Pedal-Powered Diwheel

Christopher Draper, Bennet Strong, Spencer Wang

Thomas Jefferson High School for Science and Technology

Engineering Research Lab

5/23/2025

Table of Contents:

- **Abstract - Page 3**
- **Introduction - Page 4**
    - Problem Statement - Page 4
    - Literature Review - Page 5
    - Objective - Page 9
- **Methodology - Page 9**
    - Project Plan - Page 9
    - Full Procedure Write-Up - Page 13
    - Test Procedures - Page 17
    - Material List - Page 18
- **Results - Page 19**
- **Discussion - Page 21**
    - Conclusion - Page 25
- **References - Page 26**

Abstract

Designing an accessible, pedal-powered vehicle that puts a twist on the traditional bicycle, featuring parallel hubless wheels to improve low-speed stability. This project aims to develop a functional prototype and explore the potential of hubless wheels in the transportation industry. It explores the design, construction, and testing of a pedal-powered diwheel utilizing centerless wheels. Motivated by the desire to create an alternative mode of transportation that is both cost-effective and mechanically innovative, our team developed a functional prototype capable of traveling long distances in a straight line without derailing or losing balance. Drawing from prior designs, especially the Bevel's Advocate project, we employed a gear-driven drivetrain, a triangular-prism support frame, and balancing techniques to address issues such as sloshing and gerbilling. Through iterative design, testing, and adjustments, the final product demonstrated not only mechanical feasibility but also the potential for educational and engineering applications.

Pedal-Powered Diwheel

Human transportation is essential to our everyday lives. Investment in transportation correlates to positive economic growth by creating job opportunities, promoting trade, and improving connectivity among regions(USDOT). Public transportation employs nearly half a million people in the US, yet reliable transportation is still expensive for many. Many alternative modes of transportation, including bicycles and scooters, can be too dangerous and slow for road transport.

They say you shouldn't reinvent the wheel. However, the wheel has its problems. This project seeks to solve some of these issues by introducing centerless wheels. Centerless, or hubless, wheels are wheels with no spokes and no center axle. They can be propelled in several ways, including gears on the inner rim or a parallel belt. Centerless wheels have several advantages and capabilities that allow for new uses of wheels. These wheels have a lower rotational inertia and can be made lighter than spoked wheels with a center axle, allowing for improved handling(Chouhan et al., 2023). Another essential advantage of centerless wheels is that they allow for new arrangements in vehicles and other wheel-driven systems. Car manufacturers have always looked for ways to create more space above the axles to lower the car closer to the ground, but what if we did not need axles?

Problem Statement

This project will explore how a centerless wheel can be implemented for a simple means of transportation: the diwheel. A diwheel is a mode of transportation that sports two wheels, like a bicycle. The difference is that the two wheels are parallel rather than coplanar. Additionally, a diwheel setup mandates that the driver sit in between the wheels rather than above. A diwheel has two large outer wheels, usually 36 to 60 inches in diameter, encompassing an inner frame completely. This inner frame is free to rotate within the outer wheels and is supported by rollers. Diwheels struggle from their difficulty in balance, as the driver tends to slosh and tumble as the outer wheels rotate. These struggles are ever apparent in every design of a diwheel, and this project will seek a simple solution to this issue: What if the driver could entirely control the forward and back sloshing movements as well as the center of mass? The diwheel presents an application of centerless wheels, and the ideal method of structuring and powering a diwheel is still under much consideration.

Literature Review

The focus of our research was the implementation of various diwheel designs. We wanted to review designs for a wide range of applications and purposes. Specifically, we reviewed diwheel attempts ranging from backyard projects to multi-year university-level projects with high funding. There was little difficulty in finding previous research that fit our research question, mainly because there were so many different approaches to designing a diwheel. The three main types of diwheels that we reviewed were electric, pedal-powered, and tandem drive. Since a large part of our research was on the drivetrain aspect of the diwheel, this distinction between propulsion methods will be beneficial in determining our preliminary design.

One way to implement the diwheel is with motors. EDWARD(Electric Diwheel With Active Rotation Damping) was a mechanical engineering project at the University of Adelaide, built-in 2011(Cazzolato et al., 2009). It features two parallel wheels driven by a centerless wheel system. There is a seat in the middle with an electronic control interface. This design is unique because it incorporates a complex damping system to keep the inner frame stable. This design is the pinnacle of mechanical engineering when designing a regular diwheel. It extensively evaluates the physics behind diwheel motions. This is demonstrated by a more recent achievement by the EDWARD team. They managed to demonstrate inversion control of the diwheel. This means that the driver can rest stably in the upside-down position. In a regular diwheel, this would not be feasible due to a low center of mass. EDWARD is fascinating because it pushes the limits of what can be done with a diwheel and it presents special techniques that can be incorporated into future designs. For example, the combination of suspension and sensors is used to control sloshing and gerbilling(when the driver spins forward and backward).

Another source that implements centerless wheels is GeoOrbital(Burtov, 2020). GeoOrbital is a startup that designed and manufactured an electric bicycle wheel that can be custom-ordered and substituted for any regular bicycle wheel to make it electric. This design incorporates the concept of a centerless wheel running on idlers, which is required for a diwheel. The neat thing about this design is that the entire power system for the electric wheel is enclosed within the wheel. This design was engineered over multiple years and then consumer-tested by thousands who purchased the product. Issues that came up with the use of this electric bicycle wheel usually mentioned battery life or the difficulty of use without the motor. Most electric bicycles on the market allow the rider to continue pedaling the bicycle without power. On the contrary, the nature of the GeoOrbital design induces high friction between the outer wheel and the idler wheels when pedaled without battery power. However, many praised the benefits provided by the consolidated power system over the typical electric bicycle with a bulky frame. GeoOrbital is helpful for designing a diwheel because it demonstrates some common faults of centerless wheels.

A third project that implements an electric drivetrain, Fabrication of Di-wheel by Computational and Experimental Approach, uses a similar drivetrain concept as EDWARD but vastly simplifies the design(Chouhan et al., 2023). This design presents the major framework for a diwheel and creates a platform to implement control strategies to improve the ride of the vehicle. It is designed to be used in public spaces such as theme parks and national parks. The report mentions that it also fulfills the goal of creating a platform to research compact vehicles of the future. Each of these three designs above has the following in common: they are driven by an electric motor, have a central battery, and have three idler wheels connected to a triangular frame(with the exception of the third design, which uses a square frame within the outer hoop). Although GeoOrbital isn't a diwheel, it shows how the power required to run a diwheel can be enclosed within the wheel entirely, eliminating the need for an axle or drive train.

Another approach to the diwheel is a pedal-powered drivetrain. A project built by students at Dartmouth showcases this design. As a culminating project for Computer Aided Mechanical Design, students built two-wheeled pedal-powered vehicles coupled with centerless wheels in the form of a diwheel(Johnson et al., 2015). Six teams built their own pedal-powered diwheels and raced them at the end. One of those teams, Bevel's Advocate, was particularly interesting due to the extensive documentation of their engineering process. Additionally, we thought highlighting this design was vital because it has one major difference from the other diwheels we had looked at. It still has a similar chassis and outer wheel structure. However, it is pedal-driven. When we first looked into diwheel, we dismissed the idea of an electric system and opted for a pedal-powered design due to cost and mechanical engineering focus. This design would eliminate the need for electronic components and streamline the process. This design has a gear-driven lower drive wheel attached to a triangular frame and two other idler wheels. In the center of the drivetrain axle, there is a differential and a gear cassette to adjust gearing. The gearing was crucial to Bevel's Advocate because it helps eliminate the violent sloshing that occurs while the diwheel accelerates from zero by allowing for a gradual increase in speed.

Another important takeaway from this design is that it reveals the resources, including time, that were required to build the diwheel. The associated paper reflects on the commercial viability of the diwheel. It cites 500 man-hours along with $8000 in labor costs as well as material costs to be able to build wheels in a commercial setting(Johnson et al., 2015). The costs would, of course, change with improved manufacturing techniques. These cost and time figures won't necessarily apply to a school project as the team of four was able to complete the diwheel in five weeks.

One last source that we reviewed was a massive diwheel that allowed for a regular center axle to drive the outer wheels. It required two opposite-facing drivers to be seated below the center axle, each pedaling their respective side of the diwheel. The opposite-facing drivers are crucial to maintaining the center of mass. Although this design does not use a centerless wheel, it showcases how diwheels can be adapted to allow for easy steering. This diwheel was presented at the Bike Kill festival in 2008(Dicycles and Diwheels, 2022). It is an example of a pedal-powered diwheel (although it is more like a bicycle) that allows for easy steering. The downside is that it requires coordination between drivers. This design was showcased at the biking event to show off an innovative idea. It is important to note from a research perspective because it has a unique axle design that allows the axle's two sides to spin in different directions. Theoretically, this design could be applied to a centerless-wheel diwheel, but it would require a larger, stranger frame and two drivers.

After reviewing these three main types of diwheel drivetrains, electric, pedal-powered, and tandem drive, we decided to hone in on the pedal-powered drivetrain. This is because it is easy to control without the electronic components that would add another layer of complication to solving the issue of sloshing and gerbilling. Specifically, our preliminary design will borrow heavily from the successes of the Bevel's Advocate project. The vital components of this design that are different from the rest are the differential and the gearing system and a difference in structure that prevents inversion and allows for safe use.

Objective

The objective of this project is to design and build a pedal-powered diwheel that can travel 10 feet in a straight line without derailing or gerbilling. The driver will be tasked with pedaling the diwheel to get it started, avoiding sudden jolts which could send the driver rolling quickly forwards or backwards. Additionally, the balance of the diwheel will rely on the positioning of the rider, with a neutral seated position being as close to the center of mass as possible. We knew the design would be successful if we could rotate the outer wheels of the diwheel independently of the inner frame using a central gear system. A second goal of this project is to produce a comprehensive educational demonstrator, specifically a video, that helps explain the idea and potential behind centerless wheel designs or why they are a bad idea.

Methods

Project Plan

Our approach to completion will involve planning out the acquisition of materials to fit our budget, CAD designing of drivetrain components especially if something needs to be machined, and then construction. We expect this to be a long process of trial and error as we will constantly have to adjust the design to meet the standards and modifications stemming from the other subassemblies. Figures 1 and Figure 2 show preliminary sketches of the drivetrain component of the diwheel. The drivetrain component of the diwheel will involve sourcing a long chain, pedals, and sprockets from a bicycle. Sourcing these materials from a bicycle would also allow us to use other parts of the bicycle such as the brake levers, cables, and potentially brake calipers. The next step would be to fabricate the drive shaft. For this project, we are calling the main axle the “drive shaft” or “drive axle” because there is no traditional drive shaft that runs perpendicular to the axle, rather a chain that drives the axle. Our initial plan was to implement a differential in the center of the drive shaft as that would allow us to steer the diwheel and turn on a dime. Without the differential, the direction of motion would be limited to forwards and backwards. However, later on, this proved difficult with the materials we had and the time constraints, and thus we were not able to complete the differential component of the diwheel.

Figure 1

Orthogonal Sketch of Drivetrain Component

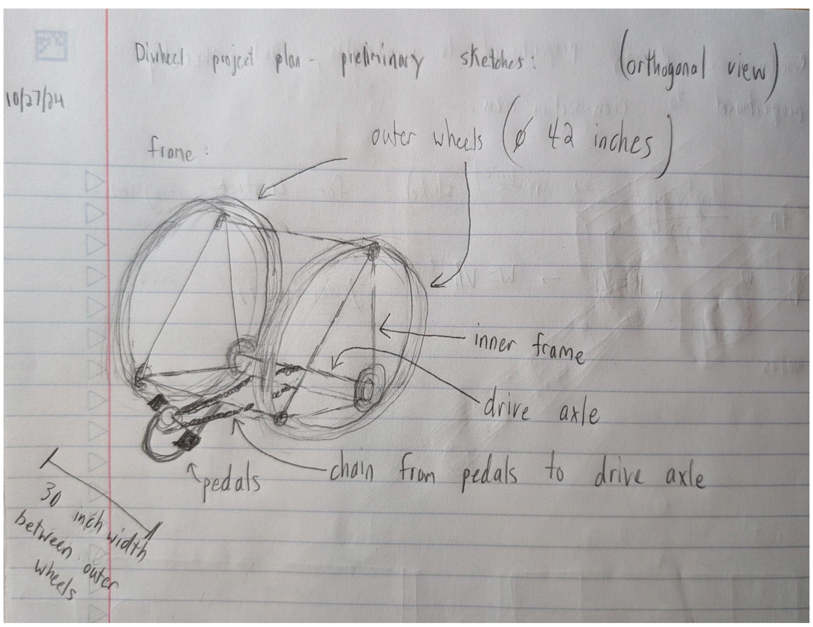


Figure 2

Top & Side View of Drivetrain Component

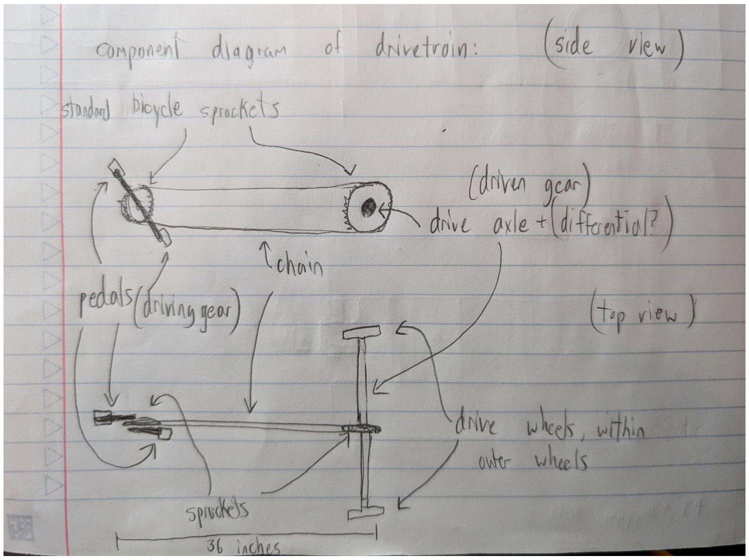


Figure 3 contains a sketch of the main chassis of the diwheel. To obtain our preferred angle of driving, our goal was to create a diwheel design that was balanced both at rest and with a driver in the seat. We theorized that we could do this through several different methods. Firstly, our chassis sits on the axle where we thought the center of gravity would be. We would use gussets and ball bearings to be able to minimize friction between the driver and the main axle. We wanted the driver to be as spread out as we could have them, so our chassis would be fairly long. This would be done by having pieces on the front and back that protrude from the main body. The front piece would house the pedals, taken from a bike, and a curved piece of tubing that protected the pedal system from accidental contact with the ground. The back piece would essentially be a counterweight. While adding weight to the back of the vehicle, a small wheel could be used to reduce friction if that piece touched the ground. These two protrusions also had another safety function if implemented correctly. They would be additional contact points with the ground to reduce the gerbiling effect. If composed correctly, the driver would be balanced, in a comfortable position, and without the risk of uncontrolled tumbling.

Figure 3

Front & Side view of Chassis Component

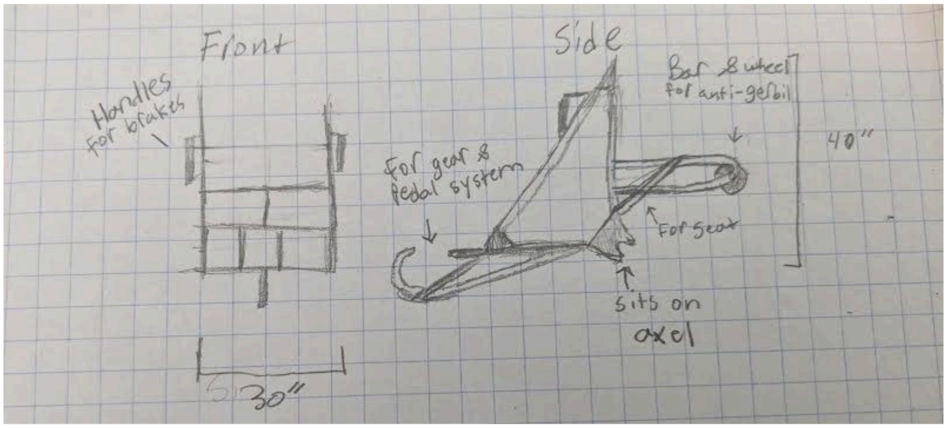
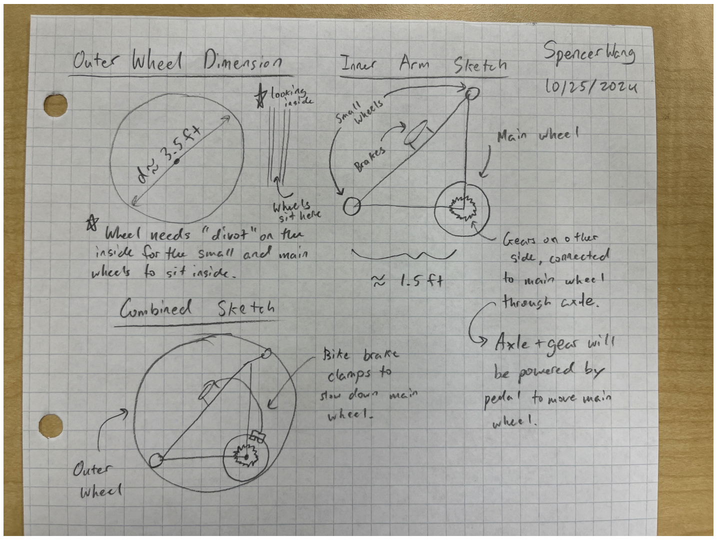


Figure 4 contains the sketch of the wheel and triangular frame holding the wheel of the diwheel. The goal is to create a minimalist wheel design consisting of three inner arms, each containing a wheel that the outer wheel will spin on. One of the inner wheels will be connected to the gear train that will be powered by the pedal mechanism. This inner wheel will be called the "main wheel" and will be the main source of movement in the overall wheel. The arms of the inner wheel will also contain hand brakes similar to those of a bicycle. The brakes will be connected to the main wheel where, when pressed, will cause the rubber clamps to contract and use friction to slow the main wheel down. This entire wheel building process can be split into two main components, the inner guts of the wheel and the braking system. The braking system will be simple to build - just deconstruct a bicycle and take the braking mechanism. The inner guts of the wheel will take longer to build as we need to first build the triangular structure where the three arms will be, and then attach the two spinning wheels and the main power wheel onto the main structure. Once the inner guts of the wheel is built, the brakes can be attached by screwing it onto the arms of the wheel and then attaching the clamp to the main wheel.

Figure 4

Side view of triangle frame and wheels.



Full Procedure

Outer Hoop and Triangular Frame

To construct the wheel's triangle frame, we will start by cutting three C-channel metal bars to the required length of 33, 30, and 23 inches using a horizontal band saw. Once cut, we will file off any sharp edges to ensure the pieces are safe to handle. Next, we will cut a steel sheet into the desired shape for the connectors, again using a horizontal band saw, and file these pieces as well to remove any sharp edges. With the arms and connectors prepared, we will weld the frame together, ensuring all components are securely joined. After welding, we will verify that the frame's shape and dimensions are correct. If they meet the required specifications, we will proceed, but if they do not, we make adjustments or repeat steps as necessary. Once everything is verified, the triangle frame for the wheel is complete.

To construct the outer wheel hoop, we will begin by cutting C-channel metal bars to the required length using a horizontal band saw. As with the triangle frame, we will file off any sharp edges to ensure safe handling. Once the bars are prepared, we will use an ironworker to bend them into a circular hoop with the correct radius. After forming the hoop, we will check that the circle's shape and radius of 21.5 inches are accurate. If the measurements are correct, we will proceed, but if they are not, we adjust or repeat the steps as needed. Once the hoop meets the specifications, the outer wheel hoop is complete.

For the guide wheels, we will start by taking a resin rod and cutting it to the required thickness of 0.75 inches for the guide wheels using the horizontal band saw. Using a drill press, we will carefully drill an axle hole with a ¼ diameter drill bit in each resin wheel. After drilling, we will verify that the outer radius, inner radius, and length of the guide wheels are correct. If everything meets the required dimensions, the guide wheels are complete; otherwise, we will make the necessary adjustments or repeat the steps. Once all parts are confirmed to meet specifications, the guide wheels are finished. For the drive wheel, using the horizontal band saw, we will cut out the drive wheel from the steel sheet and file off any sharp edges to ensure a round surface. Check that the radius is to the correct measurement of 4 inches. Then, using the drill press, drill a hole of radius 0.3 inches through the center of the drive wheel. This will be where the axle of the drivetrain connects.

To assemble the full wheel, we will begin by connecting the guide wheels and the drive wheel to the triangle frame using axles, ensuring each component is securely attached. Once these parts are in place, we will loop the outer hoop around both the guide wheels and the drive wheel, carefully aligning the pieces. After assembly, we will check whether the outer wheel is able to spin freely. If it spins correctly, the wheel assembly is complete. If not, we will revisit the steps to identify and resolve any issues before rechecking the functionality. Once everything is verified to work as intended, the full wheel is completed. Because the wheel is fully symmetrical, the previous procedure is repeated for the opposite side of the diwheel.

Drive Train

The drive train component includes the axle and sprocket components. To assemble the axle, we will take the ¾ inch diameter rod and cut to length using a horizontal band saw. Deburr any sharp edges. In order to connect the axle to the rest of the frame, there will be four shaft bearing rings on the axle. To prevent them from sliding laterally across the axle, it is necessary to fasten a retaining ring on both sides of each of the shaft bearings. The retaining rings must be inset into the axle just enough so that they hold in place. To create these grooves, we'll use a lathe. Insert the axle into the lathe and secure it in the tailstock. Use the hand wheel to cut out grooves of the appropriate width in the eight indicated locations on the axle. Deburr once again to remove sharp edges. The retaining ring grooves are now complete.

Before adding shaft bearings and retaining rings, there are a few more cuts that must be made. Each end of the axle must be shaped into a non-circular form in order to connect with the drive wheels, due to the fact that simply welding these parts may not be strong enough to support a diwheel rider. To accomplish this, measure and mark a square inscribed in the end of the axle. Use a file or precise band saw to cut flats according to the markings. This must be precise to prevent wobbling of the drive wheel. Lastly, tap into the end of the axle for a bolt that will be used to secure the axle in the axial direction.

To fit and finalize the axle, begin by locating the smaller of the two sprockets. The sprocket should slide over the axle into position. If not, drill out the center of the sprocket to exactly ¾ inches then try again. Weld into place. This sprocket will remain fixed, mimicking a fixed wheel bicycle setup. There will be a pedal and sprocket attached to the chassis in the front, leaving room for modifications in the gear setup. After the sprocket is added, add retaining rings and shaft bearings by working from the inside out. The axle is now complete and ready for integration with other components.

Chassis

First, cut a 29-inch piece of square tubing and a 30-inch piece of square tubing using the horizontal band saw. On one end of the 30-inch piece, cut the end at an angle of 16o using a hacksaw. Then weld the cut side of the 30-inch bar to the middle of the bottom of the 29-inch bar.

Cut another 29-inch piece of square tube with the horizontal band saw. To the middle of the front of the second 29-inch bar, weld a 10-inch piece of square tubing cut with the horizontal band saw. Then cut an 11-inch piece of tube and cut the ends at a 33o angle parallel to each other using a hacksaw. Weld one end of this 11-inch piece of tube to the middle bottom of the second 29-inch bar, pointing in the same direction as the 10-inch bar. Weld the other end of the 11-inch piece to the top of the 30-inch bar, making sure they point in the same direction. Take a 10-inch bar and use the iron worker to bend it according to the flowchart. If this doesn't work, cut another 10-inch bar and try again. Weld this curved piece to the point where the 30 and 11-inch pieces connect.

Use a waterjet to cut four gussets based on the required design. To the first 29-inch bar, weld the gussets spaced 5.8 inches apart. Weld another 29-inch piece to the opposite notches of the gussets. Cut the ends of two 15.5-inch pieces of tube parallel to each other at 53o with a hacksaw. Weld the 15.5 inch tubes 3.25 inches from the ends of the latest 29-inch bar. Cut a 22.5-inch bar with the horizontal band saw and weld to the ends of the 15.5-inch tubes.

Weld two 10.5-inch pieces with parallel end cuts at 65o using the hacksaw to the ends of the latest 29-inch piece, facing the front. To the middle back of the 22.5-inch bar, weld a 6-inch piece cut out with the horizontal band saw. To the latest 29-inch bar, weld a 14-inch bar cut with the horizontal band saw to the middle back, facing the same direction as the 6-inch piece. To connect the 14 and 6-inch bars, cut out a 12-inch piece using the horizontal band saw and weld to the ends of both bars.

Full Assembly

To complete the full assembly of the vehicle, we will begin by welding the chassis frame to the triangle frame of the wheel on both sides, ensuring a secure connection. Once the chassis is attached, we will connect the drivetrain to the main drive wheel using axles positioned beneath the chassis. After the drivetrain is installed, we will test the vehicle to ensure it is fully functional. Is it able to roll and can the chassis hold our weight? If the vehicle operates as expected, the assembly process is complete. If not, we will troubleshoot and resolve any issues before retesting. Once all components work together seamlessly, the full vehicle is complete.

Test Procedure

To ensure the performance and integrity of the diwheel design, a series of tests will be conducted. The *Outer Hoop Functionality* test aims to determine whether the outer hoop rolls correctly and fits around the resin axles. This involves lifting the wheel off the ground to test independent rolling, followed by testing on the ground under simulated weight. Success will be defined by proper rolling in both scenarios, with failures indicating issues either with basic rolling or with load-bearing performance. The *Wheel and Chassis Compatibility* test evaluates how well the wheels and chassis fit together and support combined weight. This requires checking wheel symmetry, setting the assembly on the ground, and having someone sit in the chassis. The design will pass if it holds weight without breaking or bending and can still roll. The *Chassis Balance* test will check whether the chassis, when mounted on wheels, remains balanced with or without a person seated. After assembly, balance will first be assessed unoccupied and then with a driver, with success marked by no part of the chassis touching the ground at rest. The *Drivetrain Dependability* test will verify whether the pedals effectively powered the wheels via the drivetrain. This will involve manually spinning the pedals while the Diwheel was elevated, ensuring smooth, uninterrupted wheel rotation and chain engagement. Lastly, the *Full Functionality* test will assess the completed diwheel's operational performance. With a driver seated, the vehicle will be tested for forward movement, braking, and overall balance. The test will be deemed successful if the diwheel moves straight with minimal effort and stops reliably when brakes are applied.

Material List

Table 1 and Table 2 are our tentative list of components that comes from a previous diwheel design (Johnson et al., 2015) but they are helpful here because they encompass all of the necessary components we will need. It also gives us an understanding of what we should expect our budget to be. Table 2 outlines the components we would need to order from McMaster Carr if we wanted to incorporate a differential into our design.

Table 1

List of Drivetrain Components

Part	McMaster Number	Unit Cost	Unit Order	Needed from Unit	Total in Unit	Total Cost for Part(s)	Description
Shaft Collar	8386K18	$25.87	4	1	1	$103.48	Extra-Grip Two-Piece Clamp-on Shaft Collar for 1-3/4" Diameter
Shaft Bearing	6384K69	$13.78	4	1	1	$55.12	Plain Double Shielded for 3/4" Shaft Diameter, 1-3/4" OD
Drive Shaft Retaining Rings	97633A250	$12.30	1	8	100	$0.98	Black-Finish Steel External Retaining Ring for 3/4" Shaft Diameter
Drive Shaft	1346K33	$36.90	1	32	32	$36.90	Steel Drive Shaft 3/4" OD, 36" Length
Drive Shaft attempt 2	1346K33	$36.90	1	16	32	$18.45	Steel Drive Shaft 3/4" OD, 36" Length
Drive Wheels	8975K106	$40.88	2	1	1	$81.76	Multipurpose 6061 Aluminum 1/2" Thick, 10" Width, 1 ft Length
Hub Caps	8975K87	$8.51	1	1	1	$8.51	Multipurpose 6061 Aluminum 1/4" Thick, 3" Width, 1 ft Length
Bike Parts	–	$40.00	1	1	1	$40.00	Various bike parts from junked bikes (Rear Sprocket, Pedals, Derailleur, Idler Sprockets)

Table 2

McMaster-Carr Components for Differential

Differential	Diff Side Plates	8910K12	$16.10	2	6	6	$32.20	Low-Carbon Steel Rectangular Bar 1/4", 6" Width
Differential	Diff Flat Plates	8910K702	$21.28	1	8	12	$14.19	Low-Carbon Steel Rectangular Bar 1/2", 3" Width
Differential	Diff Case Screws	91251A345	$10.96	1	12	100	$1.32	Black-Oxide Alloy Steel Socket Head Cap Screw 10-32 Thread, 3/4" Length
Differential	Diff Shaft Bearing	6384K67	$13.47	2	1	1	$26.94	Steel Ball Bearing, Plain Double Shielded for 3/4" Shaft Diameter, 1-5/8" OD
Differential	Bevel Gear	6529K22	$37.01	4	1	1	$148.04	Steel Plain Bore 20 Degree Angle Miter Gear, 12 Pitch, 24 Teeth, 2" Pitch Diameter, 1/2" Bore
Differential	Spider Shaft	1346K11	$6.76	1	5	12	$2.82	Steel Drive Shaft 3/8" OD, 12" Length
Differential	Spider Block	9008K14	$4.40	1	1	6	$0.73	Multipurpose 6061 Aluminum
Differential	Spider Shaft Bushings	6338K415	$0.85	4	1	1	$3.40	SAE 841 Bronze Flanged-Sleeve Bearing for 3/8" Shaft Diameter, 1/2" OD, 1/2" Length
Differential	Spider Shaft Retaining Rings	93576A110	$9.16	1	2	10	$1.83	Light Duty Spiral External Retaining Ring 18-8 Stainless Steel, for 3/8" Shaft Diameter
Differential	Spider Shaft Shims	97022A216	$3.18	1	2	10	$0.64	Type 316 Stainless Steel Round Shim 0.002" Thick, 3/8" ID, 5/8" OD

Results

The performance and success of our diwheel was evaluated using the test procedures outlined above. These focused on structural integrity, balance, and drivetrain functionality. The primary metric for success however was that we achieved our objective of travelling 10 feet without derailment.

The outer hoops came out to be the correct size and they fit perfectly around the plastic guide wheels. Additionally, there was minimal friction between the guide wheels and the outer hoop as everything ran smoothly without bumps or sliding. This tells us that the chassis was properly aligned and that minor leveling issues were not a problem in the final design. Throughout the building process we considered coming up with more robust framing techniques that would make sure each weld was completed at the perfect angle. In the interest of time, we used waterjet bracket plates that helped us align the square steel bars of the frame.

In terms of chassis strength, the chassis was able to withstand a 175 lbs person without any visible deformations or breaks. The guidewheel springs were strong enough to prevent the derailment of the chassis. However, when the rider was leaned back in the recumbent position, the weight of the chassis compressed the springs, leading to the other pair of guide wheels to lose contact with the large outer wheel. To combat this, we simply extended the springs to put more down force on the chassis.

The diwheel was able to balance without either the front or back of the chassis making unintentional contact with the ground. Our decision to implement an open seat allowed the rider to easily position themselves to find the balance point. We did see two issues however. First, riders under ~120 lbs had difficulty keeping the front of the frame off of the floor. They simply weren't able to lead far enough back while also keeping their feet on the pedals. To fix this, we would add weight to the rear of the diwheel, making sure that the diwheel still balanced on its own(without a rider). Second, as the rider begins pedaling, we noticed there was a tendency for the chassis to roll backwards more than we would have liked. After the diwheel got up to speed, it would even back out. After looking into potential causes, we determined that increasing the overall weight of the frame would minimize this initial rolling. Additionally, implementing a derailleur would allow the rider to slowly shift up to faster speed with control.

The drivetrain system functioned as expected. After we got the chain to the right length on a predetermined pair of sprockets, it stayed in place as the pedals were pedalled. The freewheel worked as intended so that the rider could stop pedalling without the diwheel coming to a halt. The inner frame of the freewheel system was welded on to the axle and did not slip. The hubs on either side of the axle successfully used set screws to transfer the motion from the axle to the drive wheels. We marked the initial location of the set screws on the axle which helped us make sure there was no slipping.

Our objective of travelling 10 feet was easily achieved. The diwheel can travel at a steady 2-3 mph for long distances with consistent pedalling. This tells us we passed our full functionality test, with the exception of a proper braking system. However, as long as the diwheel is operated on relatively flat surfaces, the brake is unnecessary as the rider can easily stop the motion by putting their foot down on the ground.

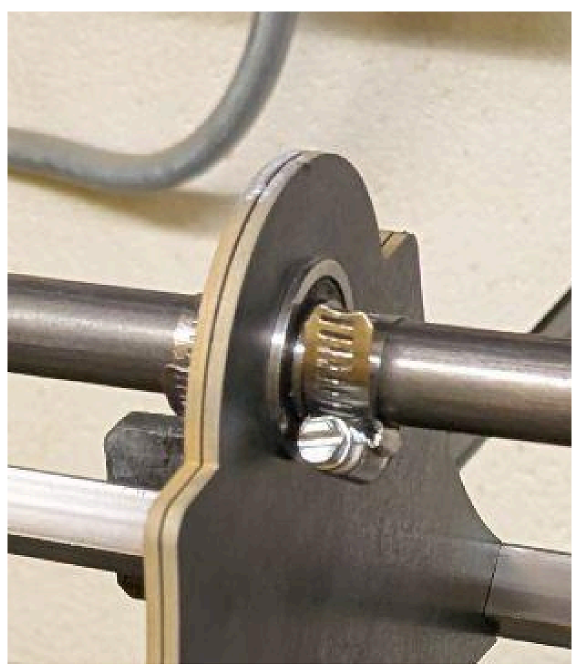
Another initial objective of this project was to create some kind of educational demonstrator. Due to the success of the physical diwheel we determined this wasn't going to be a priority, and we did not complete it nor spend any time on it. Instead, in our presentation of our findings during tjSTAR, we discussed the history of the diwheel and where our project fits in with previous research. This was our attempt to educate audiences on diwheels and hubless wheel systems in contemporary society.

Lastly, from a timing perspective, we were able to finish the diwheel over a week before the deadline, leaving us time to test and make minor tweaks to prepare for the final presentation and demonstration. Admittedly, we started building later than we would have liked but we dedicated many hours in the lab in order to stay on track to finish in time.

Discussion

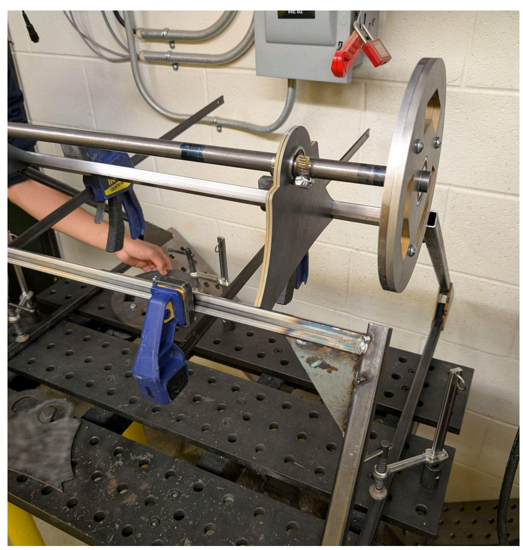
This discussion will show the process and iterations we went through while constructing the diwheel as they relate to the feasibility of diwheels in industry. We will discuss the issues we ran into along the way and the solutions or compromises we came up with.

The first step of the building process involved cutting the axle to length and then turning grooves into the axle for retaining rings that would hold the ball bearings in place internally. We decided early on that this plan was unnecessary and frankly would have been overengineered. Additionally, the nearly three-foot axle was too long to fit in the lathe without

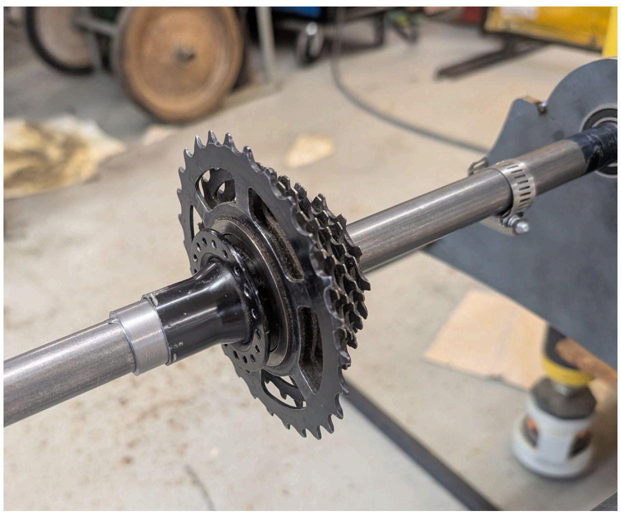


over torquing the opposite end of the axle, causing it to bend and deform. Instead of using internal retaining rings, we decided to use simple hose clamps around each side of the bearing to stop it from sliding.

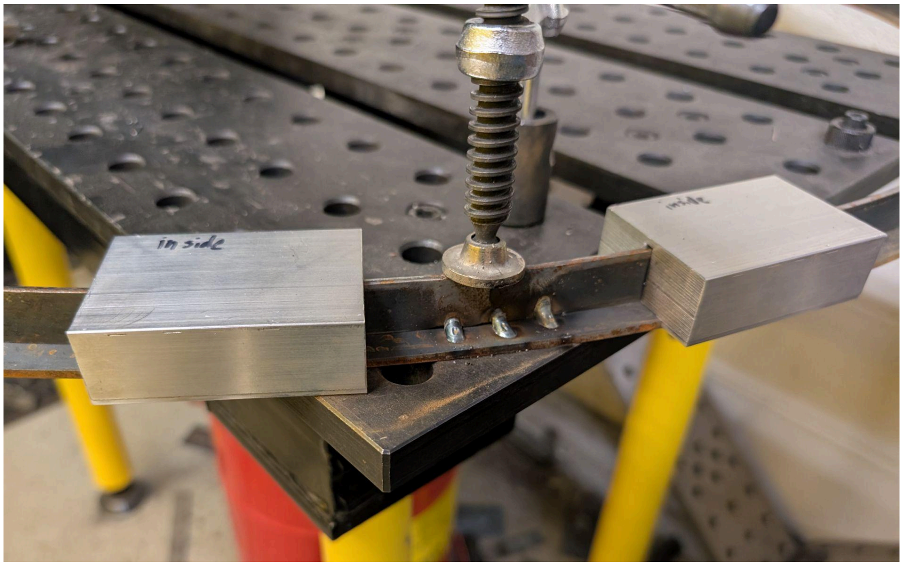
We then began on the chassis. We started with the left and right triangular frame pieces, then worked on welding the cross pieces to connect each side. This was a process of stringent alignment, with every weld being meticulously checked and leveled to ensure that the outer wheels would be straight when they were attached. We tacked on waterjet-cut angled corners to ensure that the steel tubing was welded at the correct angle each time. We still ran into issues with the final weld or two being up to a centimeter off from where we initially planned, but luckily it did not compromise the functionality of the diwheel. In order to attach the axle to the chassis we used two gussets with press-fit bearings, which were lined up with the axle to minimize friction. This involved water-jet cutting a test piece with 10 different increments of hole-diameter to find the perfect diameter for press fitting. A similar process was required for the 8” diameter drive wheels, however we opted to use the lathe to bore out the perfect diameter instead. To finish the chassis we welded the extrusion in the front that held the bike pedals where, ultimately, the chain would transfer the motion from the pedals to the axle.

When attaching the freewheel to the drive axle to connect the bike pedals to the drive train, we noticed that the center diameter for the hole in the freewheel was bigger than our axle, thus making it difficult to attach with wobbling and misalignment. To compensate for this issue, we turned a metal cylinder on the lathe to fit between the axle and the freewheel, which we eventually welded onto the axle to hold it all in place. At this point we decided to not use a derailleur and instead leave the chain permanently on one sprocket. This sacrificed variable speed and increased maneuverability, but saved us time when building and planning.



When constructing the outer wheel hoop, we used a jig that ensured that the outer hoops would align properly and stay perpendicular to the rim of the hoops while we were welding.



Finally, once all of the sub-pieces were constructed and tested, we were able to connect the chain from the bike pedals to our drive train, mount the outer wheel onto the drivewheel and guidewheels, and fasten pieces of plywood to act as a seat. Thus, completing our diwheel with full functionality.

To reiterate, the research problems we aimed to address are the following: What is the feasibility of a diwheel and what are potential applications for a diwheel? To determine this, we will look at the successes and failures of our diwheel and then compare it to previous research to see if our results corroborate existing conclusions.

We will look at the feasibility of diwheels in commercial manufacturing. Our diwheel was relatively easy to manufacture, as it lacked an internal combustion engine, a differential, and other electronic components that are featured on other diwheels, such as the University of Adelaide's EDWARD(Electric Diwheel With Active Rotation Damping) diwheel. However, our design was costly. We estimated a total cost of around 1300$. In terms of time costs, this project took an estimated 300 man-hours to complete.

Conclusion

The pedal-powered diwheel developed in this project successfully demonstrated the feasibility of using centerless wheels in a functional human-powered vehicle. Despite constraints in time, resources, and complexity, the final design achieved its primary performance goal and revealed important insights into diwheel dynamics, especially regarding balance, drive mechanics, and rider positioning. By prioritizing simplicity over electronic control systems, we created a durable, relatively low-cost prototype that can inform future work in compact and unconventional transportation systems. The project served its broader purpose by contributing to the understanding of centerless wheel applications and inspiring further exploration into their potential uses.

References

Burtov, M. (n.d.). *GeoOrbital*. GeoOrbital. https://geoo.com/

Cazzolato, Ben & Harvey, John & Dyer, C & Fulton, K & Schumann, E & Zhu, Tao & Prime, Z. (2009). *Control of an electric diwheel*.

Chouhan, A., & Prajapati, A. (2023). Fabrication of Di-wheel by Computational and Experimental Approach. *Mechatronics and Applications: An International Journal*, *2*(1). https://issuu.com/mechatrojjournal1821/docs/2118mechatroj02_c141f52cfb0393

Dicycles and Diwheels. (2022, January 19). Douglas Self. Retrieved October 18, 2024, from http://www.douglas-self.com/MUSEUM/TRANSPORT/diwheel/diwheel.htm

Economic Strength: Creating reliable and efficient access to resources, markets and good-paying jobs. (2024, June 25). U.S. Department of Transportation. Retrieved October 24, 2024, from https://www.transportation.gov/economic-strength-creating-reliable-efficient

Johnson, H. (2015, March). *Diwheel: A two wheeled, pedal powered vehicle*. Hilary Johnson. Retrieved October 18, 2024, from https://www.hilaryannajohnson.com/diwheel