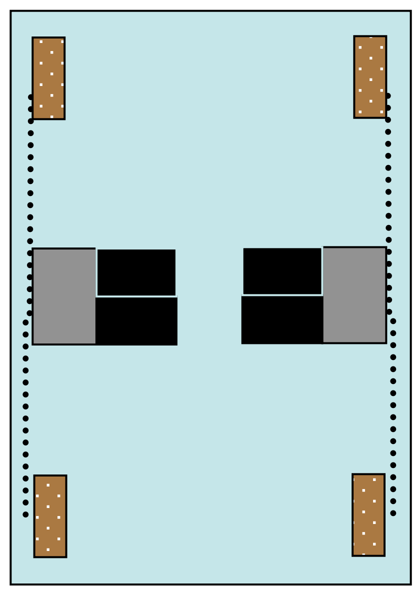
Wide with chains/transmission



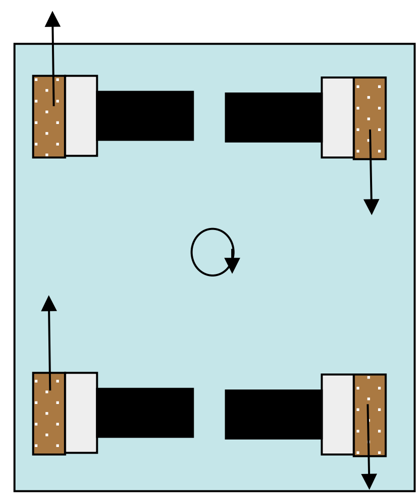
Wide direct rear, chains front



Narrow Independent

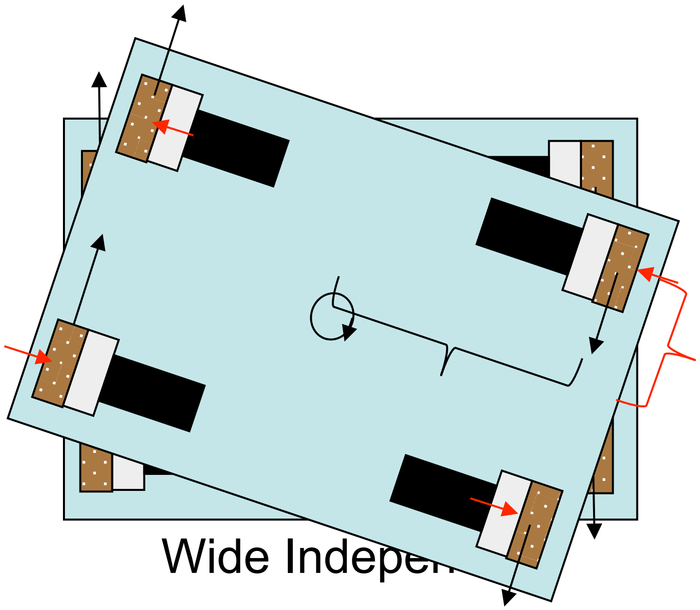


Narrow chains/transmission

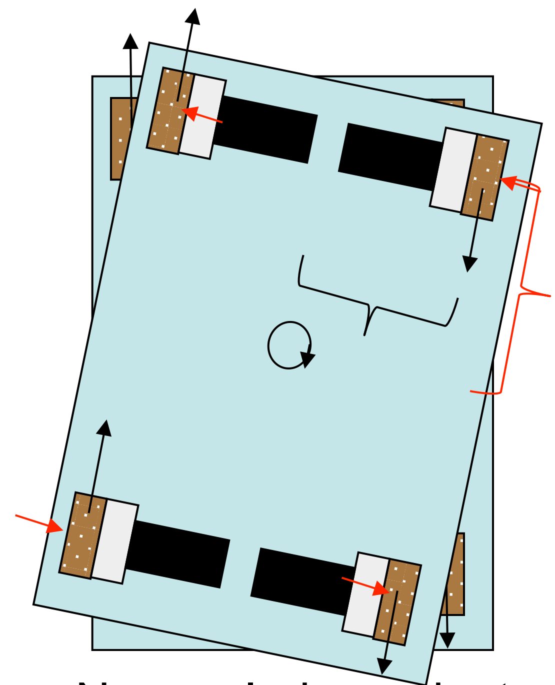


Sometimes don't need full length

Tank Drive: Four Wheels
(can use v-belts or cog belts instead of chains)



Wide Independent



Narrow Independent

Ideally, Want wheels wider than they are long.

Traction Wheels

AndyMark Tracktion Wheels

Slick and Sticky Wheels

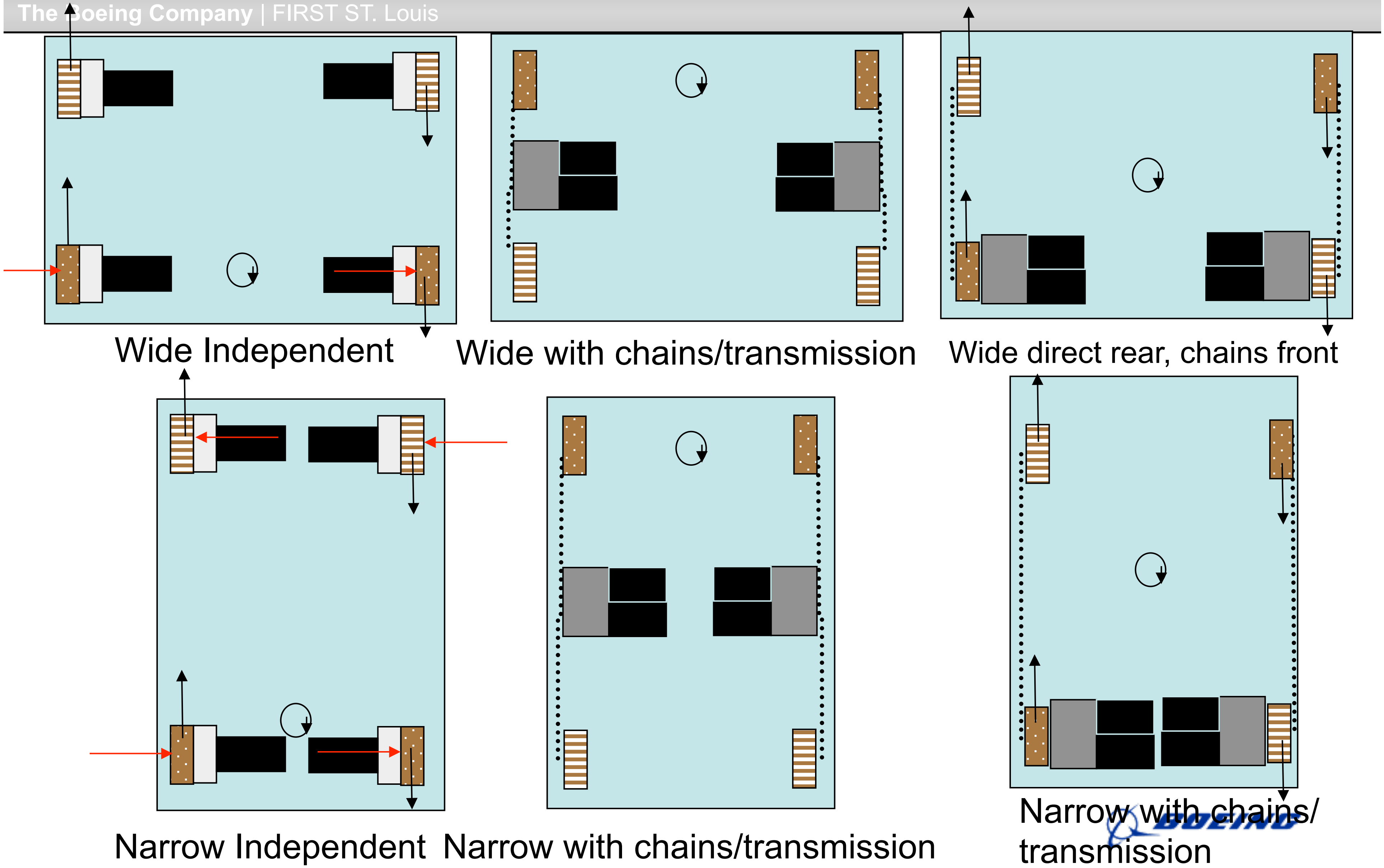
Static Coefficient of Friction = 1.0

Static Coefficient of Friction = .2

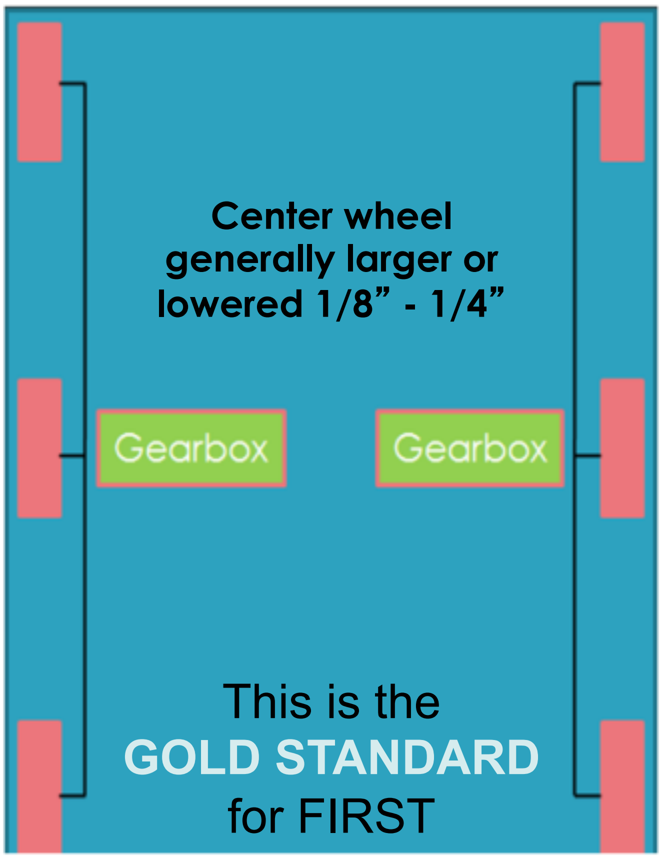
Omni-Wheels

Tank Drive: Four Wheels with Omni

(or use v-belts or cog belts instead of chains)



6 Wheel Drive – 2 Gearboxes



2 Ways to be agile:

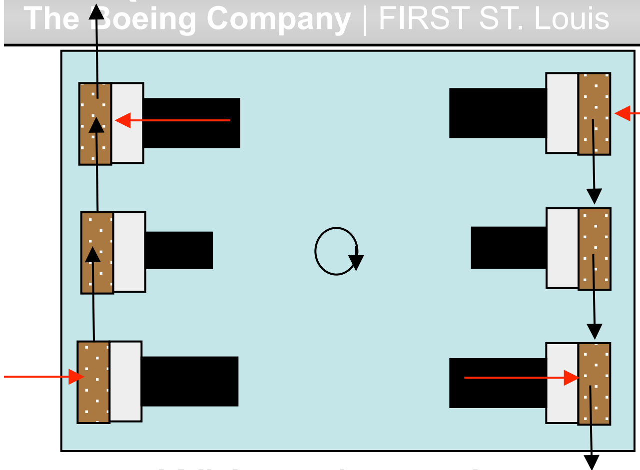
1. Lower Contact on Center Wheel
2. Omni wheels on back, front or both

Rocking isn’t too bad at edges of robot footprint, but can be significant at the end of long arms and appendages

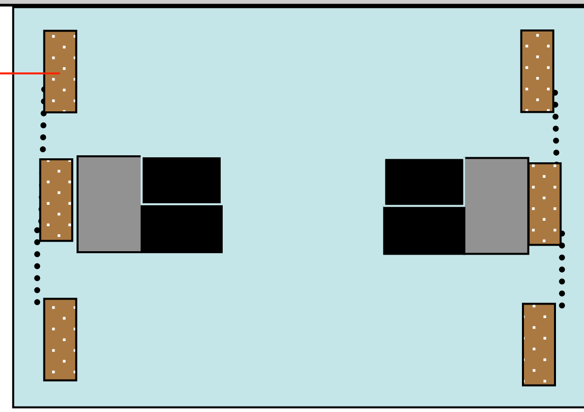
- **Pros (+)**
  - *Easy to Design & Build*
  - *Powerful*
  - *Stable*
  - *Agile*
  - *Turns at center of robot*
  - *Pushing*
  - *Harder to be high Centered*
  - *COTS Parts*
- **Cons (-)**
  - *Heavy & Costly*
  - *Turning may or may not be difficult*
  - *Chain paths*
- **Optional**
  - *Substitute Omni Wheel sets at either end*
    - *Traction: Depends on wheels*
    - *Pushing = Great w/ traction wheels*
    - *Pushing = Okay w/ Omni*

Tank Drive: Six Wheels

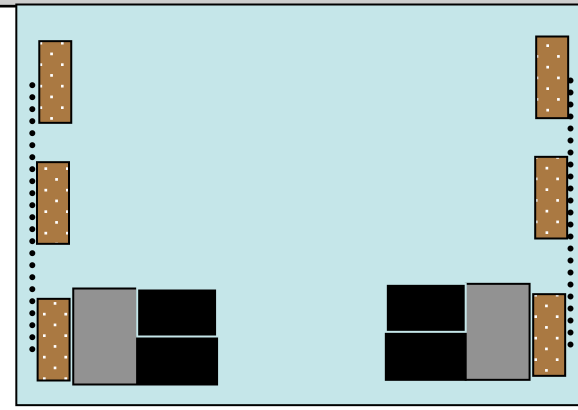
(can use v-belts or cog belts instead of chains)



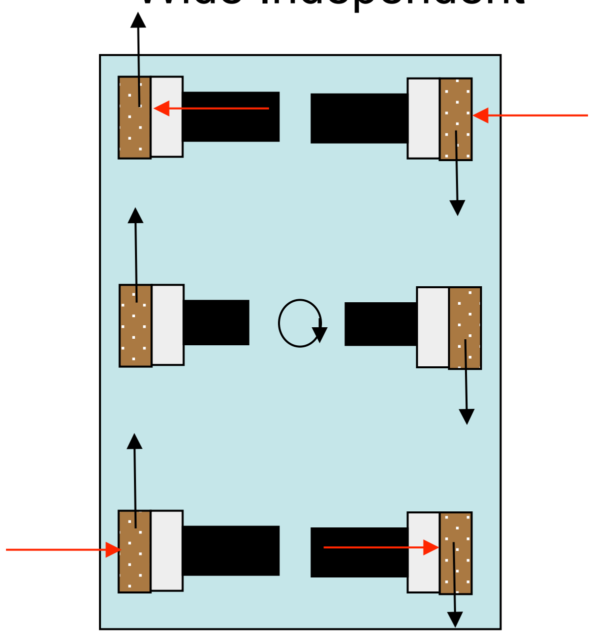
Wide Independent



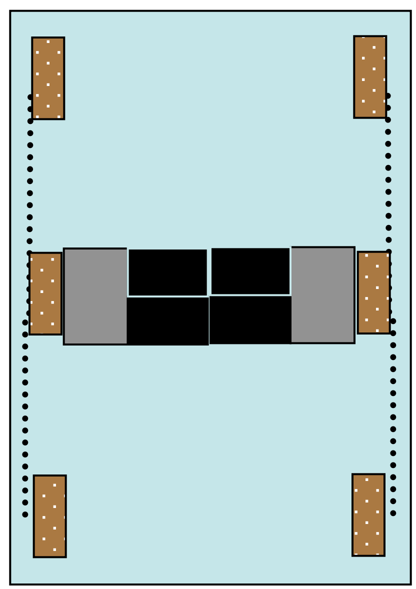
Wide with chains/transmission



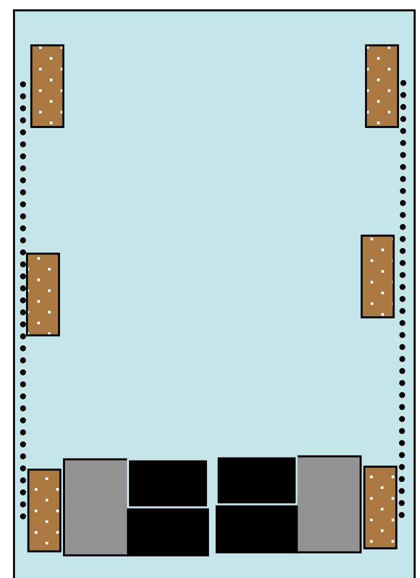
Wide direct rear, chains front



Narrow Independent



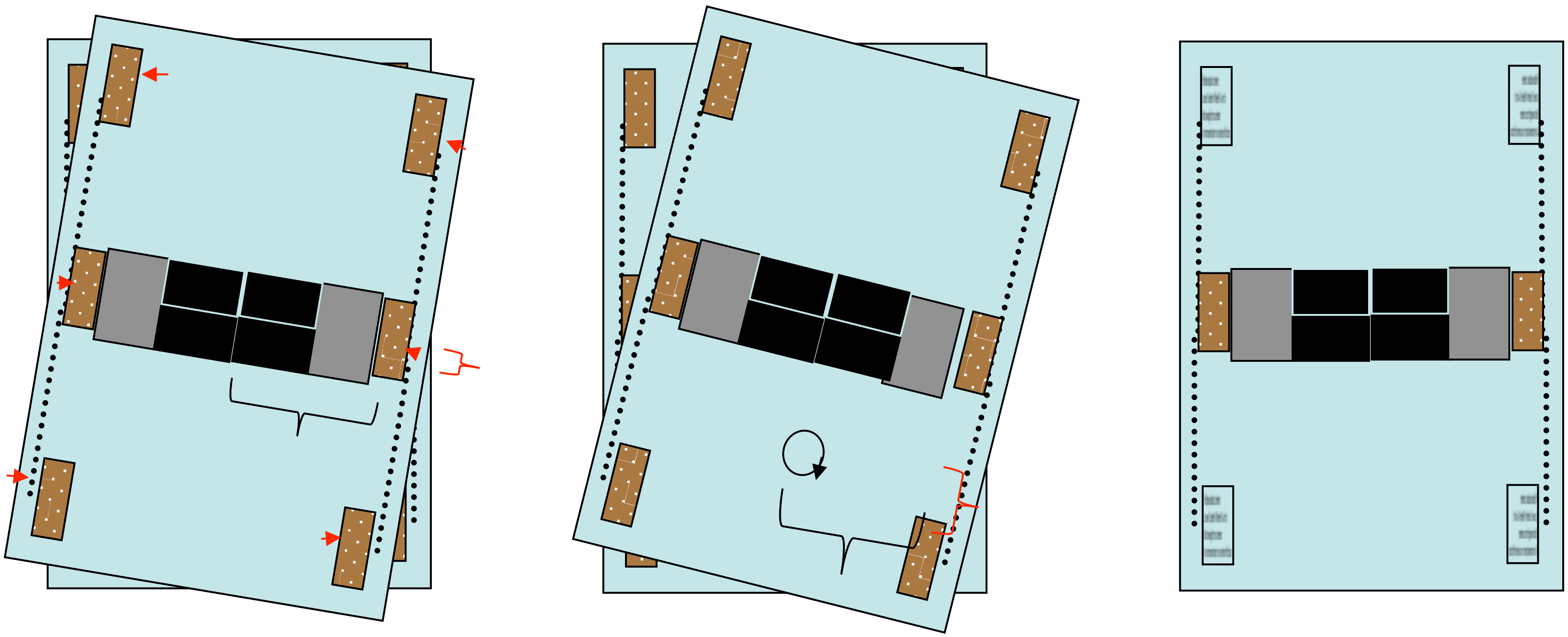
Narrow with chains/transmission



Narrow direct rear, chains front

Tank Drive: Six Wheels

(can use v-belts or cog belts instead of chains)



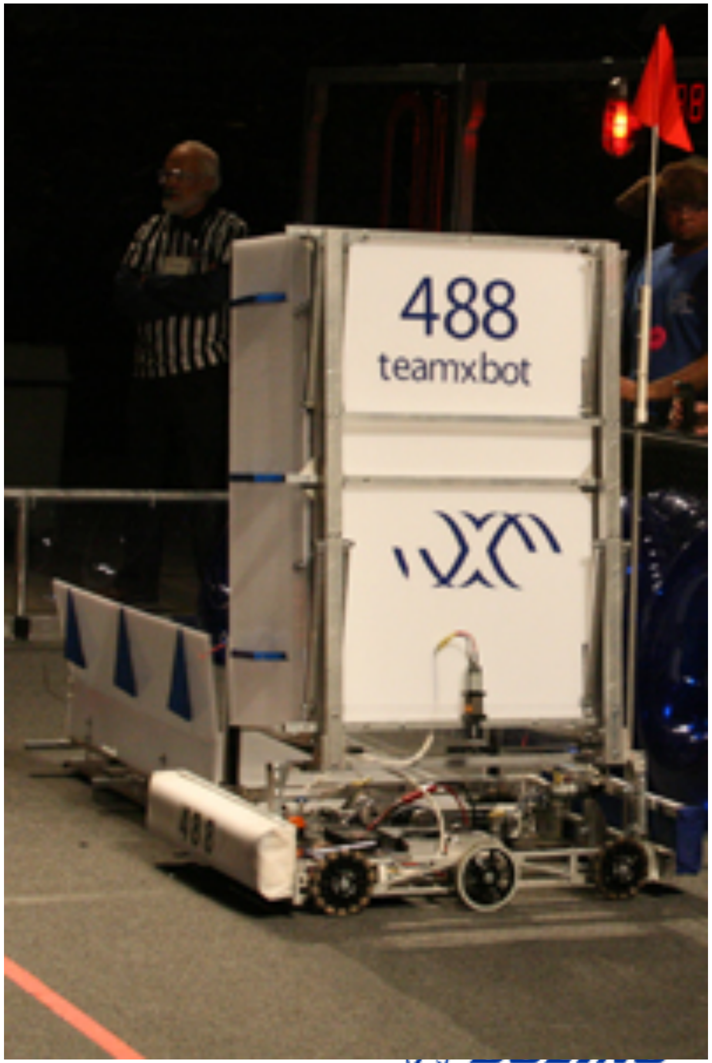
Rotate about center:
Lower Center Wheel ¼ inch
Most weight on center
No moment arm on center.

Rotate about center back or front:
Lower Center Wheel ¼ inch
Wheel pairs wider than long

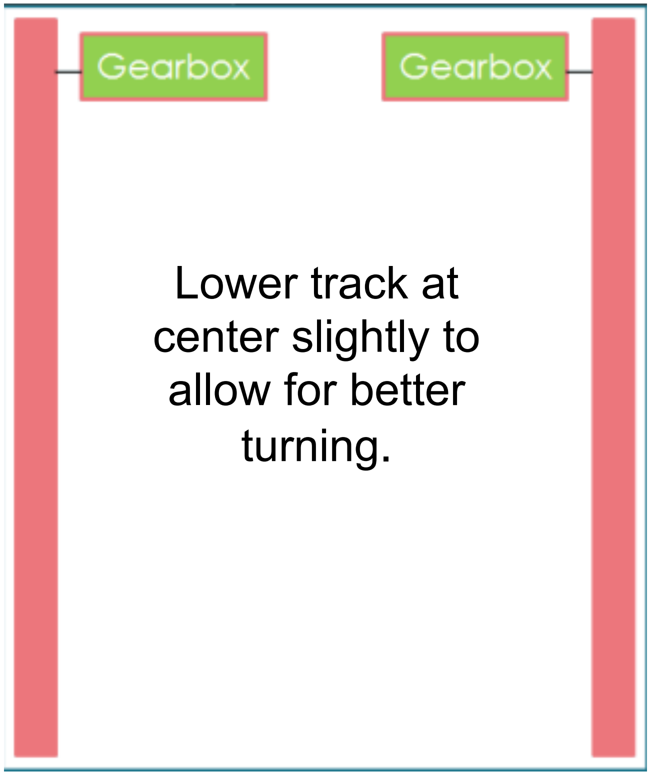
Omni front/back
Eliminate friction

BOEING

6 Wheel Drive - 2 Gearboxes Examples

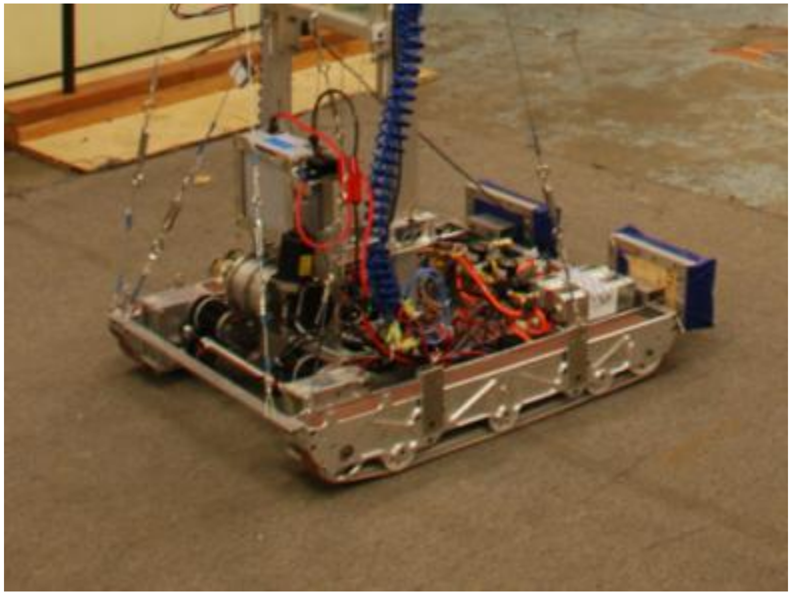


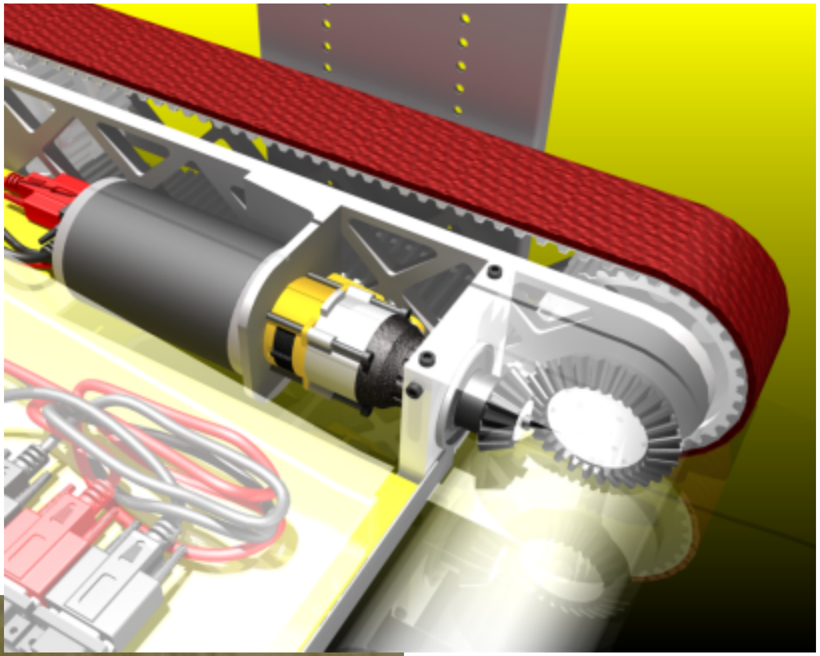
Tank Drive/Treads



- **Pros (+)**
  - *Climbing Ability*
    - *(best attribute)*
  - *Great Traction*
  - *Turns at Center*
  - *Pushing*
  - *Very Stable*
  - *Powerful*
- **Cons (-)**
  - *Energy Efficiency*
  - *Mechanical Complexity*
  - *Difficult for student build teams*
  - *Turns can tear off treads*
  - *WEIGHT*
  - *Expensive*
  - *Repairing broken treads.*

Tank Drive/Treads Examples

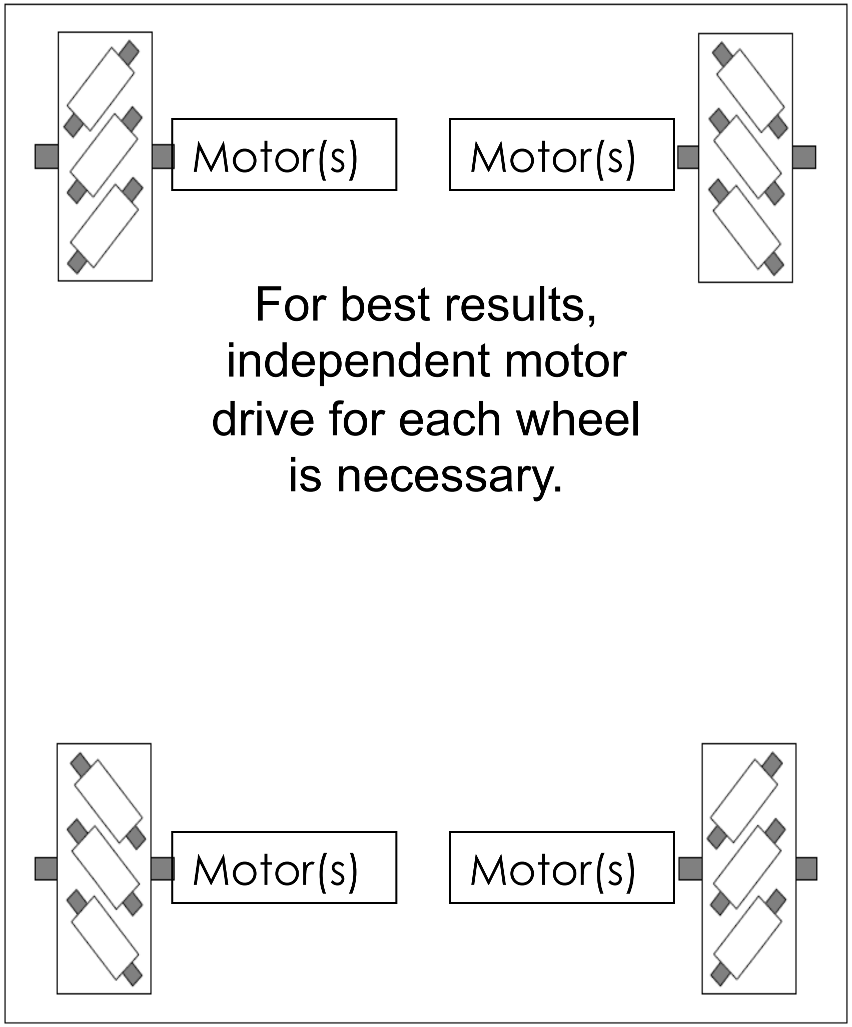




Omni-directional drives

- **"Omnidirectional motion is useless in a drag race… but GREAT in a mine field"**
  - *Remember, task and strategy determine usefulness*

Omni: Mecanum

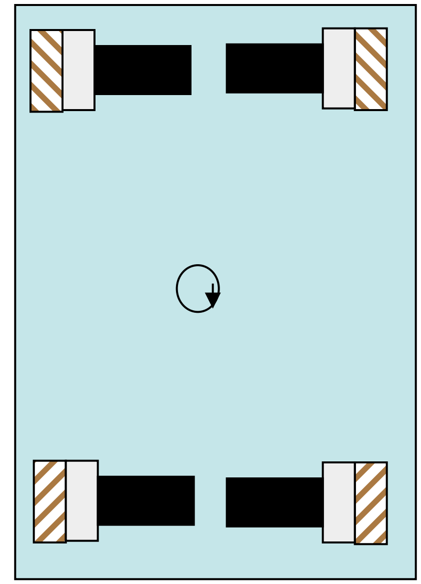


- **Pros (+)**
  - *Simple Mechanism*
  - *High Maneuverability*
  - *Immediate Turn*
  - *Simple Control*
    - *4 wheel independent*
  - *Simple mounting and chains*
  - *Turns around Center of robot*
  - *COTS Parts*
- **Cons (-)**
  - *Braking Power*
  - *OK Pushing*
  - *Suspension for teeth chattering*
  - *Inclines*
  - *Software complexity*
  - *Drift (uneven weight distribution)*
  - *Expense*

AndyMark Mechanum Drive

Bengt Ilon invented this type of wheel while working for the Swedish company Mecanum AB. The Mecanum-style drive base uses 4 wheels, including 2 right wheels and 2 left wheels. One right and left is on each side of the robot. Each wheel is driven independently. AndyMark Mecanum Wheels use bent sheet metal for the plates that retain the rollers.

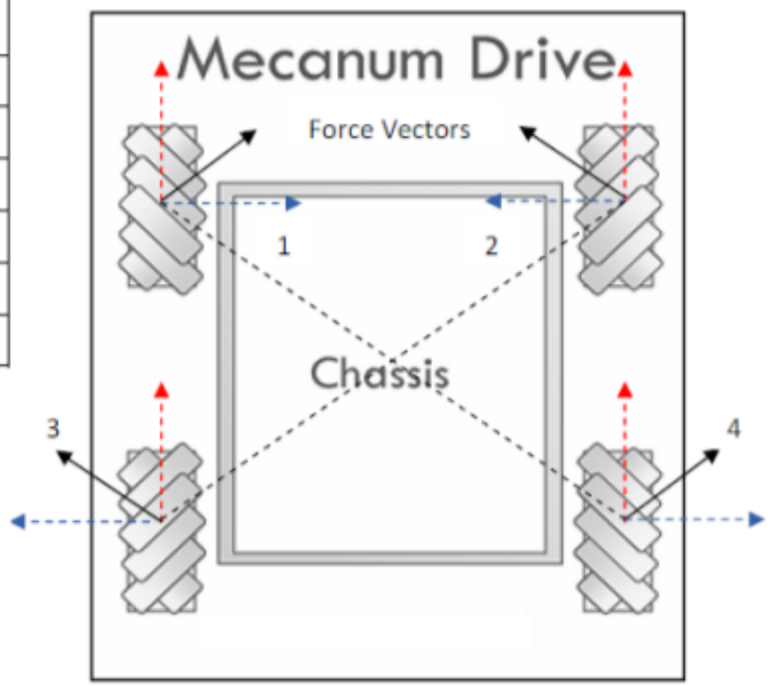
See www.andymark.com for more details.

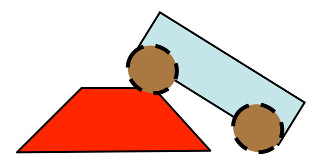


Mecanum Wheel Specs			
Wheel Size - (inches)	6	8	10
Wheel Weight - (pounds)	1.3	2.5	10
Load Rating- (pounds per wheel)	80	80	440

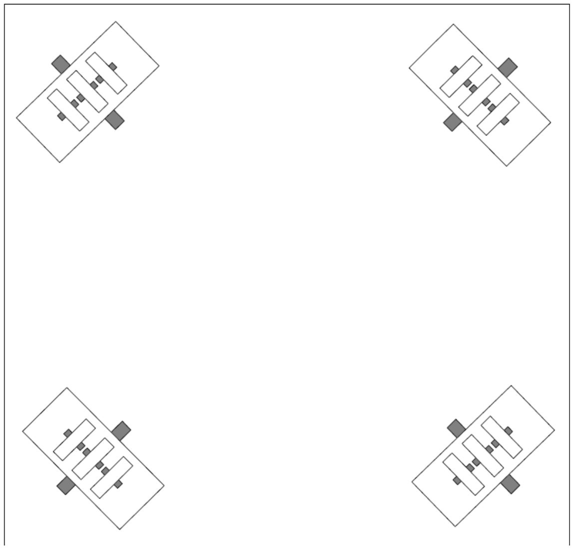
Direction of Movement	Wheel Actuation
Forward	All wheels forward same speed
Reverse	All wheels backward same speed
Right Shift	Wheels 1, 4 forward; 2, 3 backward
Left Shift	Wheels 2, 3 forward; 1, 4 backward
CW Turn	Wheels 1, 3 forward; 2, 4 backward
CCW Turn	Wheels 2, 4 forward; 1, 3 backward

To the right: This is a top view looking down on the drive platform. Wheels in Positions 1, 4 should make X- pattern with Wheels 2, 3. If not set up like shown, wheels will not operate correctly.

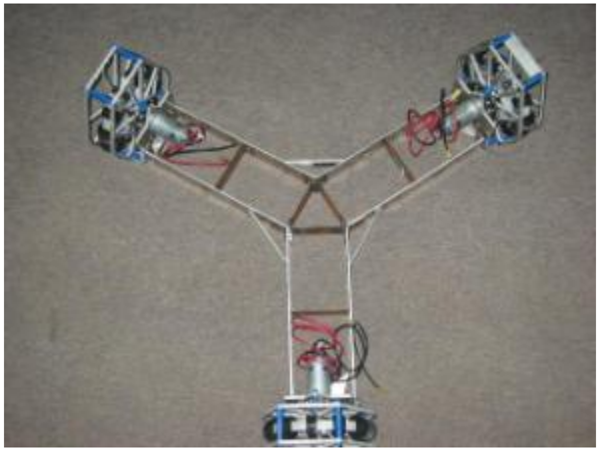




Omni: Holonomic / Killough



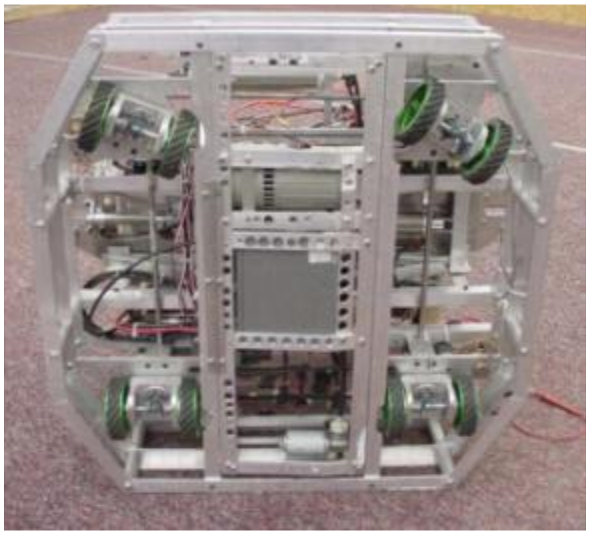
4-wheel drive needs square base for appropriate vector addition



3-wheel drive needs separated 120 degrees for appropriate vector addition

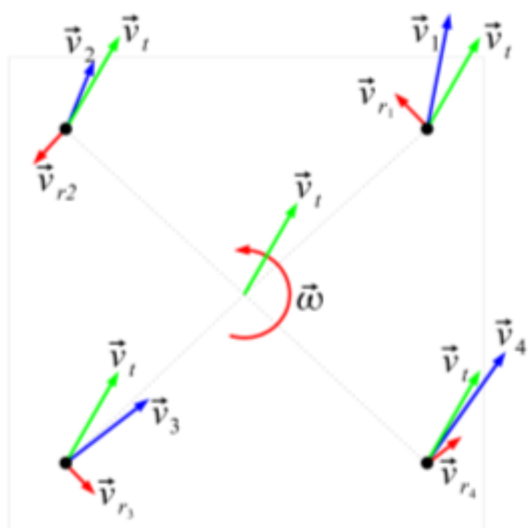
- **Pros (+)**
  - *Turns around Center of robot*
  - *No complicated steering methods*
  - *Simultaneously used 2D motion and rotation*
  - *Maneuverability*
  - *Truly Any Direction of Motion*
  - *COTS parts*
- **Cons (-)**
  - *Requires 3-4 independently powered motors*
  - *Weight*
  - *Cost*
  - *Programming Skill Necessary*
  - *NO Brake*
  - *Minimum Pushing Power*
  - *Teeth Chattering (unless dualies)*
  - *Climbing*
  - *Drifting (Weight Distribution)*

Omni: Sweve/Crab



All traction Wheels.

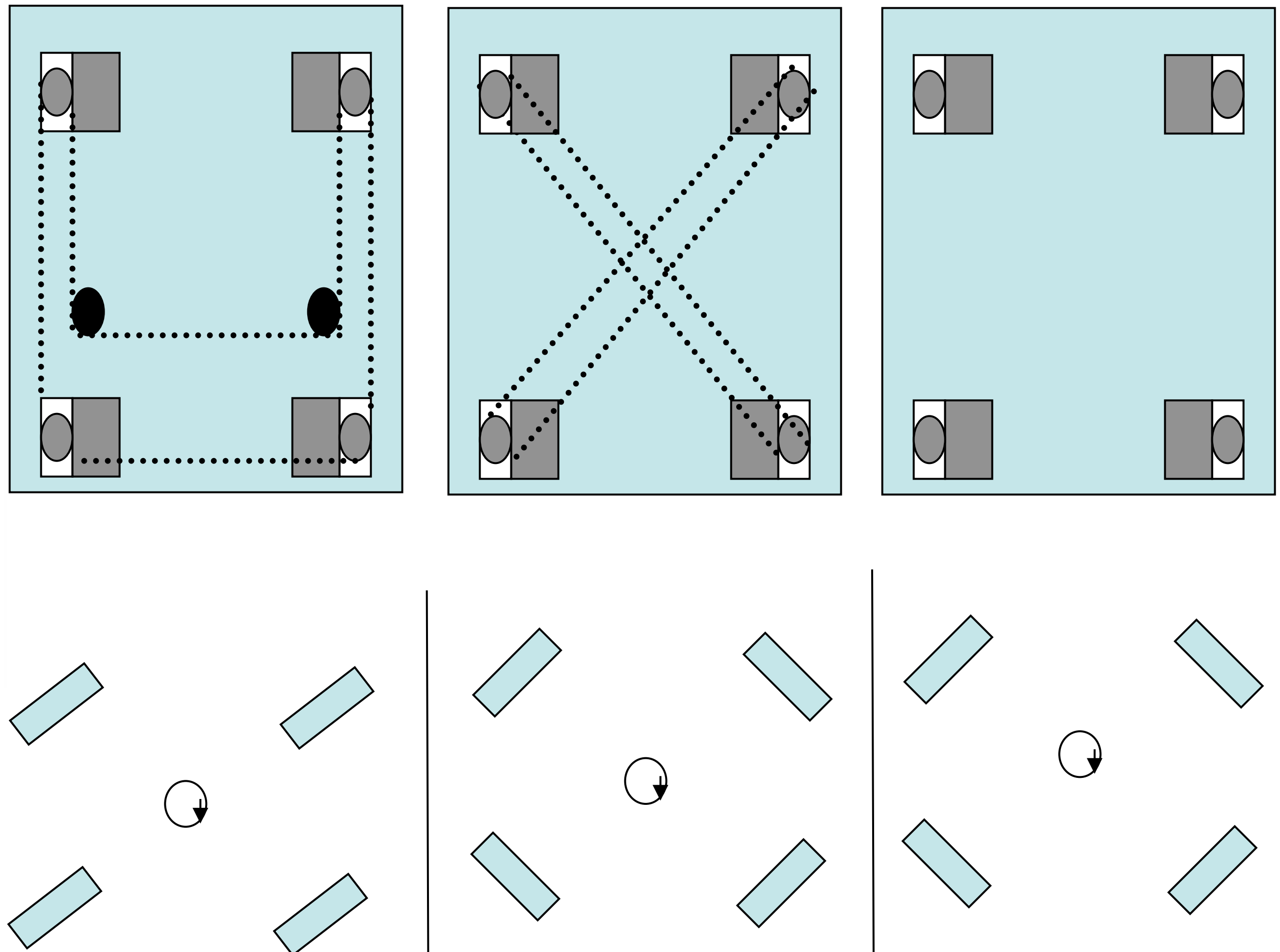
Each wheel rotates independently for steering



- **Pros (+)**
  - *Maneuverability*
  - *No Traction Loss*
  - *Simple wheels*
  - *Ability to hold/push*
  - *NEW!: COTS*
- **Cons (-)**
  - *Mechanically Complex*
  - *Weight*
  - *Programming*
  - *Control and Drivability*
  - *Wheel turning delay*

Swerve Drive

AndyMark Swerve Wheels



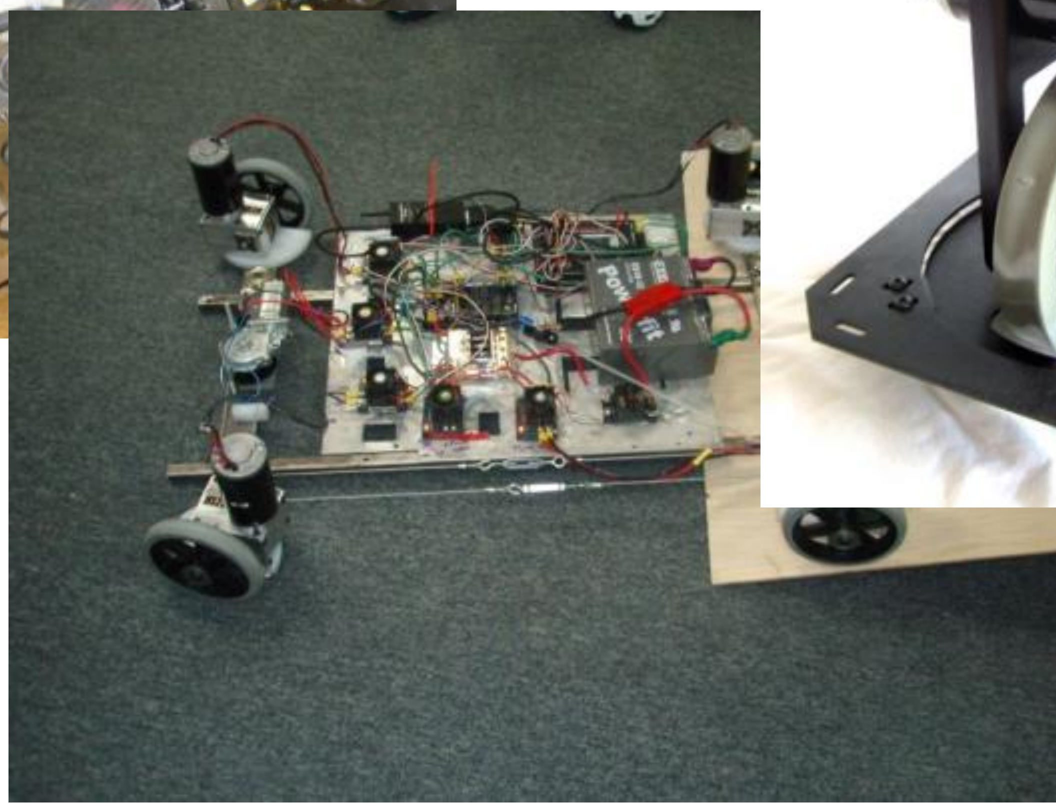
4 + 1 motors

4 + 2 motors

4 + 4 motors

Omni: Swerve/Crab Exampe

Available at
AndyMark.biz



Other Drive Systems

- **N Wheel Drive (More than 6)**
  - *Not much better driving than 6 wheel Drive*
  - *Improves climbing, but adds a lot of weight*
- **3 Wheel Drive**
  - *Atypical – Therefore time intensive*
  - *Team 16 – Bomb Squad*
  - *Lighter than 4 wheel drive*
- **Ball Drive**
- **Rack and Pinion / Car Steering**

TRACTION

Coefficient of Friction

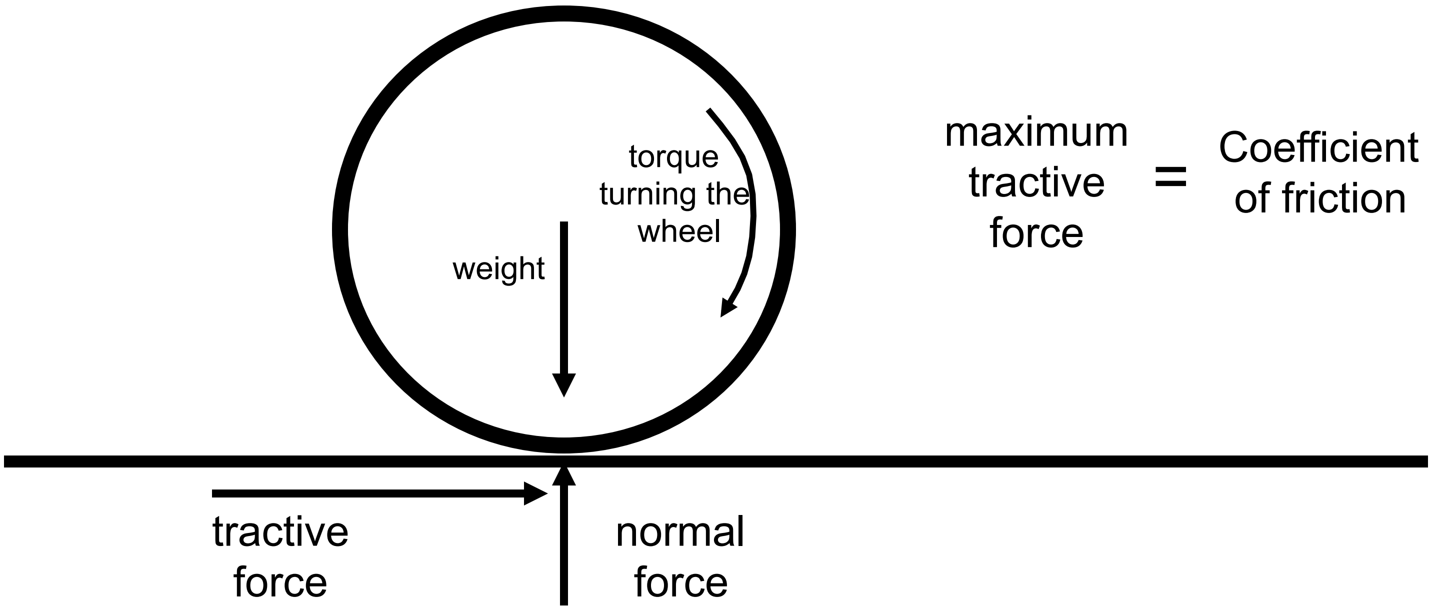
- **Coefficient of Friction is Dependent on:**
  - *Materials of the robot wheels/belts*
  - *Shape of robot wheels/belts*
  - *Materials on the floor surface*
  - *Surface Conditions*

Materials of the robot wheels/belts

- **High Friction Coefficient:**
  - *Soft Materials*
  - *"Spongy" Materials*
  - *"Sticky" Materials*
- **Low Friction Coefficient:**
  - *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!

Traction Basics Terminology

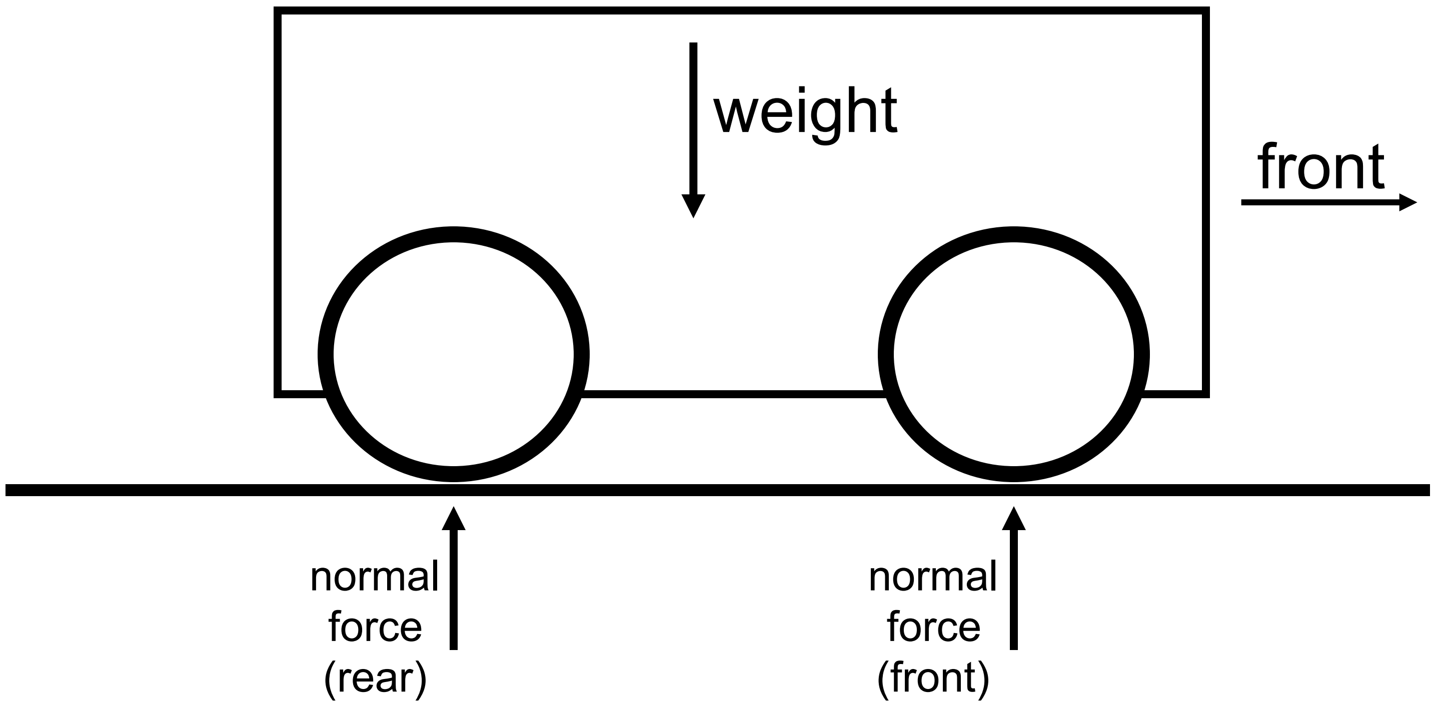


maximum tractive force = Coefficient of friction x Normal Force (Weight)

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

Source: Paul Copioli, Ford Motor Company, #217

Traction Fundamentals "Normal Force"

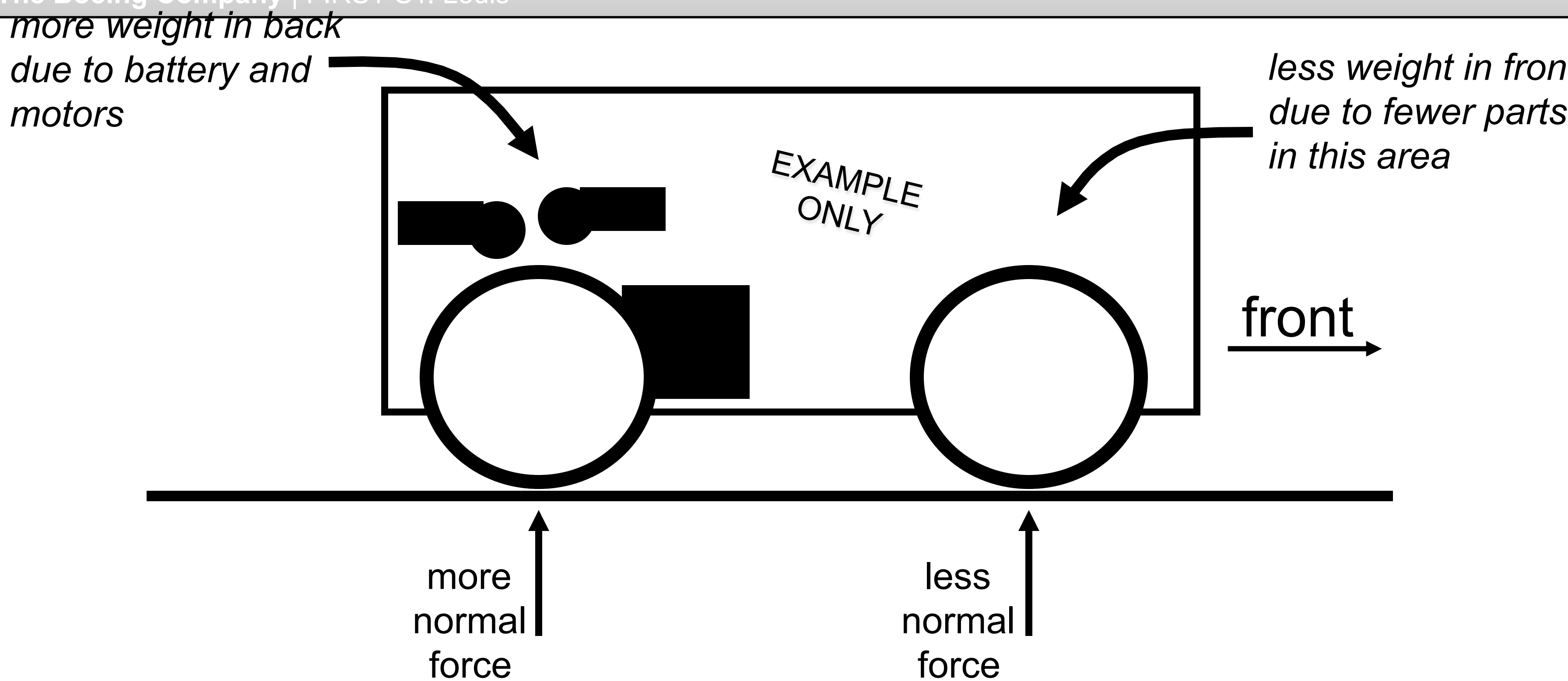


The <u>normal force</u> is the force that the wheels exert on the floor, and is equal and opposite to the force the floor exerts on the wheels. In the simplest case, this is dependent on the weight of the robot. The normal force is divided among the robot features in contact with the ground. Therefore: Adding more wheels DOES NOT add more traction -

BOEING

Source: Paul Copioli, Ford Motor Company, #217

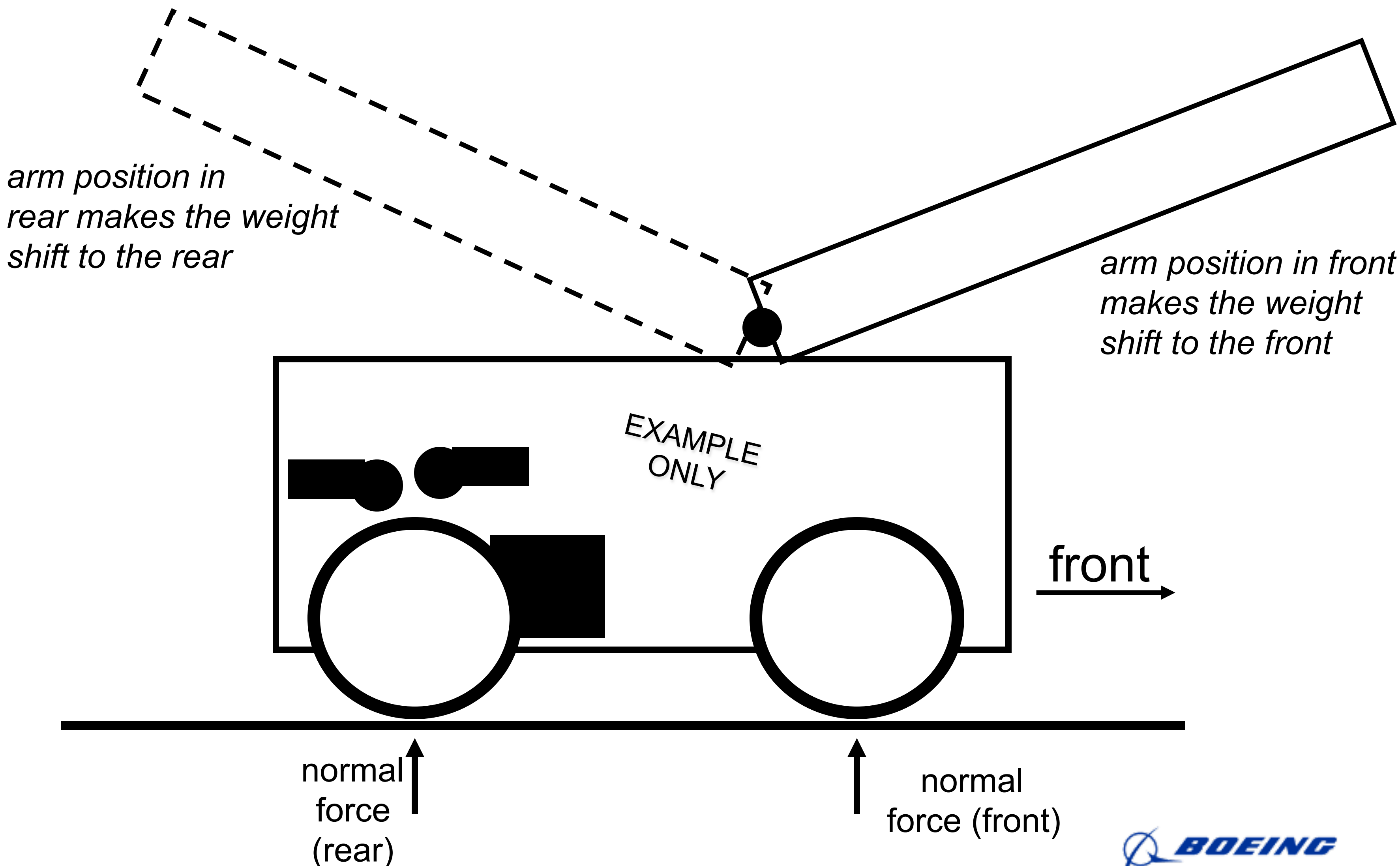
Traction Fundamentals "Weight Distribution"



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

Source: Paul Copioli, Ford Motor Company, #217

Weight Distribution is Not Constant



BOEING

Source: Paul Copioli, Ford Motor Company, #217

POWER and Power Transmission

How Fast?

- **Under 4 ft/s – Slow. Great pushing power <u>if enough traction.</u>**
  - *No need to go slower than the point that the wheels loose traction*
- **5-7 ft/s – Medium speed and power. Typical of a single speed FRC robot**
- **8-12 ft/s – Fast. Low pushing force**
- **Over 13ft/sec – Crazy. Hard to control, blazingly fast, no pushing power.**
- **Remember, many motors draw 60A+ at stall but our breakers trip at 40A!**

Power

- **Motors give us the power we need to make things move.**
- **Adding power to a drive train increases the rate at which we can move a given load or increases the load we can move at a given rate**
- **Drive trains are typically not "power-limited"**
  - *Coefficient of friction limits maximum force of friction because of robot weight limit.*
  - *Shaving off .1 sec. on your ¼-mile time is meaningless on a 50 ft. field.*

MORE Power

- **Practical Benefits of Additional Motors**
  - *Cooler motors*
  - *Decreased current draw; lower chance of tripping breakers*
  - *Redundancy*
  - *Lower center of gravity*
- **Drawbacks**
  - *Heavier*
  - *Useful motors unavailable for other mechanisms*

Power Transmission

- **Method by which power is turned into traction.**
- **Most important consideration in drive design**
- **Fortunately, there's a lot of knowledge about what works well**
    - *Roller Chain and Sprockets*
    - *Timing Belt*
    - *Gearing*
        - *Spur*
        - *Worm*
    - *Friction Belt*

Power Transmission: Chain

- **#25 (1/4") and #35 (3/8") most commonly used in FRC applications**
  - *#35 is more forgiving of misalignment; heavier*
  - *#25 can fail under shock loading, but rarely otherwise*
- **95-98% efficient**
- **Proper tension is a necessity**
- **1:5 reduction is about the largest single-stage ratio you can expect**

Power Transmission: Timing Belt

- **A variety of pitches available**
- **About as efficient as chain**
- **Frequently used simultaneously as a traction device**
  - *Treaded robots are susceptible to failure by side-loading while turning*
- **Comparatively expensive**
- **Sold in custom and stock length – breaks in the belt cannot usually be repaired**

Power Transmission: Gearing

- **Gearing is used most frequently "high up" in the drive train**
  - *COTS gearboxes available widely and cheaply*
- **Driving wheels directly with gearing probably requires machining resources**
- **Spur Gears**
  - *Most common gearing we see in FRC; Toughboxes, NBD, Shifters, Planetary Gearsets*
  - *95-98% efficient PER STAGE*
  - *Again, expect useful single-stage reduction of about 1:5 or less*

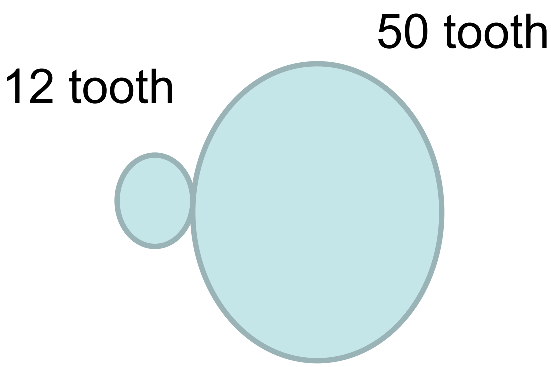
TRANSMISSIONS

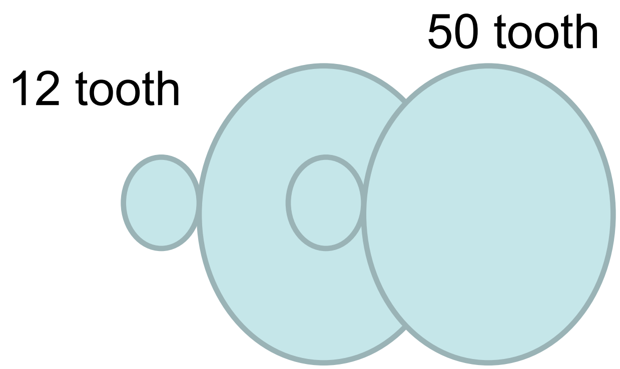
Transmissions / Gearbox

- **Transmission Goal:**
  - *Translate Motor Motion and Power into Robot Motivation*
- **Motor:**
  - *Speed (RPMs)*
  - *Torque (ft-lbs or Nm)*
- **Robot**
  - *Speed (feet per second [fps])*
  - *Weight*

Change Gear Ratios to Trade Speed for Torque

- **Slows down the speed by a factor of 4**
- **But increases the torque by a factor of 4**





- **Slows down the speed by a factor of 16**
- **But increases the torque by a factor of 16**

Transmissions – AM ToughBox

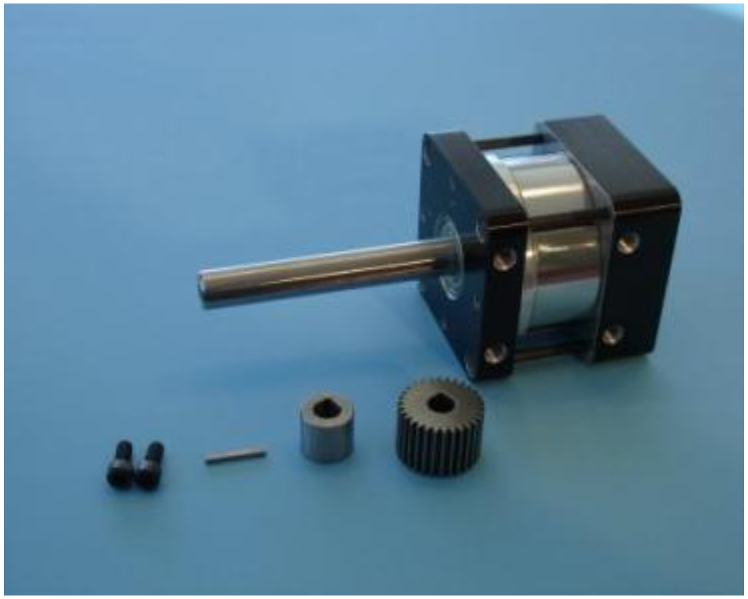
http://www.andymark.biz/am-0145.html

- **AndyMark ToughBox**
  - *Standard KOP*
  - *2 CIMs or 2 FP with AM Planetary GearBox*
  - *Overall Ratio: 12.75:1*
  - *Gear type: spur gears*
  - *Weight: 2.5 pounds*
- **Options**
  - *Ratio 1: 5.95:1*
  - *Ratio 2: 8.45:1*
  - *Weight Reduction*

Tranmissions – AM GEM500

- **GEM500 Gearbox**
  - *Planetary Style*
  - *1 CIM or 1 FP with Planetary Gearbox*
  - *Weight: 2.4 pounds*
  - *Output Shaft: 0.50"*
- **Gear Ratios**
  - *Each stage has a ratio of 3.67:1.*
  - *Base Stage: 3.67:1*
  - *Two Stages: 13.5:1*
  - *Three Stages: 45.4:1*
  - *Four Stages: 181.4:1*

Transmissions – BB P80 Series



- **BaneBots Planetary GearBox**
  - *Max Torque: 85ft-lbs*
  - *Available with or without motor*
- **Gear Ratios**

3:1	*4: 1*	*9:1*
12:1	*16:1*	*27.1*
36:1	*48:1*	*64:1*
81:1	*108:1*	*144:1*
192:1	*256:1*	

- **$79.50 - $157.25**

Transmissions – BB P80 Dual

- **BaneBots Planetary GearBox**
  - *Max Torque: 85ft-lbs*
  - *Available with or without motor*
- **Gear Ratios**
  - *4: 1 12:1 16:1*
  - *36:1 48:1 64:1*
  - *108:1 144:1 192:1*
  - *256:1*
- **$124.75 - $199.75**

Shiftable Transmission: AndyMark (AM)

- **Super Shifter am-0114**
- **Available from AndyMark**
  - *www.andymark.biz*
  - *Purchased as set*
  - *Cost with Shipping*
    - *$360.90 EACH*

Shifting Transmissions: NDB

- **Nothing But DeWalts**
  - *Team Modifies DeWalt XRP Drill*
  - *Purchase Pieces and Assemble*
  - *COST with Shipping:*
    - *$108.32 EACH!*

Compare SS and NBD

Super Shifter AM

- **2 speed**
- **Interface with**
  - *2 CIMs*
  - *2 AM Planetary Gearbox*
- **Gear Reduction**
  - *67:1*
  - *17:1*
- **Shifts on the fly**
  - *Servo*
  - *Pneumatic (Bimba series)*

Nothing but dewalts

- **3 speed**
- **Interface with 1:**
  - *Chiaphua (CIM)*
  - *Fischer Price*
  - *Globe Motor*
- **Gear Reduction**
  - *47:1, 15:1, 12:1*
- **Shifts on the fly**
  - *Servo only*

Compare SS and NBD

Super Shifter AM

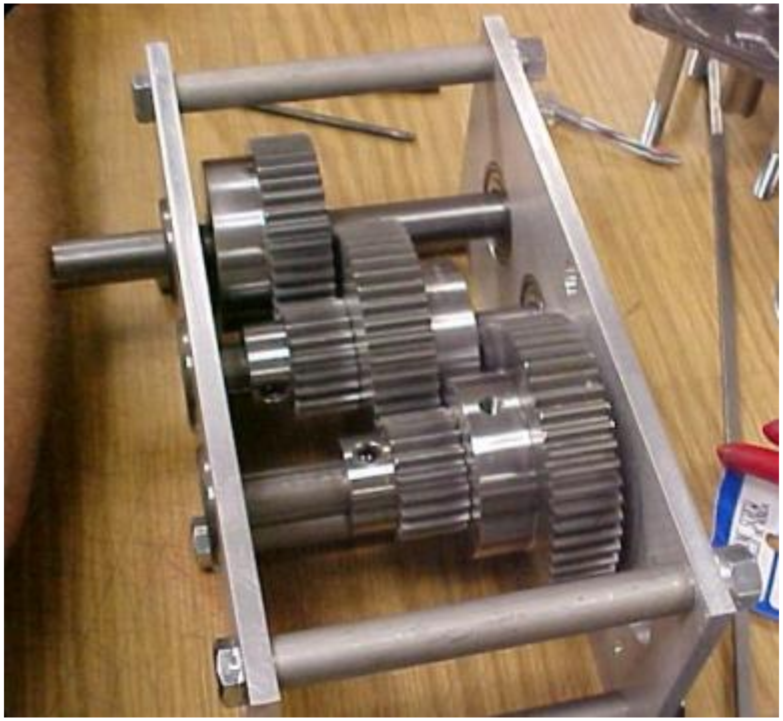
- **Weight: 3.6 lbs w/o motors**
- **Size with:**
  - *CIM: 6" x 4.25" x 8.216*
  - *FP Mod: 6" x 4.25" x 10.344"*
- **Comes with:**
  - *Optical Encoder*
  - *Servo Shifter*
  - *12 tooth #35 chain output sprockets per shaft*
- **Optional to purchase**
  - *4:1 high/low ratio*

Nothing but dewalts

- **Weight: < 2 lbs w/o motors**
- **Size**
  - *CIM: 9.5" x 4" x 3"*
  - *Other: Varies on use*
- **Does not come with**
  - *Servo*
  - *Servo Shifter*
  - *Encoder*
  - *Mounting plates*

Custom Gearboxes

- **Many teams build their own gearboxes**
  - *Built to suit*
  - *Can be very rugged*
  - *Can include single or multiple motors*
  - *Easier to add custom and Advanced features*
    - *Shift, Encoders, Straffing, etc.*



PRACTICAL AND REALISTIC CONSIDERATIONS

Remember…

- **Most first teams overestimate their ability and underestimate reality.**

Reality Check

- **Robot top speed will occur at approximately 80-85% of max speed.**
  - *Max speed CIM = 5600 rpms (NO LOAD)*
  - *Reality: 5600 x 0.85 = 4760 rpms*
- **Friction is a two edged sword**
  - *Allows you to push/pull*
  - *Doesn't allow you to turn*
  - *You CAN have too much of it!*
    - *Frequent for 4WD Systems*

Tips and Good Practices

- **Most important consideration, bar none.**
  - *Three most important parts of a robot are, famously, "drive train, drive train and drive train."*
- **Good practices:**
  - *Support shafts in two places. No more, no less.*
    - *Reduces Friction*
    - *Can wear out faster and fail unexpectedly otherwise*
  - *Avoid long cantilevered loads*
  - *Avoid press fits and friction belting*
  - *Alignment, alignment, alignment!*
  - *Reduce or remove friction almost everywhere you can*

Tips and Good Practices

- **You will probably fail at achieving 100% reliability**
- **Good practices:**
  - *Design failure points into drive train and know where they are*
  - *Accessibility is paramount. You can't fix what you can't touch*
  - *Bring spare parts; especially for unique items such as gears, sprockets, transmissions, mounting hardware, etc.*
  - *Aim for maintenance and repair times of <4min.*
    - *TIMEOUTS!*
  - *Alignment, Alignment, Alignment….Alignment*
  - *Use lock washers, Nylock nuts or Loctite EVERYWHERE*

Tips and Good Practices

- **Only at this stage should you consider advanced thingamajigs and dowhatsits that are tailored to the challenge at hand**
  - *Stairs, ramps, slippery surfaces, tugs-of-war*

- **"Now that you've devised a fantastic system of linkages and cams to climb over that wall on the field, consider if it'd just be easier, cheaper, faster and lighter to drive around it."**