2021 A-TEAM DESIGN REPORT

Dr. Don Petkau, Ph.D., P. Eng.  
Advisor

Owen Darrach  
Team Captain

Katherine Gledson  
Team Captain
1 Introduction
The University of Manitoba Association of Tiny Tractors (UMATT) strives to provide durable and user-friendly utility tractors at an affordable price.

The 2021 model (P21) leverages the lessons learned from previous UMATT P-Series tractors, information collected through a market analysis survey, and testing of various mechanical and electric sub-systems during the design process. The P21 tractor is congruent with ASABE and ISO standards to ensure user safety and device reliability. Furthermore, the P21 sees increased reliability, aesthetic enhancements, and user interface refinements compared to previous P-Series tractors.

The design and build of the P21 tractor and writing of its accompanying reports was aided by previous team members and faculty from the University of Manitoba. UMATT extends a warm thank-you to all who helped throughout the 2021 season.

Figure i: UMATT 2019 Competition Photo

2 P21 Specifications

<table>
<thead>
<tr>
<th>Overall Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length</strong></td>
</tr>
<tr>
<td><strong>Width</strong></td>
</tr>
<tr>
<td><strong>Height</strong></td>
</tr>
<tr>
<td><strong>Ground Clearance</strong></td>
</tr>
<tr>
<td><strong>Seat Height</strong></td>
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<tr>
<td><strong>Rear Tire Size</strong></td>
</tr>
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<td><strong>Front Tire Size</strong></td>
</tr>
</tbody>
</table>

**Weight Distribution**
- **Unballasted**: 50:50 (front : back)
- **Ballasted Max**: 25:75 (front : back)

**Max Speed**
- **Forward**: 20 km/h (12mph)
- **Reverse**: 12 km/h (7.5mph)

**GVW**: 400 kg (880 lbs)

Table i: Overall dimensions, tire size specifications, mass scenarios, and speed ratings of the P21 tractor.

<table>
<thead>
<tr>
<th>Engine Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model</strong></td>
</tr>
<tr>
<td><strong>Output</strong></td>
</tr>
<tr>
<td><strong>Displacement</strong></td>
</tr>
<tr>
<td><strong>Bore and Stroke</strong></td>
</tr>
<tr>
<td><strong>Oil Filter</strong></td>
</tr>
<tr>
<td><strong>Air Cleaner</strong></td>
</tr>
<tr>
<td><strong>Spark Plug</strong></td>
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<tr>
<td><strong>Stator Output</strong></td>
</tr>
</tbody>
</table>

Table ii: Specifications of the engine used in the P21 tractor.
3 Market Analysis Overview

To understand the utility tractor market UMATT developed a market survey that was delivered to a potential customer base. The survey addressed the four P’s of marketing proposed by Jerome McCarthy: Price, Promotion, Product, and Place. The following is a concise synthesis of the survey data. The full results can be found in the design log.

3.1 Price

The survey indicated that customers positively correlate the cost of a utility tractor with its quality. Additionally, the presence of dependable and legitimate warranty coverage with readily available parts and service was reported influence customer’s purchasing habits. This combination creates a high barrier to entry for small and/or new companies like UMATT as being competitive requires an appropriately priced implement with reliable and readily available service. Further discussion can be found in the Cost Summary Report.

![Cost vs. Horsepower of Current Utility Tractor Offerings](image)

Figure ii: Cost versus horsepower comparison of popular utility tractors.

3.2 Promotion

To inform a sound promotional strategy that will expose customers to the utility tractor offerings of UMATT, the survey inquired about the platforms most effective in currently persuading individuals to make a purchase. The survey results indicated that Agricultural Shows, Personal Interaction (Dealers, Sales Representatives), and traditional print ads were the preferred mechanisms. Social media platforms, online stores, and web-forums were reported as less influential.

Observing the demographic of the survey respondents showed that potential clients reside in rural areas with approximately 50% are owners/operators of a farm and the other 50% as rural residents.

3.3 Product

With many utility tractors currently in the marketplace, UMATT recognized the importance of developing a distinct product that serves the true needs of the customer base. The survey had respondents’ detail features believed to add the most value to the product. Overwhelmingly the survey identified operator comfort as a top purchasing criterion when comparing utility tractors on the market. Consequently, UMATT’s design team prioritized the development of an ergonomic tractor by employing the principles of human factors engineering. Other valued added features were mentioned with lower frequency and are identified within the body of the report in the event they informed a design decision.

3.4 Place & Marketing Strategy

UMATT will market the P21 tractor through advertising at rural agricultural dealers and by attending farm trade shows. An additional marketing campaign will see print ads in farm industry newspapers and agricultural magazines.

Despite social media being identified as having low influence on a potential customer’s purchasing decisions, UMATT will run a small and low-cost digital marking campaign. The intended result is increase brand awareness with little financial commitment. This became even more important with lockdowns limiting opportunities for more conventional exposure.
Design & Development Goals

On completion of the 2019 ASABE 1/3 Scale Competition, UMATT Council held a debriefing before leaving Peoria for the University of Manitoba. In the meeting, Council discussed the competition, advice of judges, results of the 2019 market survey, and goals for the 2020 competition year. These same goals were used in the 2021 competition year. Priorities were developed and small groups of 2-3 members were assembled to carry out an individual priority with the remaining team members assigned to a collection of smaller tasks.

Electrical Control System

The 2019 tractor’s performance suffered from major electrical malfunctions leading up to and during the 2019 competition. As such the reliability of the P21 electrical system was assigned top priority for the P21.

Previous P-Series models featured custom circuit boards that were typically rushed through development and testing. Rather than continue this trend, the electrical group began development of the P21’s electrical system only days after the 2019 competition. The goal was to leave ample time for consultations with UMATT Alumni and for proper testing. The functional requirement of the electrical control system is to control the main functions of tractor operation. A further objective/goal is the control of additional sensors and accessories.

Drivetrain

The UMATT team members identified drivetrain reliability as a priority of the team and of potential customers. As such this became a priority of design development for the P21. Previous P-Series models suffered from a short belt lifespan of the and poor engine coupler alignment. These issues were focused on to have the greatest impact on the P21’s reliability. The acceptability requirement for the drivetrain is to eliminate component failure at competition caused by design oversight.

User Interface & Operators Station

Operator comfort and control functionality was identified as a priority by the market survey and the 2019 competition design judges. The addition of new members studying electrical engineering to UMATT a complete overhaul of the operator interface was deemed possible. UMATT’s aspiration was to source a display that could be read in daylight, improve the visual interface, and improving the display’s overall functionality. The acceptability requirements for the user interface is a fully functional touch screen display with an intuitive interface.

In addition to the operator’s interface with the electrical and software systems of the tractor the operator station was to receive a fresh design. The acceptability requirement is a reduction in mass of the driver’s seat while increasing the seat’s adjustability.

Steering & Suspension

UMATT recognized that maneuverability could allow the P21 to achieve a competitive advantage in the utility tractor market. Previous P-Series models have incurred limited maneuverability as off-the-shelf spindles restricted options for A-Arm design and steering link connection points. UMATT members decided against purchased spindles to allow for in-house design leading to optimized steering and suspension geometry. Acceptability requirements for steering and suspension are improved tractor handling in all terrains while maintain or reducing cost of steering and suspension production.

Manufacturability

Manufacturability of the tractor was deemed a priority to reduce assembly costs and improve ease of maintenance and repair. In 2020 UMATT stressed the application of Design for Manufacturing and Assembly (DFMA). Designers were appropriately educated and provided a list of design standards to be applied to common features. Examples include bent flanges, holes, slots & tabs, and welding. UMATT’s objectives are to reduce assembly cost by 10% compared to the P19 and eliminate owner frustration that can arise during regular mechanical service.
5 Testing

UMATT implemented a standardized report and test plan structure to ensure test methods and their results were properly documented. This ensures quick and easy understanding of tests and their results for further reporting and use by future teams. Due to Covid 19 the P21 relies more heavily on Numerical Analysis then was initially intended, but due to Provincial and University policy there was simply no way around it for the 2020/21 competition year.

5.1.1 Exhaust Testing

Exhaust testing was the primary mechanical research area going into the P21’s development, unfortunately we had to rely on CFD analysis. Once pandemic restrictions are lifted these results will be investigated further with physical testing.

The goals of the design were to reduce the width of the design to 4 inches due to space constraints, reduce noise emissions, and minimize backpressure. The design process used will be discussed later in this report.

The final design was able to meet the size constraints, with a backpressure of only 4 kPa (0.58 PSI). Until we can complete physical testing, we will not know how the design preforms acoustically. However, the exhaust system was designed with noise reduction being a significant factor. Perforated tubing was used along with separation of chambers to allow for mixing of the exhaust gases, as well as reduce the velocity of the exiting gases. Physical testing plan will involve utilizing a recording system similar to one deployed for the competition’s sound-judging to assess the volume as well as frequency distribution of the exhaust noise.

Successive tests will be conducted at full throttle using various packing materials in the uppermost chamber such as fiberglass insulation, fiberglass wrap, stainless steel wool, and a ceramic wrap. Tests will seek to determine which material, and if necessary, the amount of material that will provide the best acoustic performance.
5.1.2 Electrical System Validation

The following actions greatly improved electrical system validation on the P21:

- Starting the design process and therefore the testing process earlier
- Building a testing harness with only the sensors and devices required for basic driving.
- Incorporating relay indicator lights in the relay and fuse printed circuit board (PCB) to check relay status and simulate the drive program.

Historically, the UMATT electrical subsection built the electrical system after the mechanical components of the tractor were assembled. To ensure there was adequate time for system improvements, the printed circuit boards and a test harness were built prior to tractor assembly.

Early in the design process, the electrical subsection identified the sensors necessary to implement the drive program. A harness with these specific sensors was built in addition to the starter harness required for the engine. Together, these two harnesses were used to test the electrical system.

A major component of electrical system validation is ensuring proper electrical connections are made. Once the components were soldered onto the control and relay boards, the individual circuits were continuity-tested to guarantee electrical components were successfully soldered to their pads. In areas with high concentration of soldered connections, continuity-testing was used to ensure there were no shorts or other accidental connections. The electrical harness was also continuity-tested to ensure the contacts were properly crimped and inserted into the correct position within the connectors.

The serial peripheral interface (SPI) protocols for P21 were written by UMATT to interface with the specific integrated circuit (IC) chips used in the electrical system. To test communication with each type of chip, light-emitting diodes (LEDs) were put in series with each of the chip’s input/output pins. A test program used the UMATT-made SPI functions to cycle through each pin, turning the LEDs on and off.

The control and relay boards were designed to enable testing of the drive function without having a fully assembled tractor. To test the drive program, the RPi was attached to the control and relay boards. The relay indicator lights were monitored to verify that the drive program was turning on/off specific devices with appropriate timing. Control board inputs and outputs that did not have an associated relay were monitored using a voltmeter.
5.1.3 Renewable Fiberglass Replacement Testing

To determine the suitability of the renewable flax fiber composite manufactured for the body of the tractor, several tests were devised and implemented to show the material would perform without issue compared to common fiberglass. Due to Covid-19, tests could only be performed with limited resources, so test methods had to be improvised instead of adhering to ASTM test methods. A 3-point bend test was conducted to determine the flexural strength of the new material, in addition to an impact test used to investigate its impact resistance. A weathering and heat resistance test were also performed. Samples of fiberglass from the 2019 UMATT tractor body were tested simultaneously to provide a comparison for the experimental material.

For the 3-point bend test, multiple samples of the renewable and fiberglass composites were tested by applying load at the midspan using a hydraulic press attached to a pressure gauge. The breaking forces of the samples were determined by dividing the pressure recorded from the gauge by the inner cross-sectional area of the hydraulic cylinder. The average breaking force of the renewable composite was greater at 17.7 kg, compared to the breaking strength of the fiberglass which was determined as 12.3 kg. The approximate flexural strengths for the renewable and fiberglass composites were 45.3 MPa and 362 MPa respectively.

The impact test involved firing a 14g projectile at multiple samples of the renewable and fiberglass composites at a speed of approximately 157 km/h. After testing, it was observed that there was no structural damage to either of the two composite materials, with the renewable composite showing only minor cosmetic damage.

The weathering and heat resistance tests consisted of exposing samples of both materials to water and heat respectively. The weathering test was performed by submerging the samples in water for 24 hours and then removing them to observe any change in appearance or delamination. No observable change in the samples was noticed. The heat test comprised of two methods of simulating the heat the body of the tractor would be exposed to: ambient and single directional heat. For the ambient heat, the samples were placed in an oven set at 170°F for 30 minutes. The renewable composite showed no change in appearance or form, while the fiberglass showed noticeable deformation. For the directional heat test, a heat gun was used to apply heat at 190°F for 10 minutes for each sample. Both materials showed equal deformation.

From the results of these tests, the renewable material is shown to be a viable replacement for fiberglass composites, with the added benefit of being more environmentally friendly for using renewable materials and being safer to produce from reduced volatile organic compound (VOC) emissions due to the materials used.
5.1.4 Utilization of Previous Years Testing

The previous two years of competition provided data to aid the development of the P21 tractor. In 2019, malfunction of the electrical systems limited the amount of mechanical performance data gathered. As such, the electrical team used the data gathered in 2019 while the mechanical team leveraged test data from UMATT’s 2018 competition performance. The data and the action for improvement follow below for both the electrical and mechanical system respectively.

The electrical team identified quality control of UMATT’s custom PCBs and wiring harness as the largest hurdle to successful performance in 2019. During competition several issues were observed:

- 12-volts was applied to several 5-volt sensors because of the PCB circuit design. This included the PMAC motor’s sine-cosine encoder.
- An incorrect variable resistor was used for adjusting the gain of SEVCON speed input signal.
- Harnesses and wires were poorly routed and proper mounting accommodations for the electrical system was not present.
- Harnesses and wires were not adequately labelled.

To address these oversights, the design process for the PCBs and electrical system began in early June compared to the latter portion of December. This resulted in rigorous testing of each component throughout the build process.

The mechanical team regarded the areas that follow as systems for redesign to improve reliability and performance of the tractor.

- Front suspension: While trailering to competition in 2018 the front suspension of the tractor collapses. Significant reinforcement was effective at mitigating this issue.
- Belt drive durability: Due to improper belt alignment and low service factor the belt life of the P18 and P19 was limited to roughly 10 hours.
- Ground clearance: During the 2018 competition the P18 contacted the scale ramp which should not occur.

Despite the shortfalls encountered during the 2018 and 2019 competition season there are several systems that performed well and will be leveraged in the P21 tractor.

- The 2018 Electronically Variable Transmission (EVT) remains in sound condition. Both the planetary gear sets and electrical components are functional.
- The locking ATV differential shows minimal signs of wear, specifically with respect to the sliding limited slip blocks.

6 Design Overview

6.1 General Features

The P21’s complete re-design was driven by consumer requirements and desires based on direct market feedback. The design process focused on the creation of an ergonomic tractor promoting operator comfort in congruence with the market survey. Attention was also given to reducing the tractor’s cost so UMATT could position the P21 as an affordable utility tractor with competitive performance.

The P21 has been designed with two sheet metal materials: HSLA A1011 steel for high stress components and 5052 aluminum for lightweight components. Moreover, parts have been designed using common sheet thicknesses including 2mm (14g), 3mm (11g), 6.4mm (1/4”), and 9.5mm (3/8”) to minimize material inventory holding costs. For efficient and repeatable production of parts CNC Laser and Water-Jet cutting was used with automation software for reduced off cuts and waste.

Several components of the P21 have been designed for automated assembly such as the frame, PCB, A-Arms, and console. These parts feature single sided welding or bottom-up assembly for efficient and scalable production with robotics or skilled labour.

The P21 features standardized M6 and M8 grade 8.8 hardware for decreased production inventory and elimination of hardware misuse. In hard-to-reach areas the P21 features weld-nuts eliminating the need for specialized tooling and/or lengthy assembly times. For non-critical parts or components that do not require disassembly the P21 has rivets for low-cost assembly.
6.2 Overall Configuration

The P21 features a traditional engine forward drivetrain arrangement allowing for versatile use of implements and accessories. The engine forward design of the P21 results in an unballasted weight distribution of 50:50 allowing for the tractor to be configured for a wider variety of loading scenarios and terrain types compared to rear engine designs.

The engine forward layout also allows UMATT’s Electronically Variable Transmission to be neatly concealed within the steering tower and underneath the seat. Despite the compactness of the drivetrain being limited the P21 more effectively distributes weight while maintaining the traditional aesthetic preferred by the market.

A rear engine design layout was considered for potential weight and cost savings, but UMATT’s current transmission could not be configured for said drivetrain layout. Design of a more versatile transmission compatible with both front and rear engine layouts is being developed but will not be implemented on the P21. To improve reliability after a poor 2019 performance changes to the drivetrain focused on the electrical control system that was problematic in previous generations.

6.3 Structural

6.3.1 Frame

Frame design began by developing a foundational geometry. This process began by identifying the geometric restrictions usually caused by the drivetrain. A tall section of the frame accommodates the height and stresses around the differential and transmission while the rest of the tractor is supported by a much shorter section. Flanges were then added creating a large C-channel frame to increase rigidity, strength, and provide mounting points for the P21’s components.

The C-channel is created with 3 parallel bends, allowing for rapid manual or automated forming that does require a welded reinforcement flange. UMATT’s P19 frame replaced the weld reinforcement with a bent section, but this was found to dramatically reduce the efficiency of the forming process making welding more economical. Additionally, both the left and right frame rails of P21 can be formed from the same laser cut blank thus decreasing inventory complexity for the tractor’s largest sheet metal component.

Areas on the P21’s frame were then analyzed in areas expected to have stress concentrations. The area expected to have the highest stress and greatest risk of failure was determined to be the attachment point to the hitch. UMATT then conducted a Finite Element Analysis (FEA) study on the frame at the hitch attachment point. A load of 1250 lbs was applied to each attachment point simulating a total load of 5000 lbs on the tractor hitch. The 5000 lb load was selected as a value having a safety factor of near 1.5 of UMATT’s previously recorded maximum hitch loading.
The initial FEA study predicted failure due to the concentration of stresses around the carriage bolt hole. Initially failure due to this stress concentration was not expected since the clamping force between the frame and hitch should distribute the load. However, UMATT wanted to ensure the frame would not fail suddenly should the bolts slip due to under torquing or loosening over time.

To reduce the stress concentration around the carriage bolt hole the following were reviewed; increasing the bolt size or adding a reinforcement plate to the frame. Increasing the bolt size above M12 would have required UMATT to stock more larger hardware despite the M12 being strong enough for the connection. Thus the frame was reinforced with an additional 2mm welded plate at the hitch connection. Another FEA study was then run on the improved design and the study found the reinforcement plate successfully distributed the load and prevented the stress concentrations from exceeding the HSLA’s yield strength.

6.3.2 Wheelie-Bars

The P21’s wheelie bar design began by identifying areas of improvement. Namely, weight reduction, lateral rigidity, and adjustability.

Weight was reduced by decreasing the tube size from 1¾” to 1”. Lateral rigidity was found to be the result of narrow mounting points on the frame and therefore they were expanded. Lastly to improve adjustability UMATT combined the bumper pad function with the adjustable height skid plate. This provided a lighter design that better used the material already present while also allowing the lowest hanging parts to be fully removed should extra ground clearance be required.
6.3.3 Hitch

The hitch would experience some of the highest loads of the entire tractor due to towing and thus required in-depth analysis during the design process. An important goal of the hitch design was to save weight without compromising structural integrity. To achieve this goal, a FEA study was performed to determine potential points of failure and regions of low stress. Based on tractor pull load data from 2017 and 2018 IQS Competitions provided by Campbell Scientific, a simulation was completed with applied loads of 8775 N (1973 lbf) rearward, and 3398 N (764 lbf) downward.

The initial analysis revealed no points of failure, with the highest stresses located at the bolt holes for mounting to the frame and on the tongue. Additionally, the simulation showed that the lowest stress regions were located on the front plate of the hitch assembly. The simulation was run again with the front plate thickness being reduced from 3mm to 2mm. The regions of low stress on the front plate remained without the introduction of new stress concentrations.

Further simulations were performed iteratively with material removed in the low stress regions until new regions of high stress became present. The resulting hitch design maintained adequate strength while reducing weight. Speaking concretely the weight of the P21 hitch was reduced by ~752 grams (16%) using Finite Element Analysis (FEA).
6.4 Drivetrain

6.4.1 Legacy EVT Transmission Design

The P21 features UMATT’s legacy Electronically Variable Transmission (EVT). The EVT acts similarly to a continually variable transmission (CVT) but features a split torque planetary gearset to efficiently transfer engine power to the rear axle without the risk of slippage and other unpredictable losses. The EVT design has proven mechanically reliable over the past 2 years despite electrical control malfunctions. For the P21 UMATT focused on addressing the electrical malfunctions as detailed in the Electrical Control section instead of making mechanical changes.

Power from the engine is diverted through a generator, AC motor controller, and finally an electric motor. This diverted power is then combined with power coming directly from the engine through the primary planetary gearset, while a secondary planetary gear set acts as a gear reduction, see Figure above. A clutch and brake permit the supply of power from the engine to be disconnected allowing for low-speed electric drive in forward and reverse.

UMATT has implemented the EVT over other possible transmission design such as manual, power shift, exclusively electric, or hydrostatic. This selection was driven by market requirements and overall drivetrain efficiency. Nearly all UMATT’s potential customers who responded to the market survey indicated the EVT would meet or probably meet their requirements. The EVT also has a theoretical efficiency of nearly 92% allowing it to outperform all but mechanical drivetrains.

The theoretical efficiency has not been validated by the limitations of acquiring a wheel dyno capable of measuring the P21’s horsepower at low wheel speed and high torque.

6.4.2 Drivetrain Layout

Previous P-Series models from UMATT which also featured the EVT were designed with linear drivetrains allowing for power transmission from the engine to transmission using a single driveshaft and linear coupler. While this allowed for an efficient and simplistic design, it also caused issues with ground clearance and poor engine mount rigidity as the engine had to be mounted below the main frame. To address both issues the engine was raised to sit on top of the frame in the initial stages of the design process. This solved issues with engine mount rigidity and ground clearance it created the new challenge of transferring engine power down to the transmission input level.

UMATT members identified several options for transferring power down to the transmission while also eliminating the secondary belt drive connected to the generator to shorten the tractor. Each option went through a sketched design phase to properly research each option. Each option was then weighed against several criteria in a matrix to select the final design. Table iii: Drivetrain Design Matrix is a summary of the matrix used and highlights what UMATT members determined were the three most viable options for the 2020 competition year. A higher score represents more desirable characteristics on a scale from 1 to 5.

<table>
<thead>
<tr>
<th>Gear case</th>
<th>Weight</th>
<th>Cost</th>
<th>Reliability</th>
<th>Noise</th>
<th>Totals</th>
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</thead>
<tbody>
<tr>
<td>Chain case</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>Belt drive</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>17</td>
</tr>
</tbody>
</table>

Table iii: Drivetrain Design Matrix
6.4.3 Belt Drive Design

UMATT has traditionally struggled with belt drive reliability, but after consultations with professionals in the field we began to develop a belt drive system. The process began by selecting Gates Carbon GT2 belts for their mechanical capabilities and lightweight, but also the local industry support available. Gates Design IQ software was then used as an aid in the determination of belt width, belt length, and shaft loading. Factors effecting these calculations were the Gates recommended service factor of 3 for gas engine drive & variable loading and the limited pulley sizes available to us based on competition-imposed restrictions for rotating components left on the engine PTO.

Several iterations of the drive were designed in Gates Design IQ as well as tested for fit and feasibility in SolidWorks. Each design featured unique serpentine patterns, tensioning mechanisms. To be accepted, a design had to meet several criteria.

- Reduced tractor length over UMATT’s P18 and P19 designs.
- Increased ground clearance
- Maintain or reduce weight of the engine sub assembly.
  - Engine, engine mounts, and belt drive.
- Substantial improvement in mounting rigidity and durability over previous P-Series engine mounts and belt drives.
- Ability for quick belt changes, tension adjustments, and the 2 minute disconnect / reconnect for competition engine testing.

Design concepts were able to quickly meet many of the design requirements by implementing a 9.6mm aluminum support structure and replacing UMATT’s normal linear coupler with a pulley mounted directly to the engine PTO. Unfortunately, weight reduction in the conceptual and final design was limited due to the increased strength and durability requirements. Each design featured an adjustable tensioner providing quick adjustments and easy belt changes.

<table>
<thead>
<tr>
<th>Engine</th>
<th>Generator</th>
<th>Driveshaft</th>
<th>Idler</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX RPM</td>
<td>3600</td>
<td>5184</td>
<td>3600</td>
</tr>
<tr>
<td>Teeth</td>
<td>36</td>
<td>25</td>
<td>36</td>
</tr>
<tr>
<td>Diameter</td>
<td>90.07 mm</td>
<td>62.06 mm</td>
<td>90.07 mm</td>
</tr>
<tr>
<td>Shaft Load</td>
<td>1208.6 N</td>
<td>2189 N</td>
<td>1980.6 N</td>
</tr>
<tr>
<td>Load Direction</td>
<td>121.12°</td>
<td>350.28°</td>
<td>199.53°</td>
</tr>
<tr>
<td>Span Tension</td>
<td>998.7 N</td>
<td>1775.5 N</td>
<td>221.9 N</td>
</tr>
</tbody>
</table>

The final belt drive design features a Gates Carbon GT2 serpentine belt drive which drives the generator as well as transmissions mechanical input. Features of the final design are...

- Direct connection between the belt drive and engine for added rigidity and reduced length
- Linear tensioning system providing easy access for adjustments and belt replacement
- Greatly improved ground clearance
- Reduced weight by 2 lb over previous designs
- Potential for much greater durability over previous designs for UMATT
6.5 Steering and Suspension

The P21 features a manual hydraulic steering system, providing the operator effortless control. The system was designed from the ground up to provide this experience. Design began with the selection of a manual hydraulic steering pump; requirements for which were balancing cost, weight, and pressure given input torque from the operator. A dual rod hydraulic cylinder was selected based on UMATT’s 2019 testing of the team’s legacy rack and pinion system.

6.5.1 Steering Geometry

While generally considered unconventional, the hydraulic steering cylinder has been placed in front of the steering axis rather than behind it. This was done to provide the maximum steering angle given the stroke of the cylinder which is limited by the width of the tractor. Due to this configuration naturally placing higher loads on the system rod ends, and other weaker components of the system were upgraded to compensate. The benefit of greater steering angle was determined to outweigh the slight cost increase.

The system is also configured with the steering links parallel to the A-Arms which eliminates bump steer. The elimination of bump steer is vital to the controllability of the tractor when traversing rough conditions.

6.5.2 Suspension

The suspension features an inclined parallel link design which ensures the roll center of the tractor remains low to the ground while also eliminating camber changes as the P21 travels over rough terrain. This ensures the P21 remains stable and controllable even in the toughest conditions. The air shocks utilized allow for up to 6 inches of suspension travel, pressure can be adjusted allowing for consistent ride height regardless of ballast configuration or loading.

6.5.3 Operator’s Interface

The P21 features a quick adjust tilting steering column which allows the operator to set the steering wheel to a comfortable height. The steering column may also be raised out of the operator’s path for a more comfortable experience during embarking and disembarking of the tractor.

The P21’s hydraulic steering pump provides a smooth feel, while the internal valving eliminates the feedback caused by the rough terrain when more traditional rack & pinion steering systems are used. While in typical automotive applications feedback is desired, given the low-speed operation of the P19 and the significantly higher shock loads no feedback is the preferred system.
6.6 Electrical System

6.6.1 Control System PCBs

The P21 utilizes two printed circuit boards (PCBs) to extend the capabilities of the Raspberry Pi (RPi) microcomputer.

The P21 control board has the combined functionality of the prototype and printed circuit boards used in the P18 tractor. This improves the signal strength as it decreases the signal’s exposure to parasitic resistances. The control board (Figure ) has four main functions:

1) Expand the input/output of the RPi. The control board provides 32 additional input/output pins for sensor input, relay, and motor control.
2) Perform simple logic required before RPi start up.
3) Separate low voltage, low current signals for the relay logic from the relays themselves using MOSFET switching.
4) Convert 12V DC to 3.3V and 5V to power the RPi and various integrated circuits (ICs). Five 15F supercapacitors provide back-up power to the RPi and ICs during brown-out conditions and cranking. Smaller, 100µF capacitors ensure a continuous power to the ICs during normal operation of the tractor.

The relay and fuse board (Figure ) provides power to all devices operating on 12V. The board was designed to improve user experience when troubleshooting. Each relay has its own LED indicator light for quick and easy diagnostics; when a device is powered, the LED turns on. The fuse blocks and relay sockets are labelled, and the fuse values are printed on the PCB to improve serviceability.

6.6.2 Software

The P21 software was constructed using a Separation of Concerns (SoC) approach. The software is separated into two main categories: the drive program and the user interface program. The drive program is written in C and is separated into self-contained modules. For example, the module responsible for communication via Serial Peripheral Interface (SPI) protocol is separate from the module that contains the functions responsible for interpreting signal input. The user interface (UI) program is for the console touchscreen. It is written in python and makes use of QtGui functions. The UI program exchanges data with the drive program to update information screens and change driving modes.

The P21 software configuration uses the RPi as the master, which controls the SEVCON motor controller. The SEVCON uses its own proprietary software which is configured to work with the P21 drive program. Seven digital outputs from the RPi are received by the motor controller and aid in controlling the speed of the electric motor.

6.6.3 High Voltage System

The P21’s High Voltage System is a component of UMAT’s Legacy Electronically Variable Transmission (EVT) Design (6.4.1) providing precise control over ground speed without the requirement of shifting gears. A generator provides 45 to 110 volts DC and up to 150 amps continuous to the high voltage system. A SEVCON Gen 6 AC motor controller then converts the power to 3-Phase AC for efficient and precise control of the EVT’s gear ratio using a Permanent Magnet AC (PMAC) electric motor. The SEVCON uses feedback signals from the PMAC motor as well as output from the RPi to control the speed of the PMAC electric motor.
### 6.6.4 Electric Kill Switch FMEA

The P21 was equipped with an Electrical Kill Switch Circuit as well as an Ignition Interlock Circuit. The Electrical Kill Switch circuit utilizes a series circuit to shut down the engine should any safety switch on the circuit be tripped or wiring damage prevent proper operation of the circuit. The Ignition Interlock Circuit utilizes a parallel circuit to prevent ignition should any safety switch not be activated during the attempted ignition. The Failure Modes and Effects Analysis (FMEA) summary for highest initial Risk Priority Number (RPN) for the Electrical Kill Switch system has been included. Except for potential hazards created by aftermarket implements outside of UMATT’s control the RPN for each hazard has been lowered to an acceptable level. For the complete FMEA of the electric kill switch system please see our Design Log.

<table>
<thead>
<tr>
<th>Potential Failure Mode</th>
<th>Potential Effects of Failure</th>
<th>Severity</th>
<th>Potential Causes/Mechanisms of Failure</th>
<th>Occurrence</th>
<th>Current Design Controls</th>
<th>Detectability</th>
<th>RPN</th>
<th>Recommended Actions</th>
<th>Action Results</th>
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<tr>
<td>Wiring Failure</td>
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<td>Accumulated wiring damage</td>
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<td>Improved guarding</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Provide instructions for proper cleaning and maintenance to prevent damage from accumulating and increase detectability</td>
<td>Updated operator’s manual</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated operator’s manual</td>
<td></td>
</tr>
<tr>
<td>Sudden shut down</td>
<td></td>
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<td>Accumulated wiring damage</td>
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<td>Provide instructions for proper cleaning and maintenance to prevent damage from accumulating and increase detectability</td>
<td>Updated operator’s manual</td>
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<td>Ignition Interlock Circuit Failure</td>
<td>Fails to start after being shut down properly</td>
<td>8</td>
<td>Accumulated wiring damage</td>
<td>5</td>
<td>UMATT Design &amp; Quality Standards</td>
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<td>160</td>
<td>Improve the tractors underside guarding</td>
<td>Improved guarding</td>
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<tr>
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<td></td>
<td>Provide instructions for proper cleaning and maintenance to prevent damage from accumulating and increase detectability</td>
<td>Updated operator’s manual</td>
</tr>
<tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>Updated operator’s manual</td>
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<td>Brake Away Switch Failure</td>
<td>Does not shut down</td>
<td>10</td>
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<td>4</td>
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<td>Modify mounts to reduce risk of damage</td>
<td>Improved Mounting</td>
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</tr>
<tr>
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<td>10</td>
<td>Dependent on external implement</td>
<td>3</td>
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<td>4</td>
<td>120</td>
<td>Improve operator education on the external implement</td>
<td>Updated operator’s manual</td>
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<td></td>
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<td>Updated operator’s manual</td>
<td></td>
</tr>
<tr>
<td>Does not shut down</td>
<td></td>
<td>10</td>
<td>Dependent on external implement</td>
<td>3</td>
<td>UMATT Design &amp; Quality Standards</td>
<td>4</td>
<td>120</td>
<td>Improve operator education on the external implement</td>
<td>Updated operator’s manual</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated operator’s manual</td>
<td></td>
</tr>
<tr>
<td>External Implement Failure</td>
<td>Fails to start</td>
<td>8</td>
<td>Dependent on external implement</td>
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<td>External Supplier</td>
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<td>480</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Updated operator’s manual</td>
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</tr>
</tbody>
</table>

Table iv: Electric Kill Switch FMEA

UMATT 2021

www.umatt.org

Winnipeg, MB, Canada
6.6.5  **Wiring Harness**

The P21 wiring harness was constructed modularly, with dedicated partitions of the harness for the engine, frame, and operators station joined together by bulkhead connections. This allows for complete assembly of each subassembly before final assembly of the P21. Additionally, each modular section of the harness was divided into bundles for functions. This would not be a feature in a production P21, but the modularity of the P21 prototype harness was an invaluable diagnostic tool for UMATT. By separating wires into smaller groups, tracing wires became much easier, improving wiring diagnostics for single functions.

The P21 wiring harness is made of 22, 18, and 10-gauge wiring providing the optimum wiring gauge for each application, minimizing harness weight and size. The harness also features a 10-colour-code design and heat shrink labelled terminations allowing for simplified wire tracing and diagnostics.

6.6.6  **Electronic Engine Control**

The P21 Features UMATT’s first electronic engine control system providing precise control of engine speed at 3 set points (Idle, Half, Full), as well as the choke. While at first this seems to provide less controllability than a traditional throttle, the P21’s ground speed is independent of engine speed. This control method allows the operator to focus on ground speed control and their task instead of controlling the engine.

Main components of the system are Pulse Width Modulation (PWM) controlled servos, an analog to PWM controller, deadman pedal and switches connected to voltage dividers providing the analog signal for each position. By isolating the engine control system from the rest of the P21’s control system, UMATT is able to ensure the deadman throttle is always functional for safe operation. Should the deadman pedal or any other safety feature of the main control system be triggered power is removed from the system and the throttle limply returns to idle. Should the electronic throttle system be damaged the throttle cable may be connected to the deadman pedal and act as a traditional throttle allowing the operator to continue until repairs can be made.

6.7  **Operators Station**

6.7.1  **Console**

The P21 user interface features several upgraded features over previous P21 models to provide a better operator experience and add value for those working extended hours.

![Image of P21 Console](Figure xxviii: P21 Console)

The consoles main features are the Display and Control System Interface, as well as the Ground Speed Lever (GSL). The console also features the ignition, emergency stop, and switches for the engine control system.

**Display and Control System Interface**

The P21’s display has been upgraded to a 900-nit brightness sunlight readable display with adjustable backlight and capacitive touch control for a more reliable and intuitive touch screen response. Because moisture and dirt hinder use of the capacitive touch functions, a multifunction keypad was added. The individual keys correspond to the bolded icons on the lower-right part of the display and vary based on the functionality of the selected page. Information on the display is provided in accordance with ASABE/ISO 3767 providing any information the operator may require in a way that is recognizable for new and experienced operators alike. The display features Home, Settings, and Diagnostic pages each providing the operator with unique insights into the P21’s functions.
Figure xxix: The home page provides vital data for operation of the tractor and may be configured to provide implement data in customizable readouts on the left side.

Figure xxx: The settings page provides options for the adjustment of common functions and access to the diagnostics menu & auxiliary input and output menu options.

Figure xxxi: The diagnostics page provides the operator with live sensor feedback and controls the maintenance warning system.

Ground Speed Lever

The P21 Ground Speed Lever (GSL) has been custom designed to provide the operator with comfortable control of both direction and speed using effortless wrist and forefinger motions. Direction and speed are adjusted by tilting the lever to the appropriate direction then sliding in the direction of travel to increase speed. To ensure safety, the GSL has been designed with a neutral interlock switch and springs returning the GSL to neutral should the operator lose control. The interlock provides an extra layer of safety as well as a calibration point for the control system.

6.7.2 Foot Controls

The brake pedals have been positioned a few inches above the floor providing greater leverage and better operator confidence in foot positioning when executing brake steering maneuvers. The pedals are constructed from lightweight aluminum while the master-cylinders and pivots are mounted on each side of the frame with compact steel brackets.

The throttle safety switch on the other side of tractor allows for UMATT’s electronic throttle to operate as a deadman throttle. The pedal has been positioned and angled such that the operator’s foot is in a comfortable position because the pedal must be depressed while operating the P21. For the best operator experience, the throttle safety switch allows for electronic engine speed control, stabilizing performance over a traditional gas pedal. For dependability, the throttle cable may be moved from the electronic servo to the throttle safety switch for traditional throttle control.
6.7.3 Seat

The P21 emphasizes operator comfort by implementing a 6-way adjustable seat base, console position, arm rest height, and tilting backrest. Supporting the seat is also a new aluminum seat base, reducing weight by 60% over UMATT’s previous steel designs while maintaining the durability of the previous design.

![Figure xxxiv: Seat Box FEA](image)

In addition to reducing weight adjustments have been added to the angle of the backrest, height of the left arm rest, as well as height, angle, and fore-aft position of the right arm rest / console.

![Figure xxxv: Seat Box FEA](image)

All of this is in addition to UMATT’s standard 6-way adjustable seat base which provides adjustment front-back, up-down, and front-back tilt. Combined with this year’s redesigned console and foot controls the P21 is UMATT’s most ergonomic tractor yet.

6.7.4 Body

Using UMATT’s new flax based “fiberglass” alternative the body for the P21 features fenders, side skirts, as well as other smaller components. The hood has been designed to provide a balance between airflow to keep the engine cool and aesthetics. The fenders have been designed for maximum strength as well as with integrated mounting features for the taillights. The fenders also feature an experimental honeycomb structure sandwiched between layers of flax which provides a significant increase in rigidity while not increasing weight.

![Figure xxxvi: Body](image)

![Figure xxxvii: Reinforcing Honeycomb Structure](image)

Yield 195 MPa 97 MPa 65 MPa 35 MPa 1 MPa
6.7.5 Serviceability

6.7.6 User Interface Reminders

The P21 operators interface provides scheduled maintenance reminders for common items on the P21. The interface is also able to adjust the engine oil service reminder based on the operating conditions of the service period by monitoring the approximate engine load determined the throttle setting and engine RPM.

6.7.7 Engine Oil Changes

Remote access to the engine oil drain has been provided allowing for clean oil changes with no risk of oil splash on to the P21. Additionally, access to the engine oil filter only requires the lifting of the P21’s hood. Filter changes are nearly drip free if the operator allows the engine oil to fully drain first, as detailed in the P21’s operators manual.

6.7.8 Other Oil Changes

Trans-hydraulic oil is used for the transmission, differential, and manual steering system on the P21. Each oil drain has been located such that oil will not pour or drip onto neighboring components. Fill ports are in open areas or hidden behind access panels requiring no additional tools for removal.

6.7.9 Battery Access

The P21 features a maintenance-free lithium-ion battery. This battery only requires periodic charging to prevent capacity degradation while the tractor is in storage for several months at a time. A 12V smart charger compatible with lithium-ion batteries is recommended, however traditional charges may be used.

6.7.10 Major Repairs

To accommodate major repairs and efficient assembly, the P21 features removable seat, engine, and steering tower assemblies. Each assembly may be removed by disconnecting a bulkhead electrical connector and removing 2 to 4 easily accessible bolts. Removals of one or more of these assemblies provides unobstructed access to the entire P21 drivetrain as well as the electrical harness.
6.8 Safety

The P21 exceeds the 2020 competition safety regulations (ASABE n.d.).

6.8.1 Guarding

The P21 is equipped with 6mm aluminum guarding protecting the operator from all hazardous drivetrain components, as well as 3mm aluminum guarding against incidental contact with all rotating components. Exhaust guarding on the P21 has also been designed to exceed the requirements of ISO 5395-3; mounting the exhaust guarding to the steering tower greatly reducing heat transfer and further decreasing the burn risk should incidental contact occur.

6.8.2 Safety Decals

The P21 features ASABE 3767: R2017 compliant safety decals informing operators of hazards they may be exposed to during regular operation as well as regular maintenance.

6.8.3 Operators Manual

The P21 comes standard with a complete operator’s manual as well as service guide both compliant with ASABE AD3600: R2016. The operator’s manual is mandatory reading material for all operators ensuring they are aware of the hazards of operating the P21 as well as the risks of using the P21 outside its intended application range.

6.8.4 Lighting

The P21 comes standard with an ASABE S279.17: R2017 and S608: R2017 compliant lighting package. The addition of a slow-moving vehicle sign, the P21 is well lit and properly equipped for work in agricultural yards, industrial facilities, and travel on roadways when required in compliance with local laws and regulations. The P21 model features compliantly designed custom headlights. Each headlight is composed of a 2x4 array of 6V, 5W LEDs. Thus, each headlight is equivalent to a 40W lamp. This headlight design produces a wider beam of light, giving the operator unparalleled awareness of their surroundings in low-light environments. The operator will also have the option to choose between low beams and high beams. In the low beam setting, the lower row of LEDs will be illuminated. In high beam mode, both rows of LEDs will be illuminated, giving the operator the best lighting situation possible.
6.9 Compatibility & Implements

To diversify UMATT’s business and further meet the needs of the customer, UMATT used a survey to identify which implements and add on kits are in the highest demand for compact utility tractors. UMATT has begun designing these implements which would be ready for 2021 release should the P21 go into production. Beginning the design process during development of the P21 allowed UMATT to ensure compatibility. Changes to ensure compatibility include increased ground clearance, increased rear fender clearances, and increased hitch strength. UMATT is in the process of constructing prototypes of the 3-point hitch and power take off kits with goals to bring them for design judging at competition.

6.9.1 Compatibility

UMATT has developed a quick attached method for rear and front mount attachments slipping easily on the suitcase style ballast mounts. Attachments are expected to be competitively priced and release in 2022.

Sprayer

UMATT is working on a high performance, medium sized sprayer for people with large yards, and pasture weed control. It is expected to be available in widths from 12 to 21ft.

Snowblower

UMATT’s snowblower will feature a lightweight aluminum frame, high strength steel auger & impeller, and a high voltage electric drive allowing for front or rear mounting to the P21, and superior operator visibility over the competition. The high voltage electric drive system allows for comparable performance to competitors models with 10-15% more HP.

Lawnmower

UMATT’s lawnmower will be available in a variety of widths allowing for compatibility with a wide range of customer applications, from wide open spaces to heavily treed yards. While the P21 is not zero turn, its lockable differential will prevent excessive tearing and lawn damage.

6.9.2 Power Take Off (PTO)

While the P21 does not feature a traditional 540 or 1000 RPM PTO it has been equipped with a versatile high voltage DC PTO. Up to 100 amps continuous, 150 amps peak may be drawn by implements connected to the P21 when the tractor is set to GenSet mode to supply power to a stationary external load. During normal operation, the P21 can provide up to 75 amps continuous or 100 amps peak to mobile implements for a variety of applications. To ensure compatibility with non-UMATT implements conversion kits will also be available.
7  Cost Summary

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<th>System</th>
<th>Purchased</th>
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<th>Total</th>
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<td>2) Transmission</td>
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Table v - Manufacturing Variable Costs

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<td>MSRP</td>
<td>$15,000</td>
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</table>

Table vii - Total Cost

Table v shows detailed breakdown of purchased and fabricated parts in each major system in the P21. The fixed and total costs are shown in Table vi and Table vii, respectively.

The Period Manufacturing cost of the P21 of 18% was the same as the previous model. This is because the same manufacturing techniques in the previous year’s tractor were used in the P21.

The Research and Development (R&D) cost of the P21 was set to 4% to reflect the minimal amount of R&D required for this model. Similar to the previous year, most of the R&D was geared towards reliability issues. The mechanical system added a new belt drive to raise the engine, but the transmission remained the same a previous year. The electrical system overhauled the drive software and added a new printed circuit board for relays and fuses.

The P21 enters the market with a MSRP of $15,000 USD ($18 859.50 CDN), with a total manufacturing cost of $11,549.18 per unit for a production run of 3000 units. This provides a profit margin of 23%, which is 2.5% lower than the previous model’s margin of 25.5%. The decrease in profit margin is to compensate for the marketing limitations imposed by the COVID-19 pandemic. This profit margin still allows for dealers, year-end incentives, and promotional events, but places the P21 at a lower, more attractive price than competing models.
UMATT Team

For 2021 UMATT made a small modification to the team’s leadership structure. Our administrative position was replaced with a new Vice Design Electrical to better reflect the direction of the team’s designs. This involved a redistribution of duties and will help the team ensure electrical aspects of the tractor continue to develop.

UMATT is made up of many team members and led by seven Council members. Council members are responsible for the team’s organization and the project overall. Team members are responsible for duties assigned and those they take on themselves. Team members are also able to take on smaller aspects of the design such as the wheelie bars, hitch, seat, exhaust, and console.

UMATT works closely with Alumni members and sponsors to help provide team members with opportunities outside of the classroom for professional development throughout the year. UMATT members have access to SolidWorks modeling software and training as well as training on the tools and equipment available to the team. Members are also able to tour and learn about sponsors’ facilities, products, and manufacturing processes.

8.1 2019/20 Team Acknowledgements

Due to the COVID-19 pandemic, many UMATT members lost their chance to see their final year’s tractor at competition. UMATT would like to take this opportunity to thank these graduating members. Their hard work has laid the foundation for future P-series designs.

To our 2019/20 Co-Captains, Evan Upgang and Tony Dziedzic: we thank you for your years of hard work and dedication, leadership, and friendship.

UMATT hopes to see you all again as Alumni members.

Figure iii: UMATT Council Structure

Co-Captain (Owen Darrach & Katherine Gledson)
Administrative, organizational, leadership and management responsibilities

Vice-Captain (Jean Le Heiget)
Assisting the Captains and other Council members in their roles while organizing recruitment and team building events

Design Chair (Douglas McMillan)
Responsible for overseeing the overall design of the tractor

Vice-Design Chair (Maksym Khoma)
Assisting the Design Chair in their role with the tractor’s mechanical systems

Treasurer (Stephane Le Heiget)
Budgeting, sponsor communication, and university communication

Vice Design Electrical (Andrew Savignac)
Assisting the Design Chair in their role with the tractor’s electrical systems
9 Acknowledgements

UMATT would like to take this opportunity to thank the following companies, groups and individuals for their contributions to UMATT during the 2021 competition season: MacDon Industries, Elmer’s Manufacturing, the Engineering Endowment Fund, the Agricultural Endowment Fund, John Deere, Ramsey Chain, Auburn Gear, mayr, Motenergy, Ogura Industrial Corp., Endries ASABE, and the University of Manitoba. Without their support, we would not be where we are today.

10 References


