Group G - F117942, F212053, F232825,
F118767, F133377, F133071, F126225

Hex Track

A Large Scale, Semi-Autonomous Crop Sprayer

F117942 - (Team Leader)	Overview and Cabin
F212053 -	Suspension and Traction Mechanism
F232825 -	Chassis and Mounting Mechanisms
F118767 -	Powertrains (Motor and Cooling)
F133377 -	Powertrains (Fuel Cell and Battery)
F133071 -	Autonomous Driving and AI Features
F126225 -	Fertiliser System

1. Vehicle Description

As the United States of America (US) farming industry moves closer and closer to an autonomous and machine focused world, manufacturers are pushing to be at the forefront of this development. Over the past 70 years the number of farms in the US has dropped drastically from around 7 million to 1.89 million in 2022 [1]. Subsequently, the average US farm has doubled in size for the same period. The number of farmers has also reduced over this period meaning more land is needed to be farmed by less people. More recently, commercial arable farms have expanded to scales of up to and beyond 54000 acres (219km^2). These two considerations served as the basis for the decision to design a large-scale crop sprayer. A crop sprayer was chosen over a traditional tractor as crop spraying can be easily achieved with autonomous driving. The intention was to design within a unique selling point of bees, who are essential crop pollinators. By aligning the vehicle's foundations with this, the aim is to create a product that is eco-friendly and sustainable, reflecting a commitment to both agricultural innovation and environmental responsibility using hydrogen power and fuel cells. These design intentions formulate the brief of developing a farming vehicle to fulfil the role of semi-autonomous, eco-friendly, large-scale crop caring with the constraints of further development needed in fuel cell technology and hydrogen refilling in order to achieve this.

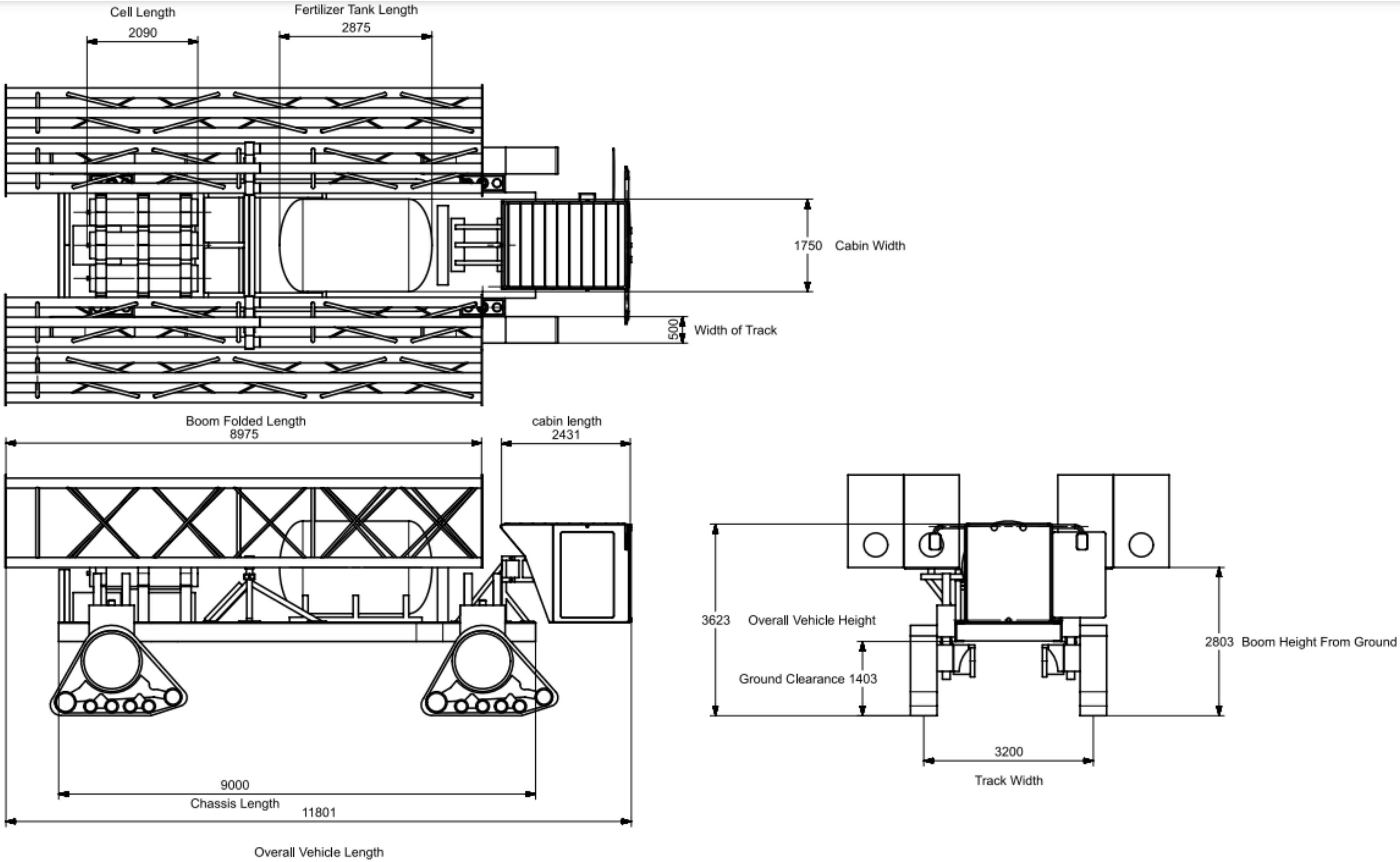
Typically, farmers are very reluctant to change especially when the perception is that their jobs are at risk. This is very prevalent with the introduction of autonomous farming vehicles. Therefore, one of the main objectives of Hex Track is to ease the change between fully manual and autonomous farming. The semi-autonomous feature in the form of a detachable cabin provides a unique solution to this issue. Further objectives of Hex Track are listed as followed:

- Sustainable and Eco friendly through hydrogen power
- Reduce labour requirements
- Reduction in fertiliser usage
- Ease of farming and maximising field efficiency with autonomous and AI features
- Increase crop yields
- 24/7 operation
- Increased protection in adverse weather conditions

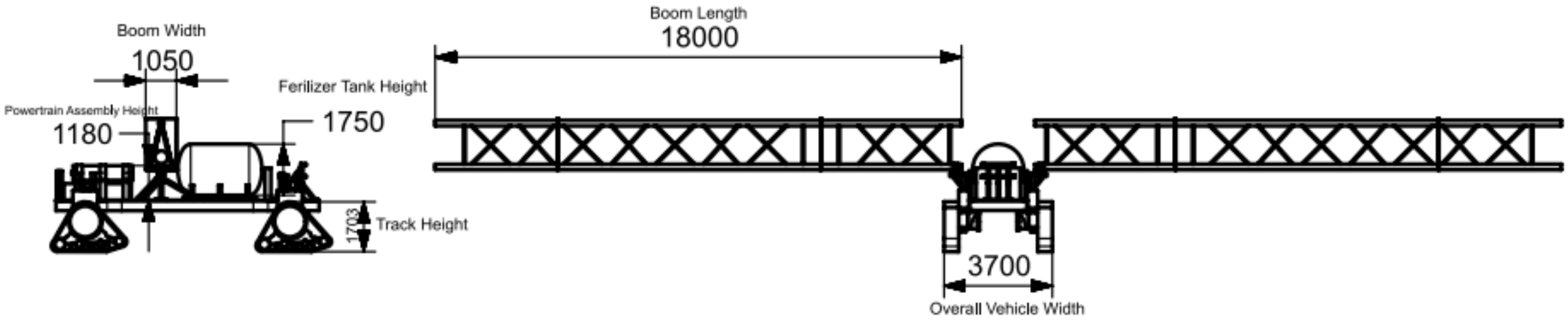
Further to this, the vehicle is required to perform in certain operating conditions. These are highlighted in table 1 below.

Table 1 – Expected operation conditions

Operating condition	Expectation	Justification
Time	To have the ability to operate 24/7	Allows for continuous farming leading to increase in crop yields
Weather	To run as expected in all weather conditions and climates	The US experience extreme weather conditions
Soil conditions	To run in both muddy and dry soil conditions	Must work in all seasons and not tear up the ground
Crop growth stages	Adjustable ride height	Accounts for all crop growth stages
Terrain	Powertrain is able to function in all conditions and reasonable inclines	Vehicle must be able to cope with terrain changes on farms



SIZE	A4	SCALE	1:100	MATERIAL	N/A	
LINEAR TOL UOS	±0.5	DRAWING TO BS8888		FINISH	N/A	
ANGULAR TOL UOS	±0.5°	ALL DIMENSIONS MM		DRAWN BY	Alfie Toone	
Loughborough University				PROJECT GROUP	Group G	
				TITLE	Hex-Track -With Cabin	
				DRAWING NO.	1	
				MODULE NO.	DATE	29/11/2024
				24TTC006	SHEET	1 OF 1



SIZE	A4	SCALE	1:200	MATERIAL	N/A
LINEAR TOL UOS	±0.5	DRAWING TO BS8888		FINISH	N/A
ANGULAR TOL UOS	±0.5°	ALL DIMENSIONS MM		DRAWN BY	Alfie Toone
Loughborough University				PROJECT GROUP	Group G
				TITLE	Hex-Track - No Cabin
				DRAWING NO.	2
				MODULE NO.	DATE 29/11/2024
				24TTC006	SHEET 1 OF 1

3. Vehicle Package

3.1. Table of headline figures

Power	460 kW
Range	200 km
Top Speed	32 km/h
Unladen Mass	15.02 t
Max Dimensions	3.70 x 3.50 x 11.80 m
Boom Size	36 m
Tank size	6000 l

3.2. Table of definitive targets

<table>
<tr><th>Parameter</th><th>Target</th><th>Specification</th><th>Justification</th></tr>
<tr><td>Dimensions with Cab HxWxL (m)</td><td>3.90 x 3.50 x 9.80</td><td>3.70 x 4.50 x 11.80</td><td>Vehicle is larger than initially benchmarked due to the extra length of cabin and height of boom arms.</td></tr>
<tr><td>Dimensions without Cab HxWxL (m)</td><td>3.90 x 3.50 x 8.00</td><td>3.70 x 4.50 x 10.00</td><td>Slight overhang from the boom arm increases overall length and height. This is still within other vehicle lengths on the market</td></tr>
<tr><td>Ground clearance (m)</td><td>1.40 – 2.00</td><td>1.40 – 2.00</td><td>Targets easily achieved keeping to expected operating conditions</td></tr>
<tr><td>Unladen Mass (t). (Empty fluid tank & no cab)</td><td>15.80</td><td>15.02</td><td>The removable cabin reduces the mass, explaining the difference compared to the target set from benchmarking</td></tr>
<tr><td>Total Mass (t) (Full fertiliser tank & Cab attached)</td><td>20.00</td><td>24.01</td><td>Mass of fertiliser tank was underestimated. Suspension and ground pressure specification still met despite mass increase.</td></tr>
<tr><td>Fully loaded with Cab weight distribution</td><td>40 : 60 (F : R)</td><td>57.9 : 42.1 (F : R)</td><td rowspan="2">Changes are attributed to packaging requirements, specifically the location of the underestimated mass of the fertiliser tank</td></tr>
<tr><td>Unloaded without Cab weight distribution</td><td>45 : 55 (F : R)</td><td>40.3 : 59.7 (F : R)</td></tr>
<tr><td>Max boom length (m)</td><td>41.00</td><td>38.00</td><td>A shorter boom length was required to reduce total bending stress and length of vehicle when folded</td></tr>
<tr><td>Fertiliser tank size (L)</td><td>7000</td><td>6000</td><td>Saves 1400 kg, reducing the laden weight</td></tr>
</table>

3.3. Bending moment and shear force diagram

To calculate the bending moment (BM) and shear force diagrams (SF), the vehicle is simplified into a beam and roller pin diagram (Appendix A). The two tracks are resolved as roller supports with the weights of the subsystems parameterized as distributed and point loads. The BM and SF diagrams can be seen in fig 1 respectively.

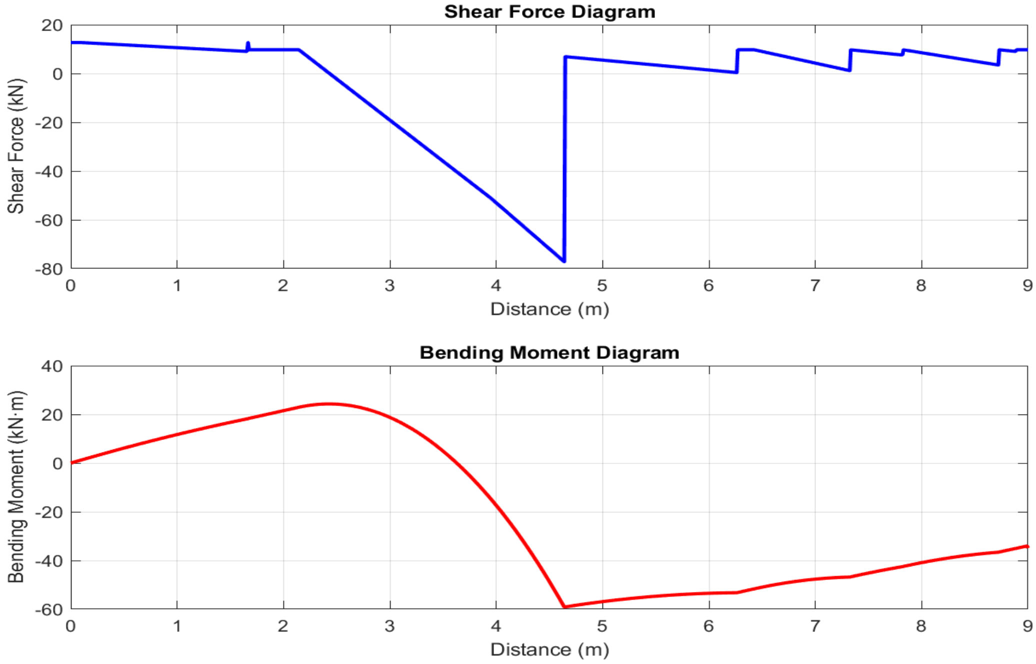


Fig 1 Shear force and bending moment diagrams

3.4. Weight and balance chart

As can be seen in fig 2, the weight distributions for the vehicle's four operating weight conditions are shown and how they have changed over the project's timeframe. The conditions arise due to having a detachable cab and a significant additional weight when the fertiliser tank is fully loaded. The final weight distributions are calculated using the diagram in appendix A and equations in appendix B.

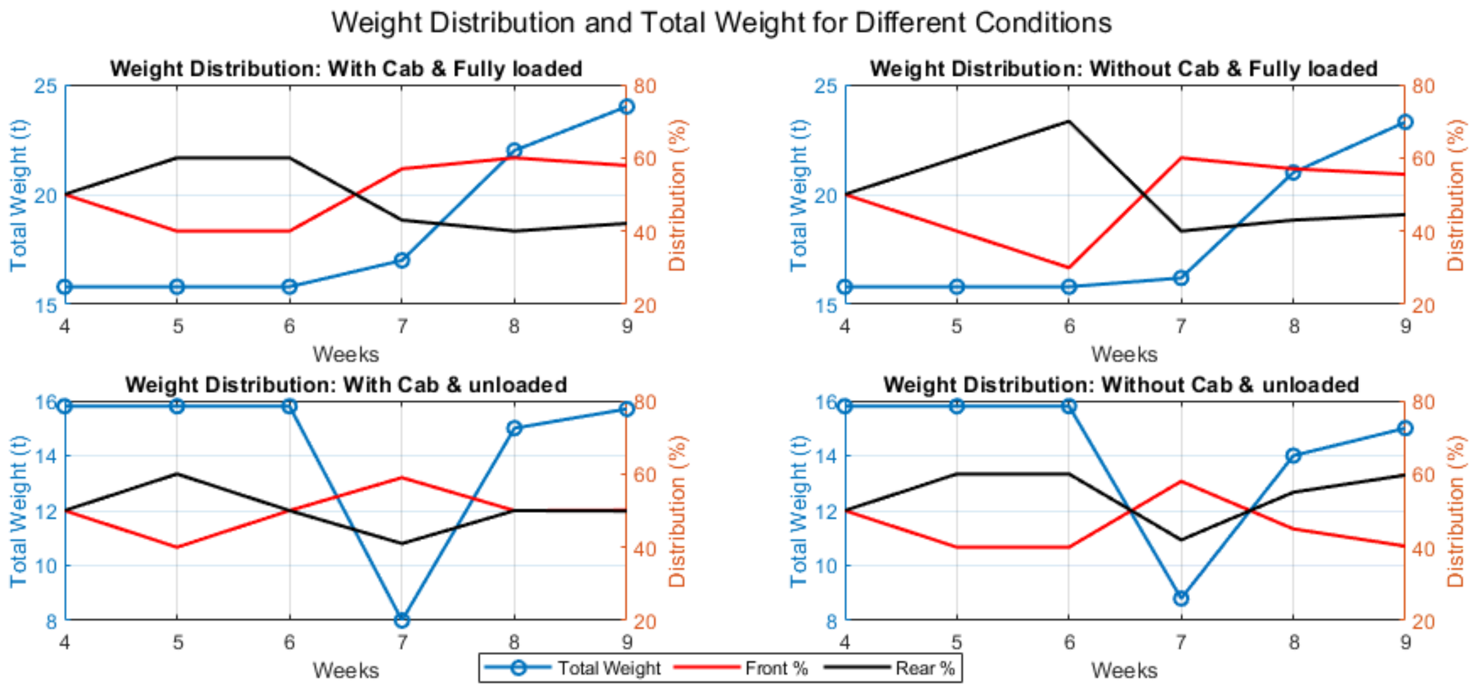


Fig 2 Weight distribution for different loading conditions

4. Vehicle Specification

4.1. The Cabin

Component	Target	Specification	Justification
Internal dimensions (m)	1.5x1.7x1.5	1.5x1.7x2.4	Extra length added on the top surface to increase the area for the solar panel and battery storage.
Solar panel	3 kW	1.2 kW*	3 kW was a large overestimate of power requirements from the cabin
Leisure battery	1x 24V Lithium ion 600 Ah	1x 48V Lithium ion 300Ah	48 V batteries are often optimised for solar invertors as well as having an improved performance in high power applications.
Charge controller	150 A	100 A	Requirement based on leisure battery and solar panel adjustments.
Lighting (external)	4x 4000 lumen 30W	4x 4000 Lumen 30W 2x 1000 Lumen 8W	Extra lights were added in areas like the steps and mounting mechanism.
Lighting (internal)	3x 300 Lumen 5W LED	2x 300 Lumen 5W LED	3 LED's was a considerable amount of light for a small cabin, so this was reduced to save on power requirements.
Subframe	High strength steel	6061 T6 Aluminium alloy	Aluminium alloy provides very similar strengths while reducing the mass by over 300 kg.
Mass	<500 kg	686 kg	Mass was reduced by change of subframe Material. However, due to not accounting for the mass of the battery, glass and attachment frame, it was still over the target.
Seat dimensions	To accommodate the 5th and 95th percentile male and female farmer	1.14(h) x 0.60(l) x 0.55(w)	The average US farmer is 58 years old so anthropometrics for this age group are used. Height adjustable to allow for different sized people.
Noise requirement	60 dB(A)	70 dB(A)	Increased to ensure damage or component failure can still be heard.

*Note that solar panels with dimensions similar to the cabin (2.3 x 1.84 x 1.5 m) currently only produce around 500W. Projected advancements in technology are needed to meet the specification.

4.2. Suspension and Tracks

Component	Target	Specification	Justification
		Suspension	
Suspension struts load limit per corner	6.25 Tonnes	25 Tonnes	Vehicle overall mass exceeded initial target. Adjustments made to account for this. Note that the specification includes a 5:1 safety factor
Suspension hydraulic piston travel	600 mm	600 mm	Target met Ground clearance requirements and operating conditions
Suspension passive (in track)	250 mm	200 mm	This is an acceptable travel for in field operation.
Suspension assembly materials	Steel	Hydraulic Cylinder – 4140 low Alloy Steel Overall construction – 6016 Series Aluminium	Included aluminium in construction to decrease assembly mass
Hydraulic suspension (overall assembly mass)	1200 kg	795 kg	Mass reduction possible due to optimized selection of overall materials
		Traction mechanism	
Track width	500 mm	500 mm	Meets ground pressure target while maintaining minimal rut width
Track sprocket wheel diameter	1300 mm	1150 mm	Reduction as torque targets were met and ground clearance requirements were exceeded
Track roller wheels	1x 330 mm 1x 400 mm 16 x 250 mm	1x 330 mm 1x 400 mm 8 x 250 mm	Number of the smallest passive rollers reduced to improve simplicity and minimise assembly mass
Overall material choice for tracks and suspension	Overall – Steel Track material – Steel	Overall – 4140 low Alloy Steel Track material – Neoprene Rubber	Rubber chosen for track material to reduce vibration and ground pressure.
Mass per track assembly	1500 kg	1350 kg	Fewer roller wheels reducing overall mass
Brakes	Drum Brakes	Reversed motor operation and regenerative braking	Less additional complexity – functions perfectly well for low vehicle speeds
Steering	Skid Steer	Four track steering combined with skid steer	Less ground churning when turning – meeting the operating conditions
Turning radius	To be able to turn easily at the end of a field	Essentially zero	Combination of differential and 4-wheel steer allows for high manoeuvrability at low speed

4.3. Chassis, Cabin attachment and Support frames

Component	Target	Specification	Justification
Chassis			
Dimensions (m)	To fit within the targeted overall vehicle dimensions	2.5 (w) x 0.36 (h) x 9 (l)	These dimensions fit within the overall vehicle dimension targets and designed to help package subsystems
C-shape dimensions (m)	To be able to support the sprung vehicle mass	0.35 (h) x 0.15 (l) x 0.01 (wt)	Sufficient shape to support the vehicle parts while keeping a low deflection and bending stress
No. of cross members (m)	To be able to support the specification mass of the vehicle combined with its weight distribution	13 Rectangular hollow sections - 0.2 (w) x 0.33 (d) x 0.01 (wt), 2 'X' shapes made from hollow sections.	Added and dimensioned to reduce deflection when at maximum load. Cross members add torsional rigidity when driving on uneven terrain, working towards the given operating conditions.
Material	High strength steel	High strength steel	Industry standards dictated this choice and backed up by bending stress and deflection calculations
Mass	2000 kg	2305 kg	Mass increased due to the use of cross members to support the components with high mass
Cabin attachment			
Dimensions (m)	To fit within the desired packaging	1.12 (w) x 1.23 (h) x 1.56 (l)	To attach the cab to the floor of the chassis and provide sufficient ground clearance and ease of entry.
Material	Titanium alloy	High strength steel	Chosen to significantly reduce costs and mass whilst still supporting the cabin weight with suitable stresses and deflections.
Mass	To limit the amount of added mass while still providing sufficient strength	372 kg	Mass optimised through the change in material
Supporting Frames			
Hydrogen storage materials	Steel	Aluminium alloy	Provides sufficient strength whilst keeping mass low
Hydrogen storage dimensions (m)	To sufficiently package the hydrogen tanks	2 (w) x 1.8(h) x 1.2 (l)	Designed to handle specific loads and fit within available chassis space to correctly package the hydrogen tanks and fuel cells.
Boom arm attachment materials	Steel	Steel	Industry standard for heavy duty subframes and chosen due to the total mass and length of the boom arms
Boom arm attachment dimensions	To sufficiently support the boom arm and	3.91 (w) x 1.25 (h) x 2.31 (l)	Ensures it supports the expected mass of the boom arms. Dimensions considered to help with packaging

4.4. Powertrains

Component	Target	Specification	Justification
Power	400 kW	Max power: Fuel cell + battery = 440 kW	Sufficient to meet operational demands.
Torque	3000 Nm	Max torque: 3000 Nm	Able to meet terrain demands set out in operating conditions.
Powertrain total mass	2500 kg	2300 kg	Reduced due to smaller battery and motor mass.
Range	200km	200 km at 32 km/h (6.25 hours of constant use)	Designed to meet operational range needs.
Fuel cell (PEM)	Power output: 300 kW	3x Ballard FC move-XD Max Power output: 360kW Power per stack:120 kW	Meets power targets with additional capacity for flexibility.
Lithium-ion Battery	Capacity: 75 kWh Voltage: 350 V	Capacity: 30 kWh Voltage Range: 300 V-400V Power: 80 kW	Decreased due to lower capacity required.
Motors (Values per motor)	Type: PMS motors No. of motors: 4 Peak power: 75 kW Continuous power: 55 kW Peak torque: 750 Nm	Type: MI-F 485 50 PMS motors No. of motors: 4 Peak power: 110 kW Continuous power :55 kW Peak torque: 750 Nm	Sufficient to meet operational power and torque demands.
Thermal management	Prevent overheating in extreme conditions under continuous loads.	Type: Direct liquid cooling	Liquid cooling is highly effective for motors, battery, and fuel cells under continuous loads.
Hydrogen tanks	Ensure sufficient fuel supply to maximise range and efficiency	Mass of Hydrogen: 60 kg Pressure: 700bar No. of tanks: 3	Meets range and efficiency targets based on operational simulations.
Control systems	Ensure efficient power and voltage management across all systems	Integrated power management system (EMS, DC-DC converters, Inverter, BMS)	Manages power flow between fuel cell, battery, and motors, ensuring reliability and efficiency.

4.5. Autonomous and AI Features

Component	Target	Specification	Justification
Cameras:	360° Field of View (FOV)	120° FOV	Wide coverage but narrow enough to focus on tasks. Reduces cost of having too many cameras.
	16 + 4 Cameras	2 Standard cameras (up to 50 m) (90° FOV) 4 Multispectral cameras (30 m) (30° FOV)	Combination of standard camera for general use, mapping and multispectral for crop and soil assessments. 2 wide angle cameras are enough to provide 120° FOV with some overlap.
LiDAR:	360° FOV	360° FOV	Full coverage in field for mapping and obstacle detection.
	6 LiDAR's	4 Long range LiDAR (200m) (120° FOV) 2 Short range LiDAR (30m) (90° FOV)	Combination to carry out multiple tasks such as plant detection, path planning and terrain analysis. Short range sensors overlap with long range to reduce blind spots directly near the vehicle. Combination of ranges for precise imaging.
RADAR:	360° FOV	360° FOV	Full coverage for safety and precision of navigation and mapping.
	6 RADARs	4 Long range RADARs (200m) (90° FOV) 2 Short range RADARs (30m) (90° FOV)	Long range sensors on the front and rear detects moving obstacles earlier and will provide a 360° FOV. Two short range RADAR on each side covers blind spots and detect objects such as people by the side of the vehicle.
AI Algorithms:	Row Detection and Line Tracking	Row Detection and Line Tracking	Maintains precise row alignment.
	Object Detection	Object Detection	Identifies plants and weeds for targeted action.
	Depth Estimation	Depth Estimation	Aids obstacle avoidance, preventing plant damage.
	Coverage Path Planning	Coverage Path Planning	Ensures full coverage without overlap.
	Row Following & Crop Line Detection	Row Following & Crop Line Detection	Keeps vehicle centred, avoiding plant damage.
	Dynamic Window Approach	Dynamic Window Approach	Avoids unexpected obstacles.
	Model Predictive Control	Model Predictive Control	Smooth path-following with real-time adjustments.
	Pure Pursuit	Pure Pursuit	Simple and effective for moderate-speed tasks.
Computer System:	Neousys Industrial Computers	OnLogic Karbon 803 High Performance Rugged Computer	Easier and simpler to install.

4.6. Fertiliser System

Component	Target	Specification	Justification
Tank capacity	7000 l	6000 l	This reduction saves 1400 Kg while still providing 115 acres of coverage (a 20-acre reduction from target capacity).
Tank material	High-density polyethylene	High-density polyethylene	The material is still compatible with industry-standard storage liquid fertiliser, especially after the capacity reduction.
Tank dimensions (m)	2.3 (l) x 1.8 (d)	2.0 (l) x 1.75 (d)	Tank size is decreased by reducing capacity. With the given dimensions, a 6000l capacity could be achieved at 90% fill.
Tank mass at empty	330 kg	300 kg	Reduction due to dimension change
Tank mass at capacity	10,130 kg	8,700 kg	Uses a 1.4kg:1L ratio for fertiliser and an empty tank mass to provide these values
Boom arm material	6061 T6 Aluminium alloy	7075 T6 Aluminium alloy	The use of 7075-T6 alloy ensures the arm can tolerate vibrations and heavy loads due to its improved stiffness and fatigue resistance.
Boom arm dimensions (m)	0.75 x 0.75 x 21.0 (per side)	0.75 x 1.50 x 18.0 (per side)	Boom mass and length were overestimated, which led to a stress value higher than the 6061-T6 alloy's yield strength. With a change of materials and dimensions this was rectified.
Boom arm mass	1160 kg	1252 kg	7075-T6 (2800kg/m^3) results in an increase in total mass despite a shorter boom arm compared to 6061-T6 (2720kg/m^3)
Nozzles & spacing	Straight stream ceramic with 50 cm spacing	Straight stream ceramic with 50 cm spacing	Standardised regardless of boom dimension changes.
Nozzle ASABE droplet size	Very Fine	Medium	A medium classification was used to ensure the maximum amount of fertiliser contacts the crops.
Nozzle Pressure	5 bar	4 bar	The introduction of air support system using the venturi effect allows for a reduction in the nozzle pressure to reduce damage and maintain efficient spraying
Fertiliser (NPKS)	Soybean – 20:40:20:20 Corn – 15:15:6:4	Soybean – 20:40:20:20 Corn – 15:15:6:4	NPKS are industry standard values set for every crop and should not be deviated away from.

5. Business case

5.1. Executive Summary

Overview

This Business report outlines the proposed financial, marketing and technological development needed for Hex Track to be considered viable. Hex Track will be positioned as a high value item due to the technical complexity and scale. Below highlights the major considerations within specific areas of the business. Overall, Hex Track is proposed as a successful and enticing product for investors. A well-established market ensures customers have sufficient capital to purchase the high-priced vehicle.

Headline Figures

- Vehicle price: **$700,000**
- EBITDA: **$300,000**
- Initial investment needed: **$13,000,000**
- Payback point: **7.5 years**
- ROI: **26.7%**
- Market: **Illinois & Iowa**
- Autonomous tractor market expected to reach **$4.15B** in 2029

Market & Sales

Hex Track will be sold in **Illinois** and **Iowa** where majority of major corn and soybean farms are located, generating a harvest valued at $44 Billion [2] in 2023.

R&D and manufacturing will last **3 years** and managed with **Six Sigma** processes to ensure quality throughout.

Sales will be conducted through **direct distribution channels** with **live demonstrations** and **marketing to begin in Year 3** of the R&D phase to develop interest and exposure.

Costs Breakdown

Manufactured in **Montana** for close proximity to major market states, **zero VAT** and low corporation **tax at 6.75%.**

Bespoke vehicle specific subsystems to be manufactured **in-house. All else to be outsourced** to reduce R&D costs and production set up**.**

Investment needed: **$13 Million** broken down into a two-stage process. Year 1 - **R&D: $12 Million**, Year 3 Marketing: **$1 Million.**

Costs for one vehicle to be produced is broken down into Recurring and non-recurring costs and valued at **$400,000** Giving an EBITDA of **$300,000.** Product lifetime is set at **10-15 years** and a **Lifetime volume of 150 units**

Finances

Numbers based on a **2.5%** proposed inflation rate for the first 5-years.

- **ROI: 26.7%**
- **Annualised ROI: 3%**
- **Net profit** after 5 Years**: $16.48 Million**
- **NPV** after 5th year of trading**: $22.6 Million**
- **Payback point: 4.5 years**

Risks

Key risks, issues and dependencies that could hamper the project's success include:

- Poor hydrogen infrastructure – Investment allocated to improve this
- Supply chain failure – Reduce just-in-time stock
- Farmer reluctance to purchase – Warranty, detachable cabin and lease agreements combat potential issues that might arise

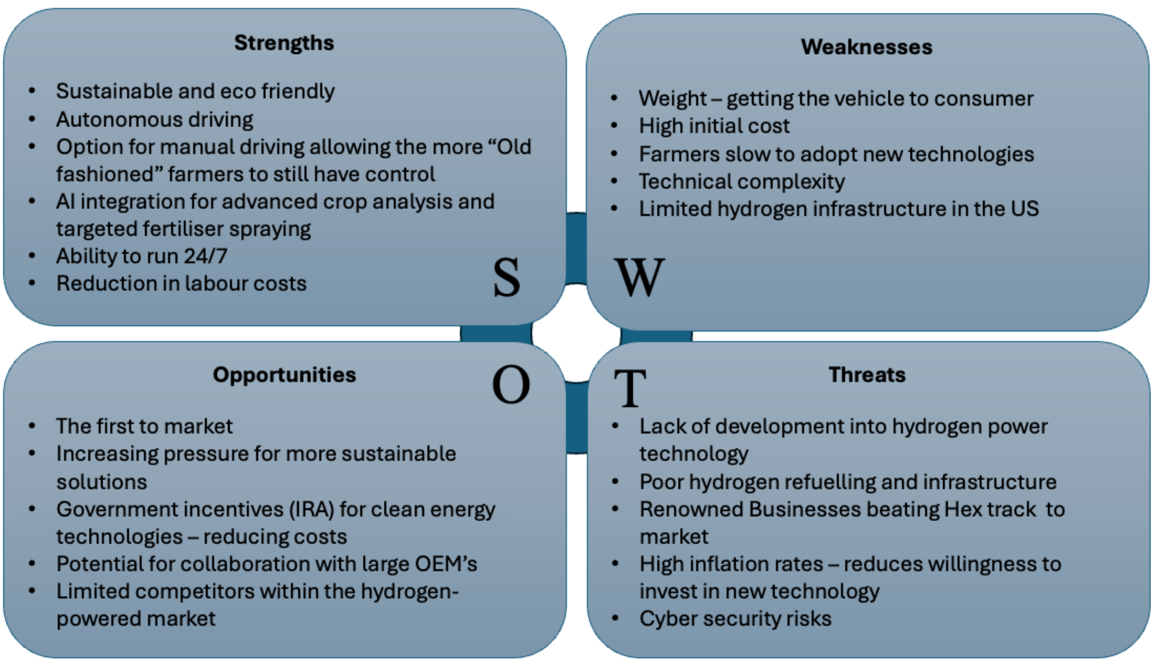
5.2. Marketing, Sales and Project Management

Hex Track's target market consists of large-scale corn and soybean fields across the US, especially in states like Illinois and Iowa where the combined harvest for these crops was valued at $44 billion in 2023 [2]. These crops are grown on more than 170 million [3] acres of farmland in the US indicating a sizable target market. Precision farming methods are being used increasingly by this market to maximise yields and optimise resources.

North America is expected to remain the fastest-growing market due to its large-scale farms. As seen in fig 3 the autonomous tractor market is expected to grow to $4.15B by 2029, due to farmer shortages and the growing need for farming efficiency. Currently top agricultural equipment manufacturers (John Deere, Fendt and Case IH) hold 93% of the market share in the US [4]. Therefore, Hex Track's initially market share will be small at 0.5% with the view to grow to 5% by 2035 evidenced by the SWOT analysis below and the expected CAGR (Continuous annual growth rate) of the autonomous tractor market.

Fig 3 US autonomous tractor market prediction [3]

Hex Track is positioned as a high-value product, due to its technological advancements and size, warranting an expected unit price of $700,000, aligning with typical costs for large agricultural equipment. Sales will be conducted through direct distribution channels, specifically targeting large farms and agricultural cooperatives to ensure sufficient capital. Initial vehicles will be sold to small scale local farms to aid in problem solving any issues that might arise. Partnerships with established local dealerships, who are educated on all systems and agricultural equipment reviewers will further expand reach. Hex track will be promoted using live demonstrations in major farming regions and collaborations with sustainability programs. The project is expected to have a 3-year lead time from research and development to full-scale production and will be managed using Six Sigma processes to ensure quality throughout. Marketing and initial product engagement will begin in year three.



5.3. Engineering, Production and Sourcing

Research and development (R&D), and manufacturing costs are determined using the top-down method. Manufacturing will occur in Montana, US, due to its close proximity to key markets, minimising transport costs and reduced repair call out times. Furthermore, Montana has a low corporate taxes, and zero VAT.

Cost type	Costs	Rough value ($1000)	Justification
Recurring costs (per vehicle)	• Materials • Transport (In bound & Outbound) • Labour • Manufacturing processes	• 120 • 50 • 200 • 30	Values are based on typical costs within engineering companies. E.g. 4x manufacturing employees per vehicle @$50,000 per annum.
Non-recurring costs	• Tooling • R&D • Machinery • Infrastructure	• 200 • 5000 • 2000 • 4800	Rough initial estimates based on start-up costs for large businesses in the US. R&D capital raised will be allocated to these costs

Hex track will be manufactured using a range of outsourced and in house subsystems. The in-house manufacturing will consist of high value bespoke parts and assembly of outsourced components. Outsourcing is chosen for systems to retain quality and offset initial R&D costs.

Manufacturing	Subsystem	Reasoning
In-house	• Cabin • Cabin attachment • Boom arm • Suspension	Bespoke parts with unique, vehicle specific designs that would be difficult to outsource and could be more costly due to the complexity and tailored tooling required.
Outsourced	• Chassis • Tracks • Powertrain • Fertiliser tank • AI and autonomous features	• Research and technology development already carried out by reputable businesses. • A full working system can be purchased for the powertrain, reducing cost of assembly • Established manufactures can produce the fertiliser tank and chassis instead of setting up the in-house infrastructure which would be costly

Having established R&D and manufacturing costs, a breakdown of the costings involved with selling one vehicle can be seen below. This allows the net profit and profit margin to be calculated to help inform the financial assessment later.

Per Vehicle	$1000
Revenue	700
Costs of sales and other expenses	400
EBITDA	300
Montana corporation Tax @6.75% [5]	279.8
Dealership commission @10%	251.8
Net Earnings (Profit Margin)	251.8 (36%)

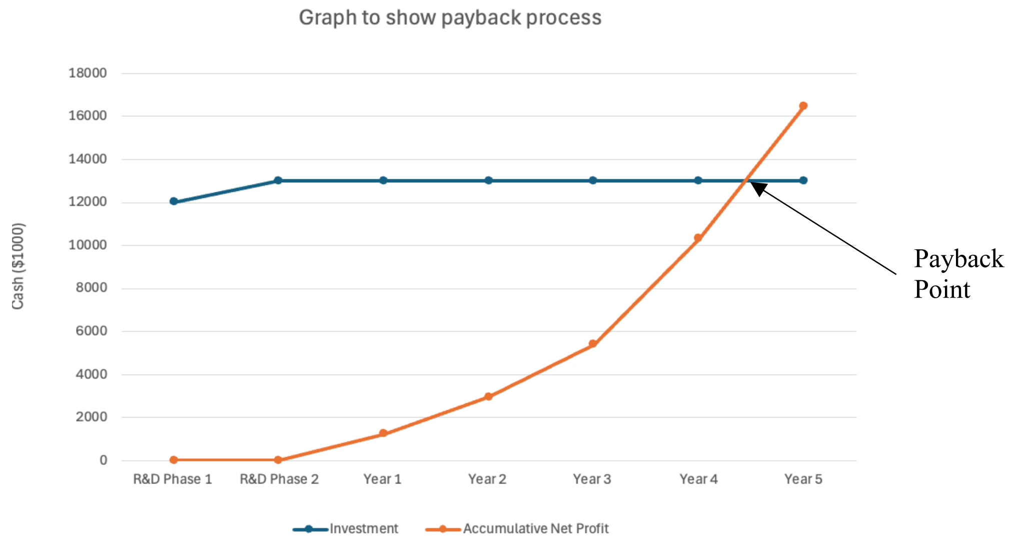
The product lifetime is set at 10-15 years. This is based on typical agricultural machinery lifespans. However, as Hex Track has a large number of new technologies that have the potential to make significant advancements over the product lifetime, for example hydrogen power and AI, this might ultimately reduce the product lifetime. It is expected that over thid lifetime, the volume will be 150 units.

5.4. Financial assessment

Due to the scale and high cost of Hex Track's sub systems and technology, a large initial investment of $13 million will be needed to fund the 3-year R&D and manufacturing. This will be divided using a two-stage investment process consisting of $12 million for R&D and production in year 1 and 2 and a further investment of $1 million in year 3 for marketing. The investment will be raised through bank loans, share capital and government grants. From this a simplified, projected profit and loss can be formulated. The federal Planning Bureau expects inflation in the US to fall to from 3.1% in 2024 to 1.8% in 2025 [6], so a rounded average of 2.5% will be used to project the next 5 years.

All Numbers x $1000	R&D Phase 1 (Y1-2)	R&D Phase 2 (Y3)	1	2	3	4	5
Investment	12000	1000	0	0	0	0	0
No. of sales	0	0	5	7	10	20	25
Sales revenue per year	0	0	3500	3500	7000	14000	14000
Net profit accounting for previously established costs. *(Adjusted for inflation @2.5%)*	0	0	1259	1719	2455	4910	17500

From this, total net profit and net present value (NPV) can be calculated as **$16,480,000** and **$22,602,000** respectfully. The tabulated information can also be graphically represented to show the projected payback for investors.



Finally, the return on investment (ROI) and annualized ROI are calculated below where the number of years invested, n, is 8.

$$ROI = \frac{Net\ profit - Initial\ investment}{Initial\ Investment} \times 100 = \frac{16480 - 13000}{13000} \times 100 = \ 26.7\%$$

$$Annualized\ ROI = \left((1 + ROI)^{\frac{1}{n}} - 1\right) \times 100 = \left((1 + 0.267)^{\frac{1}{8}} - 1\right) \times 100 = 3\%$$

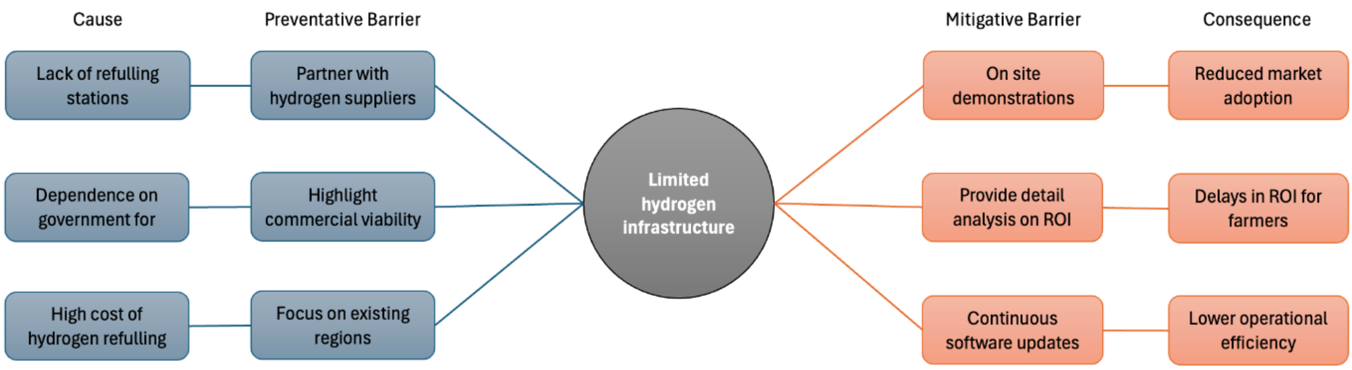
Due to the high risk involved in starting up this business and long payback period, a high ROI is required to justify initial investment. As the company becomes more established it would be expected for profit margins and ROI to reduce. Initial ROI and annualized ROI indicates that the vehicle is financially viable and provides a sufficient financial incentive to attract investors.

5.5. Risk, Issues, Assumptions and Dependencies

When establishing a product, key risks and issues must be analysed. Market opposition is a major risk to Hex Track since American shareholders could be hesitant to invest in semi-autonomous equipment until there is definite proof of ROI. Furthermore, Corn and soybean farmers frequently have narrow profit margins, which makes upfront large purchases a major concern. To counteract this, marketing will consist of live demonstrations to ensure confidence in the product. Warranty and lease agreements will also be offered to help spread the cost and prevent major payments for damages or part failure. Further risks and dependencies are laid out below. A cash contingency reserve of $1,000,000 will be set aside to aid financial instability in the event of any unaccounted-for risks.

- Supply chain failure – Hex Track consist of many outsourced parts leading to production risks – managed through reducing just-in-time stock
- Increase in solar panel power output per unit area – to reduce the detachable cabin's dependency on the powertrain
- Legislation changes – Potential for stricter legislation on sprayer use (FIFRA), particularly in windy conditions or near water, could lead to costly redesigns – managed through contingency reserve.
- Reduced interest in autonomous farming – addition of detachable cabin to allow for manual driving.

The SWOT analysis threats section highlights the US' inadequate hydrogen infrastructure as a significant risk. Hex Track's uptake and operation is hampered by the absence of refuelling infrastructure, especially in rural farming areas. However, this drawback also offers the project a significant chance to establish itself as a market leader. The project can capitalise on the growing need for sustainable solutions across industries by becoming among the pioneers of hydrogen-powered agricultural equipment. Due to its early arrival, the company can work with suppliers of hydrogen to develop infrastructure while establishing sustainability standards for the sector. This further aligns with the governments Executive Order 14057 [7], which predicts net-zero emissions by 2050. Below is an illustration of this analysis using a bowtie diagram



The project assumes that the adoption of sustainable farming technologies will continue to grow, driven by increasing environmental pressures and government incentives. It also anticipates the continuous reduction in the cost of hydrogen technology and the development of hydrogen infrastructure in rural areas. By addressing all risks and leveraging opportunities, the project is well-positioned to achieve its goals and drive transformation in the agriculture sector.

6. Conclusion

6.1. Technical conclusion

In conclusion, Hex Track, as a concept, provides a unique alternative to current conventional farming practices. With its advanced technical developments in sustainable power and the use of AI systems, the vehicle is well positioned to radically change how farmers spray crops. Designed specifically around corn and soybean farms in Illinois and Iowa, Hex Track is projected to have a market share of 5% by 2035. This is justified by the autonomous tractor market having a projected value of $4.15 billion by 2029 [2].

The autonomous driving capability of the vehicle reduces labour costs, increases efficiency and improves ease of farming. Additionally, the detachable cabin allows for manual driving, if preferred. This flexibility addresses a key concern among farmers that their jobs are at risk or significantly changing due to the move towards more autonomous farming. Autonomous driving also enables the potential for 24/7 operation meeting the time operating condition established at the beginning of the project. Furthermore, variable suspension ensures that the vehicle can be used at all crop heights and the tracks reduce soil compaction by distributing the vehicle load

Hex Track offers an extremely sustainable and environmentally friendly alternative to current crop sprayers on the market. Its hydrogen powered fuel cell powertrain significantly reduces carbon emissions by up to 89% [8] (for renewably made hydrogen) compared to the traditional diesel-powered tractors. The power system also satisfies all operating criteria, such as range and sufficient torque for different topography. However, to ensure the success of Hex Track, sizeable investment is needed to improve the hydrogen power infrastructure within the US. This includes development and deployment of refuelling stations, specifically in rural areas to aid in 24/7 operation. Addressing this infrastructure gap is crucial to reducing range anxiety and making hydrogen-powered machinery a viable option for farmers. Simultaneously, technological advancements in solar panel power per unit area will significantly reduce the cabin's dependency on the fuel cell and batteries, further improving the overall energy sustainability. The use of artificial intelligence for crop health monitoring and environmental analytics can significantly reduce chemical usage through targeted spraying. This approach not only decreases costs on chemicals but also reduces the environmental impact of pesticides and insecticides and specifically their impact on pollinators such as bees. The spraying system and fluid tank are designed to align with industry standards and adhere to legislative requirements, such as the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA).

Finally, for Hex Track to be brought to market a $12 million investment would be needed to fund a 3-year R&D and manufacturing, with an extra $1 million allocated for marketing in year 3 of the R&D stage. The vehicle will be priced at $700,000 with a profit margin of 36% per vehicle. This leads to an ROI of 26.7%, providing an enticing opportunity for prospective investors given the time invested and payback period of 7.5 years. Overall, Hex Track is considered technically and financially viable while meeting the initial brief, objectives, and design USP set out at the beginning of the project.

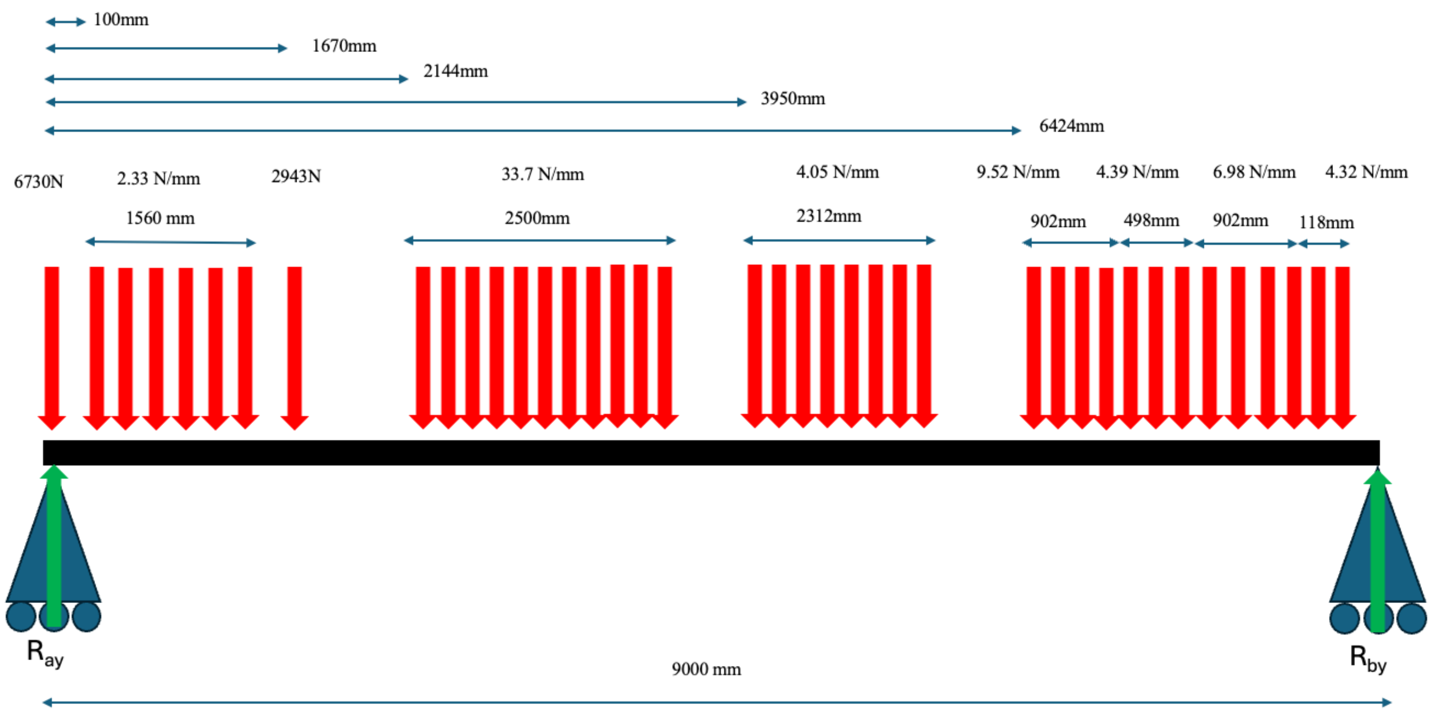
6.2. Teamwork conclusion

Overall, the team worked cohesively and with limited issues. Meetings were held twice a week excluding the Friday clinics with aims and objectives and deadlines laid out at the beginning of the week. The concept was easily chosen through a unilateral vote, and subsystems were chosen by individual members and distributed evenly. Despite this, as team leader, a mistake was made when assigning materials to a group member as opposed to the fertiliser system leaving a key subsystem underdeveloped. Although this was ultimately rectified post the presentation stage, it provided a valuable lesson in taking time to fully break down a vehicle's subsystems before assigning them to team members.

Throughout the project, a Gantt chart (Appendix C) was used to keep track of progression of subsystem development and key deadlines. The use of predicted end and start date vs actual end and start date was critical in identifying when certain aspects of the vehicle were not meeting deadlines. It is evident that CAD deadlines where not met towards the end of the project due to external factors. However, this was not a major issue due to a 5-day contingency plan set up by the team leader. In conjunction with this, an agile Kanban project management tool was used to assign tasks, keep a log of completed task and record what aspects of the design where in progress and in a backlog. An example of this is shown for week 8 in appendix D. The combination of the two tools meant that all aspects of the project were fully accounted for and didn't allow for any key actions to go unmonitored.

Appendices

Appendix A: Simply supported elementary beam theory diagram to support bending moment and shear stress calculations.



Appendix B: Weight distribution calculations

$$FRONT\ LOAD\ PERCENTAGE = \frac{R_{ay}}{R_{ay} + R_{by}} \times 100 \qquad REAR\ LOAD\ PERCENTAGE = \frac{R_{ay}}{R_{ay} + R_{by}} \times 100$$

Appendix C: Gantt Chart

Hex Track

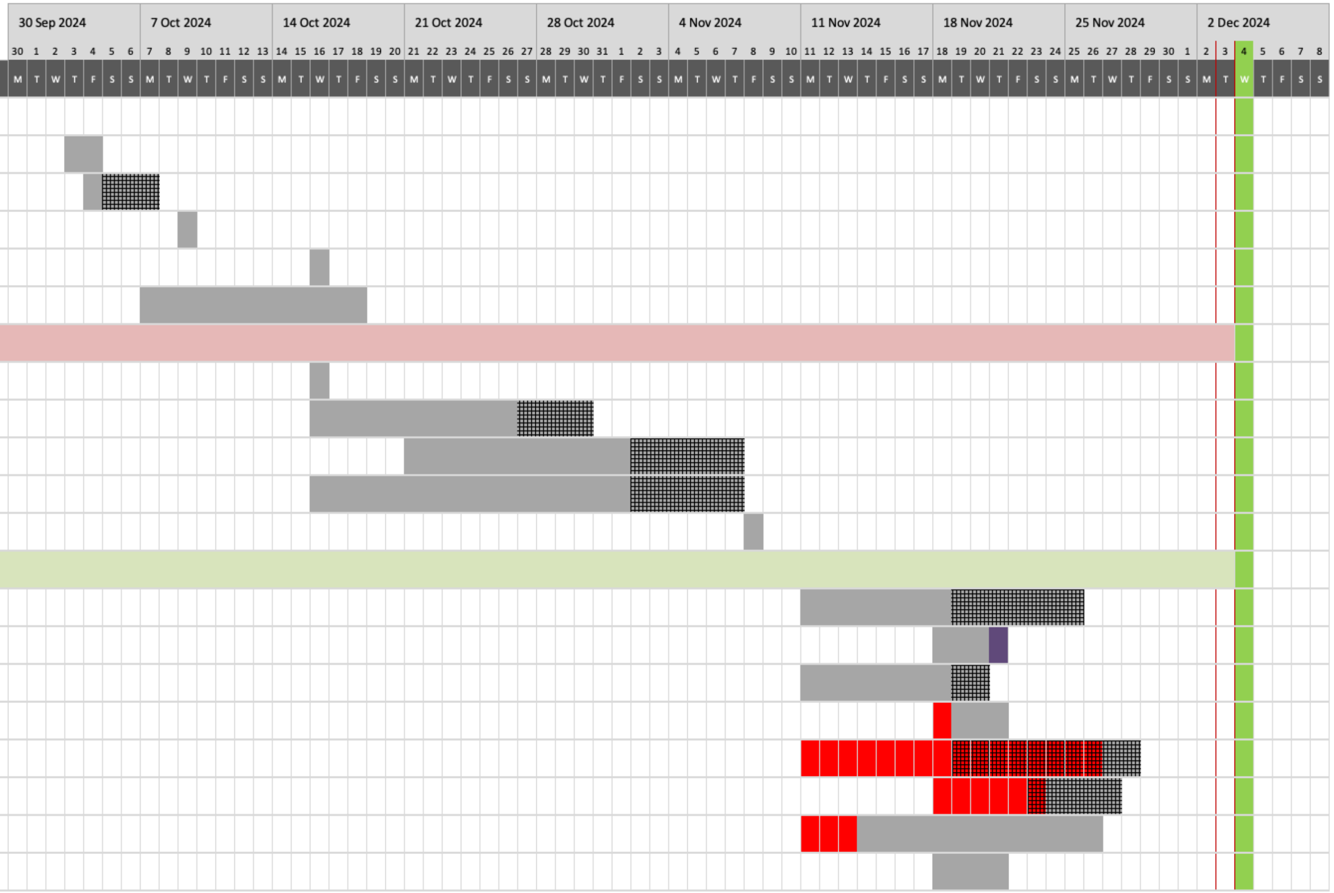
Group G
Matthew Longley

Key:	Not Started on time	Completed on time	Finished Ahead of Schedule	Over schedule

Project Start: Thu, 03/10/2024

Display Week: 1

TASK	ASSIGNED TO	PREDICTED START	PREDICTED END	PROGRESS	ACTUAL START	ACTUAL END
Phase 1 Title						
Decide on 3 potential concepts	All Group	3/10/24	4/10/24	100%	3/10/24	4/10/24
Finalise concept descion	All Group	4/10/24	4/10/24	100%	4/10/24	7/10/24
Decide on 3 iterations of this design	All Group	9/10/24	9/10/24	100%	9/10/24	9/10/24
Review Drawings	All Group	16/10/24	17/10/24	100%	16/10/24	16/10/24
Milestone 1 - Drawing submission	All Group	7/10/24	18/10/24	100%	7/10/24	18/10/24
Phase 2 Benchmarking & Boxed Cad						
Sub system devision	Individuals	16/10/24	16/10/24	100%	16/10/24	16/10/24
Initial Benchmarking	Individuals	16/10/24	26/10/24	100%	16/10/24	30/10/24
Rough Cad with box dimensions	AD&ML	21/10/24	1/11/24	100%	21/10/24	7/11/24
Presentation written	All Group	16/10/24	1/11/24	100%	16/10/24	7/11/24
Week 6 Presentation	All Group	16/10/24	8/11/24	100%	8/11/24	8/11/24
Phase 3 - Finalaised Cad and Business Plan						
Suspenstion Specification	AT	11/11/24	18/11/24	100%	11/11/24	25/11/24
Suspenstion CAD	AT	18/11/24	21/11/24	100%	18/11/24	20/11/24
Cabin Design Specification	ML	11/11/24	18/11/24	100%	11/11/24	20/11/24
Cabin Design CAD	ML	18/11/24	21/11/24	100%	19/11/24	21/11/24
Chassis and Cabin Mount Specification	AD	11/11/24	18/11/24	100%	27/11/24	28/11/24
Chassis and Cabin Mount CAD	AD	18/11/24	22/11/24	100%	24/11/24	27/11/24
Powertrain Specification	RB & AMK	11/11/24	18/11/24	100%	14/11/24	26/11/24
Powertrain CAD	RB & AMK	18/11/24	21/11/24	100%	18/11/24	21/11/24



AI and Autonomous Features Specification	ND	11/11/24	18/11/24	100%	17/11/24	22/11/24
AI and Autonomous Features CAD	ND	22/11/24	25/11/24	100%	24/11/24	27/11/24
Fertiliser System Specification	SK	11/11/24	18/11/24	100%	11/11/24	22/11/24
Fertiliser System CAD	SK	18/11/24	20/11/24	100%	18/11/24	19/11/24
Final CAD Design	AD	22/11/24	24/11/24	100%	24/11/24	27/11/24
Report Writing & Video						
Report written		11/11/24	29/11/24	100%	5/11/24	2/12/24
Suspenstion video		27/11/24	29/11/24	100%	27/11/24	30/11/24
Cabin video		27/11/24	29/11/24	100%	27/11/24	30/11/24
Chassis and Cbain mount video		27/11/24	29/11/24	100%	27/11/24	30/11/24
Powertrain video		27/11/24	29/11/24	100%	27/11/24	30/11/24
AI and Autonomous Features video		27/11/24	29/11/24	100%	27/11/24	30/11/24
Fertiliser System video		27/11/24	29/11/24	100%	27/11/24	30/11/24
Video edited		29/11/24	30/11/24	100%	30/11/24	2/12/24
Video submitted		2/12/24	2/12/24	100%	2/12/24	2/12/24
Report submitted		3/12/24	3/12/24	100%	3/12/24	3/12/24

Appendix D: Week 8 Kanban

As the project progressed completed jobs from “in progress” were moved into the “completed” section.

Week: 8

Category	Breakdown	Assigned	Backlog	To do	In Porgress	Complete
Vehicle	-	Group G		Bending moments and shear force diagram Vehicle cad packaging	Buissness plan Weight and Balance chart	ML selected as Team leader Subsytems divided up and individualy assigned Drawing Submission Presentation Rehearsals Cad bounding boxes Presentation Delivery
Meeting Attendance & Team leader requirements Report	-	Group G & ML	-		Gantt Chart Kanban	Week 1 : All attended Week 2 : All attended Week 3 : All attended (Apart from AD due to illness) Week 4 : All attended Week 5 : All attended (Apart from ND & RB due to illness) Week 6 : All attended Week 7 : All attended Week 8 : All attended Introduction written
Subsytems	-	-	-	-	-	-
Chassis & Cabin mount	-	AD	-	-	-	-
	Chassis	AD	Cad Specification	Bending analysis Video recording		Benchmarking of key competators Benchmarking presentation slides Initial design
	Cabin mount	AD	Cad Specification	Bending analysis Video recording		Benchmarking of typical systems that could be used. Benchmarking presentation slides Initial design
Powertrains	-	RB & AM-K	-	-	-	-
	Fuel cell	RB		Record Video	Cad Specification	Benchmarking of key competators Benchmarking presentation slides Initial design Calculations for size
	Battery	RB		Record Video	Cad Specification	Benchmarking of key competators Benchmarking presentation slides Initial design Size calculated
	Motor	AM-K		Record Video	Cad Specification	Benchmarking of key competators Benchmarking presentation slides Initial design Motor choice made
	Cooling	AM-K		Record Video	Cad Specification	Benchmarking of key competators Benchmarking presentation slides Initial design

Dynamics	-	AT	-	-	-	-
	Steering and Braking	AT		Record Video	Intergration with vehilce	Benchmarking of key competators Benchmarking presentation slides Initial design Concept change decided on with group Specification written Cad
	Suspension	AT		Record Video	Intergration with vehilce	Benchmarking of key competators Benchmarking presentation slides Initial design Stress analyis complete Cad Specification written
	Traction Mechanism	AT		Record Video	Intergration with vehilce	Benchmarking of key competators Benchmarking presentation slides Initial design Cad Specification written
Autonomous & AI Featuers		ND		Record Video	Specification Alogrithms and sensor array designing	Benchmarking of key competators Benchmarking presentation slides
Cabin	-	ML		Record Video	Intergration with vehilce	Benchmarking of key competators Benchmarking presentation slides Initial design Cad Calculations for solar panel and subframe Specification written Bending analysis for the subframe
Fertilisers system	-	SK		Record Video	Intergration with vehilce	Benchmarking of key competators Benchmarking presentation slides Initial design Calculations for tank size Cad Specification written

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