final report

Project code: P.PSH.1169

Prepared by: Kraig Schulz
Autonomous Tractor Corporation

Date published: 18 January 2020

PUBLISHED BY
Meat and Livestock Australia Limited
PO Box 1961
NORTH SYDNEY NSW 2059

Autonomous diesel-electric feed truck concept vehicle

This is an MLA Donor Company funded project.

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

The vision of this overall development project is to create an autonomous livestock feed truck and feed bin concept vehicle with an Autonomous Tractor Company diesel-electric/digital drive train. In Phase 1, this project, will specify the high-level concepts and detailed design of the autonomous concept vehicle. Once the Phase 1 design stage is completed, and agreement to proceed is secured from MLA, and ATC, it is anticipated the program will evolve into further phases to build, install and carry out in-field testing of the electric, autonomous platform in a feedlot environment. ATC intends to integrate its electric truck platform with available sensors and feed dispensing mechanisms so that the speed of the vehicle is automatically adjusted to match the rate of feed dispensation in the bunk, ensuring even, consistent levels across the length of the bunk. The design calls for the mixing unit to be powered by electric motors (as opposed to mechanical gears and / or hydraulic drives).

Executive summary

Current cattle feeding vehicles are deficient in several ways that this project intends to ameliorate:

- The mechanical drive train is inefficient and lacks the durability of an electric system
- It is challenging to ensure the speed of the truck matches the rate of feed dispensation into the bunk, leading to uneven feeding and lost time in dispensing the feed
- Countless chains, gears and sprockets are a maintenance problem
- Drivers are expensive and in short supply, especially experienced drivers
- Varying the speed of the mixing system vs. the feed auger is challenging to do with a mechanical drive and leads to suboptimal mixing / dispensing rates as the composition of the feed changes from load to load and as the feed bin gets closer to empty

This proposed development will involve the collaboration of two key companies in feedlot equipment and autonomous vehicle development.

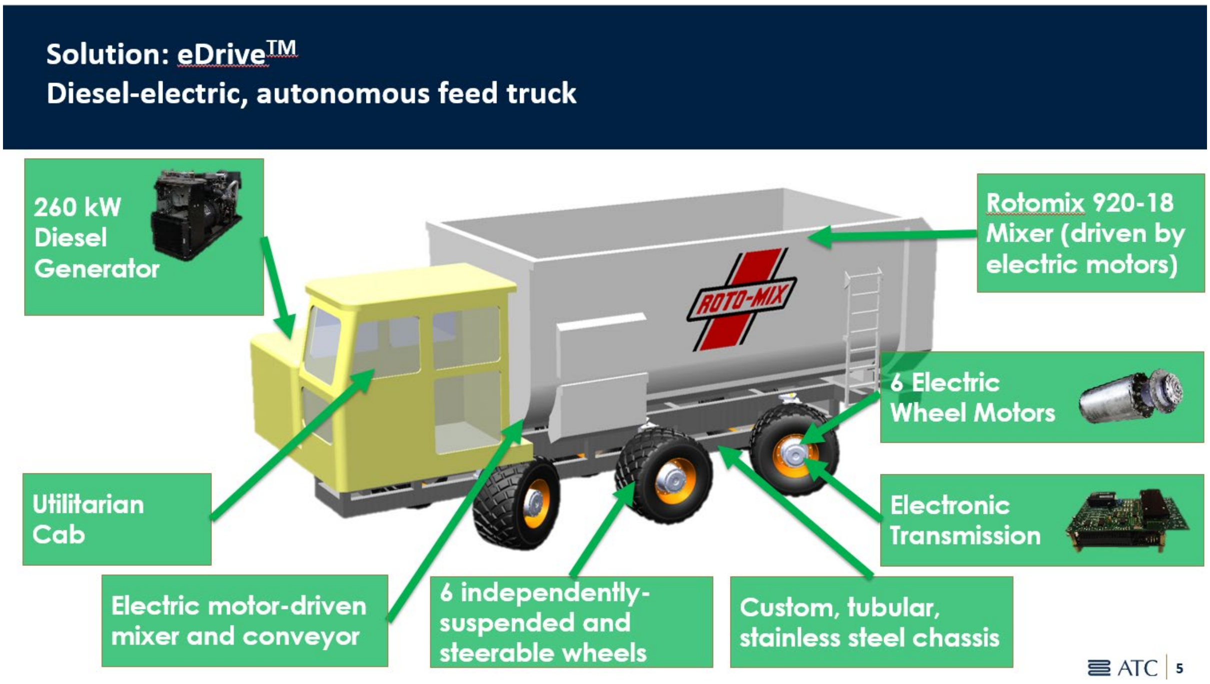
ROTO-MIX is a leading manufacturer of livestock mixing and feeding equipment, compost mixing equipment and manure spreaders. The company was founded in 1984 and has grown to include an additional manufacturing facility in Hoisington, Kansas as well as a retail location in Scott City, Kansas. The marketing arm has over 150 dealers providing local sales and service in the U.S. and sales in over 35 international markets including Australia. Roto-mix's history of innovation in feed mixers has led to millions of dollars of investment in R&D to ameliorate some of these problems (e.g., hydraulic control of the auger).

Autonomous Tractor Corporation (ATC) develops autonomous electric tractors for tilling, harvesting, and hauling applications in the agricultural sector. The company provides electric conversion kits for JD 4930 Sprayers equipped with custom oil-cooled generators, proprietary drive electronics, and oil-cooled wheel motors, which helps to reduce fuel consumption and improve service life. Autonomous Tractor Corporation was founded in 2012 and is based in Saint Michael, Minnesota. To-date, ATC has invested nearly $6M into the development of its electric drivetrain and autonomous vehicle controls.

The vision of this overall development is create a new feeding platform by converting and integrating a ROTO-MIX truck/feed bin to an Autonomous, diesel-electric/digital drive train concept vehicle.

At the successful completion of Phase 1 ATC developed the detailed design and revised costings for the electric hybrid, manned feedlot feed truck, including:

- Full CAD model of a diesel-electric feed truck
    - Custom-built tubular steel chassis with simple cab
    - Series hybrid electric drive train
    - 6 independently suspended, powered and steerable wheels
    - Roto-mix 920-18 mixing and dispensing mechanism powered by independent electric motors
    - Manually-driven feeding platform
- Bill of materials and cost estimates
- The aim of the design is to rectify the above-mentioned issues with current feed trucks and, ultimately, cut total cost of ownership and operations by 30%



The team was very pleased with the results of the CAD modelling and feels confident that this model will serve as an excellent starting point for the prototyping work in Phase 2. There are many details that still need to be worked out (e.g., exact routing of each of the conduit lines that carry the wires and hydraulic fluid) but, in ATC's experience, these details are best addressed during the prototyping phase. The decisions made for each of these details are then documented in the CAD model so that, during commercialization, all final designs are consistent in the prototype and the CAD model.

The team has selected the major components for the prototype vehicle and got estimates from suppliers for each of these major components. Note: All costs are in USD.

Item	Quantity	Cost
Frame (Chasis)	1	$ 10,000
22.5" Tires and Rims	8	$ 6,000
eDrive™ Wheel Motors	8	$ 50,000
160 hp Cummins Engine	2	$ 17,000
Operator Cab	1	$ 6,600
Roto-Mix 920-18 Mixer (New)	1	$100,000
Electric motors for paddle, auger and dispenser on mixer unit	3	$ 36,000
Wires, conduit, hydraulic hoses and fittings	Multiple	$ 10,000
Machining Time @$125 / hr	200 hrs	$ 25,000
TOTAL		$260,600

Once in full-scale production, labor is not anticipated to be a significant component to the cost of the vehicle. ATC anticipates the total cost of an eDriveTM feed truck will be no more than and, potentially, ~10% less than a conventional feed truck.

The final feed truck is expected to offer many benefits versus conventional feed trucks:

- Reduced feeding time (more cattle fed earlier)
- More efficient route planning
- Reduced feed wasted on the ground
- More even dispensing of food along bunk
- Near-zero downtime for drivers (illness and other absences)
- Reduced accidents
- No driver training / break-in period

If all of these benefits amounted to:

$0.001 / pound savings in feed costs

X 25 lbs / day / head

X 100,000 head

= $2,500 / day savings

Or

= $912,000 / year for an “average” feed lot.

Table of contents

1 Background

Current cattle feeding vehicles are deficient in several ways that this project intends to ameliorate:

- The mechanical drive train is inefficient and lacks the durability of an electric system
- It is challenging to ensure the speed of the truck matches the rate of feed dispensation into the bunk, leading to uneven feeding and lost time in dispensing the feed
- Countless chains, gears and sprockets are a maintenance problem
- Drivers are expensive and in short supply, especially experienced drivers
- Varying the speed of the mixing system vs. the feed auger is challenging to do with a mechanical drive and leads to suboptimal mixing / dispensing rates as the composition of the feed changes from load to load and as the feed bin gets closer to empty

This proposed development will involve the collaboration of two key companies in feedlot equipment and autonomous vehicle development.

ROTO-MIX is a leading manufacturer of livestock mixing and feeding equipment, compost mixing equipment and manure spreaders. The company was founded in 1984 and has grown to include an additional manufacturing facility in Hoisington, Kansas as well as a retail location in Scott City, Kansas. The marketing arm has over 150 dealers providing local sales and service in the U.S. and sales in over 35 international markets including Australia. Roto-mix's history of innovation in feed mixers has led to millions of dollars of investment in R&D to ameliorate some of these problems (e.g., hydraulic control of the auger).

Autonomous Tractor Corporation (ATC) develops autonomous electric tractors for tilling, harvesting, and hauling applications in the agricultural sector. The company provides electric conversion kits for JD 4930 Sprayers equipped with custom oil-cooled generators, proprietary drive electronics, and oil-cooled wheel motors, which helps to reduce fuel consumption and improve service life. Autonomous Tractor Corporation was founded in 2012 and is based in Saint Michael, Minnesota. To-date, ATC has invested nearly $6M into the development of its electric drivetrain and autonomous vehicle controls.

The vision of this overall development is create a new feeding platform by converting and integrating a ROTO-MIX truck/feed bin to an Autonomous, diesel-electric/digital drive train concept vehicle.

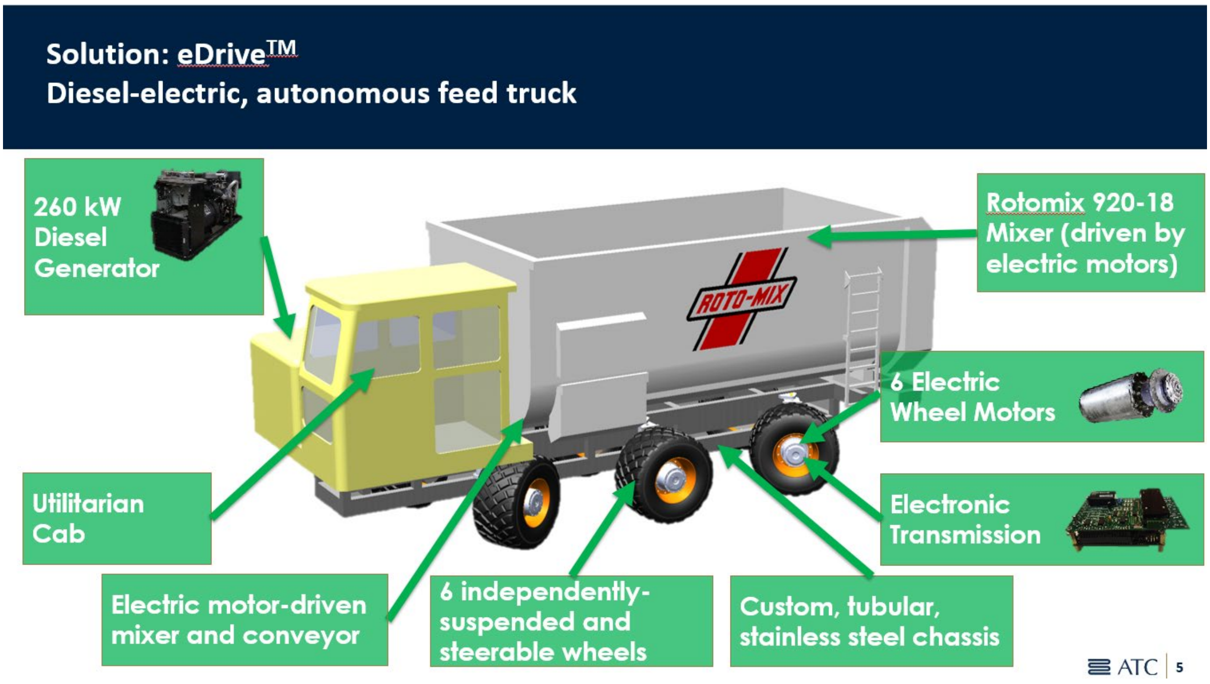
2 Project objectives

2.1 Objectives

At the successful completion of Phase 1 Roto-mix and ATC will have developed the detailed design and revised costings for the electric hybrid, manned feedlot feed truck, including:

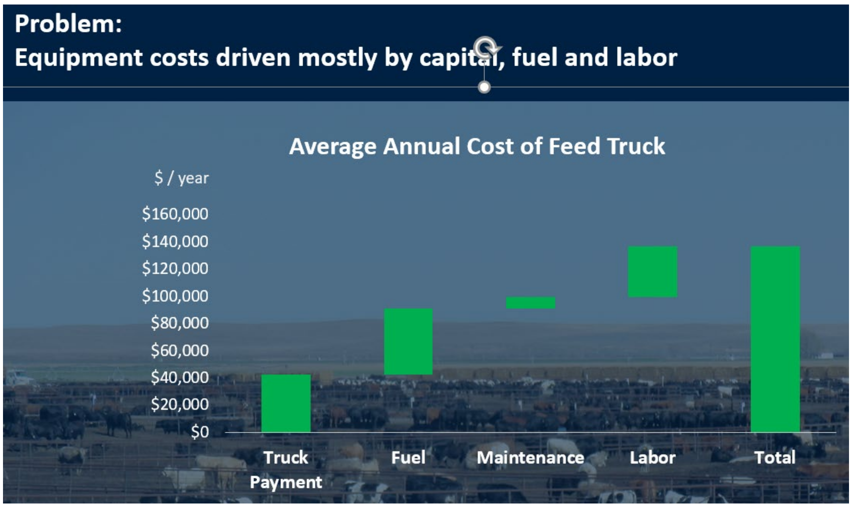
- Full CAD model of a diesel-electric feed truck
  - Custom-built tubular steel chassis with simple cab
  - Series hybrid electric drive train
  - 6 independently suspended, powered and steerable wheels
  - Roto-mix 920-18 mixing and dispensing mechanism powered by independent electric motors
  - Manually-driven feeding platform

- Bill of materials and cost estimates
- The aim of the design is to rectify the above-mentioned issues with current feed trucks and, ultimately, cut total cost of ownership and operations by 30%



2.2 Anticipated Benefits

The two images below depict the current costs of feed trucks and the potential savings:



Competitive pricing and improved operating costs create compelling owner economics

Costs	Conventional Feed Truck	eDrive Feed Truck	Potential Savings	
Truck with Mixer	$ 42,396	$ 42,396	$ 0	Assume 8 year loan at 5% Savings achievable with volume
Annual Maintenance	$ 10,200	$ 2,550	$ 7,650	Assume 6 hours / day @ 365 days / year
Fuel	$ 48,750	$ 39,000	$ 9,750	Assume 6 hours / day @ 365 days / year EDRIVE = 20% less
Truck Costs	$ 101,346	$ 83,946	$ 17,400	
Labor	$ 37,500	$ 7,500	$ 30,000	Assume one operator manages 5 trucks
Total Operating Costs	$ 138,846	$ 91,446	$ 47,400	
Savings (truck only)			**17%**	
Savings (total)			**33%**	

Total savings = $69 / head profit improvement

Additional benefits of the system could amount to significant cost savings for lot managers

- Less fuel consumption
- Improved durability and life-span of the feed truck
- More even dispensing of food along bunk
- Reduced feeding time (more cattle fed earlier) due to matching of the speed of the feed dispenser with the speed of the vehicle
- Electric motors replace mechanical drivetrain for the mixing unit and feeding auger
- More efficient route planning of the vehicle around the pens and elevator
- Less or no driver training / break-in period
- Reduced feed wasted on the ground
- Near-zero downtime for drivers (illness and other absences)
- Reduced accidents

If all of these amounted to just:

- $0.001 / pound savings in feed costs
- X 25 lbs / day / head
- X 100,000 head
- = $2,500 / day savings

Or

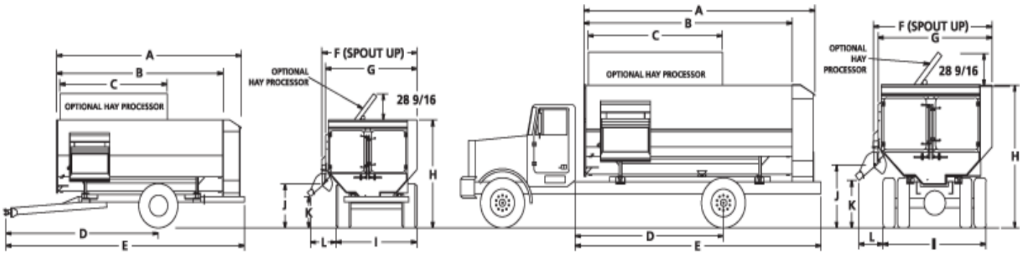
= $912,000 / year

3 Methodology

3.1 CAD Model Methodology

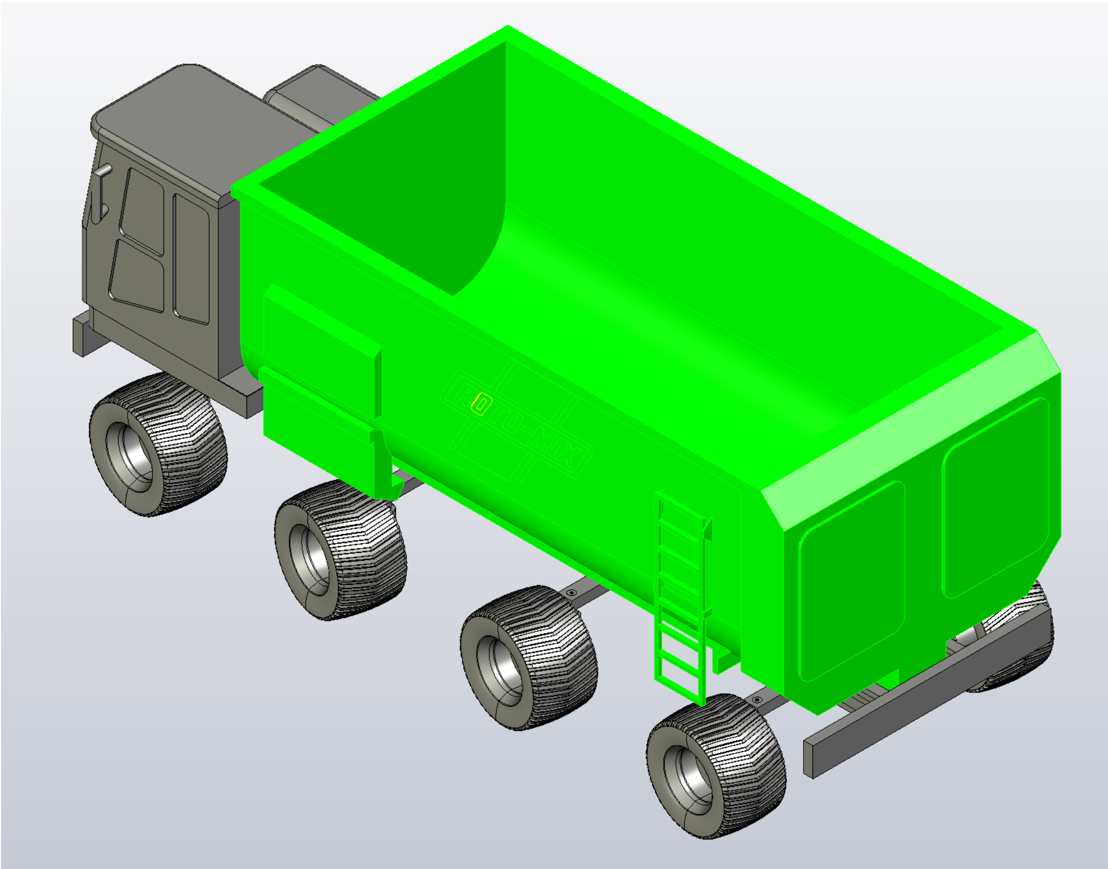
There was sufficient publicly-available information about the Rotomix 920 unit on the Rotomix website (https://rotomix.com/index.php/products/horizontal-rotary-feed-mixers/truck/920-18)

Specifications



Ref.	Dimensions, Weight, Capacity	920-18
	Weight–Stationary–Less Motor, lb. (kg)	20,485 (9291.8)
	Weight–Truck Unit–Installed, lb. (kg)	21,685 (9836.1)
	Weight–Trailer with Tires, lb. (kg)	25,085 (11378.3)
	Weight–Hay Processor, lb. (kg)	1,750 (793.8)
	Rotor Diameter, in. (cm)	84½ (215)
	Inside Length, in. (cm)	216 (549)
	Inside Width, in. (cm)	113½ (288)
A	Overall Length–Mixer Only, in. (cm)	231¾ (589)
G	Overall Width–Mixer Only, in. (cm)	118¾ (302)
F	Overall Width–Spout Up, in. (cm)	122¾ (311)
E	Overall Length including Trailer, in. (cm)	300 (706)
E	Overall Length–Stationary Drive, in. (cm)	250 (635)
H	Height of Mixer–Base to Top, in. (cm)	93¾ (238)
	Height of Mixer–Oil Bath Drive, in. (cm)	99¼ (252)
H	Height on Trailer–Standard Tires, in. (cm) ‡	130 (330)
H	Height on 36/40" Truck Frame, in. (cm)	134 (340) 40 (101.6)
H	Height on Stationary Scale Frame, in. (cm)	101¾ (258)
	Spout Width–Truck and Trailer, in. (cm)	48½ (123)

Using this information the team built a CAD model of the Rotomix 920 unit to integrate into the overall design.



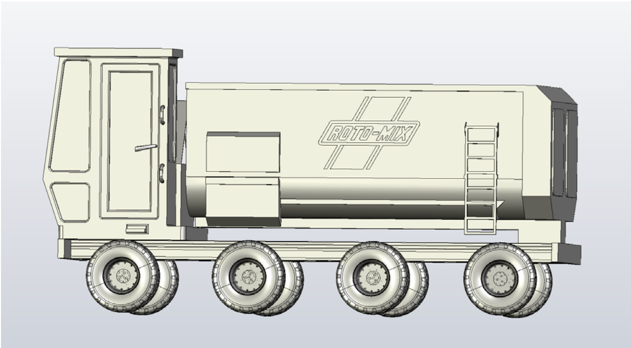
3.2 eDrive™ Methodology

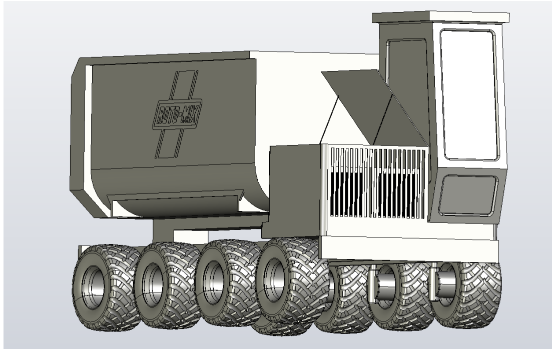
The eDrive™ system has been developed and tested by ATC in its facility in St. Michael, Minnesota, USA. The electronics, motors and generator were designed by ATC and underwent hundreds of hours of testing to help inform the specifications used in designing the Feed Truck.

4 Results

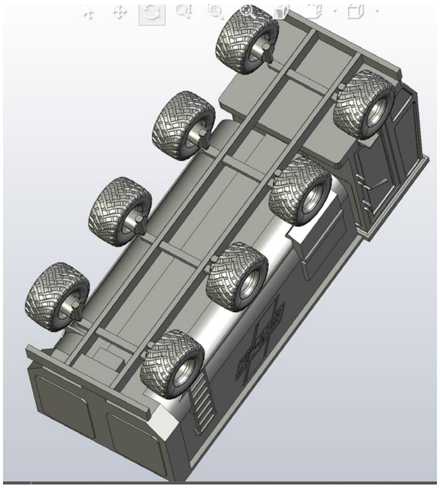
4.1 Chassis

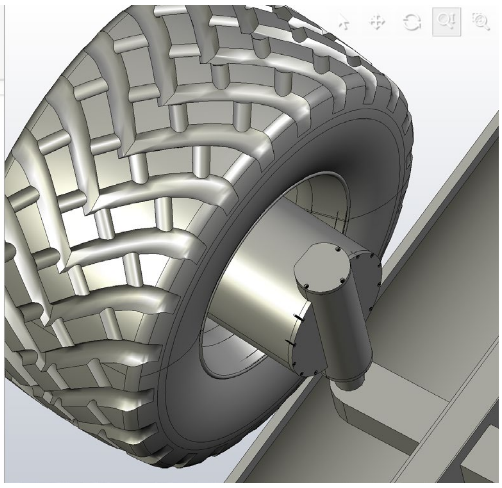
The complete chassis was designed to include sufficient room for the cab, dual engines, generators and mixer unit on top. The use of dual engines is expected to reduce manufacturing costs (see Section 2) and improve efficiency and reliability.



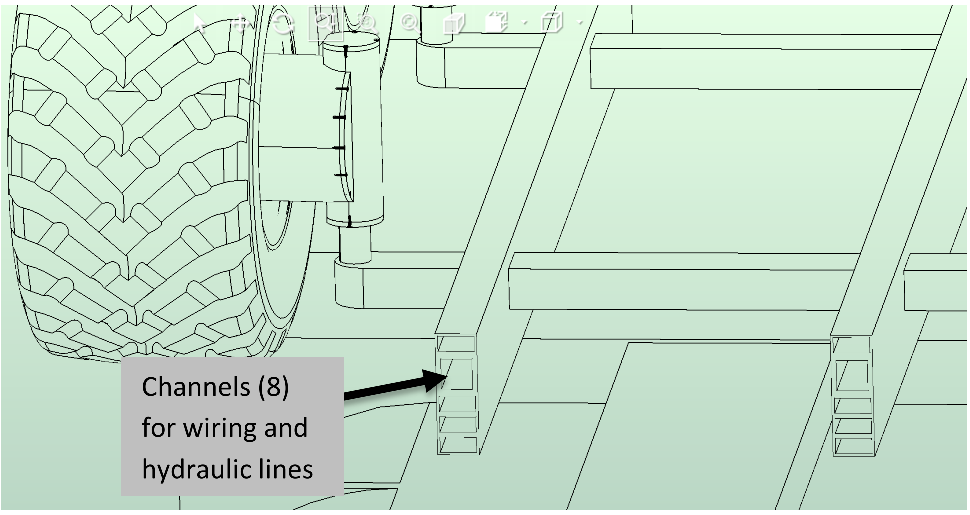


The under-side of the chassis was designed to accommodate the mounting of 8 wheels with ATC's electric eDrive^{TM} motors mounted directly to the chassis. The motors all turn independently, helping to reduce the vehicle's turning radius – very important for larger vehicles working in a feed lot where navigating tight turns can be important for efficiency and safety reasons. The motors also include a suspension cylinder that smooths the ride over uneven roads in the lot.

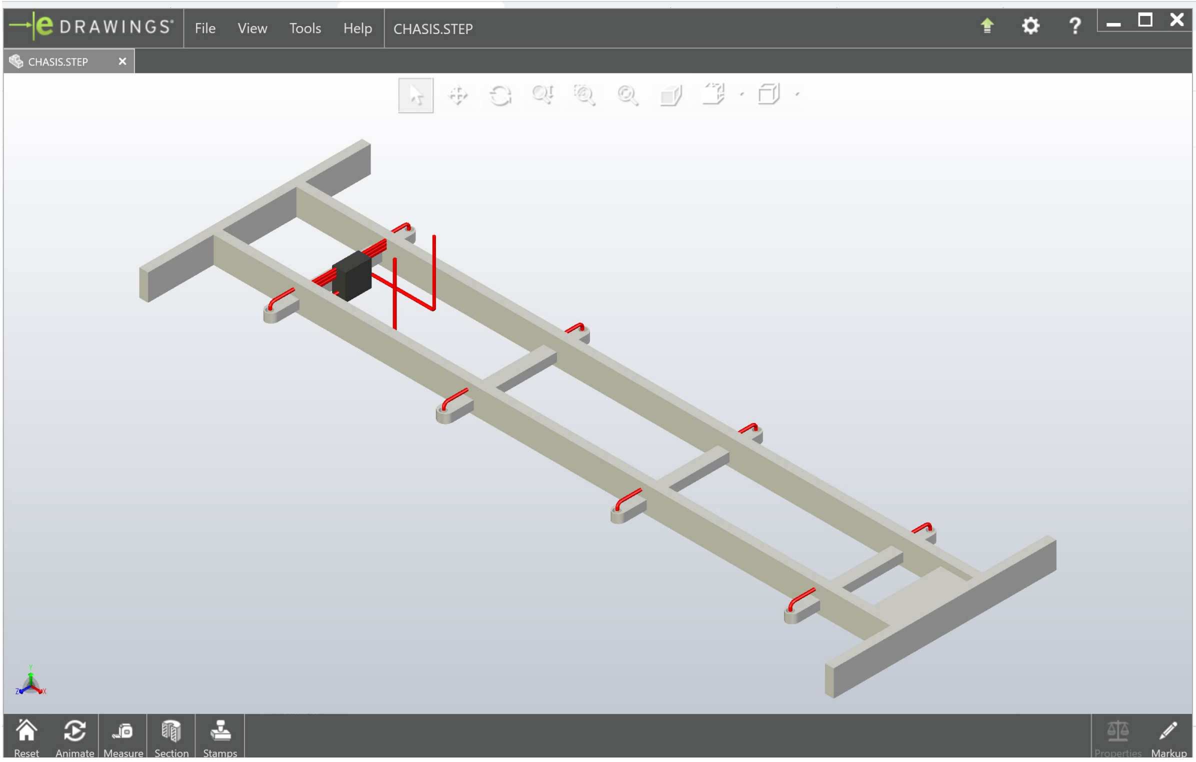




All of the wiring and hydraulic ooling lines are run through the cavity of the tubular steel frame components.

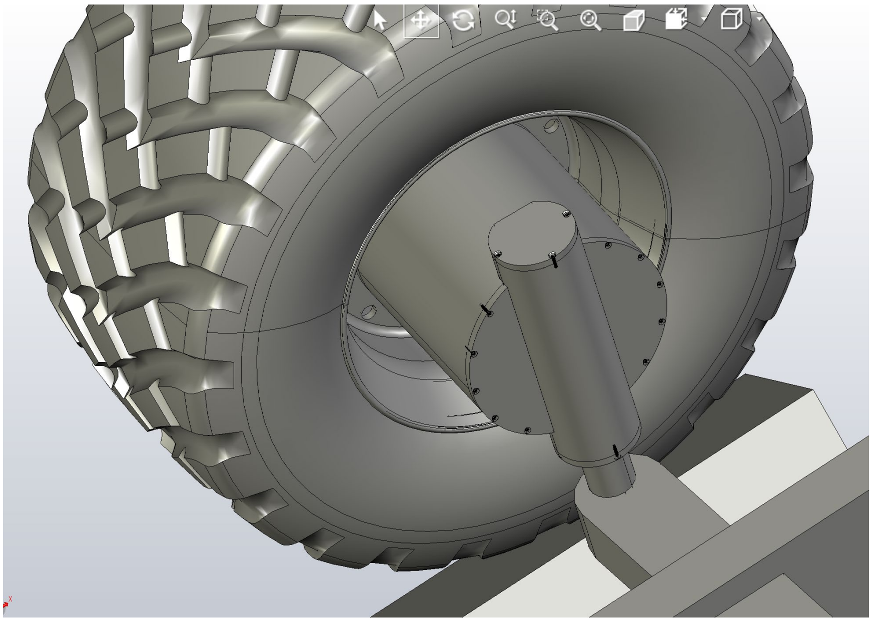


The following diagram shows the routing of the hydraulic and electrical lines from the channels in the chassis to the motor mounts.



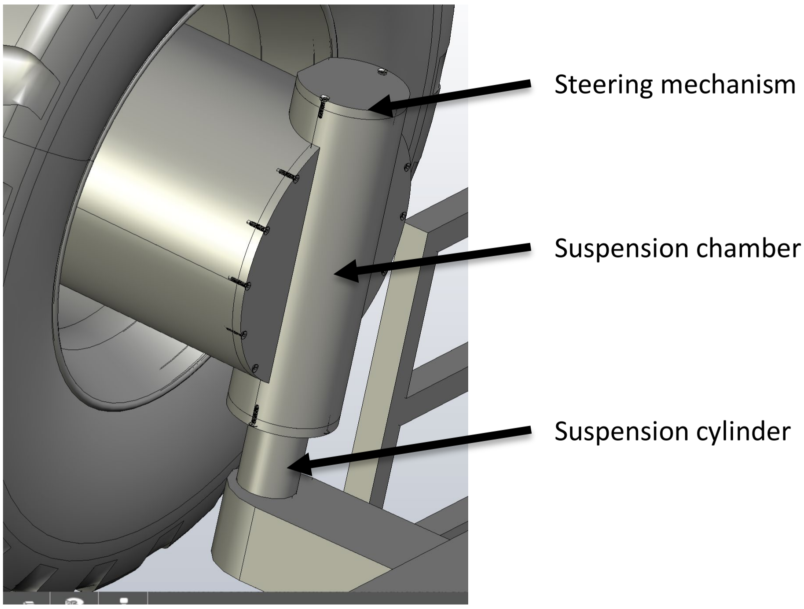
4.2 Motors

ATC's eDrive™ electric motor mounts to the frame and directly to the wheel rim as shown below.

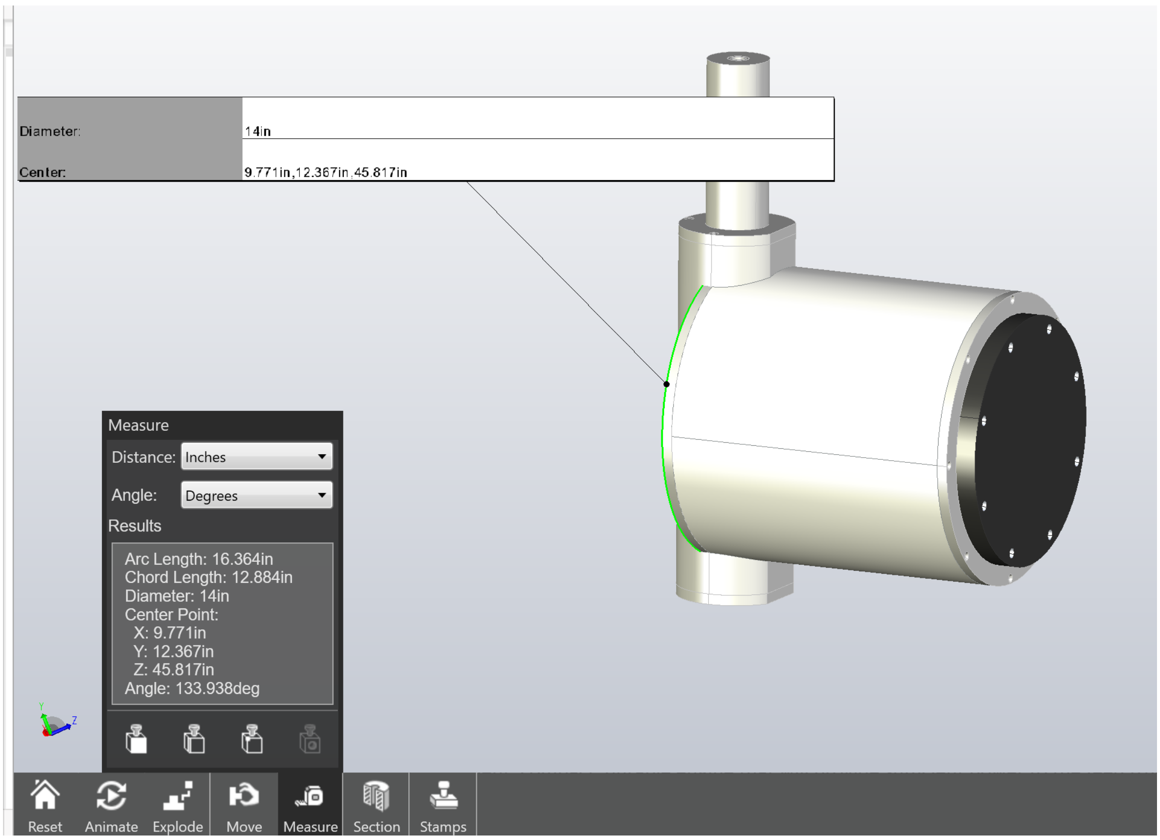


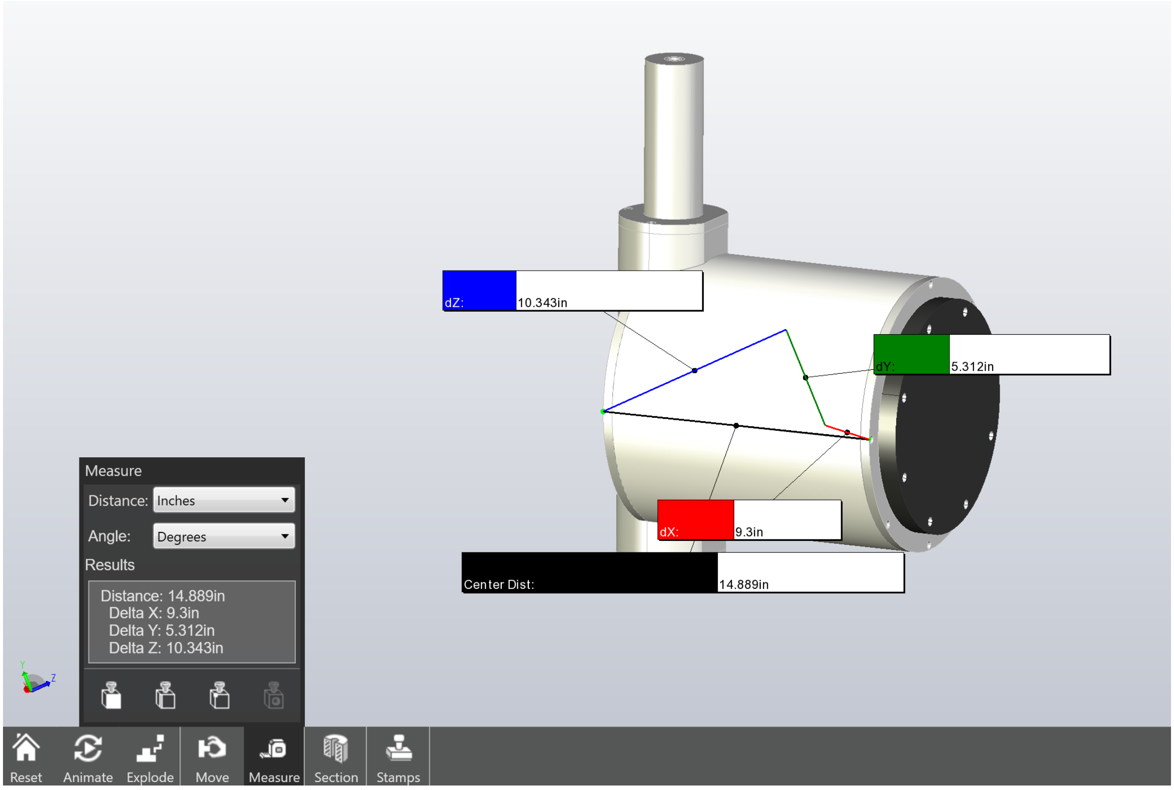
The wheel motor has an integrated suspension and steering system for each wheel. The suspension cylinder has approximately 8 inches of travel using the hydraulic pump inside the wheel motor to push hydraulic fluid into and out of the top and bottom chambers of the cylinder housing.

The steering mechanism also works off of the hydraulic pump inside the wheel motor. Hydraulic fluid is pumped into / out of the left and right chambers inside of the left and right chambers of the steering mechanism that rotates around the suspension cylinder.



ATC's eDrive™ electric wheel hub motor is designed to produce approximately 45 hp continuously and approximately 90 hp for a short period of time (e.g., 30 seconds). The motor measures 14 inches in diameter and is 18 inches long, including the suspension / steering column.

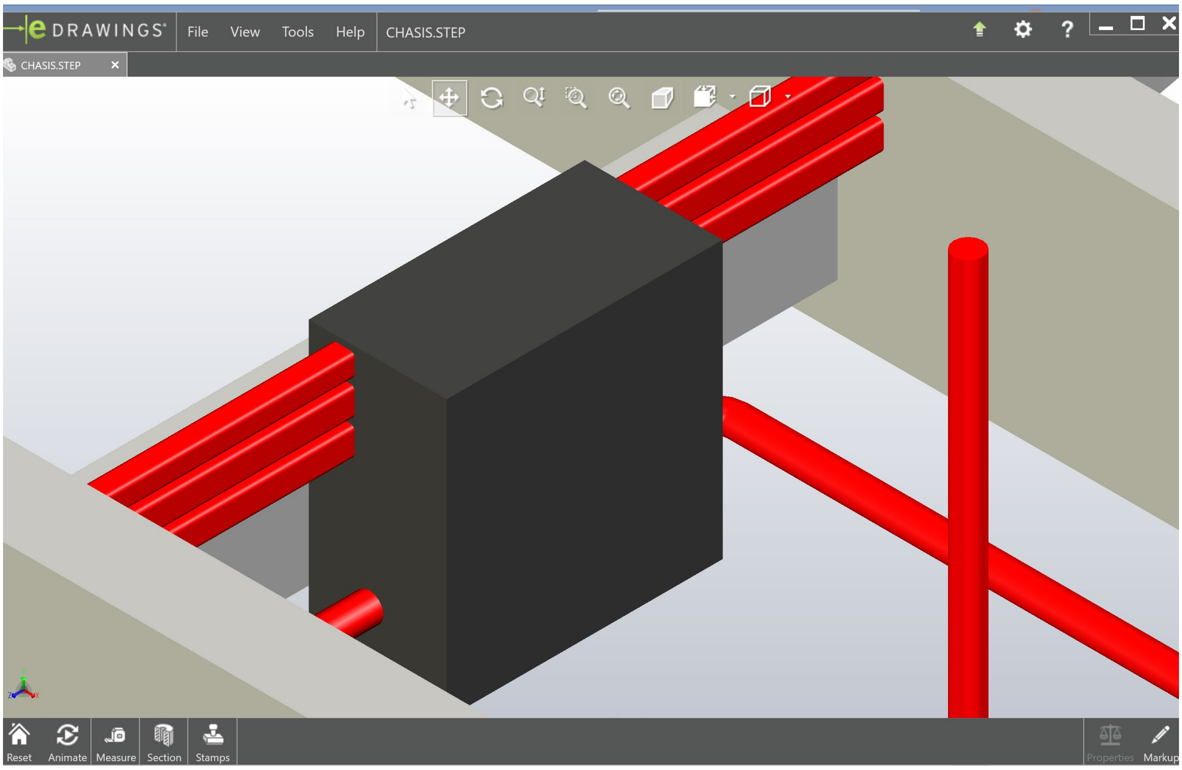




Since the motors' speed is determined by one of the engines / generators and the mixing unit's speed is determined by the other engine / generator the amount of feed dispensed at any position along the bunk can be controlled with tremendous precision. This should help reduce wasted feed and allow for faster feeding compared to a vehicle where a single engine controls both the vehicle's speed and the speed of the mixing / dispensing unit.

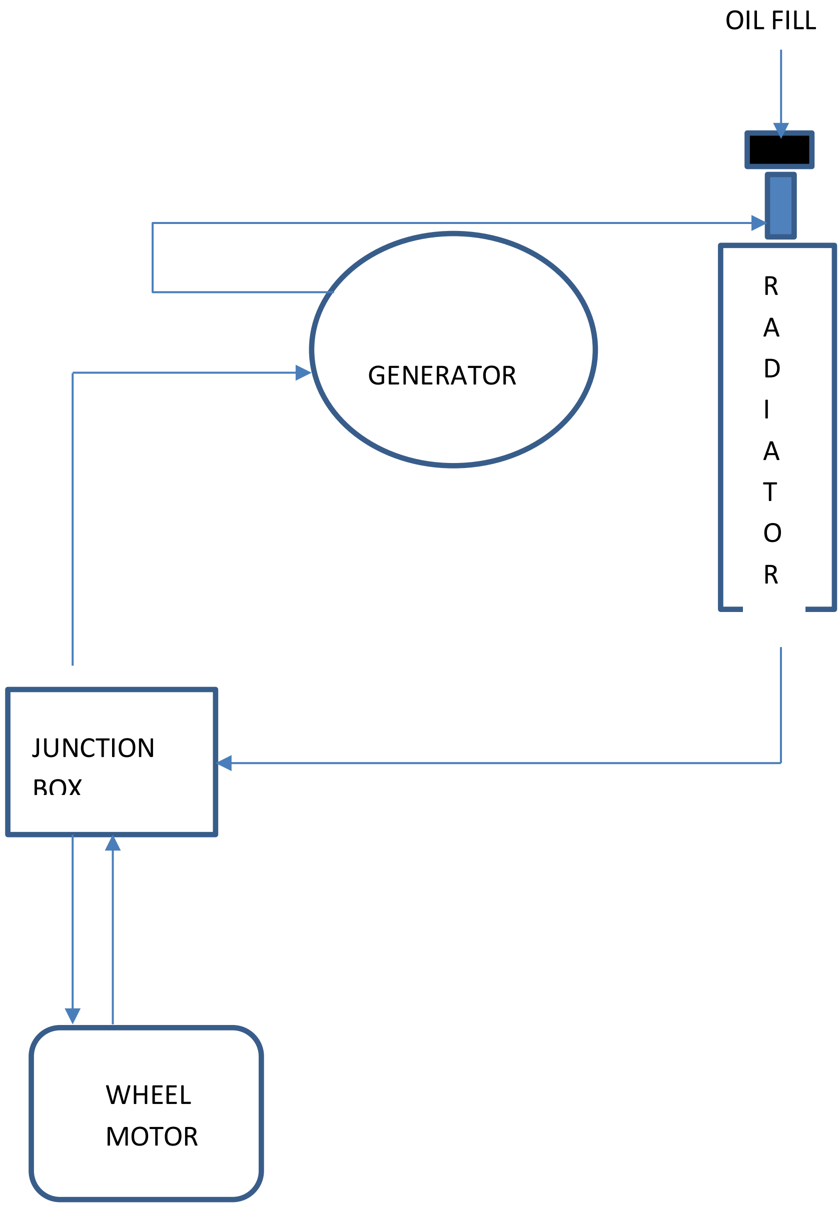
4.3 Electronics and Hydraulic Cooling System

A central junction box sits in the lattice work of the frame. All hydraulic lines for motor cooling / lubrication and electrical wires providing power to the motors run through this junction box.

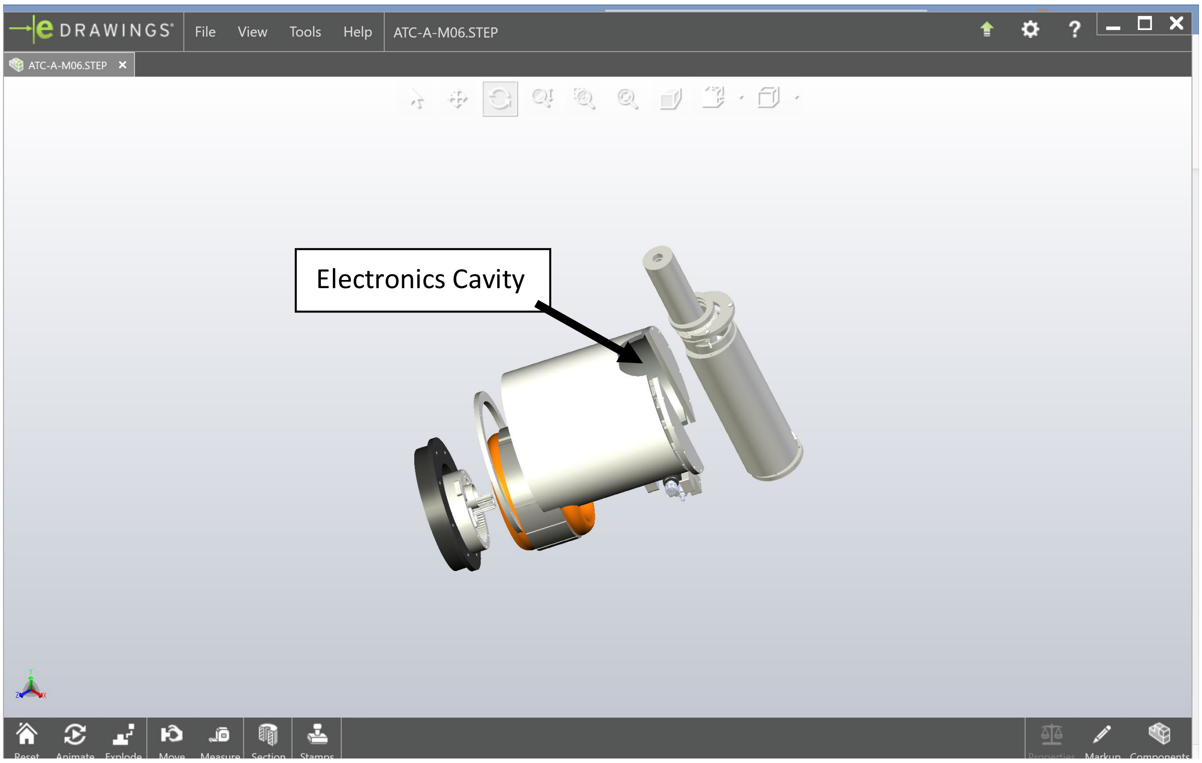


Below figure shows the flow line diagram, which has electric line and hydraulic line in single 1inch conduit. The conduit consists of 4 #16 wires, 6 #10 wires, one 0.5 inch hydraulic line that allow for hydraulic fluid to cool the motors and electronics and to lubricate the motor.

Six wires from each generator are taken into a single conduit which also has hydraulic lines coming from the radiator. All of these hydraulic lines and wires are routed to the junction box. From this junction box a set of wires and lines is routed to each wheel motor being contained within the conduit. High temperature hydraulic fluid from generator goes to radiator where it cools down and then fed to wheel motor via electrical conduit.



The electronics fit into the back of the motor in the cavity shown below. The electronics include IGBTs and two custom printed circuit boards designed by ATC.



4.4 Prototype Budget

The team has selected the major components for the prototype vehicle and got estimates from suppliers for each of these major components. Note: All costs are in USD.

Item	Quantity	Cost
Frame (Chasis)	1	$ 10,000
22.5" Tires and Rims	8	$ 6,000
eDrive™ Wheel Motors	8	$ 50,000
160 hp Cummins Engine	2	$ 17,000
Operator Cab	1	$ 6,600
Roto-Mix 920-18 Mixer (New)	1	$100,000
Electric motors for paddle, auger and dispenser on mixer unit	3	$ 36,000
Wires, conduit, hydraulic hoses and fittings	Multiple	$ 10,000
Machining Time @$125 / hr	200 hrs	$ 25,000
TOTAL		$260,600

The second component of estimating Phase 2 costs is labor. ATC has budgeted for a team of 4 people, some of which will be part-time on the project and some of which will be full-time as noted below. The total time to build the prototype is estimated to be approximately 9 months from start to finish. A high-level calendar of activities follows.

Team

Title	Cost / hr	Hours	Total Cost

Engineering Lead	$145	440	$ 63,800
Engineer	$100	990	$ 99,000
Machinist	$ 50	990	$ 49,500
Mechanic	$ 35	1320	$ 46,200
TOTAL			$258,500

The total cost of the project is estimated by summing up the material costs and the labor costs and adding in estimated overhead of 10%:

Materials	$260,600
Labor	$258,500
Overhead (10%)	$ 48,310
TOTAL	**$567,410**

5 Discussion

5.1 Milestone 1 Objectives

The Objectives for Milestone 1 were to:

- Exchange a fully-executed Contract with MLA
- Initiate the exchange of Project funds compliant with MLA policies and procedures
- Kick off the Project with the ATC team, review the work plan and objectives, etc.

5.1.1 Exchange a full-executed Contract with MLA

ATC worked closely with the MLA team to get the contract drafted, reviewed and signed. MLA visited ATC several times and engaged in multiple conference calls over the course of developing the project proposal. ATC also worked closely with MLA's Project Management team to facilitate project funding in compliance with MLA's requirements.

5.1.2 Initiate the Exhange of Project fund compliant with MLA policies and procedures

ATC also worked closely with MLA's Project Management team to facilitate project funding in compliance with MLA's requirements. The exchange of funds was initiated on 30 August, 2019.

5.1.3 Kick off the Project with the ATC team, review the work plan and objectives, etc.

Project Kickoff: The ATC team gathered and reviewed the relevant materials developed over the course of the last year as the project was being scoped out. The final Proposal was reviewed by the ATC team and agreed on a work plan they believed to represent a feasible means of achieving the overall project objectives within the time and budget constraints outlined in the Agreement.

5.2 Milestone 2 Objectives

The Objectives for Milestone 2 were to:

- Develop high-level CAD model of Rotomix 920 mixer unit;
- Select cab;

- Select generator and engine;
- Complete frame design

5.2.1 Develop high-level CAD model of Rotomix 920 mixer unit

Based on the images from the CAD model presented above the ATC team feels confident that this high-level CAD model can be completed so that the prototyping of the physical feed truck can be completed efficiently. Remaining work to be done in the CAD model include more detailed wiring and hydraulic line routing. This will be completed during Milestones 3 and 4.

5.2.2 Select cab

This has been completed at a high level as per above. Additional work needs to be done to appoint the cab with appropriate functionality for the operator. ATC will work with Custom Products of Litchfield to complete the design of the cab prior to building the prototype in the next Phase of work.

5.2.3 Select generator and engine

The engine has been selected. As per above, it is a Cummins R2.8 4 cylinder, 161 hp Turbo Diesel engine. Two of these engines will be used in prototyping, one for the wheel motors and one for the mixer motors.

5.2.4 Complete frame design

The lattice-work, tubular steel frame has been designed in a way that is very similar to the ATC SPIRIT tractor prototype. Screen shots of the design are presented above.

5.3 Milestone 3 Objectives

The Objectives for Milestone 3 were to:

- Review overall vehicle concept
- Review chassis
- Review motor specifications
- Review controller specifications

5.3.1 Review overall vehicle concept

Based on the images from the CAD model presented above the ATC team feels confident that this CAD model has been developed to the point that the prototyping of the physical feed truck can be completed efficiently. No remaining work has been identified pending review by MLA. It is anticipated that Milestones 4 can be completed quickly after review by MLA.

5.3.2 Review Chassis

This has been completed at a high level as per above. The chassis as designed meets the design requirements of road-ready size and weight; sufficient room for the cab, engines, motors and mixer unit; and structural strength to withstand the requirements of payload and off-road use conditions.

5.3.3 Review motor specifications

The key requirements of the motor were to: 1. Fit inside the wheel hub; and 2: provide sufficient power (approximately 20 hp continuous for each wheel motor). This has been achieved as per the above.

5.3.4 Review controller specifications

While details of the controller are proprietary to ATC the goal of meeting this milestone was to ensure that: 1. There was sufficient room in the cavity of the motor to house the electronics; and 2. The wiring could fit in the chassis cavity, running between the generator, junction box and motor. This has been achieved as per the above.

5.4 Milestone 4 Objectives

The Objectives for Milestone 4 were to:

- Final Report
- CAD design review
- Submission to MLA

5.4.1 Final Report

Based on the images from the CAD model presented above the ATC team feels confident that this CAD model has been developed to the point that the prototyping of the physical feed truck can be completed efficiently. No remaining work has been identified pending review by MLA. This report contains all of the key elements outlined in the Proposal and positions the team well to draft a Phase 2 proposal.

5.4.2 CAD Design Review

The CAD model has been reviewed by both ATC and MLA and was deemed sufficient as the basis for the prototyping work proposed for Phase 2.

5.4.3 Submission to MLA

This report will be submitted to MLA in draft form and, pending feedback from MLA, submitted in final form by January 20, 2020. ATC apologizes that the timing of the project slipped compared to the proposal but the delays have been discussed with MLA and we anticipate having greater control over project timing in Phase 2.

6 Conclusions/recommendations

6.1 Conclusions

The team successfully created a CAD model of sufficient detail that ATC feels prototyping can begin. A preliminary budget and timeline for the Phase 2 prototyping has also been completed.

7 Key messages

7.1 Key Messages

- Producers need to focus on sustainability of red meat production. This includes both environmental sustainability as well as economic sustainability
- Given the increasing scarcity of labor in rural areas not only in Australia but globally attention must be put on reducint human labor in the production of red meat
- Electrification of off-road vehicles such as feed trucks is an enabling technology for both environmental and economic sustainability in the production of red meat as well as other agricultural commodities