MECH2110

Warman – Conceptual Design Report

Group – W01-07-team-2

Due 5:00 PM, Friday 7th April 2023

Semester 1

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Introduction

The Warman design and build Competition (Engineers Australia, 2023) is a goal post to assess the creative aptitude and pragmatic problem-solving skills of students across Mechanical and Mechatronics disciplines. For the 2023 competition the objective is to design, build and demonstrate an autonomous proof of concept prototype for a safe transportation system for hazardous materials. To achieve this goal, students are required to construct an autonomous robot capable of successfully completing the challenge within the confines of the stated rules. The competition requires the autonomous system, that is constrained to a cube of 400mm³, to successfully complete a series of tasks across the zones shown in figure 1. It will begin operation with the “Setup/Start Zone”, separately collect both “Propellent” and “Oxidizer Fuel Vessels” from their respective “Drop Zones” and deposit them within their respective “Silos”. This series of tasks must be completed as successfully as possible within the shortest amount of time to maximize points receivable.

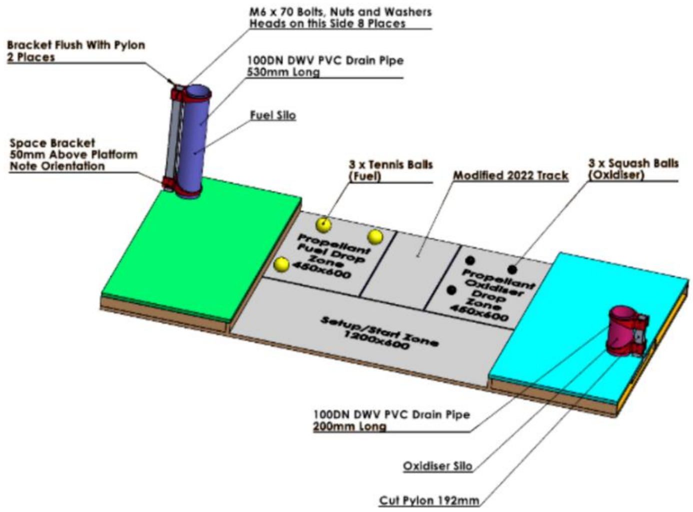

Figure 1 - 2023 Warman Track

Problem Formulation

The formal problem formulation process was followed to derive an appropriate problem statement of work to be performed by the team throughout the design process of the Warman competition.

Iteration 1:	Pick up tennis balls (fuel Vessels) to then place them safely into the fuel storage bin. Afterwards to avoid the need to mix dangerous chemicals the squash balls (oxidizers) will be considered, via the same process of picking them up and dropping them into the oxidizer tank.
Iteration 2:	A total of 6 spheres (3 tennis balls [fuel vessels], and 3 squash balls [oxidizer vessels]) are to be collected and deposited into relevant silos according to designated type without mixing of types.
Iteration 3:	Prototype a system capable of separately collecting propellant fuel and oxidiser vessels and depositing them in their respective silos.
Iteration 4:	Prototype a system capable of collecting and depositing vessels of designated types and depositing them into relevant silos without intermingling of types.
Final:	Prototype a system capable of collecting and depositing vessels of designated types into relevant silos without intermingling.

Name: Alec S.
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Individual Section – Alec S.

Engineering Analysis

INPUT: Squash (oxidizer vessels) and tennis balls (fuel vessels).

Prototype Input Variables	Input Constraints
Max load to support	≤0.59KG
Squash Ball collection Area	450x650mm (0.27 m^2)
Tennis Ball Collection Area	450x650mm (0.27 m^2)
Diameter of Fuel vessels	65.8mm $\pm$ 0.4mm
Diameter of oxidizer vessels	40mm $\pm$ 0.5mm

OUTPUT: Dispensed squash and tennis balls.

Prototype Output Variables	Output Constraints
Height of oxidizer tank	200mm (+50mm platform)
Height of fuel tank	530mm (+50mm platform)
Diameter of fuel tank	260mm
Diameter of oxidizer tank	260mm

SOLUTION VARIABLES:

- Method for collecting vessels.
- Method for raising and transferring collected vessels.
- Electrical system design
- Size of device (Within Limits)
- Shape of device (Within limits)
- Manufacturing of parts
- Placement of Vessels/ Device

RESTRICTIONS:

- Maximum weight of 6KG
- Device to start and finish in "Setup/Start Zone".
- Device to start and finish in a 400mm "cube"
- All subsystem must be assessed with appropriate risks, and controls put in place.
- Autonomous design
- Fuse must be used for electrical subsystem.
- Runtime of 120 seconds
- Setup time of 120 seconds.

CRITERIA FOR SUCCESS

- Cost of prototyping
- Cost of final production
- Complexity
- Speed of operation/setup.
- Reliability
- Weight
- Safety rating
- Competition Score

PRODUCTION QUANTITY:

1 Unit

USAGE: **Warman Design and Build Competition**

- > 20 setup and pack down operations for testing and competitive purposes.
- > 50 hours of rigorous workshop testing
- Two reliable runs in local competition (MECH2110 Course Content).
- Two reliable runs at international Warman Design and Build competition.

Solution Discovery 1 – Fork-lift Pickup Sub-system

The scope of this solution provides a theoretic for pickup up and “storing” input balls, following the constraints of the Warman project. Figure 3 shows a detailed sketch of “fork-lift” pickup system.

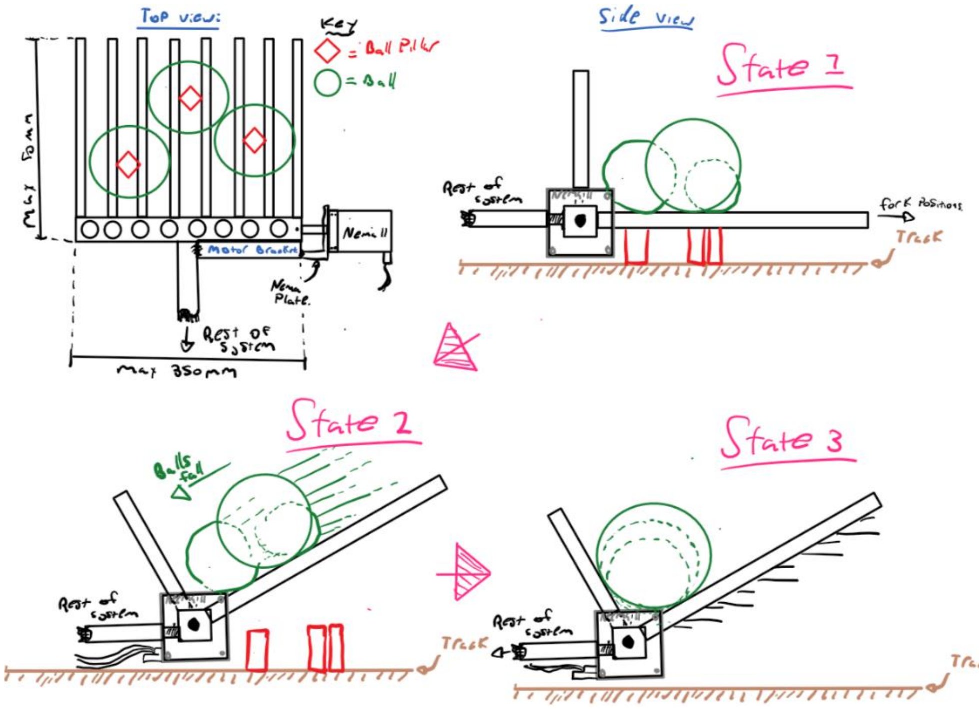

Figure 2 - Fork-lift Subsystem

As shown in figure 2, the fork-lift pickup system works on the stipulation that each ball will be suspended by a fixed distance using a “pillar” assumed to be smaller than the payloads. The system works by first pushing out a fork-like arm between the track and the bottom surface of the payloads (Stage 1). Next, the stepper motor attached to the fork turns counterclockwise, picking up all the balls caught within the area and forcing them to roll downhill into the trapped position (stage 2/3). Finally, once the balls have had a chance to rest on the grating, the rest of the robotic system can then act to pull the armature into the next position (stage 3), be it directly towards the silo, or the subsequent payload dispensing subsystem.

Opportunities

The theoretical forklift system provides several avenues for opportunities in the Warman design competition should it be chosen for use in the final design of the Warman device, these include:

- Ability to collecting all payloads in a wide area with one swift action.
- Relatively simple action, with no sensors required for operation.
- Can be hard-coded and/or created to suit specific payload positions.
- Can be quickly deployed, since only one degree of freedom is required (subject to deployment strategy).

Challenges

Additionally, several challenges will need to be considered when selecting this subsystem for collecting payloads within the Warman competition. These challenges include:

- Is limited by the start region restriction (400cm^2). The collection area is 600x450mm, and hence could miss payloads should they be located too far away from each other.
- Works on the assumption that the pillars for the balls are small enough to fit between the slots of the fork and are smaller than the ball.
- Low tolerance appetite with a high risk of being disqualified from a run if the device creeps lower than expected, since it will be assumed to hover within the “restricted” track region.

Solution Discovery 2 – Crane Transmission Subsystem

The scope of this solution involves a theoretical method of providing a reliable traversal system from an initial position (constrained to 400mm^3) to an extended distance, and back again. The detailed sketch for the Crane Transmission system can be found in figure 4.

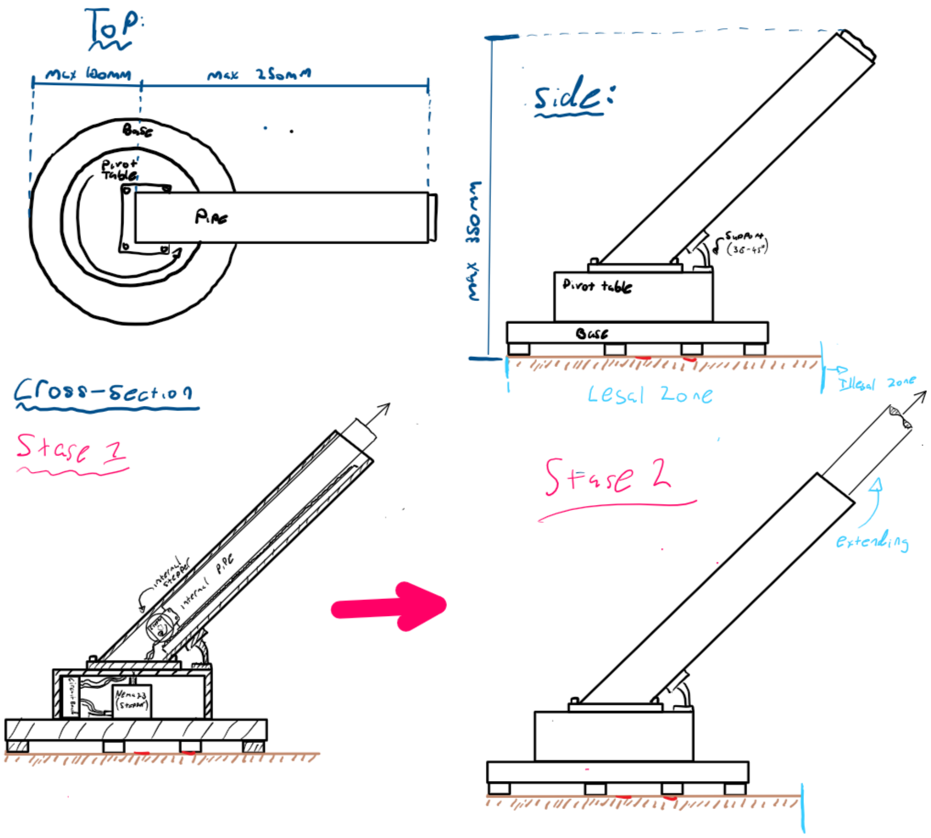

Figure 3 - Crane Transmission Subsystem

As shown in figure 3, the crane transmission system relies on two motors to gain 3 degrees of freedom from a statically deployed position. A stepper motor located on the base (within the pivot table) controls the rotation of the device. Next, internally to the long pipe (see cross section), a smaller geared motor is attached to an "internal" pipe and is setup to run along a fixed gear rack. As the geared motor turns along the fixed gear, the internal pipe will extrude from the resting position as shown in Stage 2. This allows for the initial system confined by the constraint (400mm^3) to extend beyond the 'illegal' zone, above each region where payloads are distributed. A secondary sub-system should be then deployed from the end of the extended pipe to collect the balls, and then rotated via the pivot table motor deposit them into the required vessels, before returning to the base position, completing the run.

Opportunities

This transmission system provides several opportunities if selected for the Warman device solution. These include:

- Only requires 2 motors to achieve 3 degrees of freedom (X, Y and Z).
- Statically placed, resulting in avenues for error compared to dynamic systems.
- Can be scaled up to fit a third internal pipe for more range.

Challenges

Several challenges have been identified with this system, which should be considered if it is used within the final Warman design. These include:

- Will likely require a heavy base counterbalance, especially if a secondary pipe is used to gain extra range.
- Hard coded coordinates will require extra attention since the system will require conversion for fixed (support) and pivoted angular displacement, assuming stepper motors do not additionally skip steps.

Solution Discovery 3 – Motor Carriage Transmission System

The scope of this solution involves a theoretical method for a transmission system for the Warman device. The key difference between this type of transmission system and that in the second discovery solution, is that the system relies on a self-contained dynamic motor carriage system. The detailed sketch for the motor carriage system is found in figure 5.

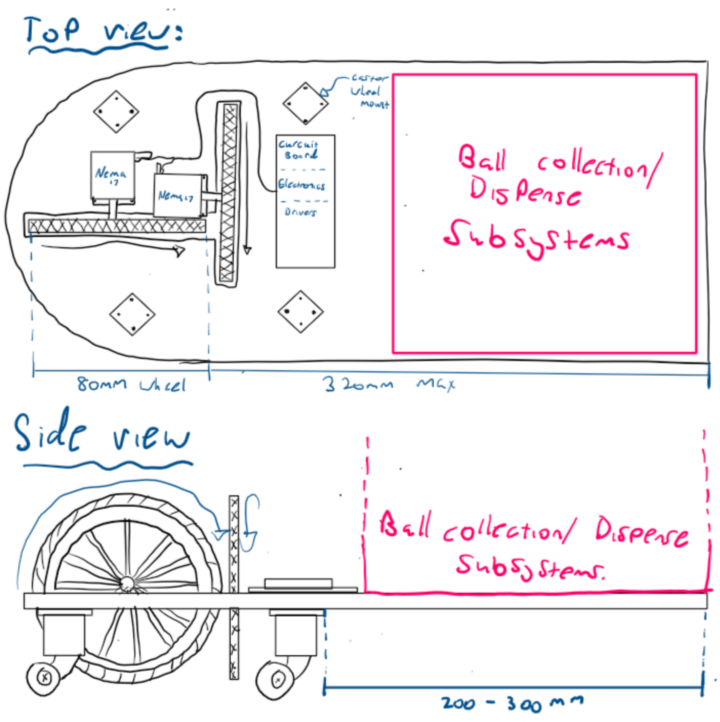

Figure 4 - Dynamic Motor Carriage System

As shown in Figure 4, the dynamic motor carriage system is composed of two intersecting 80mm wheels, each attached to a driving stepper motor. To assist in the balance and drive capabilities of the carriage, 4 motorless castor wheels are spaced around the motorized wheel assembly. The design also includes a large frontal area for the assembly of a ground-based ball collection and dispensing system (such as that shown above in solution discovery 1). Another key design principal for this solution is the fact that beyond the final castor wheel, there is no ground contact for the vehicle, meaning that the front of the system can be driven and suspended beyond the illegal payload zones, which may allow for some close-range collection methods to be used. Since the system is self-contained using stepper motors, it can also easily drive out of and into the starting position at the beginning and end of operation.

Opportunities

Through the design process of the motor carriage system, several opportunities for using this type of transmission system for the Warman Device was identified:

- Allows for the use of simple ground-collection subsystems since the front of the device can be suspended in illegal zones.
- Large, designated ball collection/ dispense sub system area allows for a range of subsystem usage.
- Provides a lot more dynamic freedom for operations performed by the system.

Challenges

The motor carriage system has several challenges must be considered should it be used as the primary transmission system in the Warman device:

- Dynamic systems tend to generate large uncertainties, especially without sensors during longer operations.
- Centre of mass of the device must always be on the wheeled side of the device to avoid tipping.

Final Solution

Each of the subsystems presented above, with their opportunities and challenges in mind, have been analysed in table 1 to include their relative weighting against the set of key success criteria listed above in order to determine the most suitable approach for completing the Warman challenge.

Table 1 - Final Solution decision matrix

Criteria	Weighting*	Solution 1 – Fork Pickup Subsystem		Solution 2 – Crane Transmission System		Solution 3 – Motor Carriage Transmission System.	
		Predicted	Weighted	Predicted	Weighted	Predicted	Weighted
Simplicity	5	6	**30**	5	**25**	3	**15**
Reliability	4	4	**16**	8	**32**	4	**16**
Qualification chance**	3	3	**9**	9	**27**	4	**12**
Speed	2	7	**14**	4	**8**	7	**14**
Safety	5	8	**40**	7	**35**	7	**35**
Cost	1	8	**8**	6	**6**	5	**5**
Point Potential	5	4	**20**	7	**35**	4	**20**
Total Points:			**<u>137</u>**		**<u>168</u>**		**<u>117</u>**

***Note, points are distributed based on 0 "performing poorly in this category", while 10 "performs best".**

**** Also note, Qualification chance refers to the risk of the machine becoming "Disqualified" for any reason.**

As shown in table 1, through the decision matrix analysis solution 2 appears to have the highest scoring potential for its incorporation in the final Warman design. This solution provides a reliable, reasonably cheap and safe method for translating into the illegal zones, collecting the balls from above (using a claw or pincer) and translating them to the end-area.

The challenges associated with this method will still likely need to be addressed, but ultimately will rely on the other subsystems being used in conjunction with this translation method before a suitable solution can be put in place to offset the balance and translation coordinate calculations. In any case, the potential opportunities for this solution far outweigh the perceived challenges, providing a cost-effective method of translating in 3 dimensions.

While scoring lower in the overall categories, the motor carriage translation system and the fork pickup system will still be considered when completing the search phase and bringing together all other solutions, since the scores considered in the matrix above may shift depending on accompanying subsystems and designs.

Individual Section – Callen N.

Engineering Analysis

The following criteria is to be met when the final design solution is met:

- Cannot exceed a weight of 6 kilograms
- Must stay within 400mm³ max area
- All designing and construction is done by the team
- Set-up within 120 seconds
- No mixing of vessels
- Must comply with the safety criteria of NSW and Newcastle University (UON) standards
- Not exceeding the set budget
- Relatively cheap and portable system

INPUTS: Set fuel vessels (tennis balls) and oxidiser vessels (squash balls) situated within a certain area.

Variables:	***Constraints:***
Fuel vessels (Tennis Balls)	Diameter: $6.54cm \leq \emptyset \leq 6.86cm$ Mass: $56g \leq m \leq 59.4g$ Vessel Quantity: 3
Oxidiser vessels (Squash Balls)	Diameter: $39.5mm \leq \emptyset \leq 40.5mm$ Mass: $23g \leq m \leq 25g$ Vessel Quantity: 3
Vessel holder (M12 Nut)	

OUTPUTS: Delivery of the vessels to their respective containment silos located in different zones.

Variables:	***Constraints:***
Silo dimensions	Diameter: $\emptyset 110mm$ Height (Oxidiser): $200mm$ Height (Fuel): 530mm
Zone dimensions:	Fuel vessel's area: 450 x 600mm Oxidiser vessel's area: 450 x 500mm Working area: 1200 x 600mm

Success Criteria

The following will determine whether the system is regarded as a 'success':

- **Collect and deposit the fuel vessels into its respective containment silo.**
- **Collect and deposit the oxidiser vessels into its respective containment silo.**
- **Does not cross contaminate the vessel types in the collection or distribution.**
- **Remain within the work area boundaries.**
- **Collection and distribution of all the vessels under the 120 second mark.**
- **Ensure the system remains within the dimension and weight limitations as provided in the guidelines and restraints.**

Constraints

The following constraints are mandatory when designing the prototype system:

- **Completed system does not exceed the 6kg limit.**
- **Battery operated while fuse protected.**

- **Has a maximum setup time of 120 seconds by ONE team member during testing phase.**
- **Must be an automated system, no manual control.**
- **Completed system must have an 'On/Off' switch, cannot be wired together as part of 'setup phase.'**

Solution Discovery 1 – Hollow tube collection sub-system

This design solution solely focuses on the pickup and storage system for the fuel and oxidiser vessels. The following solution meets the requirements necessary for the Warman Challenge. Figure 4 depicts a rough sketch of the pickup system.

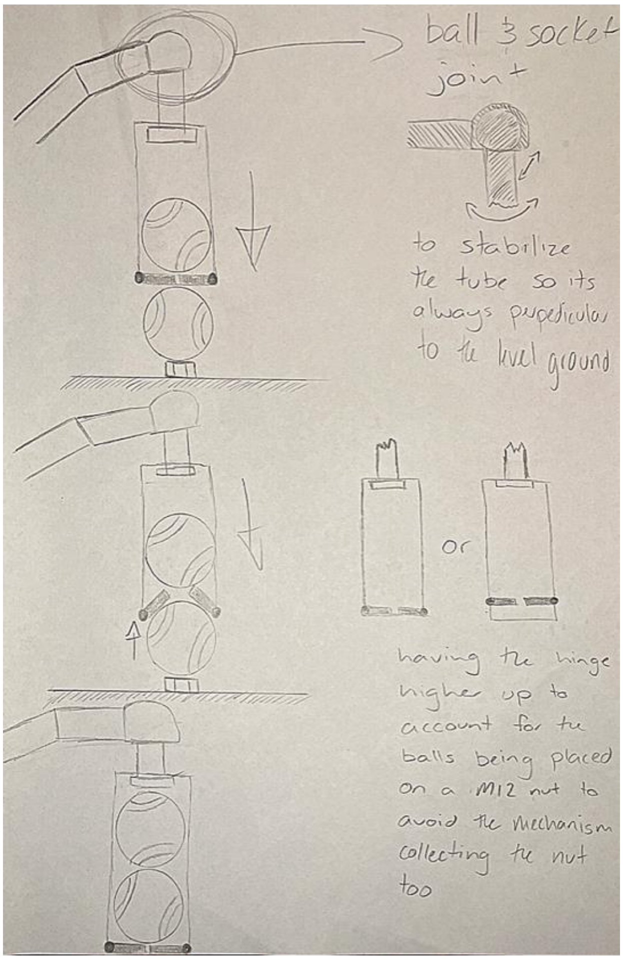

Figure 4 – Hollow tube collection sub-system

As seen above in figure 4, a hollow tube is suspended from the main arm of the system using a ball and socket joint. This joint allows a free range of motion for the tube to realign itself so that it is perfectly perpendicular to the level ground the vessels are placed upon no matter the angle at which the arm is inclined. The 'hatch' located at the entrance of the tube can consist of two or one flap that will bend upwards to allow the vessels access inside and will return to the horizontal position and hold the vessels inside. When dispersal into the respective silos, the hatch will open in the opposite direction (facing downwards) and drop the vessels directly into the containers. The vessels can also be placed on an M12 nut to stop any movement of the vessels. Due to this, the hatch can be placed slightly higher inside the tube to remove the risk of accidentally picking up the M12 nut along with the vessel.

Opportunities

- Simple design that only requires downward force to pick up the vessels.
- Self-adjustment due to the ball and socket joint removing any mechanism necessary to align the tube to the balls.

- Can be achieved without the use of sensors by hardcoding the system, however sensors can still be implemented if desired.
- No need for an external storage device as the tube can pick up, hold and disperse the vessels without needing to transfer them to another storage device.

Challenges

- The base will require a counterbalance to stop any risk of the system topping over before, during and after the vessels are collected.
- The ball and socket joint will need to be able to glide smoothly and freely back to the perpendicular state, if not the tube will attempt to pick up the vessel at an angle that may move or shift the vessel out of place and cannot be picked up.

Solution Discovery 2 - Stationary Counterweight Crane sub-system

This design solution focuses on a stationary traversal system from a starting position within 400mm^3, extending out towards an assigned distance, and back to the starting position again. The sketch for the Stationary Counterweight Crane sub-system can be seen below in figure 5.

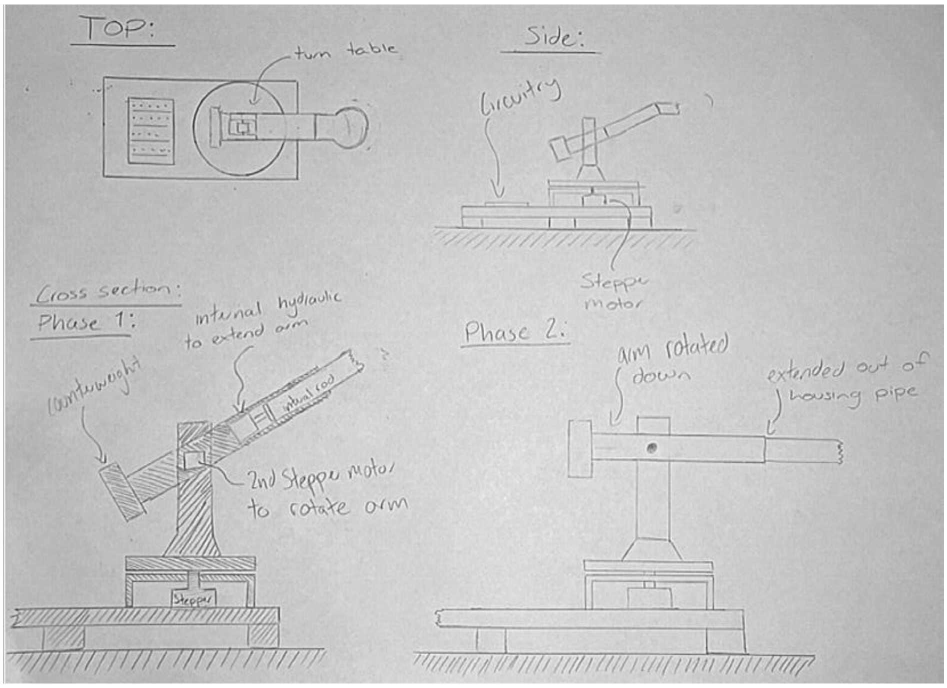

Figure 5 – Stationary Counterweight Crane sub-system

As seen above in figure 5, the system is situated on a stationary platform which is composed of two stepper motors and a separate motor required to move the parts required. The first stepper motor is located beneath a secondary platform where the main tower is placed on a turn table, allowing the system to rotate a full 360° (which is not necessary for the system's design). The second stepper motor is in the main tower unit which is solely used for raising and lowering the pickup system for the vessels. There is a counterweight on one end of the crane arm to ensure neither the tower nor the arm topples over due to the weight. The arm will be a hollow casing for a rod which can be extended to a limited range due to the restrictions placed in the criteria, a small motor will push the rod, extruding from the casing to extend the arm length over the restricted zone to collect and disperse the vessels.

Opportunities

- Stationary base allows to have fewer moving parts making the design as simple as it needs to be.
- Having a stationary base also allows accurate placement of the system and easier repetition of testing phases and leaves little room for error when setting up.

- Extendable arm casing and internal components can be extended further by increasing the hollowed-out area inside the casing or by adding an additional third internal rod.

Challenges

- The longer the arm reaches, the more weight and stress are placed on the casing and system. The material for the casing and system will need to be carefully selected in addition to correctly distributing the weight evenly amongst the system. The counterweight in the arm should assist in reducing the weight distribution but will add stress onto the arm once extended.

Solution Discovery 3 – Mobile Counterweight Crane sub-system

This design solution focuses on a mobile traversal system from a starting position within 400mm^3, extending out towards an assigned distance, and back to the starting position again. The difference being the system is now able to move in a lateral direction due to the wheels attached to the base of the design. The sketch for the Mobile Counterweight Crane sub-system can be seen below in figure 6.

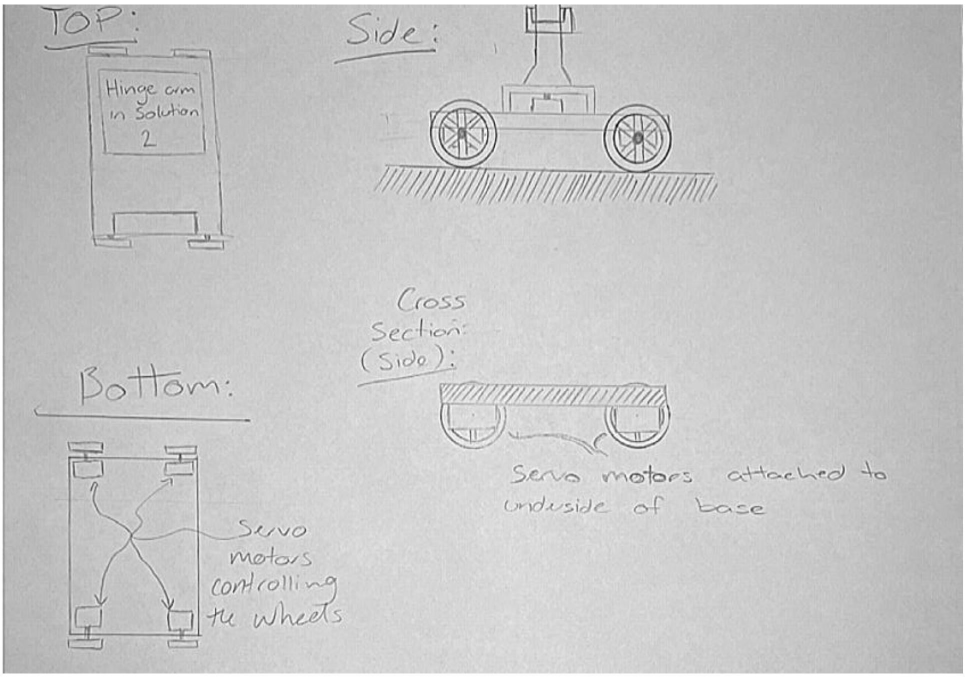

Figure 6 – Mobile Counterweight Crane sub-system

As seen above in figure 6, this design solution incorporates the crane from Solution Discovery 2, however, it is placed on a level bed with four wheels attached. The four wheels are each run by individual stepper motors to transport the system laterally along the allowed area which reduces the size of the base and the maximum arm length required in the stationary solution. Due to the portable nature of this system, it allows a certain range of dynamic motion and allows for an up-close collection that cannot be achieved if the design was stationary. Additional machinery that may be required that is not included in the figure above, is the use of sensors to communicate when it is close to the edges of the restricted zones and any other obstacles (vessels, M12 nuts) in may run into.

Opportunities

- Reduces the need for a large arm length which reduces the risk of the arm casing snapping or toppling over as it can simply drive closer to the target.
- Base area can be condensed to a smaller area to primarily the tower and arm with all the additional circuitry located underneath.

Challenges

- Far more complex and will require a lot of hard coding to communicate the wheels, the arm, and the collection system altogether as one.

- The use of sensors will further complicate and add uncertainty to the system, this is where simply coding the information will be easier.
- High risk of errors within so many moving parts (delayed start to a motor, interference for the wheels, etc.)
- Not a fixed starting point with the moving wheels and going off the brief mention of error risk in the last point, one of the stepper motors may begin before or after the other, thus the system will be moving at an angle rather than in a straight line laterally.

Final Solution

The final solution that has been decided upon will be a combination of many of the systems developed by the group. Starting with Callen's Solution 2 - 'Stationary Counterweight Crane sub-system' which will act as the base and main tower of prototype, ruling out any complications of using a mobile or kinetic system. The main tower will be altered in such a way the counterweight arm is neglected entirely and is combined with Alec's Solution 2 - 'Crane Transition Sub-system' which will be situated in a normal/perpendicular angle to the tower allowing for the telescopic arm to extend out into the restricted competition zones. The base of the tower will be placed on a swivel to allow for range of motion which is controlled using a Stepper Motor.

The collection and distribution part of the prototype system comes from James' Solution 1 - 'Comb sub-system' which will be modified to join to Alec's telescopic arm solution as mentioned above to accurately collect the vessels and distribute them within the restricted competition zones.

Individual Section – James W.

Engineering Analysis

The final solution shall be the following criteria:

- 400 mm^3 max area
- ≤ 6kg
- homogeneous non-discrete system
- Keep vessel types segregated
- operate on Li-ion batteries
- Comply with NSW and UON safety criteria
- set-up within 120 sec
- Designed and built by team

INPUT: Uncollected designated fuel (tennis balls) and oxidiser (squash ball)

<u>Input Variables</u>	<u>Input Constraints</u>
Size of Fuel (tennis ball)	C 206 –215 mm ⌀ 65.4 - 68.6mm
Size of Oxidiser (squash ball)	C 124.1 - 127.2 mm ⌀ 39.5 - 40.5
Number of balls	≤ 6
Weight of load	≥ 0.59 Kg

OUTPUT: designated spheres placed in receptacles

<u>Output Variables</u>	<u>Output Constraints</u>
Work area of fuel (tennis balls)	450 x 600 mm
Work area of oxidiser (squash ball)	450 x 600 mm
Deposit area and relative height of fuel (tennis ball)	200 mm ± 5 mm
Deposit area and relative height of oxidiser (squash ball)	530 mm ± 5 mm
Work area of Prototype	1200 x 600 mm set-up zone
Maximum set-up volume of Prototype	400 mm^3

Success Criteria

Prototype will;

- Collect ≥1 tennis ball and deposit the same number into the relevant silo
- Collect ≥1 squash ball and deposit the same number into the relevant silo
- Not touch the base plate of any area other than the starting area
- Fit into the 400mm cube area
- Complete the task within 120 sec

Constraints

All solutions have been designed with the expectation that the base of the prototype is static relative to the lateral position of the designated spheres and silos. All solutions have been designed with XYZ movement being designed from a common zero position. Each design uses some form of arm to reach out the vessels and the silos. Arms are separate systems to the collection mechanism and while mentioned in the solution information it is not considered the focus of the solution.

Solution 1 – (Comb sub-system)

This design utilises multiple sets of loose pivots organised like a comb that will drop down onto the vessels, opening around the vessels and closing again once past a designated diameter. This can be either sized for the two separate types of vessels or have a closed position that can work for both. The comb is intended to be mounted to an arm which will be in tern attached to the fixed base outlined above.

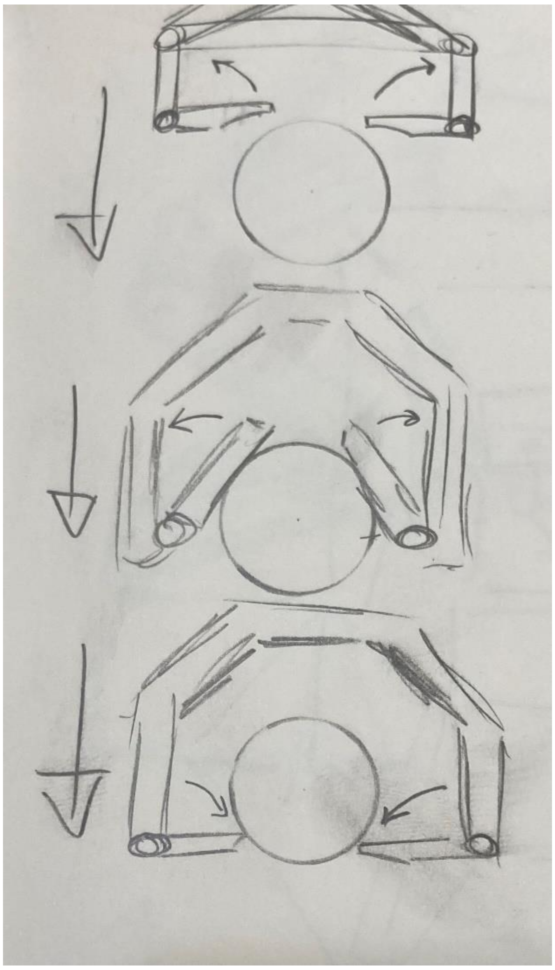

Figure 5 - Comb-style Pickup Sub System

Opportunities

- The design of the comb sub-system minimises mechatronic parts in the capture sub-system
- Can be easily made using a laser cutter or with other rapid prototyping methods allowing for easy tuning to of the system and iteration
- Van be orientated to collect all 3 of each vessel type simultaneously given an optimal orientation.
- Can be made of lightweight materials without reduced rigidity
- Does not require any code for the mechanism to engage

Challenges

- Intended for use with an actuated arm, may be more difficult to deploy from starting zone.
- Requires either two separate arms to collect both classes of vessel or a single arm to be tuned to collect both classes of vessel increasing the work time
- An articulated arm will require servo or stepper motors at each joint for accurate movement
- All forces imparted on the base must be resisted by the base, all leverage from the extended arm must not topple the prototype, requiring sufficient mass in the base limiting the mass available to the arm/arms and comb

Solution 2 – (Mechanical claw sub-system)

This design will use the resistance forces imparted on the head to activate a cam and close the jaws around the vessel which will cause the cam to lock. The head will contain a small plate which will connect to the cam, this plate will push against the ball which will turn the cam and jaws to the closed position. This design would be most optimal with a screw actuated scissor mechanism or an articulated arm.

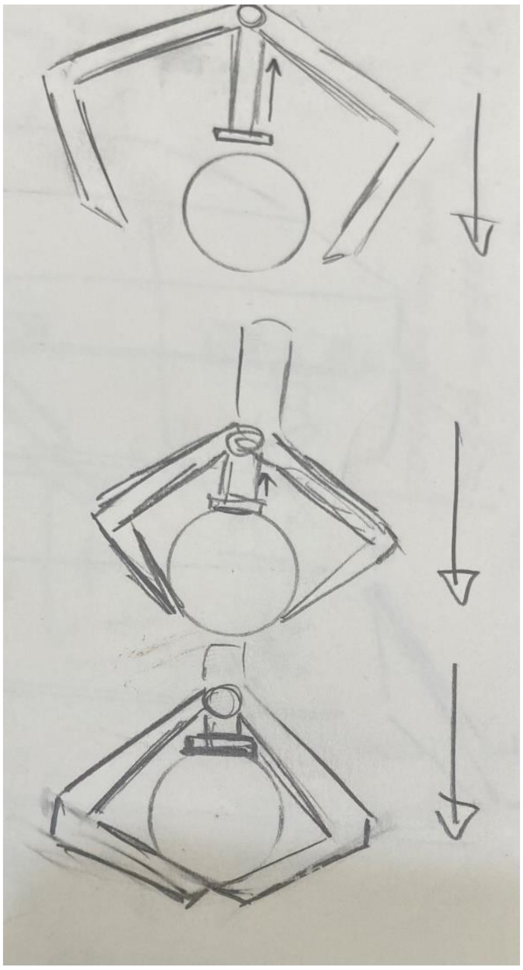

Figure 6 - Mechanical Claw Sub System

Opportunities

- Relies entirely on mechanical forces with no electric components for the collection of vessels
- Works of simple physical properties of geometric shapes
- Able to be built from sheet material allowing the use of a laser cutter

Challenges

- Does not have a method to deliver the vessels to the silo
- A release mechanism likely to need electronic components
- Will need to pick vessels individually
- Will need multiple claws to collect both vessel types with all relevant mechanisms needing to be present in each claw

Solution 3 – (Swivel Crane)

This design will fold into the 400 mm cube area for set up and be able to expand to reach both silos from a designated zero position. The crane will move the head along the X and Y axis with a swivel base able to move the body of the crane. This design is intended for use with ***Solution 1 - (Comb Sub-System)*** for the retrieval and deposit of the vessels into the silos.

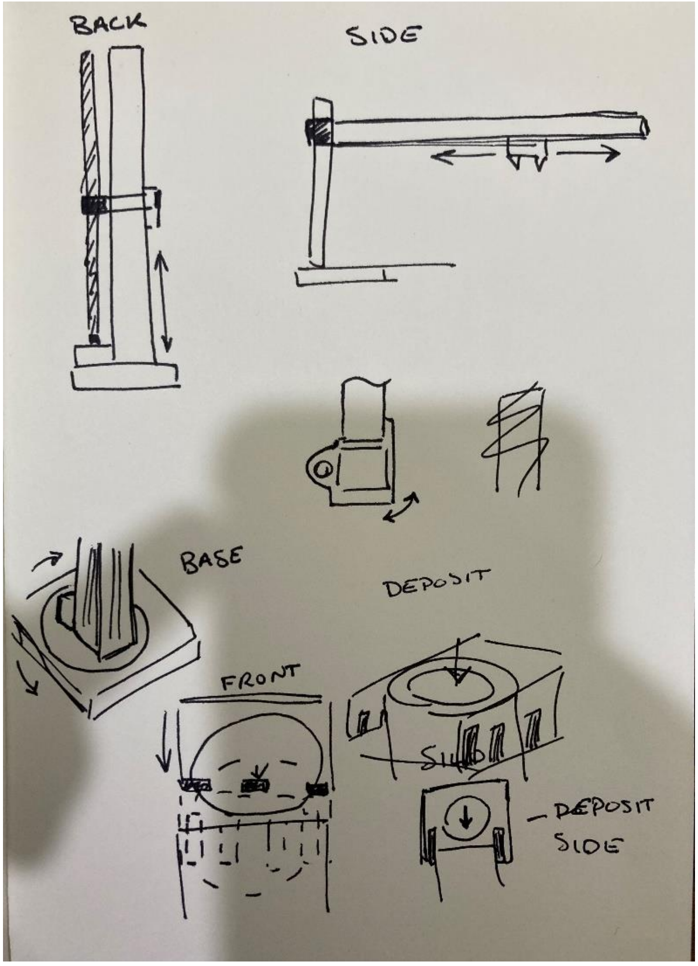

Figure 7 - Swivel Crane

Opportunities

- Collection and deposit of vessels relies on purely mechanical movements
- Will require a maximum of three mechatronic systems to move deployed crane
- Can use many off the shelf components from commercial 3D printers
- All parts could be made using laser cut or 3D printed parts
- System can be optimised to collect multiple vessels at a time as in Solution 1
- System can be optimised to collect both types of vessels using the same head as in Solution 1

Challenges

- Deployment of crane likely to require multipole mechatronic systems
- Collecting vessels individually slower than collectively
- System will need to have sufficient mass in the base and at zero position to not tip at maximum extension
- Steppers will be required to carry grater mass increasing likelihood of missed steps

Final Solution

Each of the subsystems presented above has been analysed in table 2 to include their relative weighting against the set of key success criteria listed above in order to determine the most suitable approach for completing the Warman challenge. The sub-system with the highest weighting will then be applied to the group solution if applicable and integrated with the sub-system solutions of other group members.

Table 2 - Sub-system solution weightings

Criteria	Weighting*	Solution 1 – Comb Sub-System		Solution 2 – Mechanical Claw Sub-System		Solution 3 – Swivel Crane	
		Predicted	Weighted	Predicted	Weighted	Predicted	Weighted
Simplicity	5	9	**45**	4	**20**	4	**20**
Reliability	4	7	**28**	5	**20**	4	**28**
Qualification chance**	3	8	**24**	7	**24**	4	**12**
Speed	4	9	**36**	3	**27**	6	**24**
Safety	3	7	**21**	6	**18**	7	**21**
Cost	1	7	**7**	8	**8**	5	**5**
Point Potential	5	8	**40**	7	**35**	4	**20**
Total Points:			**201**		**152**		**130**

***Note, points are distributed based on 0 "performing poorly in this category", while 10 "performs best".**

**** Also note, Qualification chance refers to the risk of the machine becoming "Disqualified" for any reason.**

From this weighting system 1 proves to be the best sub-system for application to the Warman Competition task. System 1 (James - Comb Sub-System) will be utilised as the collection method for the final system. Some modification is required to with the other sub-systems to be utilised in the final system (system 1 will be referred to as tool head while interacting with other sub-systems). The comb will now feature a pivot joint at the top of the body to allow for natural leveling while in operation. A motor or servo will be mounted above the body to allow for 180° tilt in both XY and YX directions relative to 0.

This system will interact with modified versions of System 2 (Callen – Stationary Counterweight Crane System), and System 2 (Alec – Crane Transition Sub-System). The head will be extended on an elevated telescopic arm mounted on a swivel base plate allowing the tool head to move freely within the competition area.

Individual Section –Joshua Wall

Engineering Analysis

Input

Scale model propellent fuel (Wilson Tour Competition Tennis Balls) & oxidiser (Yellow Dot Squash balls) vessels

Variables	Constraints
M12 nut thickness (mm)	10.585±0.215
Scale model type (ball)	Wilson Tour Competition Tennis Balls
Diameter (mm)	67±0.16
Weight (g)	57.5±1.5
∑ Vessels to collect	3
Scale model type (ball)	Yellow Dot Squash balls
Diameter (mm)	40±0.5
Weight (g)	24±1
∑ Vessels to collect	3

Output

Separately deposited propellent fuel vessels into their respective silos

Variables	Constraints
Silo inner diameter (mm)	104
Silo outer diameter (mm)	110
Fuel silo height (mm)	530
Oxidiser silo height (mm)	200
Distance between 400mm³ build volume, centred on "Start Zone", and further silo centre (mm)	1311.726

Solution Variables

- Vessel collection subsystem
- Vessel depositing subsystem
- Translation subsystem of vessels from respective "Drop Zone" to "Silo"
- Optimised location of system & vessel relative to "Silo"
- Locating & positioning method
- Mechanical design
- Electrical design
- Construction materials

Restrictions

Warman device

- Total weight ≤ 6 Kg
- Autonomous, isolated, continuous system
- Fit within a 400mm³ build volume
- All electrical systems
    - Battery powered, fuse protected
    - Begin operation with one physical switch
    - No peripheral/wireless connection
- Cannot damage Warman competition track

Warman competition

- Assemble in "Setup/Start Zone" within 120 seconds
- Begin & end track attempt only contacting "Setup/Start Zone" and within 120 seconds
    - Cease movement after 120 seconds
- Demonstrate safe operation & risk assessment
- Different vessel types cannot contact simultaneously on; the track, Warman device, opposing silos

Criteria

- Repeatable results
- Simplicity of design
- Speed of task completion
- Accuracy

Production Volume

- 1 unit

Usage

- Two functional runs both locally & internationally
- Successfully compete in the Warman Design and Build Competition, without receiving a Zero RUNscore

Solution 1 – Propellant collector/depositor

The "Propellant collector/depositor" subsystem is designed to directly handle the propellant vessels. A hardcoded movement subsystem will place the collector/depositor within appropriate range of the pre-coordinated locations of the vessels on the track. Four RGB sensors, illustrated in figure 8, will correctly centre the aperture opening over the propellant through feedback to the hardcoded system. Once in place the four retrieval arms will lift the ball into the subsystem. The aperture will expand when the ball is within range to receive it without releasing any currently collected propellant vessels.

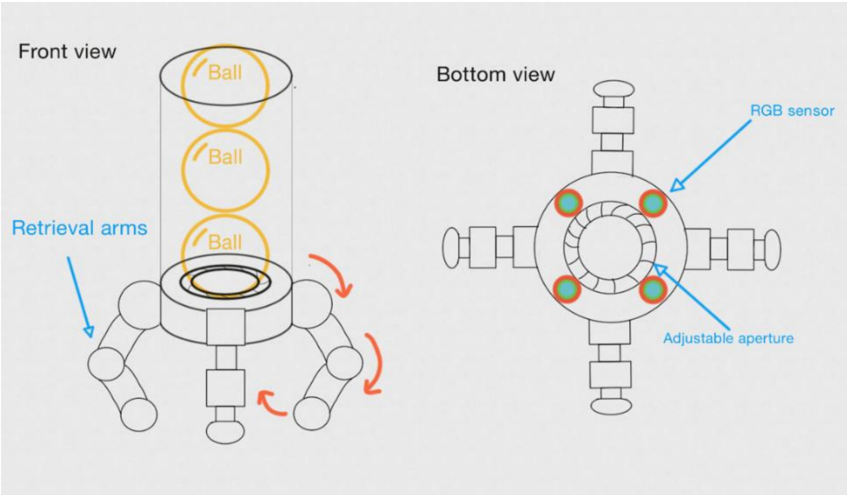

Figure 8 - Propellant Collector/depositor

Once all three vessels of the respective propellant types have been collected, the collector/depositor will then be positioned by the hardcoded system above the correct silo with error correction from the RGB sensors. Once aligned, the four retrieval arms will lock onto the silo, the aperture will fully open and release all propellant vessels.

Opportunities

The design of the "Propellant collector/depositor" enables numerous opportunities for the final Warman device:

- Potential misalignment with both the propellant vessels and the silo can be minimised by allowing this subsystem to fine tune the positioning.
- This subsystem can collect both fuel types with ease due to the adjustable aperture, varied range retrieval arms, and the versatile nature of RGB sensors.
- Traditionally apertures are complex to manufacture, but 3D printable apertures are both fast & low-cost to produce. Similarly, aspects of the design are complex and non-standard, but FDM allows for a low-cost option without sacrificing design functionality.

Challenges

This design has several challenges to consider if used in the final Warman device:

- Collecting the vessels individually is a bottleneck to the speed of the overall device.
- If the final Warman device is a static system, the weight of this subsystem will be significant at its furthest point from the initial "Start Zone".
- If the retrieval arms do not apply adequate force and/or have adequate friction, the propellant vessel is likely to be lost.

Solution 2 – Ranged collector/depositor

The "Ranged collector/depositor" subsystem is designed to allow the propellant vessels handling subsystem to perform all required movements on the 2023 Warman competition track. Illustrated in figure 9, the bulk of this subsystem stays within the 400mm³ build volume that is within the "Start Zone", seen in figure 9. The "Ranged collector/depositor" box represents any potential propellent vessel handling subsystem.

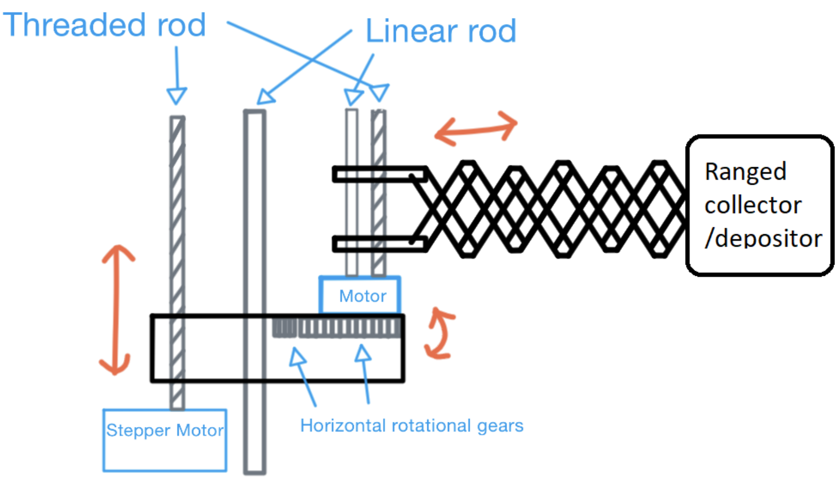

Figure 9 - Ranged collector/Depositor

The positioning of the "Ranged collector/depositor" will be handled by three mechanisms:

- Translation in the z-axis is achieved by a threaded rod attached to a stepper motor and linear rods for stabilisation, like a 3D printer. This conveys a platform housing the other movement mechanisms.
- On the platform, horizontal rotational gears attached to a servo (not visible in figure 9) allows for adjustment of the angle of the "Ranged collector/depositor" relative to the platform.
- The final mechanism directly attached to the "Ranged collector/depositor" is a horizontal scissor lift mechanism. A modified version of the z-axis mechanism controls the compression of the two end members of a traditional scissor lift mechanism to allow for extension or contraction of the mechanism.

Opportunities

The design of the "Ranged collector/depositor" has varied opportunities for the final Warman device:

1. The z-axis mechanism allows for accurate positioning of the propellant vessel handling subsystem. This can assist for fine tuning any sagging that may occur when extending over long distances.
2. Usage of stepper motors/servos, metal gearing & rods will generate a large amount of weight, but this will also act as a counterweight when extending over long distances.

Challenges

This design has several challenges to consider if used in the final Warman device, some of which are opportunities when if used in conjunction with “Solution 1 - Propellent collector/depositor”:

- While the z-axis mechanism is accurate, the scissor lift mechanism will require error correction at varied extension distances due to sag. This can be calculated through testing but will require a testing prototype as soon as feasible.
- The use of a scissor lift mechanism for extension and contraction in conjunction with a geared angle adjustment is not as accurate as desired. But if the handling system is similar to the design of “Solution 1 - Propellent collector/depositor” and contains error correction for misalignment then this inaccuracy would be negligible.

Solution 3 – Mass damper base

This subsystem uses mass dampening to allow the operation of higher speed movements of heavier components without destabilising or disorienting the overall system. Connected to the base frame are four high-speed servos, illustrated in figure 10, which control the position of the steel inertial mass using guide wire. Using calculated inertial forces caused by another subsystem e.g., extension outwards of the scissor lift mechanism found in “Solution 2 - Ranged collector/depositor”, an equal and opposite force can be generated by movement of the inertial mass. Rubberised, high friction feet will also be attached to the feet of the base to enhance stability.

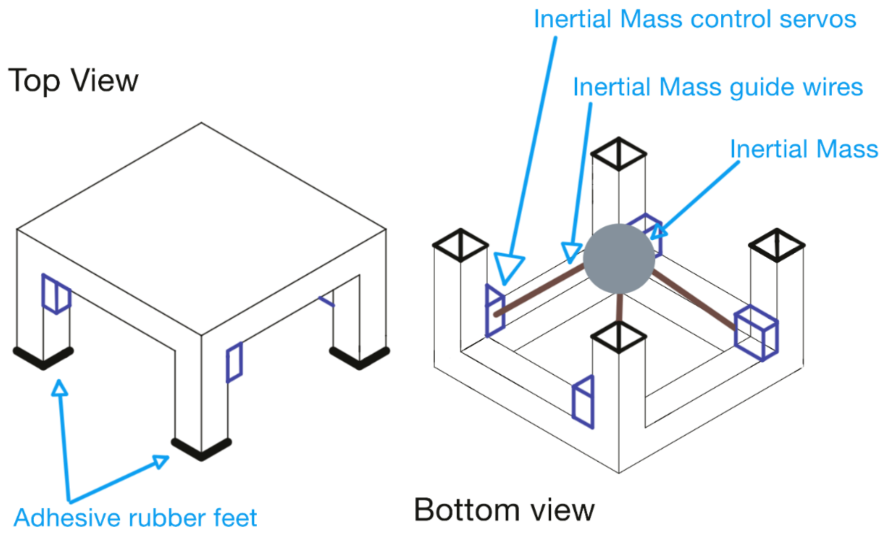

Figure 10 - Mass Damper Base

Additional fine tuning can be achieved using accelerometers during the testing phase to work with real-world values. Incorporating live values from an accelerometer whilst the device is running would allow for fine tuning error correction due to variances such as loose fittings, unstable loads, etc.

Opportunities

The “Mass damper base” provides some unique opportunities for the final Warman device:

- Under normal operating conditions with the mass dampening, finer accuracy will be achieved with normal movement speeds.
- With the damper system, increased movement speed will allow for faster completion of the challenge and in turn, more points.

Challenges

This design poses some challenges if used in the final Warman device:

- If the system is not accurately tuned, or does not have adequate safeguards, there is inherent risk with moving a large inertial mass via an automated system.
- There are limitations on the direction and value of the inertial movements produced by other subsystems that the mass damper system would be capable of dampening. Both the size of the inertial mass and the position of the servos will have a significant impact on this.

Final Solution

The potential design solutions listed above have been collated into table 3 below and assessed against the criteria outlined in the engineering analysis. Weightings relative to the importance of these criteria have been assigned with respect to the restrictions and solution variables.

Table 3 - Final Decision Matrix

Criteria	**Weighting**	**Solution 1 - Propellant collector/depositor**		**Solution 2 - Ranged collector/depositor**		**Solution 3 - Mass damper base**	
Speed of task completion	**4**	7	28	6	24	9	36
Accuracy	**5**	10	50	7	35	8	40
Simplicity of design	**2**	4	8	2	4	2	4
Repeatable results	**3**	10	30	7	21	8	24
Totals			116		84		104

Ranking Scale: 10 (Highest) – 0 (Lowest)

From table 3, "Solution 1 - Propellent collector/depositor" is observed to be the highest scoring solution. The task of propellent vessel handling requires both accuracy and delicacy due to the vessel's volatility. Of the provided solutions, solution 1 is best suited for use in the final Warman device and has overarching compatibility with a variety of other subsystems.

The "Propellent collector/depositor" is a versatile subsystem that corrects its positioning in the X & Y planes using the RGB sensors. The required positioning of the subsystem can be loosely defined thanks to the retrieval arms wide range for vessel collection and physical self-correction for silo alignment when depositing.

The speed of collection is delayed due to the mechanism's limitation of individual collection but in turn, accuracy is heightened when compared to collective collection. This delay is slightly mitigated by the aperture mechanism which allows continued collection of vessels before depositing.

Final Solution – Group Decision (6-8 pages)

Ultimately, with the search phase concluding, each team member presented their proposed solutions to the rest of the team in an open forum, highlighting the foreseen challenges and opportunities for each of the designed subsystems. Table 4 summarized the set of design principals that were developed based on the comparison of the solutions in order to reduce risks, costs and foreseeable challenges within the final solution for the Warman competition.

Table 4 - Solution Principals Summary

Avoid…	Like shown in…	In Favour Of…	Like shown in…	Reason
Dynamic Transmission Systems	• Motor Carriage Transmission system • Mass Damper Base • Mobile counterweight crane	Static Transmission systems	• Crane Transmission system • Stationary counterweight crane • Swivel crane	With the introduction of system dynamics, significant penalties to simplicity and reliability due to error checking and code complexities were foreseen to be significant challenges across solutions.
Systems reliant on sensors	• Propellant Collector/Depositor	Systems that have reliable hardcode potential	• Forklift Pickup System • Comb-based pickup system	Systems reliant on sensors will tend to introduce more vectors for error. Systems which have rely on error checking have been excluded for this reason. Systems with some level of error checking, but favouring the model is still to be considered.
Current-based Motors	• N/A	Step-based motors	• All discovered transmission systems	Stepper motors provide a method for the tracking of movements and distances traversed, without the need for complex electronics or encoders. In all designs this was favoured over DC motors.

Through the design principals described in Table 4, the mechanical and electrical systems of the teams proposed Warman device have been conceptualized to suit these criteria. Overall, the system has been split into 4 key mechanical partitions:

- The crane base.
- The central motor drive.
- The cascading linear arm.
- The comb-style toolhead.

In addition to one electrical subsystem, inclusive of a PCB design.

Mechanical Subsystems

Crane Base

The Crane Base is the pivotal support of the overall prototype design. The main purpose of the base is to swivel the main tower in a 360° range of motion to allow the telescopic arm to reach into the restricted zones to collect and distribute the vessels. The Crane Base is in figure 11 below.

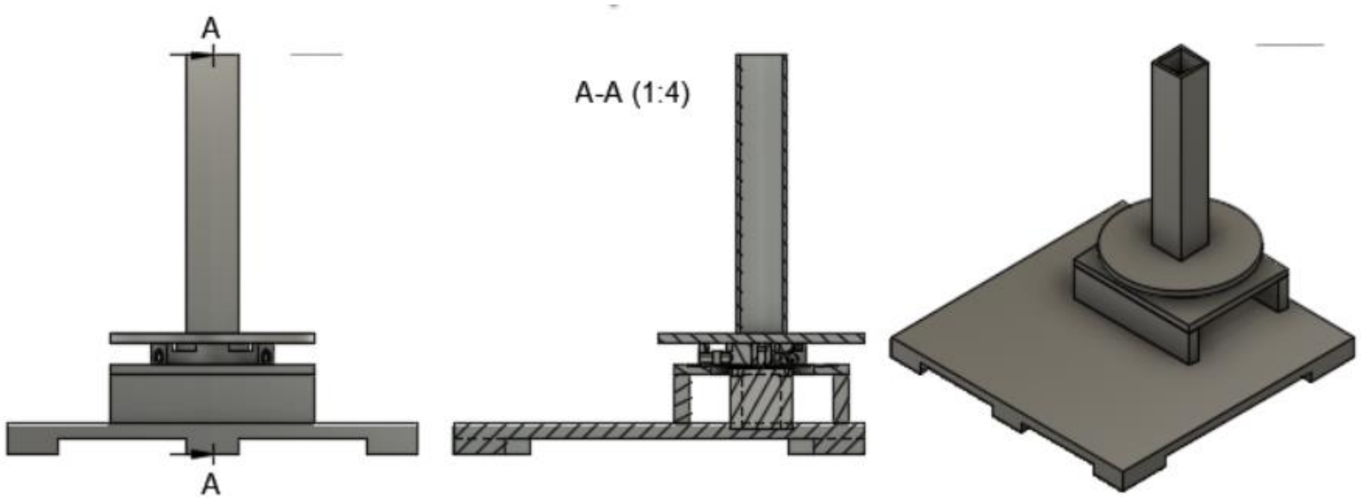

Figure 11 - crane base and main tower schematic

As above in figure 11, the main base plate is 400 x 400mm in area, which is where the main electronics for the prototype system will be situated, alongside the stepper motor located underneath the platform seen which will operate the swivel to rotate the main tower. The main tower is a hollow square tube of a 50mm outer diameter and a 40mm inner diameter that reaches to 270mm high fitting comfortably inside the cubic area. The Central Motor Drive will be connected onto the side of the tower at a perpendicular angle, and at this height with the addition NEMA23 stepper motor controlling the pitch of the telescopic arm will gain the clearance for the deposit into the vessel silos.

Central Motor Drive

The central motor drive of the Warman device aims to provide both connection and a motorized rotational pivot point between the crane base and cascading linear arm of the device. The model of this part is shown in figure 12.

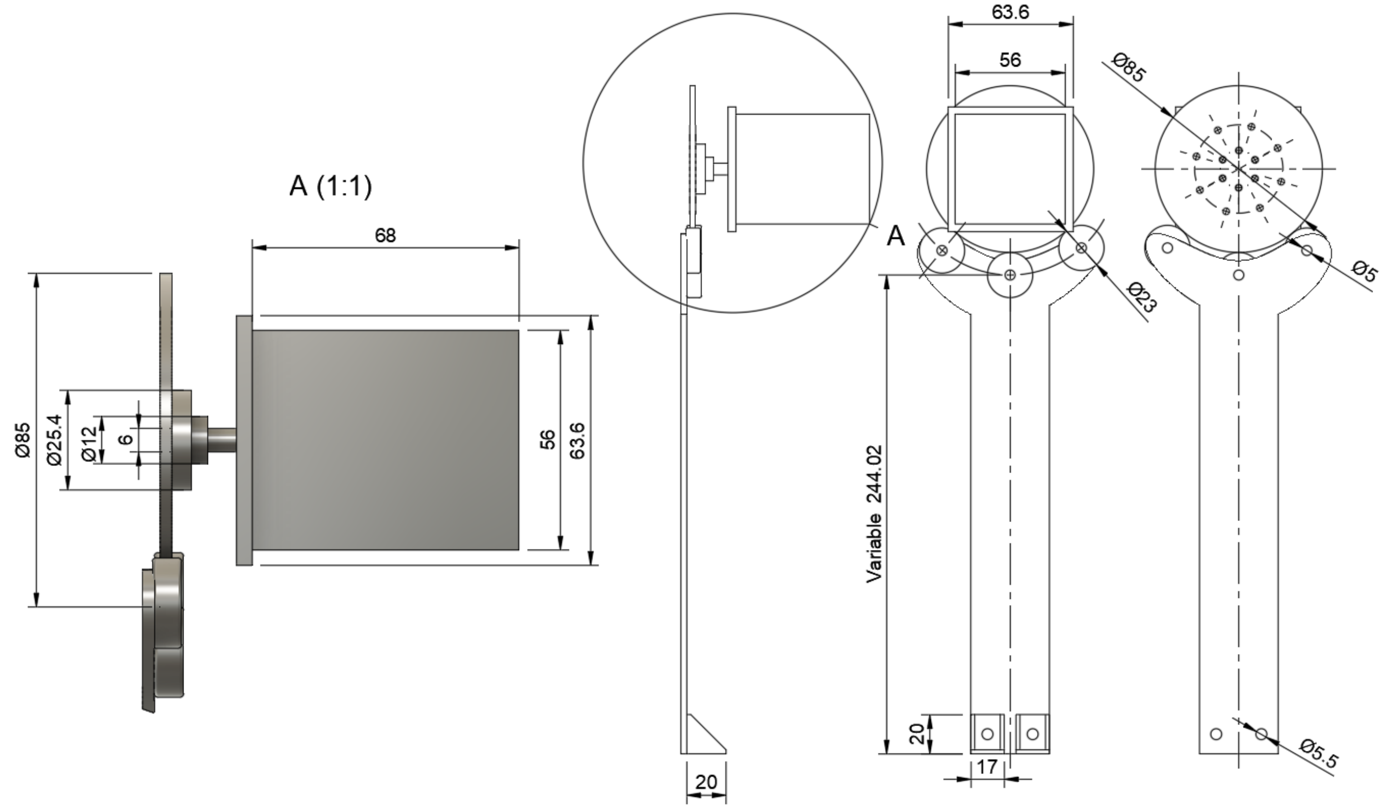

Figure 12 - Central motor Drive of the Warman Device

As shown in figure 12, the central motor drive has been modelled using the Nema23 high torque stepper motor and is shown attached to a custom 63.6mm plate. Extending beyond the plate, attached to the motors drive shaft is a 25.4mm universal hub, which provides solid attachment to a larger custom 85mm mounting plate. The plate has 8 5mm mounting holes (for m5 screws) which can be utilized to provide a solid mounting point for the cascading linear arm. To assist in supporting the load attached to the drive shaft is an elongated gantry arm which provides supporting rollers to the 85mm mounting disk. This supporting arm will attach to the rotating plate at the cranes base. The selection of the high torque motor also aims to provide a suitable drive torque to overcome the large forces associated with the loaded extended cascading arm.

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Cascading Linear Arm

The cascading linear arm is a succinct way of staying within the build volume when retracted, shown in figure 13, while stilling being able to cover long distances, as shown in figure 14. The subsystem can bridge the space between the static system's location within the "Start Zone" and both the vessel and silo locations, allowing the tool head to interact. A series of 3D printed gantries run along lengths of V-slot aluminium extrusion to provide the extension. The extension is controlled by a Nema23 high torque stepper motor through a GT2 timing belt that is hinged about the design using smooth idler pulleys.

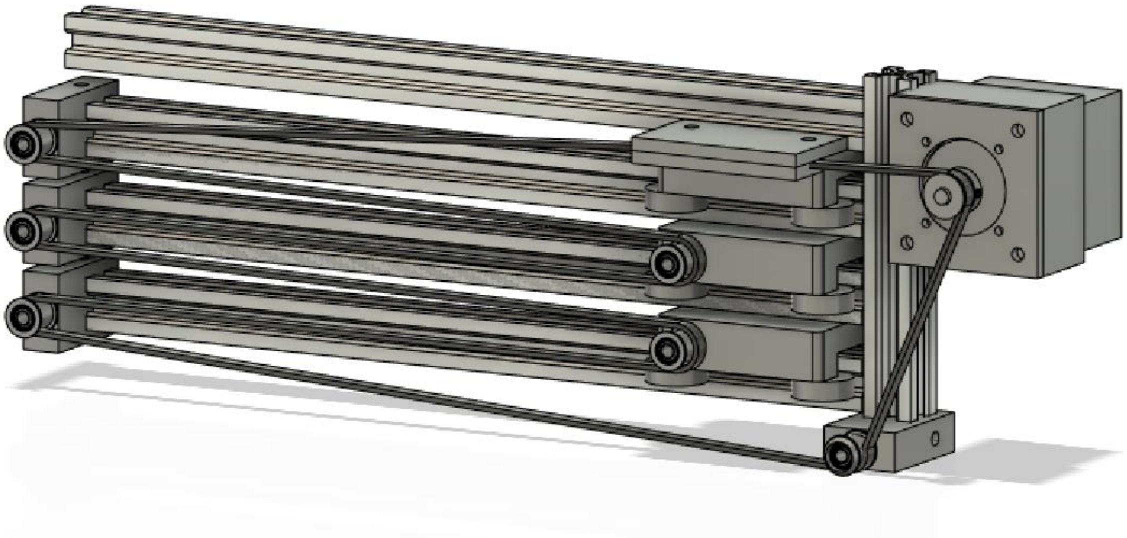

Figure 13 - Cascading Linear Arm (Retracted)

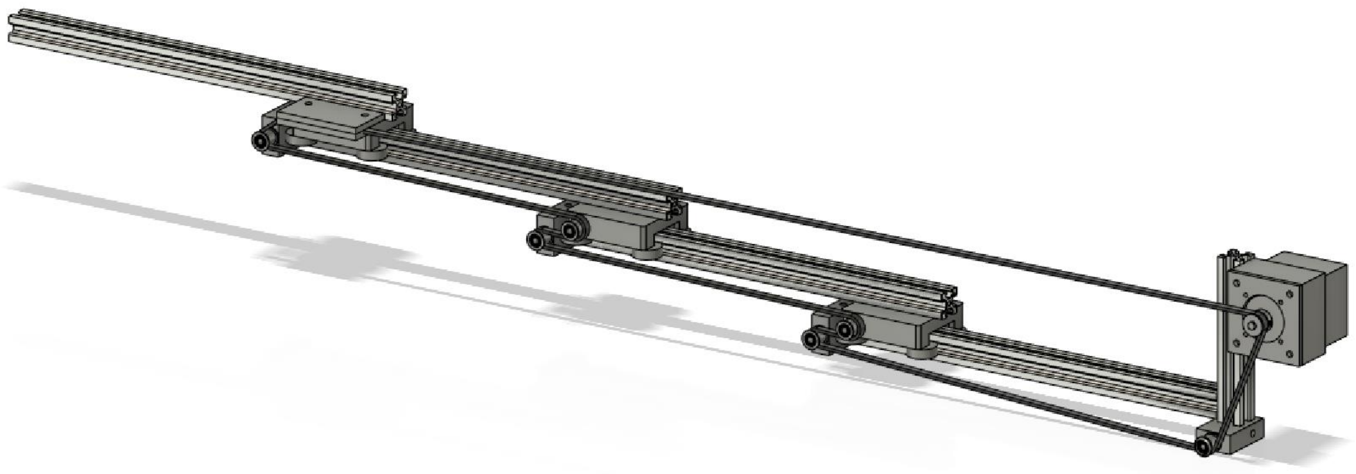

Figure 14 - Cascading Linear Arm (Extended)

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Claw Ball Catch (tool head)

The claw ball catch (tool head) uses simple pivots to collect both types of vessels. The tool head design was chosen for its simplicity in design and manufacture, all drawn parts are designed to be laser cut with iteration and adjustment planned into the design. Multiple iterations of catch arm length and shape will be tested to find optimal arm design for the collection and storage of both vessel types.

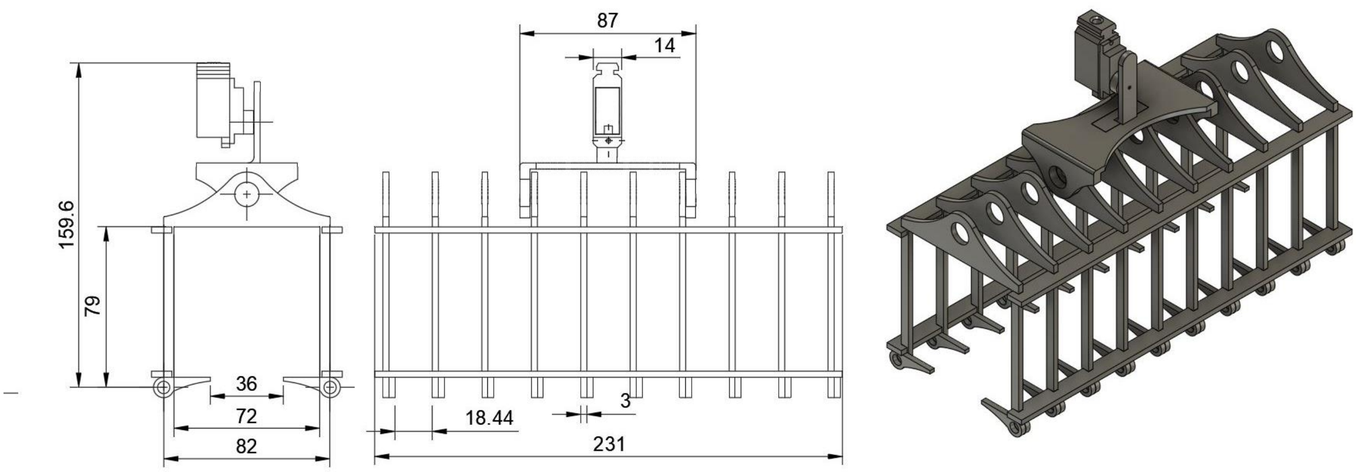

Figure 15 - Tool head Assembly

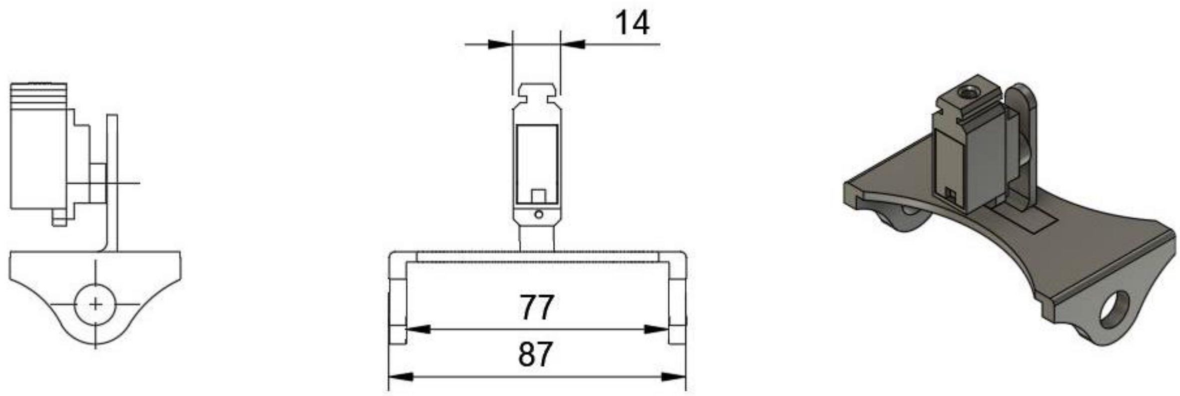

Figure 16 - Tool Head Pivot Design

The top of the head is mounted on a pivot centralised t the tool head to allow for the head to self-level. A 1.9kg rated servo motor will be attached to this pivot allowing the dead to tilt and deposit the vessels into the silos, the servo is attached to the cascading linear arm in the v-slot channel and secured with a grub screw. The tool head will be made from 3 mm acrylic or MDF so that rapid adjustments can be made during testing before the remake of a part to minimise design waste.

Electrical System

For the electrical subsystem, the Raspberry Pi Pico (H) was selected as the primary microcontroller for use within the final design of the Warman device. This controller was decided for the final design since through the MECH2110 course content (Carr, 2023) all team members are familiar with the device. A diagram of the electrical system can be found in figure 17. An enlarged version is found in Appendix B.

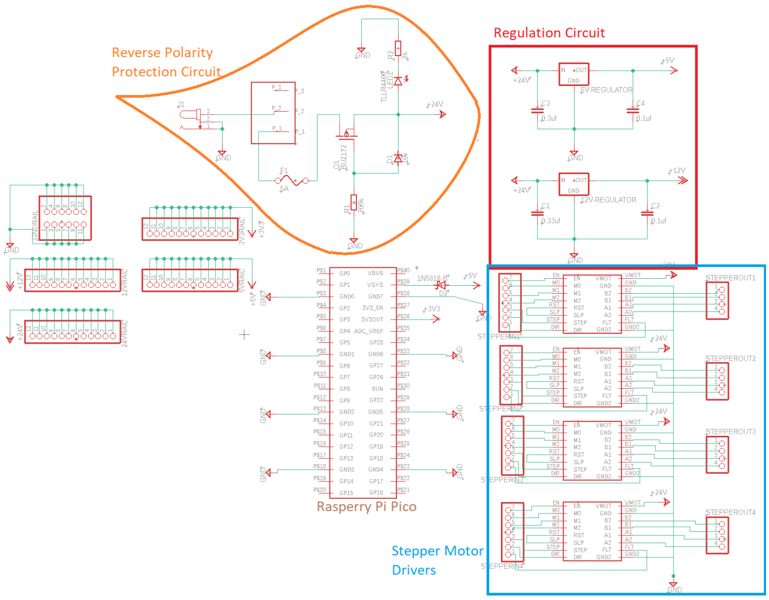

Figure 17 - Electrical circuit design

As shown in figure 17, the system relies on a 24v battery and includes the capabilities to power up to 6 stepper motor drivers, in addition to 3 regulated voltage sources (12v, 5v and 3.3v). The circuit is additionally protected by a reverse polarity PnP transistor gate. As per design specification, accommodation for a switch and appropriate (20x5mm) fuse has been included. A PCB has also been designed and is ready for fabrication, shown in figure 18.

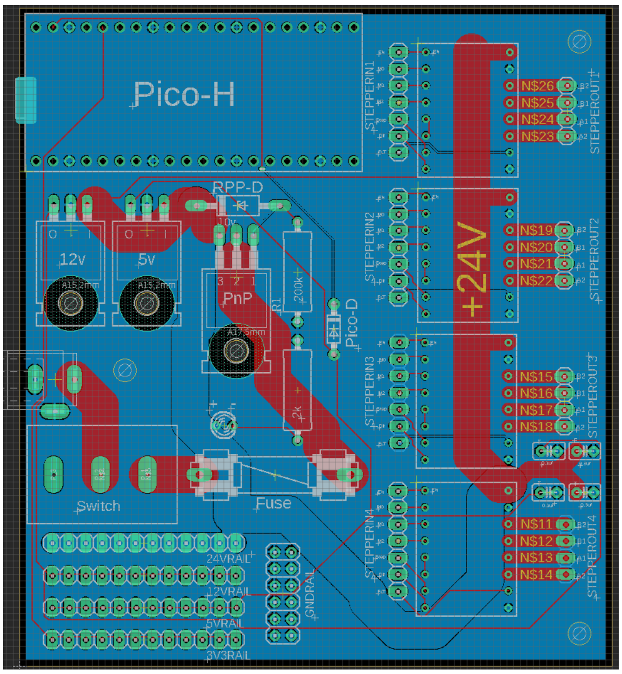

Figure 18 - PCB design for the electrical subsystem

Final Assembly

In operation, the Warman device will operate under a series of hardcoded movements, with the vessel locations being coordinated during setup to correspond with said movements. The initial position of the device is shown in Figure 19.

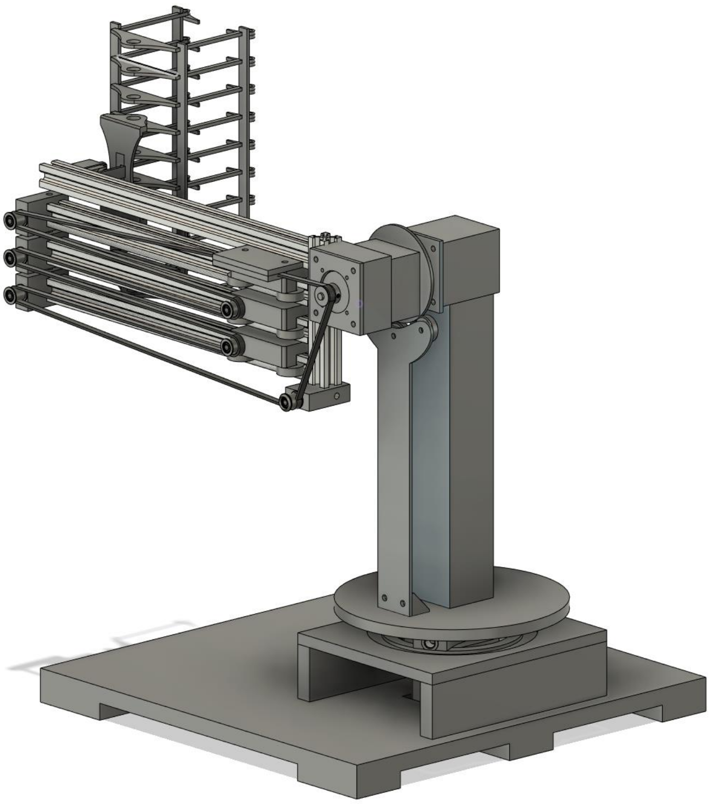

Figure 19 - Initial Position of the Warman Device

When activated, the linear arm cascades outwards, pitches downward and tool head rotating horizontally so that the tool head will engage with the vessels, as seen in figure 20.

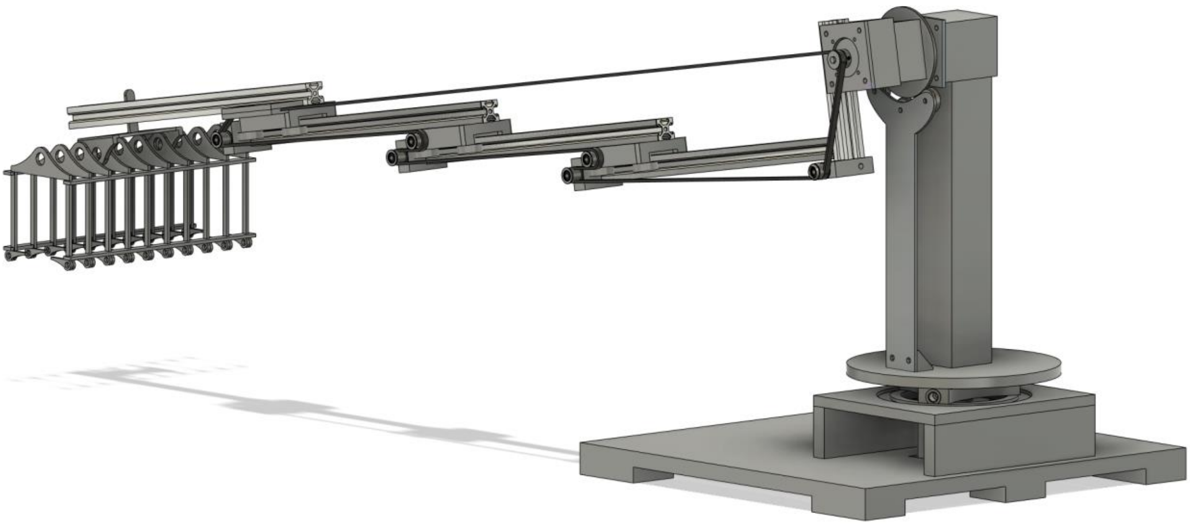

Figure 20 - Warman Device Tilting to collect Vessel's example.

Once the vessels have been collected, the tool head will then be positioned at the opening of the vessel's respective silo and tilt to release the vessels, as illustrated in figure 21.

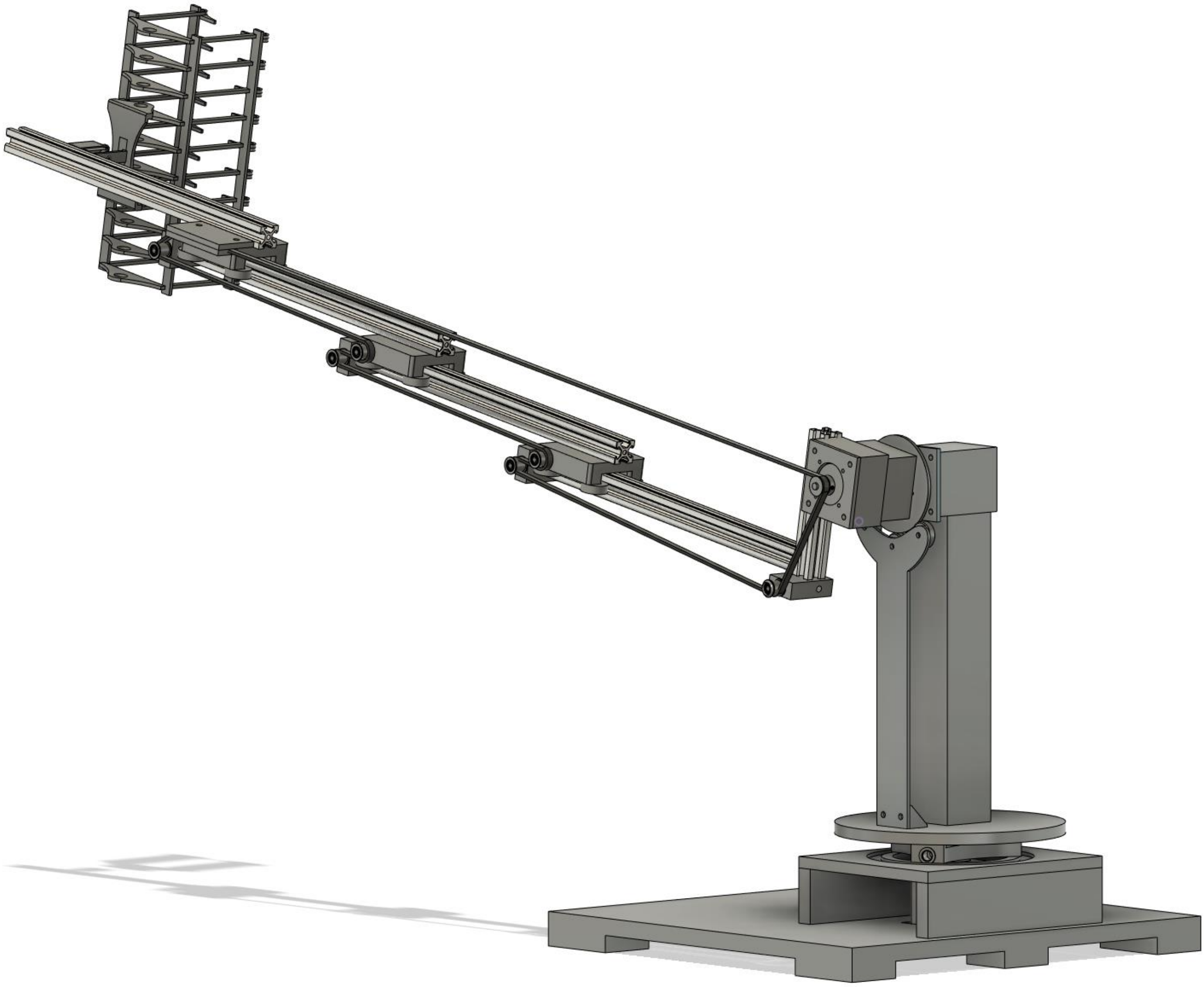

Figure 21 - Warman Device Silo Placement Example

This process will be repeated for the uncollected vessels before finally returning to the initial stage position, completing the run.

The build of the device will make use of the part inventory table located in Appendix A, which describes the parts on hand, in addition to the parts which require fabrication or backorder for production.

Risk Assessments

Construction Risk Assessment

Table 5 - Construction Risk Assessment

Hazard Identification and initial Risk Rating			Control measures and Residual Risk Rating		Remaining Hazards	Actions required
What are the steps of the activity / items of equipment?	**What are the potential hazards?**	**Risk Rating based on Risk Matrix**	**What control methods or measures will be used to reduce the likelihood and/or the consequence of an illness or injury from those hazards?**	**Residual Risk Rating based on Risk Matrix**	**What hazard remains?**	**What additional actions are required (by who and in what timeframe) to raise the level of control?**
Welding (flux core)	Burns	Minor	Use of appropriate flux core welding PPE (Personal Protective Equipment) including welding mask, correctly rated gloves, heat resistant clothing and leather boots.	Low	N/A	Ensure flux cools appropriately before touching circuit board.
Welding (flux core)	Toxic fume inhalation	Moderate	Operate welder in well-ventilated space with adequate respirator PPE	Medium	N/A	Ensure equipment is checked and ventilation on.
3D Printing (PLA, PLA+, PETG, etc)	Toxic fume inhalational and microplastic exposure	Moderate	Operate printer within well-ventilated environment or within ventilated enclosure	Low	N/A	N/A

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3D Printing	Burns	Minimal	Do not touch headed surfaces while machine is in operation	Low	N/A	N/A
Installing heated inserts	Burns	Minimal	Keep hands away from hot end, store soldering iron in correct cradle while not in use.	Low	N/A	Assume hot end Is still hot at all times.
Metal Drilling	Cuts/Abrasions	Minimal	Clean swarf from drilled holes with brush or similar implement, debur all drilled holes before further handling	Low	N/A	N/A

Device Operation Risk Assessment

Table 6 - Operational Risk Assessment

Hazard Identification and initial Risk Rating			Control measures and Residual Risk Rating		Remaining Hazards	Actions required
What are the steps of the activity / items of equipment?	**What are the potential hazards?**	**Risk Rating based on Risk Matrix**	**What control methods or measures will be used to reduce the likelihood and/or the consequence of an illness or injury from those hazards?**	**Residual Risk Rating based on Risk Matrix**	**What hazard remains?**	**What additional actions are required (by who and in what timeframe) to raise the level of control?**
System power on	Electrocution	Minor	Manual toggle switch in power line while connecting to battery power	Low	N/A	N/A
System operation (damage to wiring)	Electrocution	Minor	All exposed wiring to be contained within sleeving or spiral binding.	Low	Pinching or strain during motion	Wiring should be routed away from potential pinch points and have slack to accommodate motion when fixed to moving parts.
Physical contact with moving parts	Cuts/abrasions , crushing injuries	Minor	Keep extremities clear while machine is in operation. Have isolator switches well clear of moving parts.	Low	N/A	N/A
Set-up of system in track/testing	cuts/abrasions	Minor	Clear away all burs and swarf during production of system.	Low	Cust/abrasions from thin materials	Cover or roll all edges too thin to be deburred

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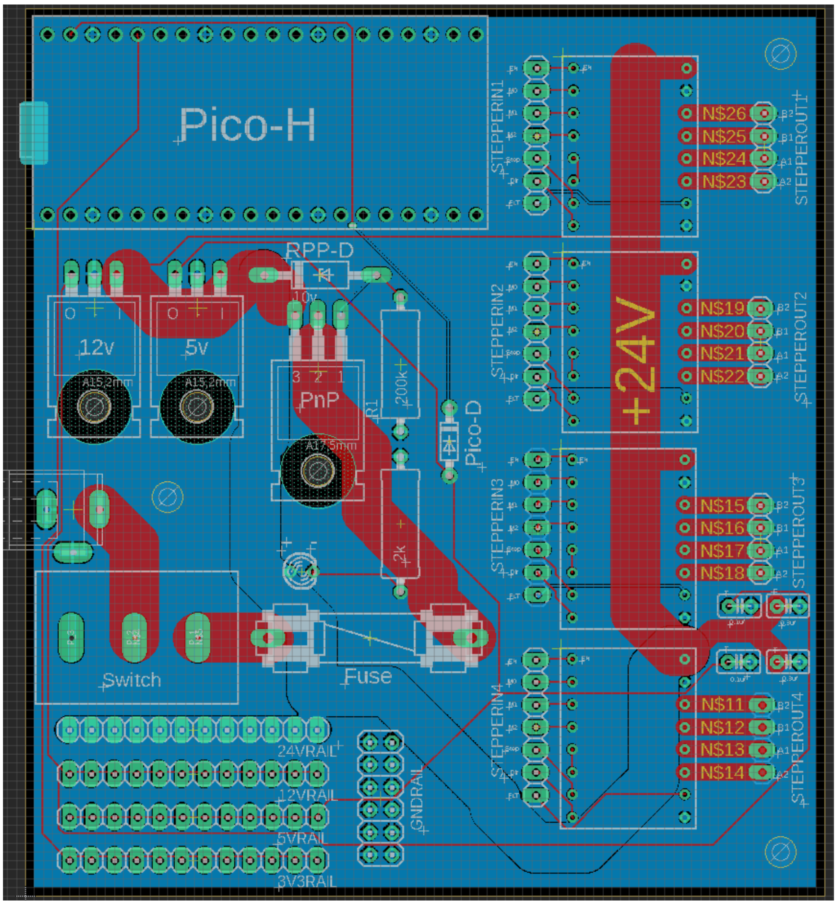
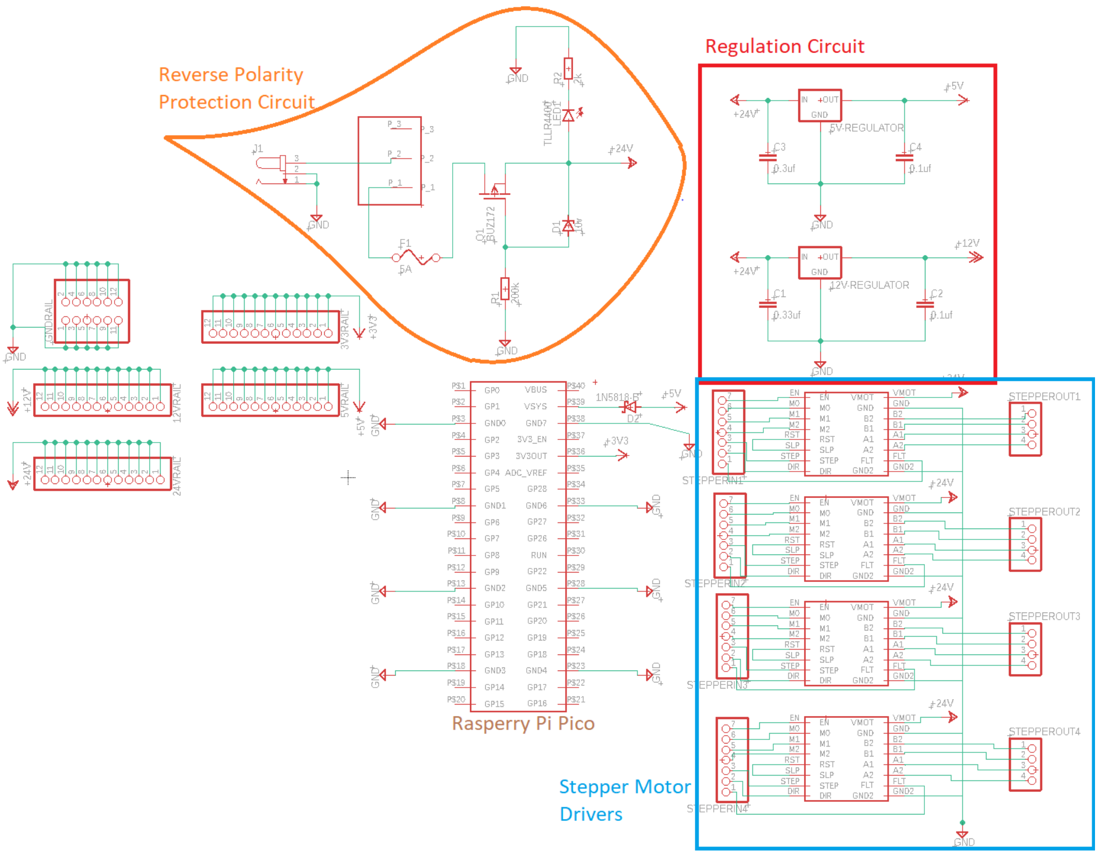
Appendix A – Team Inventory

	Part Name	On Hand	Supplier
Hardware	V-Slot 20 x 40mm - 500mm	**5**	Makerstore
	V-Slot 20 x 20mm - 500mm	**3**	Makerstore
	V-Slot C-Beam - 250mm	**1**	MakerStore
	GT2 (2mm) Timing Belt (meters) - 5mm	**4**	MakerStore
	Belt Torsion Spring	**4**	Makerstore
	90 Degree Corner Bracket	**10**	Makerstore
	Vslot Wheels	**11**	MakerStore
	20-tooth GT2 Timing Pulley	**6**	Makerstore
	GT2 Idler Pulley	**1**	Makerstore
	Actuator Pulley Plate	**1**	Makerstore
	NEMA17 Right Angle Mount Plate	**2**	Makerstore
Other	Drop-in T-Bolt 25mm Drop-in T-Bolt	**8**	Makerstore
	Tee Nuts (25 Pack)	**1**	MakerStore
	Double Tee Nut	**7**	Makerstore
	M5 Low Profile Screws - 25mm/10 Pcs	**1**	~
	M5 Low Profile Screws - 30mm/10 Pcs	**1**	~
	M5 Low Profile Screws - 15mm/10 Pcs	**1**	~
	M5 Low Profile Screws - 15mm/10 Pcs	**1**	~
	M5 Low Profile Screws - 8mm/10Pcs	**1**	~
	M5 Low Profile Screws - 6mm/25 Pcs	**1**	~
	M5 Nut - Pack of 10	**1**	~
	M5 Jam/Thin Nut - Pack of 10	**1**	~
	M5 Low Profile Screws - 10mm/10 Pcs	**1**	~
	Precision Shim - M5 6.5x5x1mm	**12**	~
	50 x 50 mm 2mm gal tube (meters)	**5**	~
	40 x 40 mm 3 mm steel tube (meters)	**3**	~
	16mm OD gal rod (meters)	**1**	~
Motors	Nema 17 Stepper Motor 560mN.m - Version B	**2**	Makerstore
	Nema 23 Stepper Motor – High Torque – 2.45N.m OR Nema 23 Stepper Motor – standard Torque – 2.45N.m	**0**	Makerstore OR Makerstore
	5203 Series Yellow Jacket Planetary Gear Motor	**0**	ServoCity
	9g micro servo (1.6kg)	**1**	~
	DC hobby motor - 130	**1**	~
	5V stepper with controller 1/64	**1**	~
Electrical	Voltage Regulator (12v)	**0**	~
	Voltage Regulator (5v)	**0**	~
	Voltage Regulator (3.3v)	**0**	~
	24v Battery	**0**	~
	5A fuse	**0**	~
	DC Barrel Jack	**0**	~

	Rocker Switch	**0**	~
	PnP Transistor	**0**	~
	20mA LED's	**0**	~
	12v zenner diode	**0**	~
	200k Resistor	**0**	~
	2k Resistor	**0**	~
	A4988 Stepper Driver OR DRV8825 Stepper Driver	**0**	~
	Raspberry PI Pico H	**0**	~
	0.22uf Capacitor	**0**	Jaycar
	0.1uf capacitor	**0**	Jaycar
	Schottky Diode	**0**	Core Electronics
	Rasbery Pi Pico (male headers)	**1**	~
	HC-SR04 ultrasonic sensor	**1**	~
	Stepper moot controller module	**1**	~
	EasyDriver – stepper motor driver	**1**	~

Appendix B – Electrical Subsystem Diagrams





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