University of Southern Queensland

Incitec Pivot Fertilisers

Smart Nurse Tank Concept Guide

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Disclaimer

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Abstract

This user guide contains the workflow and progress of developing an integrated control system which is further embedded in an automated refill procedure from a nurse tank to a sectioned sprayer. The system enables the pumping liquid fertiliser product (Easy N) from the nurse tank into a section sprayer with automated start and stop once the sprayer was filled; allowing the operator to refill fast and safe without the need to exit the cab of the tractor. This report will cover the system developed currently and the goals for future integrations.

The specific architecture and features of the system can be described in three parts; the nurse tank trailer itself with pump and plumbing, the control system that manages the refill process once signalled to do so, and the remote monitoring system for the nurse tank level. The current method of refill is to fill the sprayer in a “top fill” manner through the top hatch via a hanging boom arm, rather than a docked and cam locked fitting.

The automated nurse trailer in this guide is flexible to any section sprayer which can be top filled via its hatch and has no requirements on the type of tractor or machine which is coupled with the sprayer implement. The report has two main sections: one covering the ‘v1’ prototype developed by UniSQ (pictured in Figure 1), and a proposal for a second version suited for commercial use based on the learnings from this project.

Figure 1: UniSQ John Deere 6120R with croplands section sprayer implement and IPF autofill nurse tank trailer

Contents

1. Original design for nurse trailer

1.1 Hardware

The Autofill Nurse Trailer commissioned and outlined in this guide is a prototype development incorporated as part of an automation goal for precision application of fertiliser. The trailer has several notable features including a 7500 L chemical reservoir, a 1500 L clean water rinse tank, onboard 15 kVA 3-phase generator and accompanying 3-phase ~ 3-inch Aussie pump. The pump then connects to a 3-way electric ball valve which either cycles product back into the reservoir or outputs to an installed crane/boom arm to the section sprayer.

Chemical product is filled in the 3-inch inlet while fresh rinse water is filled through the 2-inch inlet. The valves currently installed on the trailer are outlined on the trailer schematic diagram (see Appendix A) can be described as follows:

- Valve 1, selects which liquid tank is fed to the pump, either the chemical or fresh water
- Valve 2, is connected to the pump, allowing selection to either pump through the system or output drain the product.
- Valve 3, is then the electric ball valve connected to the control system, which selects if product should cycle back to the chemical reservoir or pump out through the crane/boom

The output boom has a fitted flow meter inline to analyse the current flow rate to the output, and is utilised in the automation procedure, monitored by the control system. The onboard generator features a 12 V crank start battery which is further utilised in providing power to the overarching control system.

Photos from different angles of the trailer are shown in Figures 2, 3 and 4. A more detailed outline of the steps taken to construct the foundation of the nurse is outlined in Appendix A along with the trailer schematic diagram.

Figure 2: IPF autofill nurse tank trailer with fitted boom arm and 3-phase generator

Figure 3: Autofill nurse trailer 3-phase pump and valves V1, V2

Figure 4: Autofill crane/boom arm, generator, and electronic valve V3 visible in back between generator and rinse tank

1.2 Control systems

This section will outline the control system architecture and the design for the v1 trailer. The original intention for this project was to use off-the-shelf products for the control and automation – however due to difficulties with finding the right product fit the project team opted to design our own from consumer electronics. Appendix items B and C go into detail on what is in the two boxes installed on the sprayer and trailer, and this section will focus on the functionality and purpose of the control boxes as a unit. It is expected (and desired) that an off-the-shelf solution will be found for the v2 trailer.

The autofill procedure involves:

1. The machine reversing the sprayer underneath the boom arm to the fill point.
2. As this occurs, the sprayer hatch needs to be open, allowing the crane/boom to lower itself into the hatch.
3. Once inserted, the “Master” control box onboard the sprayer signals to “Salve” on the trailer. Here, the generator should have already started on the machine’s arrival, and the pump should be running and cycling the chemical product back to the main chemical reservoir.
4. Once the slave receives the signal it will change the ball valve 3 direction; allowing the product to begin filling.

5. Throughout this process the master monitors the sprayer tank level via an installed liquid level sensor, and once filled to a specified level, the master once again signals the slave to return the ball valve to its default cycle fluid mode.
6. Lastly, the generator and pump shut down and the boom arm retracts from the sprayer, the master motor box then closes the hatch, and the operator is ready to continue with the spray task.

This functionality has been demonstrated at the Tosari Crop Research Farm (TCRC), and the entire procedure takes less than 2 minutes to complete. Refer to Appendix B, for a functional overview of the autofill procedure for better understanding of how these control boxes communicate and actuate various process throughout the procedure to fill the sprayer implement successfully and autonomously with a press of a button.

1.2.1 Master control box

The first part of this procedure to automate was the opening and closing of the sprayer hatch, which involved adding a geared 12 V motor with high torque to the master control box mounted on the sprayer. A draw wire was attached to the hatch and linked to a pulley attached to the motor. This pulley was 3D printed in resin, to ensure strength and resist weather conditions and can be seen in Figure 5.

Following this, a submersible liquid level sensor was added to the sprayer tank to allow the “Master” to monitor current levels. Alternate sensors were considered such as ultrasonic but was avoided due to the motor of the sprayer causing too much agitation in the liquid surface during operation. This sensor was installed with a gland on the section sprayer and lowered to lowest most point within the tank. It should be noted that this sensor is 4-20 mA signal output at 24 V and hence required a voltage booster built into the control box along with voltage dividing resistors to convert this signal to a 1-5 V scale. This is further outlined within the master motor box schematic in the Appendix Item B. The master control box is shown in Figure 5.

For the v1 trailer, the trigger for the refill process was set up to be a remote relay board, allowing the operator to press a button to have the entire procedure commence. The current refill workflow from the user’s perspective is as follows:

1. Initial setup of the trailer, by rotating the crane/boom arm into position, setting all valves to the required state, and starting the generator to power the Slave setting valve V3 to default and letting the product cycle until the procedure commences. (From here the trailer can be left unattended)
2. The operator then reverses the sprayer implement underneath the fill-point and presses “button 1” on the remote relay key fob to open the sprayer hatch. Here the operator raises the 3-point linkage which attaches the sprayer implement to the tractor to insert the boom into the hatch fill-

point, rather than an automated lowering/retracting of the boom with a linear actuator as depicted in the flow chart.

3. Once aligned, the operator presses “button 2” on the remote relay key fob to have the Master signal the Slave to begin the fill. Once received, the Slave triggers the ball valve to begin filling the sprayer implement.
4. Once full to the desired level, the Master control box signals the Slave to stop the fill, and the Slave then triggers the ball valve V3 back to default position. Here the operator waits a short delay for the boom to finish draining remaining product before lowering the 3-point linkage, rather than the Slave monitoring the flowmeter and automatically extending the actuator once at 0 flow.
5. Lastly, the operator drives forward, presses “button 1” again to close the hatch and they are ready to begin spraying.

The design is compatible with full autonomy however with the use of a different trigger condition based on GPS position or other autonomous machine processes. Options for more sophisticated triggers for the system will be revisited in Section 2.2.

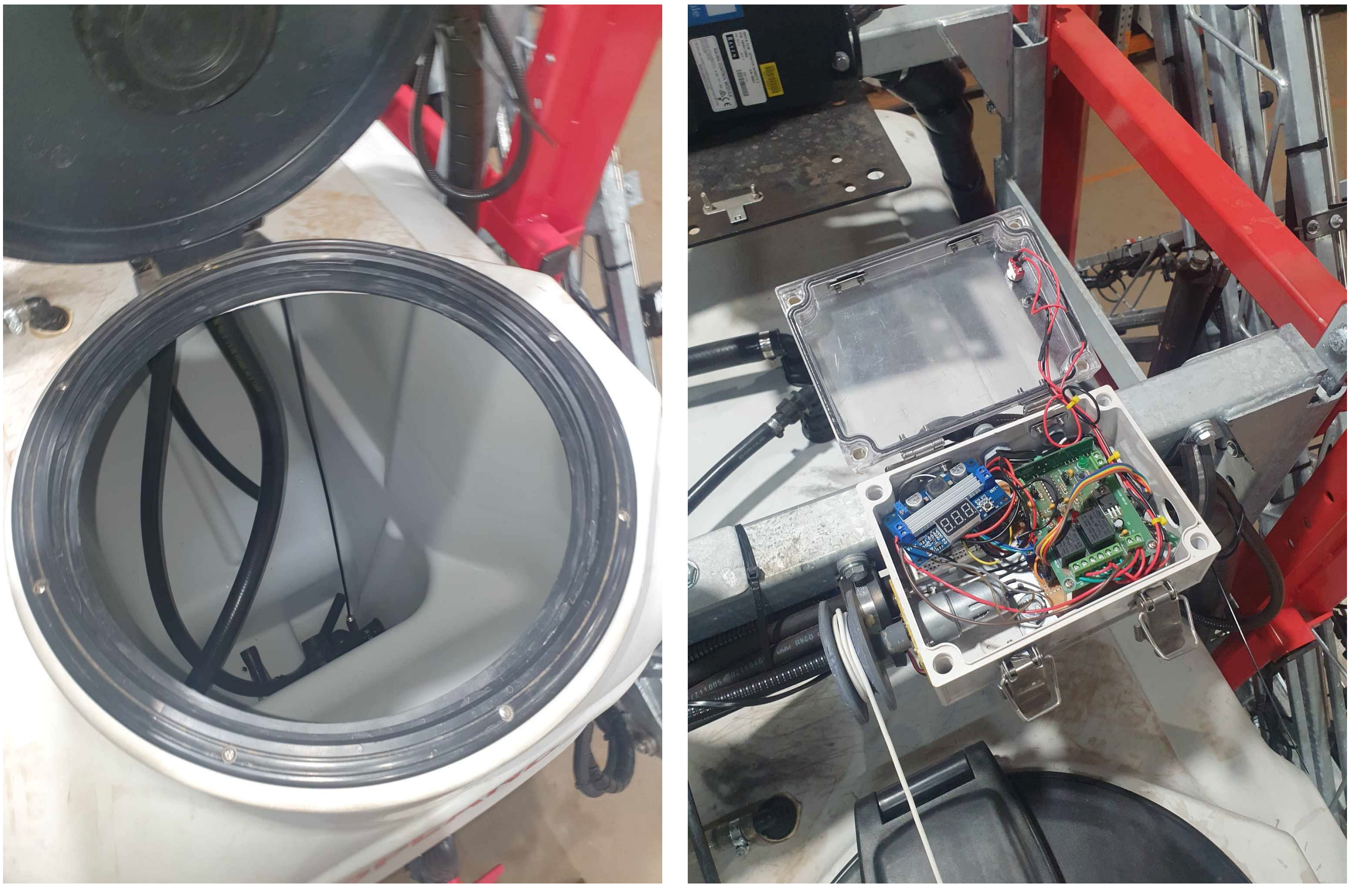

Figure 5: Open Sprayer hatch with submersible liquid level sensor inside tank (left) and MASTER control box (right)

1.2.2 Trailer slave controller

The second half of the automation procedure required a Slave controller to be assembled and installed on the trailer. This Slave currently only actuates the electronic ball valve 3, with other modules such as a linear actuator and the flow meter to be added. The control circuit for the Slave is much simpler, with the same Arduino Nano microcontroller for logic control, NRF24L01 2.4GHz wireless module for communicating with the Master Box and is powered from 12 V supplied from the generator crank start battery. It is also worth noting that the generator battery is closer to 14 V when the generator is running due to the alternator feed during operation, because of this an LM2940CT 12 V regulator and fuse are added to the circuit to provide a stable voltage and protect the components which can be identified on the schematic in Appendix B.

For automating the valve, the controller is connected to an internal relay module which switches 12 V supply to the valve allowing it to rotate. This module is also connected to a toggle switch allowing manual override control to the ball valve.

A full control flow of the master and slave boxes in operation is provided in Appendix C. Arduino-C code for the master and slave controllers is provided in Appendix D and E respectively.

1.3 Remote monitoring of tank level

Alongside the Slave controller, an EcoSat GOLD has been installed on the trailer which is connected to a submersible liquid level sensor in the main chemical reservoir. This separate controller reads the liquid level and reports its data via satellite to an online platform. This feature has been installed to eventually allow alerts to the operator and eventually the chemical product provider that the trailer chemical supply is running low/empty. Figure 6 presents the assembled Slave control box on the trailer along with the EcoSat GOLD.

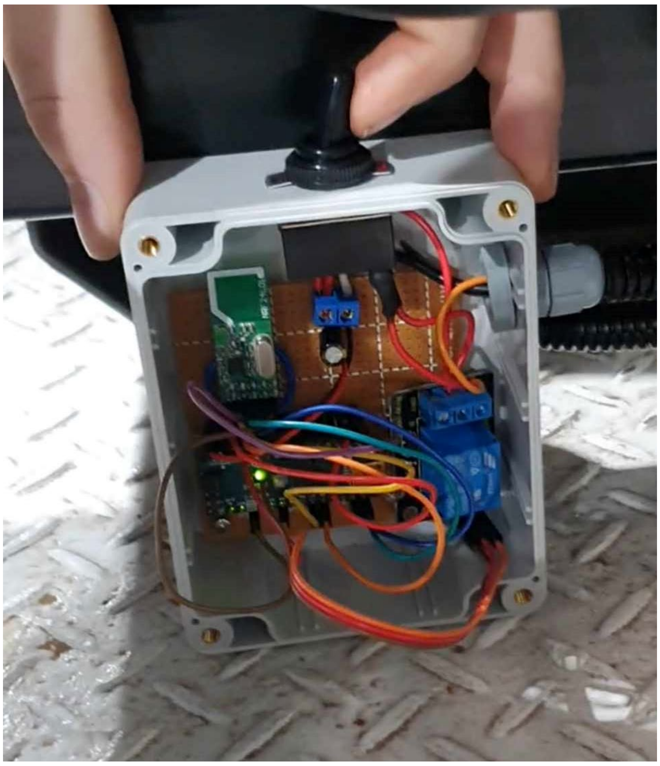

Figure 6: Trailer Salve control box connected to the 3-inch electronic ball valve (left) and EcoSat GOLD with liquid level sensor (right)

The EcoSat GOLD is a commercial of-the-shelf IoT monitoring device procured via *Station Innovation*. There are various models each with different features, however the main purpose of the EcoSat GOLD is to provide its data via satellite. The device can be connected to 4-20 mA sensors such as a submersible liquid level sensor for this application. The sensors will require manual calibration to work in this scenario as they are primarily used in water, and as such will need to be adjusted to the specific gravity of the liquid fertiliser product which is approximately 1.32 for Easy N. This calibration can be requested and configured prior to purchase. Lastly, the sensor outputs data measured in the form of millimetres, and so if volume of liquid was desired a mathematical calculation could be implemented on the IoT backend to convert the height sensor reading to a volume (this would be specific to the dimensions of the chemical reservoir utilised, which in this project the tank has a length of 3 m, horizontal diameter of 2 m, vertical diameter of 1.5 m). An example formula which is suitable for the reservoir used in this project to calculate the volume of liquid in a horizontal tank with oval ends based on the measured liquid height (h) is derived from the formula for the volume of an elliptical cylinder:

$$V = \pi h \times \left(\frac{R_1 R_2}{2} + \frac{h(R_1 - R_2)^2}{2R_1 + (R_1 - R_2) \times \sqrt{4h(R_1 - R_2) + h^2}} \right) \times L$$

Where; V = volume of liquid inside the tank

L = tank length $\approx 3000mm$

R1, R2 = tank radius of oval shaped ends $\approx 1000mm\ and\ 750mm$

h = sensor measured liquid height

The EcoSat GOLD was tested with various tank capacity levels and manually checked with a dip-stick for accuracy assessment and calibration checking. Measurements were gathered at various volumes via filling the tank and gradually draining. EcoSat results were obtained by monitoring the analog value reported by the submersible senor utilising proprietary config software provided by EcoSat for calibration usage on this project. The analog values are transformed into a height measurement (mm) using the following formula:

$$Depth(mm) = \frac{ADC - 820}{3276} \times 3000$$

The EcoSat internal ADC (Analog Digital Converter) is 12-bit with a scale of 0-4095 @ 0 – 20mA.

The Sensor outputs an anolog signal between 4 – 20mA, with a depth scale of 0-3m maximum.

This means that at an empty liquid level the anolog value read is approximately 820. The formula implemented within the EcoSat is therefore taking the current analog level measurement, minus the initial zero value, divided by the total analog measurable range, and multiplying by the sensors maximum measurable height (mm). Table 1 shows the results of an experiment to assess sensor accuracy using the two formulas and the EcoSat config software to measure the ADC value.

Manual measurement of height was gathered with a dip stick and have been utilised for accuracy assessment. Manual volume was approximated from the level markings on the side of the tank so are simply a rough estimate. Overall, the type of sensor solution attached to the EcoSat has error between 10-15mm which can be assumed to be the approximate height that the sensor is raised off of the exact bottom of the tank. This can be added to calibration via subtracting this small difference, and additional calibration should be considered when working with liquid fertiliser product instead of water. Easy N liquid nitrogen fertiliser has a specific gravity of 1.34, which would reduce the maximum measurement range of the sensor from 0-3 m to 0-2.25 m. With these considerations in mind, an API can be obtained for the EcoSat module or an alternative device, allowing data forwarding to a wide range of online IoT platforms for data visualisation and future manipulation utilising this mathematical formula.

Table 1: Open Sprayer hatch with submersible liquid level sensor inside tank (left) and MASTER control box (right)

Manual Measurement		**Sensor Calculation**			
Liquid Height (mm)	Volume (L)	ADC Value	Liquid Height (mm)	Volume (L)	Error (mm)
1445	7000	2386	1434	6959	11
1125	5500	2033	1110	5608	15
710	3000	1581	697	3216	13
365	1000	1201	349	1248	16

Once appropriately prepared, a similar formula could be implemented on a backend IoT platform for automatic calculation and data presentation to both the end-user and chemical product provider to provide frequent insights.

1.5 System and Component Cost

The costings the v1 trailer is as follows (all values are approximate):

- Base trailer — $0 (supplied by IPF)
- Main tank, pump and valves/hoses/fittings — $36,000
- Secondary rinse tank + labour and fittings — $7,000
- Generator — $10,000
- Control systems + remote monitoring system — $5,000 + $50/month for satellite IoT
- Total — $58,000 + cost of trailer

2. Changes for a production-ready smart nurse tank

Feedback for a revised version of the sprayer was collected primarily from within the project team over the course of the project but also from growers at a field demonstration in September 2023. The point of feedback are divided into (i) critical changes without which the trailer won't be a suitable product, and (ii) desirable changes that while beneficial, won't make or break the trailer. The suggestions are detailed under the same section structure as Section 1 (hardware, control system, remote monitoring system), but at a high level:

Critical changes:

- The trailer must be able to receive product into the main tank without the use of an external pump. This will require revising the plumbing configuration of the trailer.
- The main tank must have a sump pump and additional valves if necessary to facilitate fully emptying the tank and easy cleaning.
- The boom arm needs an actuator to move it into position or adjust it to different fill heights for different spray tanks.
- The pump engine model needs to be revised to be fit for long-term use (initial selection was underpowered).
- Connect flow meter and integrate into product monitoring and control system.

Desirable changes:

- Hosing: repositioning of the valve and pump might allow for a significant reduction in hosing length
- Redirecting the tank level data from the IoT providers backend to a database/website controlled by IPF
- Finding an off-the-shelf controller to use in the control system
- Adding remote start functionality to the generator or engine
- Revise the boom arm to be a single piece of pipe/hose
- Revise the positioning of the main and secondary tank to better distribute load on the trailer
- Enact some form of quality control checks for the fitting and brackets to make sure that the trailer is assembled to last

IPF personnel took some photos of the problem areas on an inspection in late 2023. The presentation will be on IPF's project folder, but has been added as Appendix G.

2.1 Hardware

The following list has focused on specific components onboard the trailer itself which would improve its usability and ease of operation.

1. The chemical reservoir needs to have an installed sump underneath to ensure that all primary chemical product can be drained from the tank. This would also make cleaning and rinsing the tank far easier with a more reliable drain.
2. The onboard pump can be changed to a petrol pump (i.e. Aussie 3-inch Honda petrol pump) to remove the 3-phase generator from the design entirely. This further improves onsite troubleshooting as an electrician will not be required for servicing, and also reduces the total weight distribution on the trailer. Pump will require remote start as a mandatory feature.
3. If the generator is removed, add a 12V battery and solar panel to keep the control system operational and charged. Investigation into specific control system utilised will be required to determine total power consumption to spec a suitable solar panel to ensure constant charge rates.
4. Relocation of the features on the trailer bed to re-distribute the weight during transport should be investigated with the removal of the generator.
5. Add a 4-way valve on the pump such that the fill points can be connected to the onboard pump rather than requiring a separate pump onsite when filling the nurse trailer with product.
6. Redesign the plumbing circuit to condense the total length of required plumbing such that less product is left idle in the lines, also move the electronic valve closer to the boom arm to reduce overflow from the system once a shut-off is triggered by the control circuit.

2.2 Control System

The current v1 prototype system is a custom-made microcontroller circuit utilising the Arduino technology stack. While this is a functional solution, it requires in house assembly and programming, see Appendix B for a detailed description of the control circuit design. Moving from an Arduino prototype to an industrial PLC (Programmable Logic Controller) is a significant step in terms of reliability, scalability, and robustness. PLCs are designed specifically for industrial applications and offer several advantages over Arduino in terms of durability, real-time operations, and industrial connectivity.

PLCs built for industrial environments offer better resistance to harsh conditions such as temperature variations, electrical noise and vibrations and excel at real-time operations which are crucial for the scenario of fast automation. PLCs are available in a wide range of sizing and capabilities which further promotes scalability to complex situations and often support a wide range of industry communication protocols such as Modbus or Ethernet/IP. Arduino was a suitable prototype solution and a great for this purpose due to the microcontrollers access to an array of these communication protocols (SDI-12, SPI, I2C, Analog, Digital, there are many I/O options). An industrial PLC that is chosen for this specific task could utilise this range of comms options for its sensors and wireless control i.e. the possibility for CANBUS if it were desired to be integrated with the tractor, but if it were planned to be used with various sprayer implements or on various different tractors, rather than integrating with CANBUS could possibly be kept all in-box on the MASTER such that it can be used anywhere on any system.

An additional consideration is that PLCs typically utilise specialised or proprietary software (often ladder logic or function block diagrams) that simplify the programming for the logic control process. This would require a redesign of the control code but could be designed for the specific system and provided to a user or grower pre-assembled and ready to go as an “off the shelf” solution.

Siemens, Allen-Bradley (Rockwell Automation), Schneider Electric, and Mitsubishi Electric are among the leading PLC manufacturers, each offering a range of PLCs suitable for different industrial needs. Other brands like B&R Automation, WAGO, Advantech and Beckhoff Automation also offer industrial-grade solutions that could serve as replacements for Arduino in industrial settings. These brands provide PLCs and industrial controllers designed for robustness and reliability in industrial environments while maintaining a degree of flexibility and ease of use. Beckhoff in particular offers a range of products, including their TwinCAT software platform and control systems which utilise PC-based control technology, combining software and hardware for automation.

Final considerations for the control system are features originally desired for the overarching workflow designed for v1 as outlined on the flowchart in Appendix C. These features include:

1. Add remote start to the generator or engine and use either another in-cab button or location tracking as the trigger for the remote start.
2. IoT device needs to ping the backend application for multiple parties to assess the current product remaining and alert when empty or need more product. This could further be added to a mobile application such that the operator could access this information from the cab which would be useful for added sensory features.
3. Add the linear actuator to raise and lower the boom in replacement of the fixed steel box-section. This installation would require specific pinout I/O on the control PLC.
4. The flowmeter cutoff signal needs to be connected to the PLC to auto raise the boom arm and signal the hatch to close once filled rather than the operator doing this themselves via the 3-point linkage.
5. The sprayer hatch needs a more powerful motor built in on the hinge which the MASTER PLC on the tractor can control.

2.3 Remote monitoring setup

The current v1 system utilises satellite connectivity to monitor only the liquid level of the chemical reservoir, and the conclusion for now though is that the EcoSat GOLD would still be appropriate for the v2 trailer. However, if more sensory units were to be installed on the trailer for monitoring other parameters alternate IoT solutions can be investigated.

Options include radio LoRaWAN IoT monitoring, Cellular connection, or Wi-Fi 2.4/5GHz. Regardless of the choice, the connection to the internet requires fast and frequent updates. LoRaWAN is common feature adopted already by many growers and there are many alternative liquid level monitoring devices offered that can be installed in replacement of the EcoSat GOLD such as the *Milesight EM500-SWL* to name one example. Cellular is a great solution if the site has no access to LoRaWAN and has significant cell coverage, and depending on the trailer location could also be setup with onboard Wi-Fi connectivity.

Additional steps desired for a new version of the nurse tanka are to:

1. Set up a backend service that draws data from the EcoSat API. IPF can then manipulate, store and control the data freely.
2. Provide options for users to set up the product level conversation from millimetres high to litres based on several common tank shapes. An example formula was used for the v1 trailer in Section 1.3.
3. Investigate how the tank level numbers can be used to improve area-wide product logistics and autonomous product requests.

Appendix

Appendix A: Nurse trailer system schematic and plumbing

The trailer chassis itself was provided by Incitec Pivot and is a simple 2 axel bare chassis dog trailer which features standard ABS braking and ring tow hitch for easy transport and an approximated capacity of 14 tonne, with a bare deck dimension of approximately 5.5m x 2.4m raised 1.3m high.

Mounted to the bed of the trailer via high tensile bolts with underside square steel section for strengthening support are two liquid reservoirs. The larger tank is 7500L capacity with the purpose of being the main chemical storage on the nurse trailer, with the secondary smaller 1500L tank simply to supply onboard fresh water for rinsing, cleaning, and safety. Both of these tanks are clear polymer and have individual fill points, 3-inch cam lock to the chemical tank and 2-inch cam lock on the clean water tank. Furthermore, all plumbing routed from the main chemical reservoir are 3-inch lines to achieve high flow rate for efficient and fast autofill procedure. Between each junction along the plumbing circuit all hoses have been fitted with cam locked fittings and adaptors (i.e. 3” Cam to 3” BSP), which allows all sections to be easily removed and serviceable or for future alternate configuration and improvement.

All valves installed along the pumping circuit are Banjo Ball-Valves, with stubby manifold valves at the inlet fill points and a combination of side/bottom load 3-way ball valves along the circuit to the boom arm. During commissioning at *The Spray Shop Toowoomba,* custom housings were fabricated out of steel to mount the various valves and plumbing on the underside of the trailer as seen in figure 3 above. The boom arm was implemented by installing a hydraulic utility crane on the trailer chassis with high tensile bolts and steel square box section underneath for strengthening support. The hydraulic ram was desired to be replaced with an electric linear actuator rated to the weight load of the boom arm but for initial prototype testing was instead replaced with a fixed length of steel to keep the boom at a fixed horizontal position. The crane itself was extended 3m with more steel such that the fill point when the crane was swung out from the trailer is a safe distance away from the trailer itself, reducing risks for the operator during reversing. Plumbing along the boom was installed with a 4m length of 3” rigid poly pipe and attached with P-clamps. Flexible 3” hose was utilised to connect the boom to the flow meter installed below, allowing the boom to rotate freely without any hose kinks as can be seen in figure 4 above.

A 3-inch 3-phase electric Aussie pump was installed on the under side of the trailer to act as the primary pump for output flow through to the boom arm and sprayer. This pump has an accompanying 3-phase generator mounted on the back of the trailer which features forklift points allowing it to be easily removed. 3-phase power cable has been routed through electrical conduit and securely fastened to the trailer chassis with saddles. Power from the 12V generator crank start battery has been accessed for delivering stable power to the flow meter, control box and EcoSat IoT monitor when the battery isolator is switched ON, with inline fusing to all devices and power regulators to avoid surges in voltage during generator startup. Details on the electrical system and the control circuitry have been outlined in flowing sections.

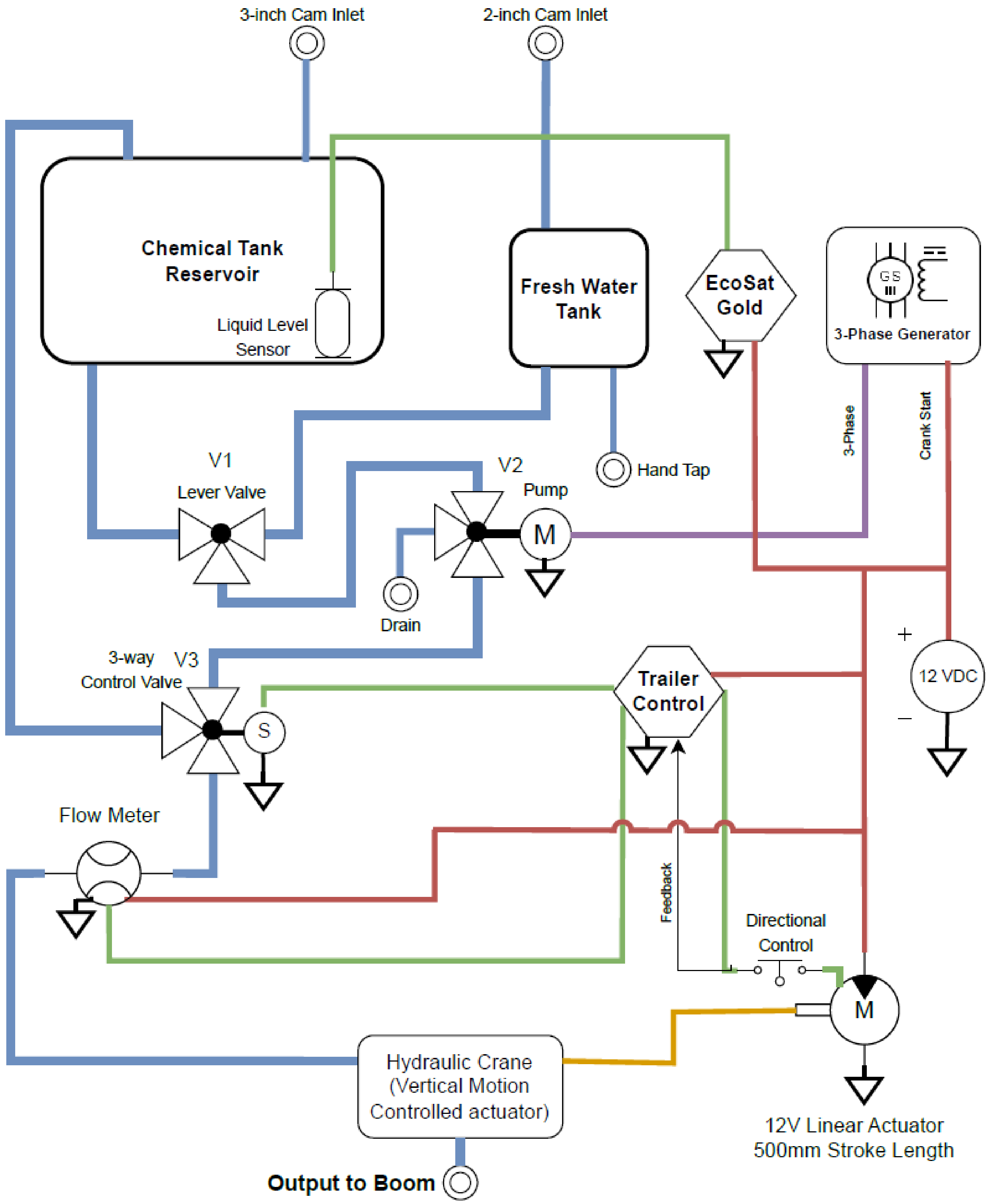

Figure 7: IPF autofill nurse trailer plumbing and components diagram

Appendix B: Control circuit design

The design and assembly of the control box circuits are currently configured on prototyping Vero board with all components soldered and routed with wires. As further discussed in section 4, there are several improvements and recommendations to the hardware utilised and the format in which it is designed. A brief explanation of each major hardware component utilised, and the construction of these control boxes is provided in section 2.1. Refer to the provided circuit schematics, attached table of components and their specific part numbers to locate datasheets and additional information. A vast majority of all components assembled in these boxes can be sourced from "Jaycar Electronics" retail or various online electronics distributors.

Components such as the Arduino Nano microcontrollers, and the NRF24L01 2.4GHz wireless modules have been connected to the circuit via female-header pins. This allows the modules to be easily removed for testing, or replacement. Other modules such as the 5V relay board in the trailer Slave box, have been connected simply via header pin cables directly to the Arduino Nano. The Arduino logic program code for both control boxes is provided in the appendix, *see items D and E*.

Hardware Components

NOTE: All part numbers are referenced to Jaycar Electronics

Component Name	Part No.	Qty.	Description
Arduino Nano	XC9206	2	The Nano is a microcontroller board based on the ATmega328, and these boards are used as the logic processors in both Master and Slave control boxes.
12VDC Remote 2-way Relay Module	LR8855	1	A pre-assembled dual relay module with 433MHz remote control. Powered from 12V, this board is switching a 5V supply from the Arduino in the Master to trigger certain functions within the code, such as opening the hatch and starting the fill procedure.
5V Relay Module	XC4419	1	A simply 5V relay triggered from a digital output on the trailer Salve Arduino for switching the ball valve V3.
DC-DC Voltage Boost Module	XC4609	1	3-35V input to 4-35V output voltage boost module with segment display. This module is used to boost the 12VDC supply to 24VDC for powering the submersible liquid level sensor in the croplands section sprayer.
NRF24L01 2.4GHz wireless transceiver	XC4508	2	This transceiver IC allows 2-way communication between the Master and Slave Arduinos on the license free ISM band. Powered from 3.3V supplied by the Arduino with added decoupling capacitors. Features SMA connection for external antenna.

L293D IC Motor Driver	ZK8880	1	The L293D is a quad half H-bridge motor driver, capable of driving 2 x DC motors. It is utilised in powering the hatch motor and controlling its speed and direction via connection to the Arduino controller.
36RPM 12VDC Gearhead Motor	YG2734	1	12VDC powered and controlled from the L293D, this motor drives at 36RPM with a maximum torque of 14kg.cm, for opening and closing the sprayer hatch. Attached to this motor is the 3D printed pulley which winds the draw cable.
LM2940CT-12 12V 1A Voltage Regulator	ZV1562	1	A voltage regulator rated to 1A for providing a stable 12VDC supply to the trailer Salve controller due to generator crank start battery >13.8V.

While the table provides a list of the major components and their function within the system, there are various consumables utilised in the construction and assembly of these control boxes, including cable glands for routing the external cables from the liquid level sensor, power, and valve; IP67 waterproof ABS enclosures; toggle switches; and an array of screws, PCB standoffs, screw terminals, capacitors, resistors, fuses etc.

There are several other notable pieces of hardware information worth considering that has been gained throughout the construction and electronics design process. The initial design had planned to utilise a NEMA17 stepper motor with accompanying A4988 stepper driver. It was later discovered that this type of motor did not provide sufficient torque to lift the weight of the sprayer hatch. Additionally, prior to upgrading the motor to a slower RPM and higher torque gearhead DC motor, the stepper configuration was tested with a belt driven geared pulley system which also over stressed the motor.

There were two submersible liquid level sensors initially procured alongside the EcoSat devices from Station innovation. One of these devices was installed with the EcoSat GOLD on the trailer for chemical reservoir monitoring, while the other was adapted to communicate with the Arduino Nano in the Master control box mounted on the section sprayer. Due to the submersible sensor requiring +24 VDC a voltage boost module is used in the circuit to upscale the 12V supply to the box. To adapt this sensor to the Arduino logic controller, the signal required conversion to a scaled voltage to then be fed to an Analog input pin on the Arduino.

Submersible Level Sensor Specifications: +24 VDC, 4-20 mA output, 0-3 m measurement range.

Converting the output signal can be achieved with a resistor dividing network.

$$R_{max} = \frac{V}{A} = \frac{5}{0.02} = 250\Omega$$

This resistor is connected between the output signal from the sensor and ground to convert the signal scale from 4-20 mA to 1-5 V. The closest E24 value of resistor is 240 ohms and has been used in the circuit and can be seen in the schematic in section 2.2. An additional $10\ k\Omega$ resistor is incorporated inline with the input signal to the Arduino to limit current flow and protect the ADC input on the Arduino. With this resistor the sensor input signal is converted to:

Level Sensor: 4-20mA, connected to 240Ω

$S_{LOW} => \ V = IR$	$S_{HIGH} => \ V = IR$
$V = 0.004 \times 240\Omega$	$V = 0.02 \ \times 240\Omega$
$V = 0.96\, Volts$	$V = 4.8\, Volts$

Now the signal is: 0.96 V – 4.8 V $\approx 1\ to\ 5V\ Scale$

Note: When the tank is empty the sensor will be read at approximately 1V, which is important for the logic control code. The analog input pin reads an along value from 0-1023 which can be mapped to a scale of 0% to 100%. When empty the analog pin will read approximately 20% due to a zero reading relating to 1 V (i.e. 1 V is 20% of the 5 V measured range).

Sensor level range: 0-3 meters

When the sprayer tank is full the reading is approximately 1.6m and using this, we can determine the cutoff value of approximately 51% from the sensor that the logic controller will need to trigger the TRAILER SLAVE to shut off the pump and fill process. This functionality of the automation system can be seen in the attached Arduino logic control code, *see Appendix D and E.*

Lastly, it is worth noting that the Master control circuit when tested has a maximum power draw of approximately 600 mA at 12 V. This value was read with the sensor powered and providing input signal, and the hatch motor running. The motor was the largest power draw on the circuit and as such has an added 800mA fuse to the L293D driver. The 12 V power for the Master box is supplied from a cigarette lighter port within the tractor cab, and the plug is fused to 4 A (This could be further reduced to 1 A). The trailer Slave controller pulls a negligible amount of power and is connected to the generator battery with an inline 2A blade fuse.

“MASTER” Control Box – Circuit Schematic

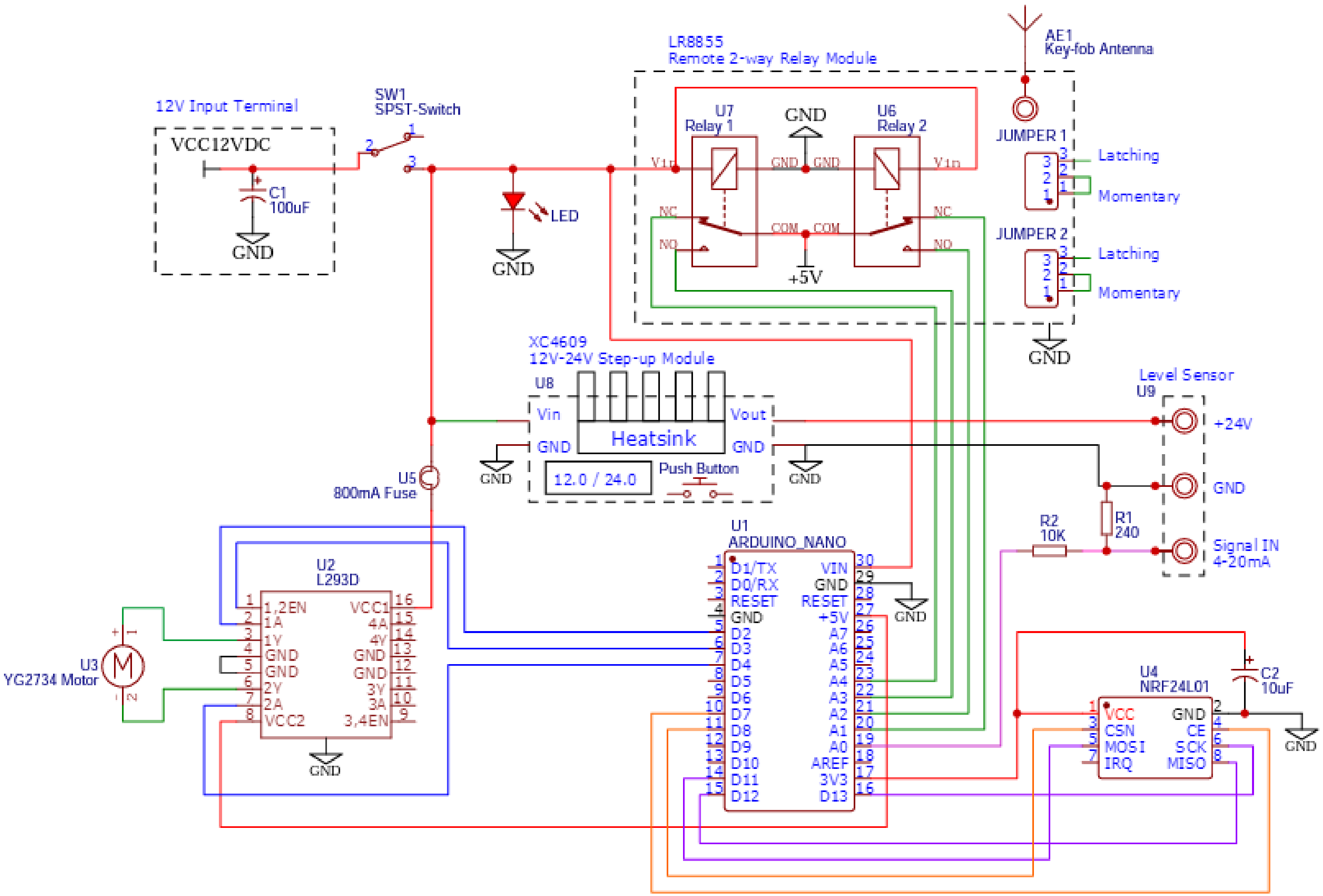

Figure 8: Master control box circuit schematic – mounted on the croplands section sprayer

“TRAILER SLAVE” Controller – Circuit Schematic

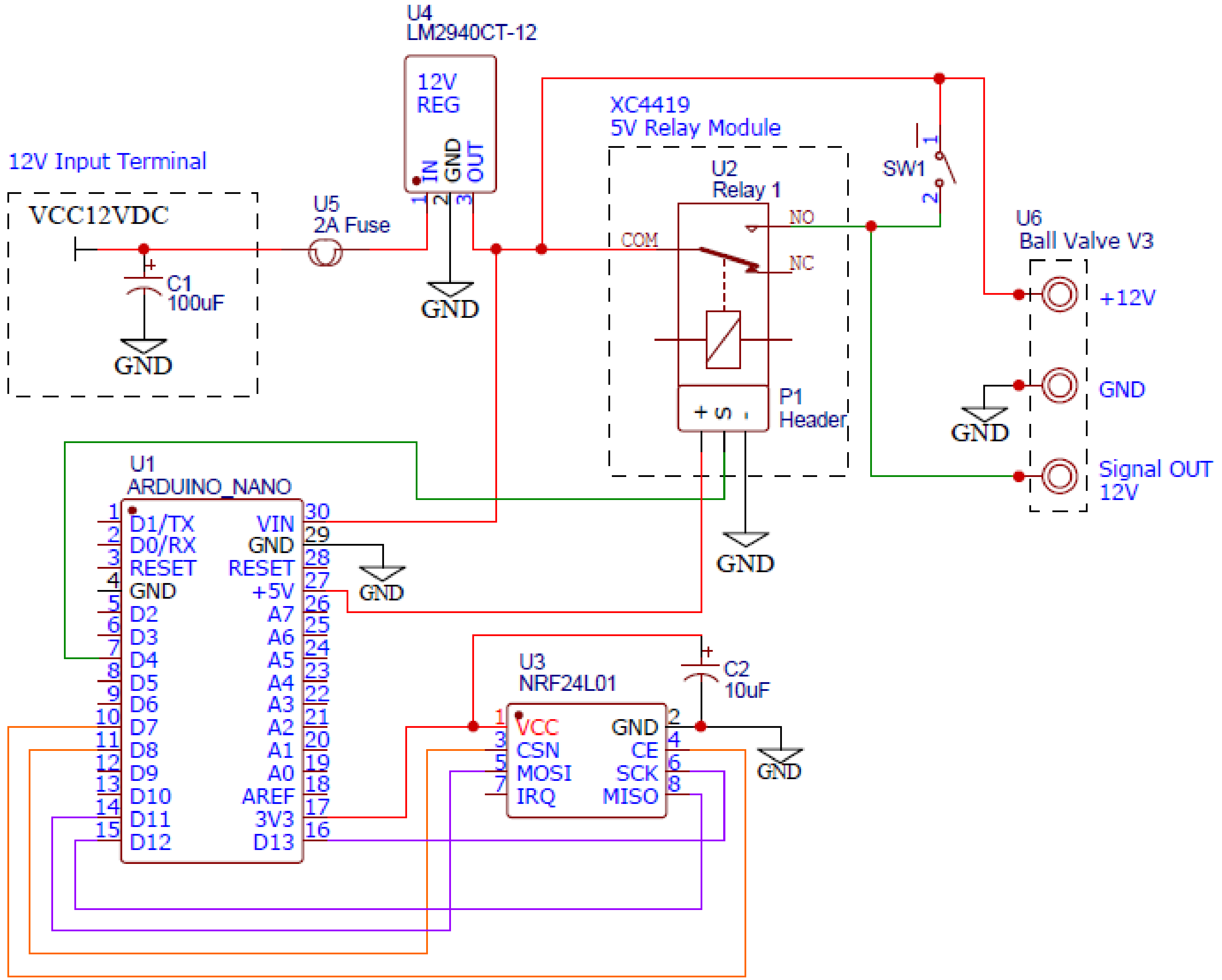

Figure 9: Slave control box circuit schematic – mounted on the IPF autofill nurse trailer

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Appendix C: Functional Overview

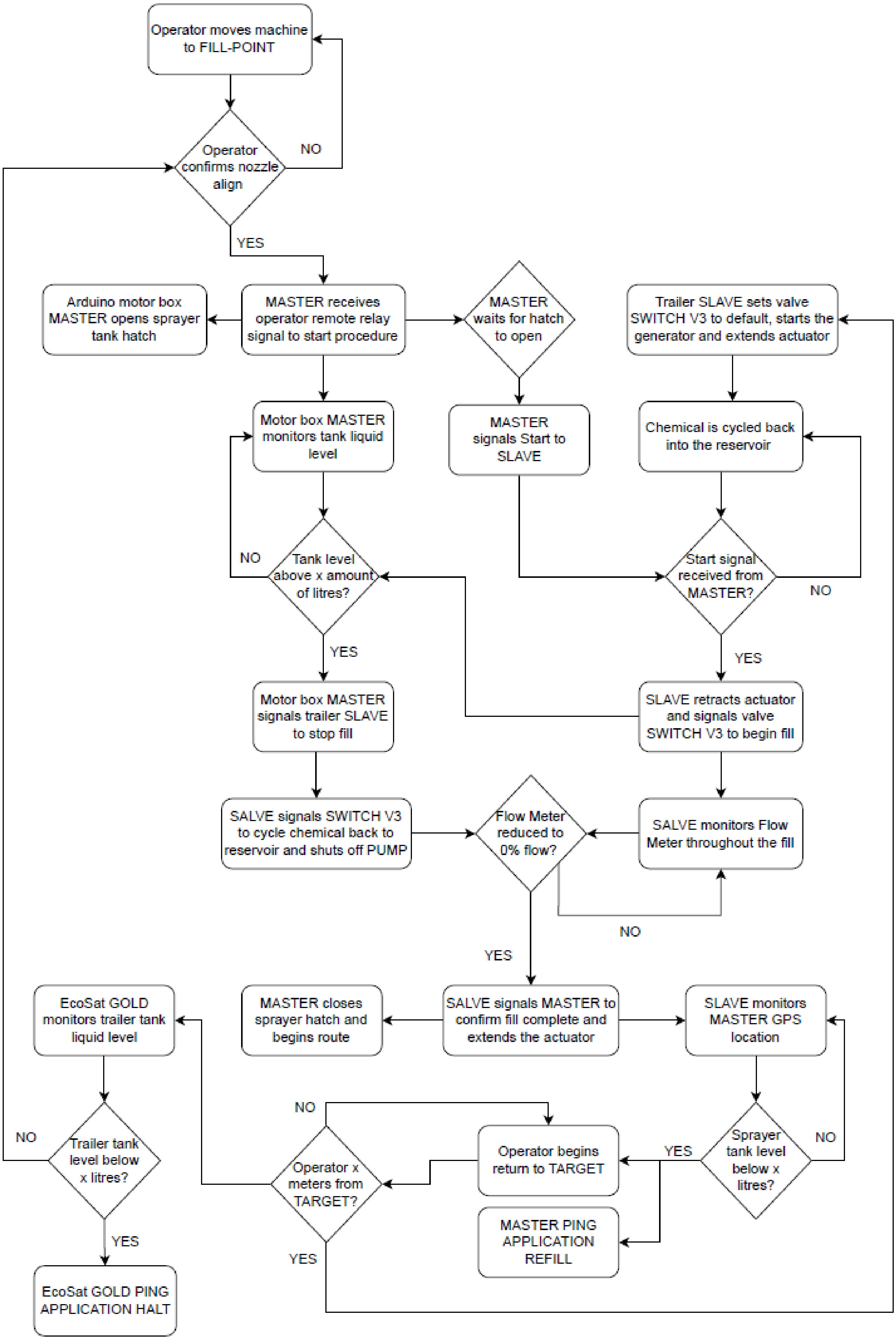

Figure 10: Autofill procedure functional overview of logic process

Appendix D: "Sprayer-side" Master Arduino control circuit code

```
// Corey Plant
// IPF - MASTER controller

// Required libraries
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>
#include <printf.h>

// Setup the wireless module
RF24 nrf(7, 8);  // CE, CSN pins on the NRF24L01
const byte linkAddress[6] = "00001"; //address through which two modules communicate.
// Motor connections
const int enA = 3;
const int in1 = 2;
const int in2 = 5;
// Define analog input pin for the relay signal
const int relay1_AnalogPin = A3;
const int relay2_AnalogPin = A2;
const int lvl_sensPin = A0;
// Variables to keep track of motor direction, valve state and relay signals
int motorDirection = 1; // 1 for clockwise, -1 for counter-clockwise
int relayThreshold = 1000; // Adjust this value based on the relay signal
int lastRelay1State = 0;
int lastRelay2State = 0;

void setup() {
  Serial.begin(9600);
  Serial.print("Initialised");
  // Set all the motor control pins to outputs
  pinMode(enA, OUTPUT);
  pinMode(in1, OUTPUT);
  pinMode(in2, OUTPUT);
  // Turn off motors - Initial state
  digitalWrite(in1, LOW);
  digitalWrite(in2, LOW);
  // Set analog input pin for the relay signal as input
  pinMode(relay1_AnalogPin, INPUT);
  pinMode(relay2_AnalogPin, INPUT);
  pinMode(lvl_sensPin, INPUT);
  // Initialise the wireles module pipe line as transmit for MASTER
  nrf.begin();
  nrf.openWritingPipe(linkAddress);  //set the address
  nrf.setPALevel(RF24_PA_LOW); //keep tx level low to stop psu noise
  // Options are: RF24_PA_MIN=-18dBm, RF24_PA_LOW=-12dBm,  RF24_PA_HIGH=0dBm.
  nrf.stopListening();  //act as a transmitter
  // NOTE: Use nrf.startListening(); to act as a reciever on the SLAVE
```

```
}

void loop() {
  // Read the relay signal
  int relaySignal1 = analogRead(relay1_AnalogPin);
  int relaySignal2 = analogRead(relay2_AnalogPin);
  // Serial.print(relaySignal1); // Use this for monitoring relay button press
  // Serial.println(relaySignal2); // Use this for monitoring relay button press

  // Check if the relay1 signal has crossed the threshold and changed state for motor
  if (relaySignal1 > relayThreshold && lastRelay1State <= relayThreshold) {
    // Move the motor
    if (motorDirection == 1) {
      // Set motor to maximum speed. For PWM maximum possible values are 0 to 255
      analogWrite(enA, 255);
      // Turn on motor for clockwise rotation
      digitalWrite(in1, HIGH);
      digitalWrite(in2, LOW);
      delay(4700); // set the time duration for the motor to rotate - CHANGE THIS AS
NEEDED
      digitalWrite(in1, LOW);
      digitalWrite(in2, LOW);
    } else {
      // Set motor to maximum speed. For PWM maximum possible values are 0 to 255
      analogWrite(enA, 255);
      // Turn on motor for counter-clockwise rotation
      digitalWrite(in1, LOW);
      digitalWrite(in2, HIGH);
      delay(3900); // set the time duration for the motor to rotate - CHANGE THIS AS
NEEDED
      digitalWrite(in1, LOW);
      digitalWrite(in2, LOW);
    }
    delay(500);
    // Change motor direction for the next movement
    motorDirection *= -1;
  }
  // Update last relay state for the motor
  lastRelay1State = relaySignal1;

  // Read the water level sensor value
  int sensor_sig = analogRead(lvl_sensPin);
  int lvl_val = map(sensor_sig, 0, 1023, 0, 100); // map the sensor signal to a scale of
0 to 100%
  // NOTE: sensor scale is analog 1-5V, so value will be read as approx 18% when sensor
level = 0
  int outint = 0;
  Serial.print(lvl_val);
  Serial.print("\n");
```

```
  // Check if the relay2 signal has crossed the threshold and changed state for the
valve
  if (relaySignal2 > relayThreshold) {  //  && lastRelay2State <= relayThreshold
    outint = 1; // START FILL
    for (int i = 0; i < 10; i++) { // Run loop multiple times to ensure message gets
sent
      nrf.write(&outint, sizeof(outint)); //send the message to the SLAVE to START
filling
      Serial.print(outint);
      delay(100);
    }

    delay(100);
  } else if (lvl_val > 49) { // check if the lvl sensor has gone above the cut-off limit
    // NOTE: A value of 50% approximately relates to 1000L in the spray tank
    outint = 2; // STOP FILL
    for (int j = 0; j < 10; j++) { // Run loop multiple times to ensure message gets
sent
      nrf.write(&outint, sizeof(outint)); //send the message to the SLAVE to STOP
filling
      delay(100);
    }
    Serial.print(outint);
    delay(100);
  }
  // Update last relay state for the valve
  // lastRelay2State = relaySignal2;
  delay(500);
}
```

Appendix E: “Trailer-side” Slave Arduino control circuit code

```
// Corey Plant
// IPF - SLAVE controller
// Required libraries
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>

// Setup the wireless module
RF24 nrf(7, 8);  // CE, CSN pins on the NRF24L01
const byte linkAddress[6] = "00001"; //address through which two modules communicate.

// Define the output pin for the valve control
const int valvePin = 4;
int message = 0;

void setup() {
  Serial.begin(9600);
  Serial.println("Starting");
  pinMode(valvePin, OUTPUT);
  nrf.begin();
  nrf.openReadingPipe(0, linkAddress);  //set the address
  nrf.setPALevel(RF24_PA_MIN);
  nrf.startListening();   //act as receiver
  digitalWrite(valvePin, HIGH); // default set the valve to cycle product to main tank
}

void loop() {
  while (!nrf.available());
  if (nrf.available()) {
    nrf.read(&message, sizeof(message));
    Serial.print(message);
    Serial.print("\n");
    if (message == 1) {
      Serial.print("Valve ON");
      digitalWrite(valvePin, LOW); // Start pumping to Boom
      delay(1000);
    } else if (message == 2) {
      Serial.print("Valve OFF");
      digitalWrite(valvePin, HIGH); // Keep fluid cycling to main tank
      delay(1000);
    }
  } else {
    Serial.print("No data");
    Serial.print("\n");
  }
  delay(1000);
}
```

Appendix F: Linak LA36 Linear actuator specification and order

BPT → Toowoomba

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LA36
Ordering example

TYPE
36 = LA36

SPINDLE TYPE
3 = 12mm
5 = 20mm
A = 8mm + magnet for adjustable reed switch
C = 12mm + magnet for adjustable reedswitch
E = 20mm + magnet for adjustable reed switch

GEAR BOX

		2,5 mm pitch	8 mm pitch	12 mm pitch	16 mm pitch	20 mm pitch
A	Gear ratio 1:18 / 2600N or 1700N	N.A.	N.A.	2 600 N	1950 N	1 700 N
B	Gear ratio 1:31 / 4500N	N.A.	N.A.	4 500 N	3375 N	N.A.
C	Gear ratio 1:46 / 6800N or 10000N	10.000 N	10.000 N	6 800 N	5100 N	N.A.
F	Gear ratio 1:7 / 500N	N.A.	N.A.	N.A.	N.A.	500 N

BACK FIXTURE
0 = M20 x 1 female adapter
1 = 12,9 mm hole (for 1/2" pin)
2 = 12,9 mm hole turned 90° (for 1/2" pin)
3 = 12,2 mm hole (for 12mm pin)
4 = 12,2 mm hole turned 90° (for 12mm pin)
5 = M12 x 1,75 male adapter
6 = M16 x 1,5 male adapter
7 = 12,2 mm hole with slot (like LA34)
8 = 12,2 mm hole with slot (like LA34) - turned 90°
A = 12,2 mm hole with slot - AISI 304
B = 12,2 mm hole with slot turned 90° in AISI 304
C = 12,9 mm hole with slot - AISI 304
D = 12,9 mm hole with slot turned 90° - AISI 304

PISTON ROD EYE
0 = M20 x 1 female adapter
1 = 12,9 mm hole (for 1/2" pin)
2 = 12,2 mm hole (for 12mm pin)
3 = M12 x 1,75 male adapter
4 = M16x1,5 male adapter
5 = 12,2 mm hole with slot (like LA34)
A = 12,2 mm hole with slot - AISI 304
B = 12,9 mm hole with slot - AISI 304
C = Ball eye Ø12,2
D = Ball eye Ø16

approx. 6.8 kg

SAFETY NUT
+ = Standard
S = With safety nut

END STOP
0 = No limit switch
1 = Limit switch
2 = Limit switch and EOS

IC
7 = IC Basic
8 = IC Advanced
9 = IC Parallel
A = MODBUS
B = LINBUS
C = CAN bus (J1939)

FEEDBACK
0 = Standard (No feedback)
B = Analogue feedback 0-10V
C = Analogue feedback 0.5-4.5V
H = Dual Hall
K = Single Hall
P = Potentiometer
5 = PWM 10-90%
6 = PWM 20-80%

IC Feedback
D = Bus (LINbus; CAN bus or Modbus)
1 = Single Hall
2 = Analogue feedback 0-10V
3 = Analogue feedback 0.5-4.5V
4 = Analogue 4-20mA
5 = PWM 10-90%
6 = PWM 20-80%

STROKE LENGTH
100 = 100mm
150 = 150mm
200 = 200mm
250 = 250mm
300 = 300mm
350 = 350mm
400 = 400mm
450 = 450mm
500 = 500mm
550 = 550mm
600 = 600mm
650 = 650mm
700 = 700mm
750 = 750mm
800 = 800mm
850 = 850mm
900 = 900mm
950 = 950mm
999 = 999mm

MOTOR TYPE
A = 12 VDC
B = 24 VDC
C = 36 VDC
1 = 12 VDC without clutch
2 = 24 VDC without clutch
3 = 36 VDC without clutch

IP DEGREE
2 = IP66 Dynamic / IP69k Static
8 = IECEx / ATEX certified
9 = Harsh environment housing (IP66/IP69k)

CABLES
0 = No cable
1 = 1,5m cable (0367046-1500)
2 = 5 m cable (0367046-5000)
3 = 0,2 m power cable with AMP connector (0367006)
4 = 1,5 m power cable +1,5m signal cable
5 = 5 m power cable + 5 m signal cable
6 = Y-cable power and signal cable in one (0367020)
7 = 5 m powercable & datacable M12x1 (Bus)

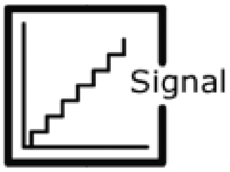
When ordering standard stroke length with endstop 1, 2, 3 or 4 the stroke length will be up to 4 mm shorter.

Figure 11: Linak LA36 linear actuator order example specification from BPT Toowoomba

Actuator with endstop signals and absolute positioning - Analogue feedback

I/O specifications:

Tip: If you wish to use the endstop signals, you will have to keep power on the brown, blue, red and black wires, otherwise the signal will be lost.

Input/Output	Specification	Comments
Description	The actuator can be equipped with electronic circuit that gives an analogue feedback signal when the actuator moves.	
Brown	12, 24, 36* or 48* VDC (+/-) *Only available on LA36 12 V ± 20 % 24 V ± 10 % 36 V ± 10 % 48 V ± 10 %	To extend actuator: Connect Brown to positive To retract actuator: Connect Brown to negative
Blue	Under normal conditions: 12 V, max. 26 A depending on load 24 V, max. 13 A depending on load 36 V, max. 10 A depending on load 48 V, max. 8.0 A depending on load	To extend actuator: Connect Blue to negative To retract actuator: Connect Blue to positive
Red	Signal power supply (+) 12 - 36 VDC	Current consumption: Max. 60 mA, also when the actuator is not running
Black	Signal power supply GND (-)	
Green	Endstop signal out	Output voltage min. V_{IN} - 2 V Source current max. 100 mA
Yellow	Endstop signal in	
Violet	Analogue feedback 0-10 V 0.5-4.5 V 4-20 mA	Tolerances +/- 0.2 V Max. current output: 1 mA Ripple max. 200 mV Transaction delay 20 ms Linear feedback 0.5 % It is recommendable to have the actuator to activate its limit switches on a regular basis, to ensure more precise positioning
White	Not to be connected	

It is recommended that the actuator activates its limit switches on a regular basis, to ensure more precise positioning. The actuator can also go into the position lost state. When the actuator goes in position lost state, the feedback level will remain the highest level until the actuator is initiated. For instance, if feedback is 0-10 V, the feedback level will remain 10V until the actuator is initialised. Both physical end stop switches need to be activated for correct initialisation of the feedback. There is no rule as to which one needs to be activated first.

Figure 12: Linak LA36 linear actuator I/O datasheet

Figure 13: Linak LA36 linear actuator with 5m cable

This actuator is a recommended addition to the current trailer design and trailer slave code. It would allow the crane/boom to be vertically controlled providing automation to the insert and retract at the fill point. The first appendage shows the order specification which was procured through BPT-Toowoomba (Bearings and Power Transmission). The second appendage is then I/O specification of the wires on the 5m cable provided with the actuator. This I/O information can be utilised in the connection of the actuator to the control system. In brief summary, the 12V Linak LA36 that has been procured has 500mm stroke length (minus 4mm due to end stops), with analogue feedback for current position, IP67, and is rated to 6800N load for supporting the weight of the crane/boom.

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