game manual 0, abridged

a guide for FTC teams

enjoy!

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Introduction

Hello! Welcome, and thank you for taking the time to read Game Manual 0, the premier resource for new and upcoming FIRST Tech Challenge teams! If you are part of a rookie or new team, we would especially like to welcome you to the FTC community. We want to make your beginning steps in FTC as seamless as possible, and offer some of our own experience and advice. Our guide was written by members in FTC teams all across the nation, many of whom have competed at the highest level.

The goal of Game Manual 0 is to compile the most extensive (hardware-focused) guide there is for FTC, as online and physical resources for FTC are few and far between. A major inhibitor for newer teams is the lack of knowledge base, as well as not knowing any experienced teams who might offer advice and support throughout the build and competition season. GM0 seeks to address these shortcomings by providing a starter's guide to the hardware in FIRST Tech Challenge.

You are currently reading the abridged version of Game Manual 0. For the comprehensive guide, use the link here: ADD THE LINK

When perusing this guide, it is important to keep in mind the authors' perspective. Many, if not most, of the teams who contributed in the writing of this guide are world-level teams in the upper echelon of FTC. This means that our recommendations are almost solely from the competitive advantage standpoint. We want to help all teams in FTC, but as our experience has been on the competitive side of the fence, certain parts of the guide may not be very helpful for some teams.

Before diving in, we would like to add a short disclaimer: this guide is *not* about how to build a specific drivetrain, linear slide, intake, etc. The purpose of GM0 is simply to provide knowledge and advice to teams about the possible options, as well as including some tips on how to get started. GM0 has knowledge and advice, but not instructions. It is of the utmost importance that all teams learn the right way (by trial-and-error), not by reading a step-by-step guide or instruction manual. Thus, while GM0 has plenty of advice, we do not have specific steps included. Good luck, and have fun in FTC!

The Game Manual 0 Writers

The contact information of the editors, as well as full credits, may be found in the unabridged version. **If you have any questions, don't hesitate to contact gamemanual0@gmail.com!**

Rookie Mistakes: Building

Problem	Solution
2 motor drivetrain - Less power - Less acceleration	**4 motor drivetrain** + More power, higher efficiency + Improved acceleration
Pushbot - Poor agility - Poor top speed	**Mecanum, 6WD, etc.** + More agile/higher top speed + Customizable gear ratios
Claw - Control 1 element at a time - Easy to break	**Intake** + Control multiple elements at a time + Much more efficient
Spur gear gearboxes - Not for high load use cases - Will break under shock load	**Planetary gearboxes** + For drivetrain and high load + Resistant to shock loads
Single/multi-axis arm - Requires high gear ratio - More complex	**Linear extension** + Generally faster than arm + Much more precise

2 motor drivetrain → 4 motor drivetrain

In general, it is not recommended for teams to use 2 motors on the drivetrain, but instead use 4. This is mainly due to the added power and increased acceleration 4 motors provide. Typically, top speed is determined by the gear ratio and the motor specifications, not the *number of motors*. **However**, acceleration is affected by the number of motors, and as FTC robots need to change direction and accelerate numerous times per match, slow acceleration has a significant adverse effect on the competitiveness of the robot. In addition, 2 motor robots may struggle to get over obstacles or climb up ramps, due to less power. Typically, it is always possible to build a competitive robot with 4 motors allocated to drivetrain, and 4 motors to other mechanisms, so there should be no reason to skimp on drivetrain motors.

Pushbot → Mecanum, 6WD, other recommended drivetrains

The pushbot drivetrain, commonly built by first-year teams using the FIRST-provided guides, should not be used as a competitive drivetrain. We do recommend teams who have purchased the Tetrix kit to build it for educational purposes only - that is, to get familiarized with the parts and basic building principles using a channel-based kit. However, we *do not advise* that teams use that pushbot at a competition due to its many flaws. The first major flaw is that the pushbot is powered by 2 motors, and as stated above, there isn't a reason to stay with 2 motors on drivetrain. Secondly, the pushbot has poor top speed and turning ability, given that the gear ratio (40:1 on 4 inch wheels) is half the speed that many teams use. Thirdly, it is not advisable to use direct drive. However, most if not all of these problems will be solved by using a four-motor drivetrain such as the ones recommended in the Drivetrain guide (Mecanum, 6WD). Therefore, it is recommended for teams to refer to the Drivetrain section and see which drivetrain would fit best for their overall game strategy.

Claw → Intake

Intakes should always be prioritized over claws, with the exception that a claw should be used for irregularly shaped objects that would be impossible to control via intake. Intakes have two major advantages over claws - the first being that intakes can control multiple game elements at a time, and the second being that intakes are indiscriminate at picking up objects, making them much more efficient. Claws can only pick up one object at a time, and the driver needs to aim the claw at that specific object to grab it. With an intake, the driver does not need to focus on one game element - instead; intakes will just pick up anything in its path, if designed properly. Claws are also prone to breakage, and thus suffer to defensive robots. They are also generally more fragile than intakes. Therefore, intakes are as a result much more efficient than claws. Nearly every competitive robot from past years have used intakes to great effect, so there is plenty of precedent.

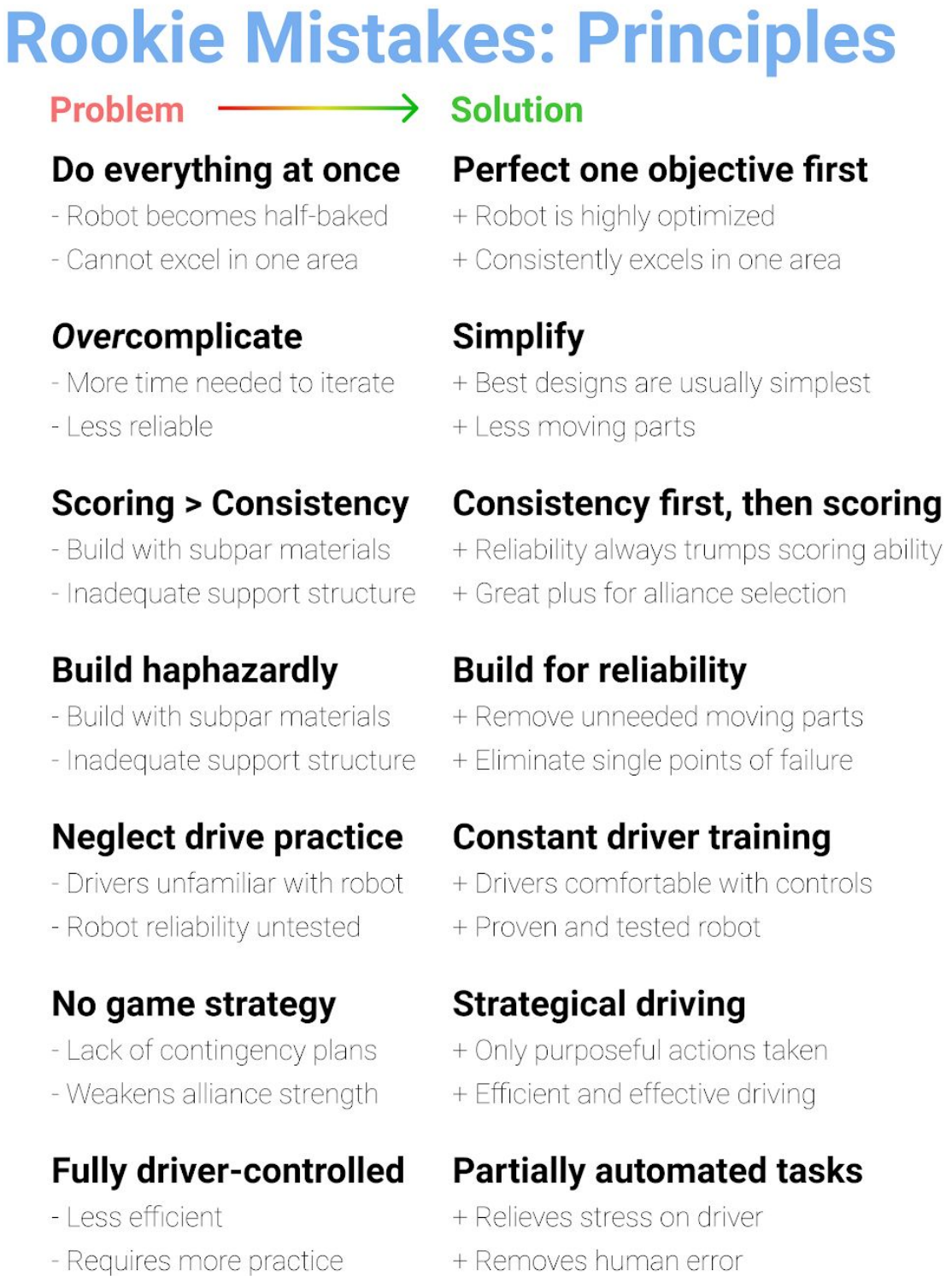
Spur gear gearboxes → Planetary gearboxes

Spur gear gearboxes have inherent disadvantages to planetary gearboxes. Spur gear gearboxes should not be used in high-load situations, primarily because the gears can strip and destroy the gearbox. Planetary gearboxes are much better suited for drivetrain and arms, due to the configuration of the sun and planet gears. In addition, spur gear gearboxes are prone to shock loads; therefore, direct drive is definitely not advisable on drivetrains. Refer to the Motor guide for more complete information on gearboxes.

Single/multi axis arm → Linear extension

Teams are generally advised to stay away from arms and move in the direction of linear slides, primarily due to the issue of complexity. This is because arms typically are less effective than linear extensions and are harder to implement properly. Arms require a high gear ratio, which usually in turn will require an expensive gearbox (e.g. VersaPlanetary) that teams may not want to invest in. Furthermore, arms must be supported extremely well to bear the torque that the motor provides. In contrast, linear extensions do not need to worry about gear ratios and gearboxes. They can be optimized to be more efficient than arms, and typically are more precise, as linear motion is easier to control than angular motion. Furthermore, linear slides can have more extension than arms, with some reaching over 3-4 feet in length.

Rookie Mistakes: Principles



Do everything at once → Perfect one objective first

A common pitfall for first year teams is trying to accomplish all the game objectives, especially in tele-op and endgame. **This is highly discouraged** because new teams do not have the experience to do so. Too often, we see teams bring half-baked robots that will attempt to do everything in a match, but excel at nothing. This robot could be much more successful if the team spent their time to perfect one mechanism. Teams should always remember the principle that a robot that can complete one thing consistently will likely be more competitive than the robot that does everything inconsistently. We recommend teams focus on one objective during tele-op/endgame and perfect it.
Typically, teams which have a solid autonomous and consistent endgame can be competitive at the Qualifier level, and this is a recommended goal for new teams.

Overcomplicate → Simplify

Another common trap that teams fall into is to overcomplicate needlessly. Simplicity and compactness are two hallmarks of engineering. While some robots are very complicated, keep in mind that those teams are generally experienced. However, many world-class teams often build designs that are ingenious yet ridiculously simple. Some advantages to simplicity are that the robot usually has less points of failure, given that the robot has less moving parts. Additionally, it takes much less time to iterate through and perfect a simple mechanism as opposed to a complicated one. Keeping things simple can be achieved through a couple of ways. First, try to limit the degrees of motion that the mechanism operates in. For example, a linear slide goes in and out in a straight line, as opposed to an arm, which rotates along an axis. Doing so will serve to eliminate forces that otherwise could adversely affect the mechanism. Another way to simplify is to build for the shortest travel distance. Obviously, the shortest distance from A to B is in a straight line, so teams should strive to keep the game elements approximately within a reasonably straight line. This can help in solving possible problems if the game elements need to change direction too many times.

Scoring > Consistency → Consistency first, then scoring

The tortoise beats the rabbit. An overused parable, but it still holds a kernel of truth. Why? Because the tortoise, which plodded along consistently, beat the rabbit, which had hot and cold streaks. A hallmark of any successful team is consistency and reliability throughout the competition season and even across seasons. Without the power of consistency, it will be nearly impossible to win games, let alone a tournament. Too many teams fall into the pit of prioritizing scoring ability more than anything else, which is a grave error. In keeping with the first tip, to perfect one objective first, this practice will serve to increase consistency. **Do not worry about scoring ability; that will come naturally after consistency**. Focus on being able to do that one thing every single time throughout your matches, and you will begin to see how

important consistency is. **This tip is equally as important during alliance selections. Top teams will prioritize teams that are consistent far more than scoring ability.** They are not afraid to look at teams who can't score much, but can contribute every time to the alliance score, rather than selecting a boom-or-bust pick.

Build haphazardly → Build for reliability

When building, teams often overlook a key principle: build for reliability. All too often, teams skimp on the quality of construction as well as materials, which leads to one of the most common reasons for broken robots: part failure. Teams also do not take into account the rigors of competition and build as if the robot will not encounter opposing robots. Sufficient driver practice will be able to better simulate in-game conditions and test the reliability of the robot. To remedy this problem, refer to the Materials Guide to gain a better understanding of what materials are recommended for use. In addition, teams often forget to account for twisting or compression forces that may occur upon the mechanism. While we cannot give any specific recommendations, do keep in mind what forces the support structure of your mechanism must bear along the full range of motion, *and* account for what occurs when it might hit another robot/field wall/field. Building more robustly is always worth the time spent. Furthermore, a common cause of robot disconnect is wiring issues. Refer to the Wiring section for more information; in short, make sure to plan ahead and leave space for wires, and use strain relief whenever possible. All these tips combined will help your robot become more reliable, a key characteristic of all world-level robots.

Neglect driver practice → Constant driver training

A persistent problem with teams is the lack of driver practice. No matter how good your robot is, the robot is only 50% of the equation. The driver(s) are the other 50% which determine the success of the team as a whole. Just like a sports team, a robotics team requires practice. Even if individual players have great talent, only practice and communication can guarantee success as a team. Even if your robot is the best in the world, and inferior robot with a competent drive team more than likely will beat your robot. Drive teams need to communicate with one another and practice for the unexpected. A high school sports team practices about 15-20 hours weekly. To be successful, that is the same amount of time that you need to devote to your robotics team. By April's world championships, many top teams had 150+ hours of practice, not including building or coding meetings. This means that 1) the teams were dedicated to daily drive practices and 2) their robot was reliable enough to survive 150+ hours of operation. Driver practice not only familiarizes the driver(s) with the robot and serves as a test of robot reliability, it also simulates in-game conditions. Learning to push the limits of your robot should be done *in practice*, not at competition. This way, drivers will become more comfortable driving under stress and pressure. Some teams even go so far as to play loud music or say distracting things during practices to add in a little extra.

No game strategy → Strategic driving

Similar to drive practice, this is something that many inexperienced teams ignore. Another sports example is handy - even with the most talented team, they won't go far without good game strategy. An inferior team with better strategy execution could even pull off an upset. Planning a strategy ensures that every second in the 2:30 game time is used to the maximum efficiency, which yields more points. For example, drivers should know exactly where the robot needs to be positioned after the autonomous → tele-op switch. Practicing this switch will save a couple of seconds when drivers have to think "what do I do now?" Knowing when to transition from a tele-op to endgame objective is equally important (hint: perfect one first) and will save valuable time. Strategy should **always be used to maximize points** - whether this is a positioning strategy to access the game elements, or a defensive strategy to hinder the other alliance from scoring. **Remember, denying the other alliance 10 points is the same value as scoring 10 points.** However, it is not advised for new teams to play defense due to the specific rules surrounding this strategy. If a team wishes to execute a defensive strategy, be sure to read all the rules as defense can incur penalties/cards if done improperly.

Fully driver-controlled → Partially automated tasks

Autonomous should not be limited to only the autonomous mode. Automating simple tasks can be a real time-saver and efficiency boost to teams. First of all, automating tasks can save time and reduce the need for driver multi-tasking. Drivers should always be controlling the robot with as few button presses as possible. For example, automatically lowering the lift with a delay after the game elements have been deposited would save a button press. This also has the advantage of eliminating driver error if the driver has too many operations to carry out and relieving stress on the driver.

Kit Guide

Chances are, you've already purchased a kit for the upcoming season. However, there might be some teams who haven't done so. Here are our recommendations on choosing the right kit for your team.

- Tetrix
  - The TETRIX build system, in a few words, is subpar to the other kit options. The TETRIX build system revolves around 32 mm aluminum c-channels, which creates plenty of mounting options. These channels have a tendency to flex under load, often requiring reinforcement using multiple channels to maintain their shape. While TETRIX channel is measured in metric units, the system employs Imperial (SAE) bolts and Imperial chain. This mix of units means that things often don't quite line up how they're supposed to. The mounting options and hole patterns leave more to be desired and restrict teams in terms of flexibility. If purchasing through the FIRST storefront, we recommend the REV starter kit instead. Not only is it much cheaper, it is also a better build system.

- Actobotics
  - The Actobotics kit has long been regarded as one of the premier kits for FTC teams for many years. Its robust 1.5" c-channel and ball-bearing based motion system allows teams to build reliable mechanisms entirely from kit parts. One advantage of Actobotics is that their channel hole pattern has many more mounting holes than a Tetrix channel, so it is less restrictive. Actobotics uses imperial units across the board, allowing for cleaner spacing and better fitting. Actobotics can interface with other kits such as REV through a variety of Pattern Adapters. Servocity (the Actobotics vendor) offers a 25% off discount for all FIRST teams, making pricing very competitive. Actobotics is a great choice and value for new teams to seriously consider, offering a solid base kit with many options to expand upon.

- goBILDA
  - goBILDA by Robotzone, the makers of Actobotics, is the newest build system on the market, being fully released in the 2018-2019 Rover Ruckus season. Even with its relative novelty, it has quickly rose through the ranks and has become one of the premier build systems in FTC. Designed for the international market, it uses a metric hole pattern, M4 screws, 8mm pitch chain, HTD 3 belt, and metric shafts (6mm D). Much like Actobotics, it is channel based with an additional extrusion system. Unlike Actobotics, however, low side channel is the foundational building material to supplement full size U-channel. Just like Actobotics, goBILDA offers a 25% discount for FIRST teams. For these reasons, goBILDA may soon become a popular robot kit in FTC.

- REV
  - The REV kit is very different from the other kits mentioned above, primarily because it is an extrusion-based system. The REV kit uses 15mm aluminum extrusion instead of channels commonly found in other kits. Thus, there is no fixed pitch, which means having fixed holes and mounting points. Extrusion systems are all based upon adjustability and flexibility - for example, tensioning chain is simple when sliding the mount or bracket increases tension. The REV system, unlike the other kits, uses metric dimensions (15 mm extrusion, M3 hardware). REV also uses 5 mm hex for their shafts, which is something that other vendors have added compatibility for. In general, REV has a steeper learning curve than other build systems (owing to the fact that in extrusion the builder must figure out the optimal mounting position, etc.), but this is not necessarily a large disadvantage. The REV kit is a great choice for teams willing to invest the time into an extrusion building system. It has the ability to upgrade parts for those wanting a further step and investment into an even more complete building system.
  - Another advantage to the REV kit is the compatibility of 15 mm Misumi extrusion. Misumi offers greater strength at a lower bulk cost. Additionally, Misumi will cut to the half millimetre for free, making it a great option for teams needing an exact cut.

Components of a Robot

When first starting to build your robot, you might be overwhelmed with where to start. However, Game Manual 0 provides plenty of resources to aid and teach teams on the important mechanisms that are in nearly every competitive robot.

The necessary mechanisms in every world-class robot are typically the drivetrain, linear extension, and intake. The complete Game Manual 0 contains a detailed description and explanation of all the possible options; however, for the sake of concision, we have only included the recommended drivetrains, linear slides, and intake types.

Drivetrain

The purpose of the drivetrain is to facilitate the movement of the robot, and thus is a mechanism crucial to the overall function of the robot. There are many possible types of drivetrains in FTC, which we have covered in the full version of the guide. All the drivetrains listed below should be powered by 4 motors. While it is possible to use two motors on the drivetrain, it is not recommended as the drivetrain is a key component of the robot.
The two different categories of drivetrain are tank (skid-steer) and holonomic. A tank drivetrain primarily utilizes traction wheels and cannot strafe (move sideways). A holonomic drivetrain, on the other hand, can strafe (move sideways), due to using either mecanum or omni wheels.

4 Wheel Drive (Tank)

4 wheel drive is recommended conditionally. 4WD has a major advantage over 2WD in that all four wheels are powere; however, 4WD with all traction wheels sometimes suffers in agility. Even though 4 wheel drive is a huge step up from a 2WD pushbot, unless it is needed to have a raised drivetrain to get over terrain, it is recommended for teams to move up to a 6 wheel drive due to the increased stability and pushing power of a 6WD.

6 Wheel Drive (Tank)

6 wheel drive is highly recommended. A 6 wheel drivetrain is a common competitive drivetrain in FTC for multiple reasons. It has fantastic traction, great turning, and by having 6 wheels, the drivetrain has more contact with the ground, helping with stability and traction. Therefore, the robot is less likely to tip over with a 6WD. There are two main types of 6 wheel drivetrains: ones with corner omnis and ones with a drop center. 6WD is one of the most competitive drivetrains, and is highly recommended for first-year teams.

8WD (Tank)

8 wheel drive is recommended. It is a distinct spin-off of the 6WD, with the center four wheels dropped. This means that when turning, only these middle four wheels are touching the ground. Thus, the 8 wheel drivetrain has more stability while turning than a 6 wheel drive. Teams can also use corner omni wheels similar to a 6WD.

Mecanum (Holonomic)

Mecanum drivetrains are highly recommended and consist of four mecanum wheels. Each wheel is powered independently by one motor. This configuration angles the velocity of each wheel, allowing the robot to strafe. The rollers on mecanum wheels form a 45 degree angle with the wheel’s axis of rotation, so the ratio of forward speed to strafe speed is less than 1. Mecanum wheels also have a tendency to slip as they have less traction than grip wheels. Despite their complexity, mecanum drivetrains are both extremely effective and easy to build, making them a good choice for new teams looking for an agile base drivetrain.

Linear Extension

Linear motion is one of the most important components of a successful robot. In most games, teams are required to reach into an area that the drivetrain cannot access in order to pick up or deposit game elements. Access of > 18” is necessary for nearly all games; >24” is preferred. In some games, an extension of 36" or more may be needed.
The two categories of linear extension are **extrusion slides** and **drawer slides**. Extrusion slides are based around the extrusion system and typically have plastic sliders that fit inside the slotted part of the extrusion. Drawer slides are commercial-off-the-shelf drawer slides customized to mount on FTC robots. Generally, drawer slides are more heavy-duty, and extrusion slides are used for light-load applications. For information on how to string and power linear extensions, refer to the rigging section in the full guide.

REV Robotics 15mm Linear Motion Kit (Extrusion Slide)

The REV 15mm Linear Motion Kit is based off of the 15mm extrusion system. This extrusion kit does not perform spectacularly out of the box. This has been partially remedied by REV as they have developed a second iteration of their slide kit, which has better tolerances on the Delrin sliders. Still, you’ll see a lot of competitive teams use this kit with multiple modifications, such as adding lots of lubricant and mounting the sliders differently. Teams have also 3D printed their own sliders, though this is probably not a great idea for inexperienced teams. Overall, this kit is lightweight, simple, and cheap. It can be a good start for teams using REV and needing a linear extension, and is generally usable out of the box.

MiSUMI Telescopic Slide Rails (Drawer slide)

The MiSUMI slide rails are arguably the number one option for linear extension in FTC. Used by many top-tier teams, these rails are sturdy and very reliable, ridiculously smooth due to the ball bearing system, and have almost no flex. MiSUMI slides are able to withstand a significant amount of load with little flex. They are also low-profile, and have a M3 mounting pattern, making it easy to attach to REV extrusion. However, MiSUMI slides have a higher price point, and it is often difficult to attach one slide to the next. Generally, the MiSUMI slides, even with their disadvantages, are one of the best price-performance options for FTC extensions.

Hafele Drawer Slides

Hafele drawer slides are a low-cost, low-weight option for teams not wanting to invest in MiSUMI slides. Hafele slides are less smooth than MiSUMI, which is to be expected given their low price point. They are unable to sustain a large amount of load, making it good for low/medium-load use cases, such as to pick up and deposit the relic in Relic Recovery. Hafele slides are a great option for teams looking for a cheap alternative to the other more expensive options at the cost of robustness.

Intake

There's one main rule when it comes to intakes in FTC: you'll always need one. Claws are most almost always outperformed by robots using active intakes simply because a claw can't compete in ease of use, speed, and versatility. Looking back at the highest-performing robots in the past seasons, the one thing that is consistent across all of them is that they use some sort of wheeled intake or roller intake. These robots were successful largely because of how easy it was for them to acquire and control game elements.
Explained below are the common and recommended types of intakes. Refer to the full section on intakes in the complete guide for a more in-depth treatment of each intake type.

Compliant Wheel Intake

The compliant wheel intake is most commonly used with large game elements such as the glyphs in the 2017-2018 season, Relic Recovery. In this game, robots had to pick up glyphs, which were 6 inch foam cubes, from the center pit and place them in the cryptobox. This game had many wheeled intakes primarily because the wheels had consistent and controllable contact with the glyphs. Wheeled intakes were able to propel the glyphs in a consistent fashion from the point of contact to the deposit plate. A wheeled intake can use different size wheels (generally 2 in. and 4 in.) to prevent jamming. Wheeled intakes operate at much slower RPM than surgical tubing intakes, as wheeled intakes are meant to pick up one element at a time. They generally require more torque than a surgical tubing intake, which is geared for speed.

Surgical Tubing Intake

Surgical tubing, sold by many different manufacturers, is a great option for picking up small game elements such as the minerals in Res-Q or Rover Ruckus. Surgical tubing intakes can, and often, have multiple sets of tubing in order to move minerals from the collection point to the holding box. This was most often seen in games such as Res-Q and Velocity Vortex, when robots had to transfer minerals from collection to a holding box. However, having multiple tubes requires that they be driven, generally by chain, which can cause some complications for inexperienced teams. Surgical tubing intakes are especially good at picking up multiple elements at a time, due to the high RPM (sometimes >1000 RPM) of the rollers.

Foam Roller Intake

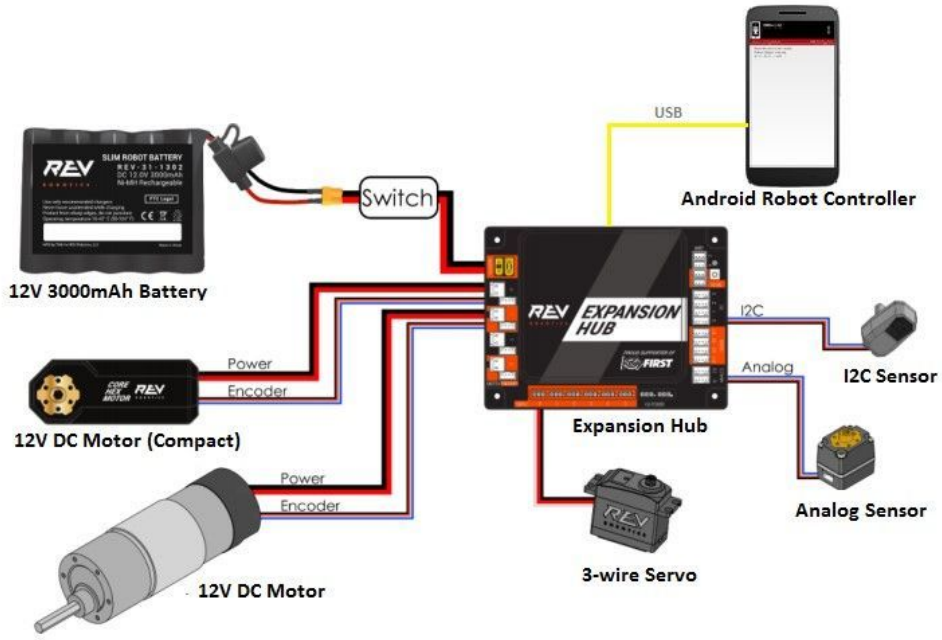
A foam roller intake uses foam rollers commonly found in the paint department of most hardware stores. It is generally used in games where the elements are balls. For example, Velocity Vortex saw quite a few teams use foam rollers to great success. Generally, foam roller intakes are the first point of contact, and then teams can use other means to transfer the element to the desired location. Usually, robots with foam rollers drive over the balls that they want to intake.

FTC Control System & Expansion Hubs

RC Phone + REV Expansion Hub(s)

This is the standard control system for teams starting out in FTC. The REV Expansion Hub is reliable, as long as proper strain relief and wiring is carried out. This includes the USB Retention Mount, as well as 3D printing XT30 stress relief mounts (LINK). The Expansion Hub connects to the Robot Controller phone through the USBmini port, and the RC phone is linked to the DS (Driver Station) phone through WiFi Direct. For more information on setting up the Expansion Hub and configuring the robot, head to REV Robotics' Technical Resources page on their website.

- USB Retention Mount
- XT30 Stress Relief
- REV Robotics Technical Resources



Vendor List

Provided is a list of vendors and the parts offered. This is especailly useful as many new teams may not know the different suppliers offered to FIRST Tech Challenge teams.

- Actuonix (www.actuonix.com)
    - Actuonix sells linear actuators and linear motion components. Expensive, but robust.
    - Teams can apply for a FIRST sponsorship.
- AndyMark (andymark.com)
    - AndyMark sells the official game field and game sets, as well as individual game parts and the SoftTiles foam tiles.
    - AndyMark also sells NeveRest and NeveRest Sport motors, TileRunner, compliant, stealth, and mecanum wheels, as well as many other items.
- goBILDA (gobilda.com)
    - goBILDA sells its own build system, complete with Yellow Jacket motors, channel, motion components, and battery. Note that the cheapest batteries are found here, the MATRIX 12V Batteries are $39.99, with the team discount they are $29.99, nearly half the price of the $50 batteries sold elsewhere.
    - Teams can get a 25% Team Discount from goBILDA.
- McMaster-Carr (mcmaster.com)
    - McMaster-Carr sells hardware and raw materials in bulk quantities. They stock nearly every type of bolt, screw, and nut possible, as well as washers, bearings, springs, etc. Purchase from them for bulk quantities of hardware, as well as the times you need a very obscure part.
    - Don't be turned off by the hidden shipping. Generally, McMaster-Carr's shipping is around the same price as other vendors, and shipping is usually next-day.
- MiSUMI (us.misumi-ec.com)
    - MiSUMI is a Japanese company specializing in industrial and manufacturing components. They sell bulk 15mm anodized extrusion similar to the REV Robotics extrusion. The 15mm extrusion can be cut to length as well.
    - MiSUMI also sells aluminum drawer slides that are popular for linear extensions. They are available in different lengths, but the most common is 400mm.
- Pitsco (pitsco.com)
    - Pitsco sells the Tetrix kit with channels, TorqueNado motors, and their own motion system.
- REV Robotics (revrobotics.com)
    - REV Robotics sells the REV build system, which is an extrusion-based ecosystem complete with motors (HD Hex, HD Planetary, Core HEX), extrusion, servos (Smart Robot Servo), brackets, and battery.
    - REV also sells the control system for FTC (Expansion Hub and Control Hub).

    - REV offers various sensors (Magnetic Limit Switch, Color Sensor, Touch Sensor, Distance Sensor, Potentiometer, etc.)
    - Additionally, electronic components such as the Servo Power Module, SPARKmini, or Blinkin may be purchased.
- Servocity/Actobotics (servocity.com)
    - Servocity sells the channel-based Actobotics build system with robust motion and structure. They also offer the Servoblock, a highly recommended part.
    - Servocity sells X-rail extrusion and linear extension kits, as well as the lead screw actuator kit.
    - Servocity sells a wide range of servos, from Hitec to Futaba, at all price points.
    - Teams can get a 25% team discount from Servocity, making it an affordable vendor.
- VEX/VEXPro (vexrobotics.com/vexpro/ftc)
    - VEXPro sells parts angled toward FRC use, but many of their parts, such as Thunderhex, can be made compatible with FTC robots.
    - VEX sells the 393 Motor, as well as the Motor Controller 29 in order for it to adapt to the Expansion Hub.
    - VEX offers the VersaPlanetary motor which allows teams to customize a specific gear ratio for their needs.
- West Coast Products (wcproducts.net)
    - Also known as WCP, West Coast Products sells products exclusively aimed toward FRC use. However, much like VEXPro, many of their parts can be used in FTC, especially in custom robots. In fact, VEXPro and West Coast Products sell many of the same parts.