

SAFETY ANALYSIS ROBOT (GROUP 1)

Benjamin Galdo-Hare, 2221722, Jospeh Garnish – 2221724, Garon Williams – 2320123, Richard Pulman – 2220260, Connor Griffiths – 2216420, Shay Quinn - 2319936



MAY 23, 2025
UNIVERSITY OF WALES TRINITY SAINT DAVID

1 Table of Contents

2	Introduction.....	6
3	Project Aims (Group)	7
4	Project Organisation	7
5	Project Manager – Benjamin Galdo-Hare (2221722)	8
5.1	Project Planning and Timeline (BGH – 2221722)	8
5.2	Communication Methods (BGH – 2221722)	10
5.3	Meeting Records (BGH – 2221722).....	11
5.4	Product Design Specification (PDS) (BGH – 2221722)	13
5.4.1	Market Requirements	13
5.4.2	Life in Service Requirements	13
5.4.3	Maintenance Requirements	14
5.4.4	Production Requirements.....	14
5.4.5	Conformance Requirements	14
6	Site Specialist – Richard Pulman (2220260)	16
6.1	Site Requirements for SAR (RP - 2220260)	16
6.1.1	Application (RP - 2220260)	16
6.1.2	The Environment (RP - 2220260)	16
6.2	Environmental Hazards (RP - 2220260)	16
6.2.1	Air Quality and Emissions (RP - 2220260).....	16
6.2.2	Water and Soil Contamination (RP - 2220260).....	17
6.2.3	Noise Pollution (RP - 2220260).....	17
6.3	ATEX Standards for SAR (RP - 2220260)	17
6.3.1	Understanding ATEX (RP - 2220260).....	17
6.3.2	Gas and Vapour Zones (Temperature Based) (RP - 2220260)	17
6.3.3	Dust Zones (Particle Based) (RP - 2220260).....	18
6.3.4	Temperature Classes (Gas Equipment) (RP - 2220260)	18
6.4	Gas Detection (RP - 2220260).....	19
6.4.1	Potentially Dangerous Gasses (RP - 2220260)	19

6.4.2	Gas Detection Tools (RP - 2220260)	20
6.4.3	Relevant Legislation and Standards (RP - 2220260)	21
6.4.4	Compliance (RP - 2220260)	22
6.4.5	Summary of SAR Environmental Report (RP - 2220260)	23
7	Design Specialist – Jospheh Garnish (2221724)	24
7.1	Design Overview (JG – 2221724)	24
7.2	Design Objectives (JG – 2221724)	24
7.3	Structural Design Overview (JG – 2221724)	24
7.4	Tooling and Manufacturing of the Monocoque (JG – 2221724)	25
7.5	Auxiliary Components and Sub-Assemblies (JG – 2221724)	26
7.5.1	Mobility System (JG – 2221724)	26
7.5.2	Sensor Array (JG – 2221724)	26
7.6	Manufacturing Design Strategy (JG – 2221724)	27
7.7	Environmental and Safety Considerations (JG – 2221724)	28
7.8	Testing and Validation (JG – 2221724)	28
7.9	Future Developments (JG – 2221724)	29
7.10	Design Summary (JG – 2221724)	29
8	Analytics and Performance Specialist – Garon Williams (2320123)	30
8.1	Performance Metrics (GW – 2320123)	30
8.1.1	Objectives (GW – 2320123)	30
8.2	Analytics (GW – 2320123)	31
8.2.1	Data Collection (GW – 2320123)	31
8.2.2	Performance Review (GW – 2320123)	32
8.2.3	Flowchart (GW – 2320123)	33
8.2.4	Reporting (GW – 2320123)	34
8.3	Future Improvements (GW – 2320123)	35
8.3.1	Mobile App (GW – 2320123)	35
8.3.2	Ai powered camera (GW – 2320123)	36
8.3.3	Optimising the battery (GW – 2320123)	36

8.3.4	Upgraded Battery (GW – 2320123)	37
8.3.5	Maintenance and Services (GW – 2320123)	37
8.4	Summary (GW – 2320123)	37
9	Materials and Sustainability Specialist – Shay Quinn (2319936)	38
9.1	Materials (SQ – 2319936)	38
9.2	Sustainability (SQ – 2319936)	40
9.3	Manufacturing Process (SQ – 2319936)	42
10	Maintenance Manager – Connor Griffiths (2216420)	45
10.1	Introduction (CG - 2216420)	45
10.2	Maintainability implementation (CG - 2216420)	45
10.2.1	Modular design and component standardisation (CG - 2216420)	45
10.2.2	Preventative and Predictive Maintenance (CG - 2216420)	46
10.2.3	Diagnostic Readings (CG - 2216420)	47
10.3	Externally Mounted Battery System (CG - 2216420)	48
10.4	Safety Analysis and Risk Mitigation (CG - 2216420)	48
10.4.1	Risk identification and analysis (CG - 2216420)	48
10.5	Risk Mitigation Strategies (CG - 2216420)	50
10.5.1	Redundant systems and fail-safe measures (CG - 2216420)	50
10.5.2	Enhanced Maintenance Procedures (CG - 2216420)	50
10.5.3	Comprehensive training and documentation (CG - 2216420)	50
10.5.4	Safety Interlocks (CG - 2216420)	51
10.5.5	Emergency isolation procedures (CG - 2216420)	51
10.6	Section Summary (CG - 2216420)	52
11	Achievement and Progress Relative to Initial Project Plan (Group)	53
11.1	Interim Viva Presentation (Group)	53
11.2	Final Design (Group)	53
11.3	Report and Presentation Completion (Group)	54
12	Successes and Failures of the Project (Group)	55
12.1	Successes	55

13	Bibliography	57
14	Appendix 'A'	65
15	Appendix 'B'	78

2 Introduction

This report outlines a project completed by six members in an engineering firm. The team were tasked with taking a project from a concept to a final design. As part of the project the team were to delegate roles, carry out research and design, and present the project to a team of board members. In the report the project will be outlined with all aspects included.

Safety is paramount in modern industrial and emergency response environments. In scenarios involving hazardous conditions, the ability to conduct inspection or hazard detection safely is a top priority and can pose significant challenges if operators need to enter these environments. This project has been set out in response to this to see if safety can be improved in this area. The design presented in this report is a multipurpose Safety Analysis Robot (SAR) which can conduct real-time gas monitoring or inspection for settings such as chemical plants, industrial sites, disaster areas or confined spaces. The purpose of the robot is to be able to enter dangerous and hazardous environments to eliminate the need to put human operators at risk.

The project has been conducted from concept to design phases with engineering research and design completed by the project group team. The team consisting of six members have conducted comprehensive research on individual aspects of the design. This report outlines the work the project team have done from taking the project from a concept phase to an effective design. Each subsystem was chosen and integrated after extensive research, which guided the robot's engineering from the ground up. These consist of environmental monitoring equipment, gas detection sensors, and a sturdy mobility platform that can traverse difficult terrains and provide precise, real-time data. As well as this the maintenance of the robot has been considered with in depth analysis on the maintenance techniques that are to be utilised when in service.

The team between them had to decide on roles, which would guide the project to its goal. This technical report documents the whole development cycle including the steps taken by the team to delegate these roles, communication methods between the team, and management strategies used in the development. The report will also outline key takeaways, challenges, improvements and team evaluation.

3 Project Aims

The aim of this project is to design and develop a mobile robotic crawler which can be used on industrial sites to improve safety by mitigating the need for operators to enter hazardous environments. The intended use is to carry out tasks such as inspection, gas monitoring and other forms of hazardous detection. The overreaching goal for this project is to improve process safety on site and provide an efficient tool for operators to carry out certain tasks.

Specifically, the project aims to:

- Design a lightweight, compact crawler with the ability to traverse rough terrain to get into harsh and hazardous environments.
- Integrate inspection and monitoring technologies to feed live data to operators via a digital app.
- Enhance safety for operators on site by reducing exposure to hazardous environments and preventing the need for entering them.

4 Project Organisation

Project organisation is essential to a successful project or multiple group members. Therefore, the key to success of the project was the team roles being allocated in a manner that meant individuals were either skilled/knowledgeable in that specific field, or they had a keen interest in it. This would enable the project to run smoothly and successfully with a good end product. To allocate the roles in this manor the team decided to each put forward their interests for the roles they wanted. This saved delegation which can lead to issues with individuals not maximising their role in the project due to being uninterested or unskilled in the area. The roles were allocated as follows:

- **Project Manager** – Benjamin Galdo-Hare
- **Analytics and Performance Specialist** – Garon Williams
- **Design Specialist** – Joseph Garnish
- **Materials and Sustainability specialist** – Shay Quinn
- **Maintenance Manager** – Conor Griffiths
- **Site Specialist** – Richard Pulman

5 Project Manager – Benjamin Galdo-Hare (2221722)

As role of project manager, it is essential to understand how to manage a team utilising proven methods of project managing to lead a successful project to a deadline. Initial research was carried out to understand these methods to be able to utilise them in the group project. Research was carried out on project managing, time management and planning, effective communication and clear goal setting. These areas of research were then utilised to manage the project.

Initial research led to an understanding that strong organisational skills and time management is crucial to a successful project. Setting out a timeline is the proven way to keep a project organised and gives the best chances at meeting the project deadline. Having a project plan aligns team efforts and prevents a last-minute rush before deadlines. A project time management plan provides and outline of what needs to be done, when it needs to be done by, and who it needs to be done by. According to the Project Management Institute (PMI) (2023), a project plan guides both project execution and control and facilitating communication amongst all personnel involved with the project. For these reasons a project plan was set up using a Gantt chart template in excel.

5.1 Project Planning and Timeline (BGH – 2221722)

Excel is a tool which excels in time management planning and is a common tool used by project managers in established engineering firms. This can be seen in the work undertaken by a company called InSite Technical who utilize excel for all project managing tasks, (time tracking, progress tracking, data collection). Along with friendly usability and downloadable Gantt chart templates (one of which were utilised for the plan) this was the chosen tool. Another tool that was considered was 'Project Planner' This wasn't used due to its complex structure which for a novice project planner would be tough to learn in a short space of time, with a short timescale for project completion.

The project plan was decided to be done in two phases. The first phase would be up until the interim Viva (part-way through the project), and the second phase would follow from this to the project deadline. This staggered phase is based on the 'Prince2 Methodology' which promotes phase reviews. This is called stage boundaries, and it enables lessons learned from the previous phases to be implemented in the next. As well as this, it provides better resource management. Each member of the team can focus on a key area for that phase rather than wasting time researching an element that could be changed from problems arising from other research/development departments. To further show the usefulness of phased rollout, Bower and Walker (2007) state phased rollout allows for identification and early mitigation of risks.

This requires having the phases split at logical places, which is why the project manager utilised the interim Viva as the section to split the phases.

Another technique used in the project plan was having milestones. The milestones defined in the project plan were deadlines for key stages in the development of the project. In the first phase of the project these included 'Idea for project decided', 'begin research and design', 'first concept design' (seen in figure 1). By having milestones, project tracking becomes an easier task and team motivation is improved. When hitting milestones, it gives the team extra motivation knowing there is progress on the project. According to Kerzner (2022), achieving milestones is a proven way that recognises team efforts resulting in increased amounts of motivation and productivity. Having milestones can also be used as a risk management tool. If milestones are failed to be hit on time, restructuring can be identified and carried out to get the project back on track. Having just one final deadline to hit, it can be hard to see where the project is in terms of completion, and it can result in a rush at the end of the project. This technique also links to the Eisenhower Matrix which is a time management tool that is used to prioritise task effectively. A snip from the project plan showing the milestones for phase 1 can be seen in figure 1.

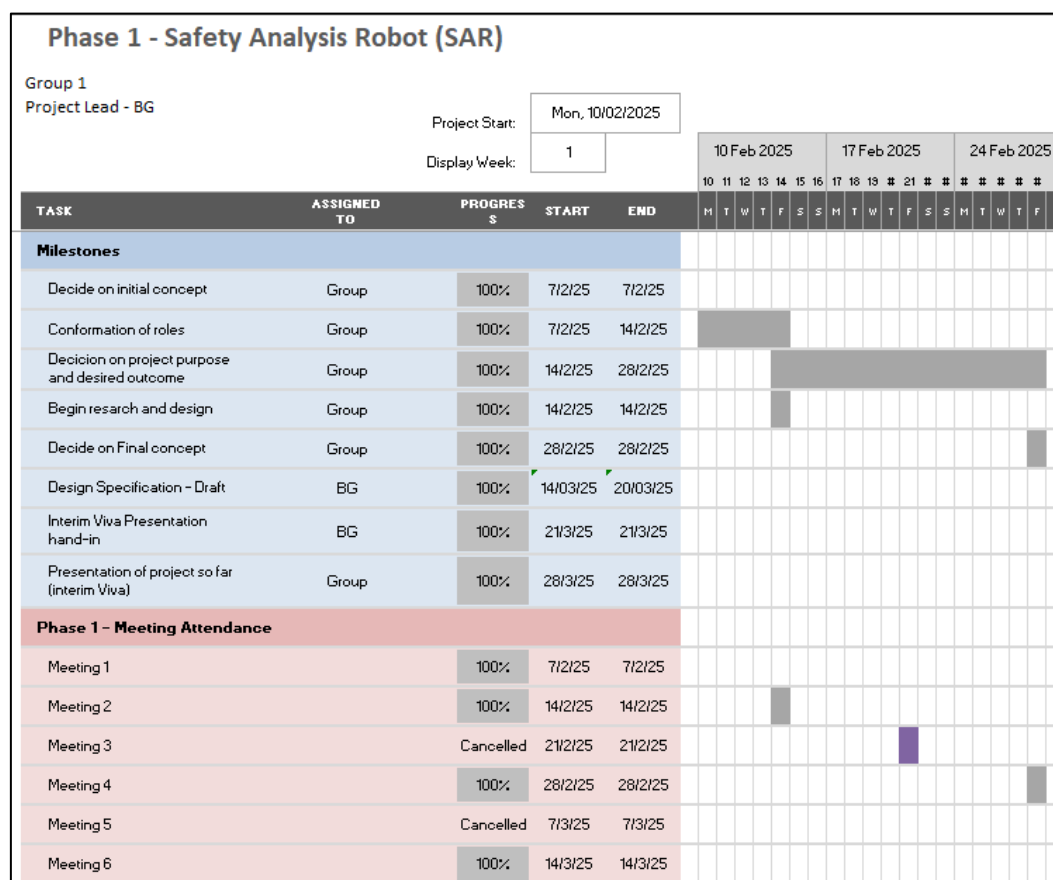


Figure 1 - Snip from the Project Plan

The project manager also wanted to ensure all members were aligned with their tasks and knew what they needed to do and when by. To do this the different sections (research/design/analytics, etc) were listed in the project plan with time scales for completion (start – end) alongside to provide a simple but informative timeframe for each task. These were in-line with the project milestones which helped ensure project timing was on track. To further align the team members with the tasks they're initials were listed next to the tasks they were required to do, see figure 2. This was important as for a project manager, having team members aligned with the tasks they are required to do to bring the project forward is essential. Throughout the project, the project manager would review progress to ensure the team were on track. The progress was marked in accordance with team feedback used through communication methods, (section 5.2).

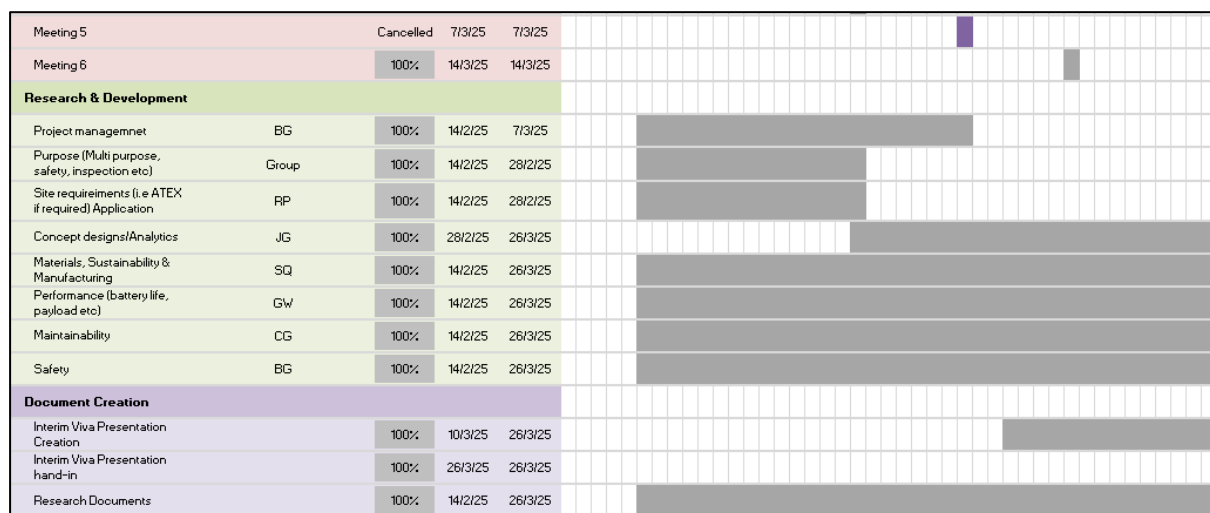


Figure 2 - Snip from the Project Plan (2)

A key trait for a project manager is to be able to handle group member concerns or issues. To ensure the team were happy with the project schedule, the draft was shared with the group to allow each member to voice any concerns they may have with the plan. Giving team members opportunity to feedback on key areas are essential for a multitude of reasons. Doyle, Francis and Tannenbaum, 1992, suggest that promoting feedback is integral to controlling project processes and allows for optimising resources, timelines and strategies. Having multiple opinions and combining them is much more powerful and resourceful than one person deciding on everything. Group members knowing they can feedback to items such as the plan is also effective at increasing motivation. Motivation for the team being an important factor a project manager must implement.

5.2 Communication Methods (BGH – 2221722)

In a project consisting of multiple personnel, it is essential that there is communication methods set out at the beginning of the project. In this project most of the work completed was

done by hybrid working. This means that rather than all work being done on site, it was largely being carried out remotely. This can pose issues in a project as communication is key to success and aligning with inter personnel and multidisciplinary tasks. According to (Zhang and Li, 2024), having a clear communication method allows a project group to adapt to changes, share feedback and innovate which is essential for hybrid project environments. To ensure the right communication method was set up, the project manager posed the question in the first weekly meeting. Different aspects were considered such as effectiveness and accessibility. Together the team decided 'WhatsApp' would be the most effective as the accessibility is good and each member had access to it. A group was set-up, and this method proved to be successful with good communication between the team throughout the project. Including virtual meetings when there were limited members on site for weekly meetings. The project manager was able to further track progress using this method and likewise was able to feedback coherently.

5.3 Meeting Records (BGH – 2221722)

Research about successful project managing also presented the need of capturing minutes of meetings for team meetings throughout the project. Capturing the minutes of meeting can be done in different ways and can include a multitude of information depending on the project managers preference. They serve as an official record of key discussion points. They also enhance accountability for all members and tasks involved with the project. In this project the key points to be taken away and included in the minutes of meeting were actions, Technical. Risks and AOB (any other business). These were identified as the most useful information to record with each section allowing group members to review. An example can be seen in figure 3, with all other MoM being included in Appendix 'a'.

Group Project 1 Meeting Minutes			
Project	Group Project – Safety Analysis Robot	Date	05/04/25
Attendees	BGH, CG, JG, SQ,		
Apologies	RP, GW		

Weekly catch-up meeting	
Item	Summary
1. Actions	- QFD to be Completed (CG Prepared)- Group - Phase 2 Project plan to be developed – complete - Continue research and develop PDS – Group - Interim viva presentation today. – complete - Develop power source for robot – GW, CG - Further research to be carried out – Group - Design development based on research - JG
2. Technical	Engineering Progress: Draft PDS completed. Members to add and refine as research is undertaken. Research carried on: safety, materials, and initial concept designs. CG added QFD to folder. Group to fill this out as appropriate. JG has completed a concept design. This will be developed further using the teams research. Materials, power source etc. Team to start looking at the end goal and bringing all the research together for a final design
3. Risks	There is a slight risk we are adding too much to the robot to be completed in time for the project completion date. Deadline is fast approaching, need to be aware of time management.
4. AOB	No issues within the group, meetings to go on as planned with availability being monitored. Phase 2 to started last week. Meeting was cancelled due to numbers low on site.

Figure 3, Example MoM from Project Document Gallery

As seen in Fig 1, actions were identified for members to complete. These actions were reviewed by the project manager prior to each meeting to see if they were still applicable and then relayed to the group during the meetings. Initials of group members were put next to the actions to clarify who was required to complete them. This provided clear incentive to group members to ensure they knew what they were required to do (used alongside and in-line with the project plan). As well as actions, the ‘technical’ section was to monitor the engineering progress. During meetings, progress would be discussed and recorded, providing an idea of how each member was getting on with their part of the project. This proved to be useful as occasionally previous MoM’s needed to be reviewed to see if progress was meeting the project timeline. Having these notes were also useful for members who couldn’t attend the meeting meaning they could review what was discussed by the other team members.

Also included on the meeting minutes was risks and AOB. Outlining risks is essential to project success as it provides clear identification of factors that can result in the project failing. There are multiple reasons a project can fail, however by outlining the risks, these can be managed

and mitigated. (Kutsch and Hall, 2005), explain that outlining risks allows teams to anticipate and mitigate factors such as inadequate planning, human factors and lack of communication. All factors of which can lead to a project failure. AOB (Any Other Business) related to any discussion points that weren't technical. More general points raised and group discussion. As a group these felt useful as it gave opportunity for any of the team to be able to raise points. Having an open point like this is great for team coherence.

In this project there were limited risks identified by the group, however there was a prominent risk which had the potential to result in the project not meeting the deadline. It was identified that the SAR (Safety Analysis Robot) was starting to get more complicated the more research was being done. This was identified at the interim viva where the members started bringing all their research into one and there were multiple tangents from the original concept that started arising. This risk was mitigated using the 'PDCA Cycle' (Plan-Do-Check-Act). This technique is a method used for continuous improvement and quality management. 'Plan', is to identify the problem (done in the weekly meeting). 'Do', is to implement the solution. This was done via a team meeting set up by the project manager to outline what could be removed from the final design without effecting performance or failing to meet the design specification. 'Check', is to monitor how the change is effective. The team realised that their tasks had become easier due to relief of some work activities and reduced research. 'Act', it to standardise the solution. In this instance it is not something that can be standardised, however, it was an opportunity to understand as a team how discussions together are essential to aligning with each other to ensure project success.

5.4 Product Design Specification (PDS) (BGH – 2221722)

5.4.1 Market Requirements

Target price:

- £13,000

Performance:

- Immediate and accurate data collection
- GPS Routing

Appearance/image/style:

- 4 Wheels
- Compact

5.4.2 Life in Service Requirements

Product Lifespan:

- Minimum of 10 years with approx. 200 hours of operational use assumed per year.
- Inspection sensors to be a minimum of 5 years before needing replacement.

Operating Environment:

- Hazardous Sites
- Unsafe areas (gasses etc)
- Confined spaces

Reliability/Durability Targets

- Drive systems required to be 1000 hours of continuous use.
- Operate effectively in temperatures ranging from -20°C to +70°C
- Component failure rate: < 5% per year per component.
- Mean Time Between Failure: Target >1000 hours.

5.4.3 Maintenance Requirements

- Mean Time to Repair: <1.5 hours
- Predictive maintenance to be implemented.
- Preventative Maintenance to be implemented.

Disposal and Recycling Requirements

- Materials disposal must be considered.
- Design to ensure disposal and waste is rarely required.

5.4.4 Production Requirements

Target Cost of Manufacture

- Cost of components: No more than £5000
- Cost of Labour: No more than £3000

Quantity

- Dependent on demand.

Manufacturing Process

- CNC machining with carbon fibre tooling.

Assembly Methods

- Design for Assembly (DFM) will be utilised
- Minimum number of components to assemble

5.4.5 Conformance Requirements

Industry/Site Constraints and Standards

- ATEX Legislations to be considered and followed.

Product Compatibility Requirements

- Inspection and monitoring devices to be available on app.
- Analytics to be available on iPhone app,

Safety Requirements

- ISO 12100 _ ISO 102181 _ ISO 12100
- PUWER
- Emergency Isolation

As seen above a Product Design Specification (PDS) was completed. A PDS outlines the attributes of a product prior to design and manufacturing which provides what is required from the design. This includes purpose, functionality and performance and helps guide the design. The PDS for the SAR was completed alongside the research carried out by the team members. A draft was originally done which outlined the aspects that needed to be confirmed. For example, all the headings were outlined. This was an added document which outlined what needed to be researched by the team giving them further direction on research tasks for the team. According to Pugh (1991), having a PDS enhances multidisciplinary teamwork and acts as a total control for all aspects of the design activity. This backs up why it was implemented by the project manager to ensure the design and development was aligned between team members and the project scope.

6 Site Specialist – Richard Pulman (2220260)

6.1 Site Requirements for SAR (RP - 2220260)

6.1.1 Application (RP - 2220260)

The purpose of the Safety Analysis Robot, or SAR as it will be known as throughout the report and presentation, is to enter environments that are inhabitable to humans. It will then be able to identify such things as.

- Evaluate access and egress in environments
- Toxic levels of gas
- Identify any repair work needed
- Can be adapted to detect radiation levels
- Live electrical grounds

6.1.2 The Environment (RP - 2220260)

As mentioned above, the SAR is to be used instead of humans, and will be applied to;

- Environments engulfed in flames
- Workplace's where there are potential toxic gases
- Workplaces with radiation levels
- Anywhere where there may be loose cables that can allow electricity to flow
- Confined spaces
- Heights

Due to the application needs of the SAR, it will be predominantly used in the steel works. However, it can be adapted to industries such as power stations.

As discussed previously, the kind of environment the SAR will be used in would be ideal for the steel works, however it can be used in other toxic workplaces such as power plants and going forward this report will look at the dangers within the steel works for the SAR to be utilised to its full potential.

6.2 Environmental Hazards (RP - 2220260)

6.2.1 Air Quality and Emissions (RP - 2220260)

Port Talbot steel works, and the steel manufacturing process has been identified as a major contributor to air pollution. Due to the emissions emitted by the blast furnaces which contribute to, sulphur dioxide (SO₂), Nitrogen oxide (NO₂), and particle emissions (PM). (Gibbs, 2000) So much so that the motorway, the M4, has a mandatory 50mph speed limit to try and help combat it (Pulman 2025)

6.2.2 Water and Soil Contamination (RP - 2220260)

Discharges from the factory have the potential to affect local bodies of water, which can then affect aquatic life and, potentially, entering the food chain. With the pollutants entering the soil and water bodies can affect agriculture biodiversity and soil degradation. (Gibbs, 2000).

6.2.3 Noise Pollution (RP - 2220260)

Due to the nature of the steel works and steel manufacturing process, the environment creates high levels of noise. Prolonged exposure to the noise can affect hearing, increased stress levels and sleep disturbance. (Gibbs, 2000).

Gibbs, G. (2000). Poor air quality puts steelworks in bad odour with locals. The Guardian. <https://www.theguardian.com/uk/2000/sep/04/geoffreygibbs>

6.3 ATEX Standards for SAR (RP - 2220260)

6.3.1 Understanding ATEX (RP - 2220260)

ATEX regulations are dictated by the European Union (EU) that govern work environments and equipment within an explosive work environment. It is based on the presence of vapours, combustible dust and any flammable gasses, it then divides the hazardous areas into zones which are based on frequency and duration in the explosive environment.

(Lloyd-Davies, 2016) Orbis Environmental.

6.3.2 Gas and Vapour Zones (Temperature Based) (RP - 2220260)

Zone-0

This is an area where a mixture of flammable gasses, air, mists, and vapours are continuously present or for prolonged periods of time. An example of this is inside fuel tanks.

Zone-1

Is an area where an explosive atmosphere is likely to occur occasionally under normal operations. For example, near pump seals.

Zone-2

This is an area where an explosive atmosphere isn't likely to occur and if it does will only exist for a short time. For example, being around fuel handling equipment. These zones are known as "auto ignition temperature (AIT) of gasses, vapours and electrical equipment. There is no specific AIT temperature, but all equipment should have it specified and is paramount that any tools are operated below the specified temperature.

6.3.3 Dust Zones (Particle Based) (RP - 2220260)

Zone-20

A work environment where an explosive atmosphere is in the form of a cloud of combustible dust is continuously present or for long periods of time. An example of this is inside a grain silo.

Zone-21

Where a dust cloud is likely to occur under normal operations. Such as, near bagging equipment.

Zone-22

Where a dust cloud is unlikely to occur under normal operations, and if it does for a short period of time. An example of this is being around powder handling.

Dusts are classified under “Minimum Ignition Energy”, MIE, and “Minimum Ignition

T Class	Max Surface Temp (°C)	Typical Gasses
T1	450	Methane
T2	300	Ethanol
T3	200	Kerosene
T4	135	Ethyl ether
T5	100	Some industrial solvents
T6	85	Carbon Disulfide.

Temperature”, MIT. Particle size plays a major role with fine dusts having a higher surface area more susceptible to ignition. (Eaton, 2022).

Eaton (2022) ATEX and explosive atmospheres. [online] Available at:

<https://www.eaton.com/gb/en-gb/catalog/lighting/atex-and-explosive-atmospheres.html>

6.3.4 Temperature Classes (Gas Equipment) (RP - 2220260)

Electrical equipment is also classified by with temperature classes (T class) based on the maximum surface temperature it can reach.

Equipment used must not exceed the gas or dust it may encounter and ideally work under the temperature of gas it may occur.

Eaton (2022) ATEX and explosive atmospheres. [online] Available at:

<https://www.eaton.com/gb/en-gb/catalog/lighting/atex-and-explosive-atmospheres>.

Health and Safety Executive (HSE) (2013) ATEX and explosive atmospheres - hazardous area classification. Available at <https://www.hse.gov.uk/fireandexplosion/atex.htm>

6.4 Gas Detection (RP - 2220260)

6.4.1 Potentially Dangerous Gasses (RP - 2220260)

The dangerous gasses found in the steel works are.

- **Methane (CH₄)**
Which is used in gas fired furnaces and can also be found in coke ovens
- **Hydrogen (H₂)**
Which occurs during water vapour splitting and reduction reactions (extracting pure iron from iron ore)
- **Carbon Monoxide (CO)**
Produced in blast furnaces and coke ovens.
- **Sulphur Dioxide (SO₂)**
Which is released when sulphur-containing ores or fuels are processed.
- **Carbon Dioxide (CO₂)**
A byproduct of combustion and chemical reduction reactions.
- **Coke Oven Gas**
Which is a mixture of CO, H₂, CH₄, and volatile hydrocarbons.
- **Ammonia (NH₃)**
Sometimes used in water treatment or off-gas scrubbing.
- **Nitrogen Oxides (NO and NO₂)**
Formed during high-temperature combustion processes.

To help regulate these gasses, there are two main pieces of legislation which are.

1. DSEAR (Dangerous Substances and Explosive Atmospheres Regulations 2002). Due to the natures of these gasses, ventilation, gas detection and hazard zoning are required and, as previously mentioned, ATEX needs to be used. (HSE, 2013)
2. COSHH (Control of Substances Hazardous to Health which include gasses such as Nox, SO₂, and ammonia due to their toxicity levels.

Health and Safety Executive (HSE) (2013) Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR). [online] Available at:
<https://www.hse.gov.uk/fireandexplosion/dsear.htm> [Accessed 2 May 2025].

European Commission (2020) Explosive Atmospheres (ATEX). [online] Available at:
https://ec.europa.eu/growth/sectors/mechanical-engineering/atex_en

World Steel Association (2021) Safety and health in the steel industry. [online] Available at:
<https://worldsteel.org/steel-by-topic/sustainability/safety-health/>

6.4.2 Gas Detection Tools (RP - 2220260)

The steelworks utilise several gas detection tools in order to monitor hazardous environments.

- **Fixed Gas Detection Systems**

These are situated in specified areas throughout the steel works and continuously monitor gas, they often use.

1. **Catalytic Sensors**

Which are effective for monitoring specific flammable gasses

2. **Electrochemical Sensors**

Which are used for detecting toxic gases i.e. sulphur dioxide and carbon monoxide

3. **Infrared Sensors**

Which are ideal for detecting flammable gasses.



Figure 4, Optical Gas Imaging Cameras

- **Optical Gas Imaging Cameras**

These cameras can detect carbon monoxide leaks from a distance which makes the situation safer when conducting experiments. An example of this is the FLIR GF346.



Figure 5 - Portable Gas Detectors

- **Portable Gas Detectors**

These are handheld devices that assess gas levels in various locations including methane LPG (Liquefied Petroleum Gas), and hydrogen sulphide and they also automatically calibrate themselves. An example of this is the SG895 ATEX Gas Sensor

Duomo (n.d.) SG895 – ATEX Gas Sensor (Detection of 10+ Gases). [online] Available at: <https://duomo.co.uk/product/sg895-atex-gas-sensor-detection-of-10-gases/>

FLIR Systems (n.d.) Leaders of the steel industry use FLIR GF346 gas detection cameras to detect harmful carbon monoxide gas. [online] Available at:

<https://www.flir.co.uk/discover/instruments/gas-detection/leaders-of-the-steel-industry-use-flir-gf346-gas-detection-cameras-to-detect-harmful-carbon-monoxide-gas/>

Health and Safety International (n.d.) Detecting deadly gases in industrial settings. [online] Available at: <https://www.healthandsafetyinternational.com/article/1842480/detecting-deadly-gases>

Sensitron (n.d.) Steel industry and gas detection. [online] Available at: <https://www.sensitron.it/en/steel-industry-and-gas-detection/>

6.4.3 Relevant Legislation and Standards (RP - 2220260)

When these tools are utilised in the steel works, the employee and employer need to adhere to certain laws and regulations, such as.

- **Health and Safety at Work Act 1974**
Which states that employers need to provide a safe work environment as reasonably practicable.
- **COSHH (Control of Substances Hazardous to Health)**
Which requires employers to evaluate the handling of toxic materials including gases
- **British Standard BS EN 60079-29-3:2014**
which specifies the requirements for the design, construction, and testing of gas detectors used in explosive atmospheres.
- **Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) 2002**
Dictates the assessment and management of risks from fire and explosion due to dangerous substances. This includes classifying areas into zones based on the likelihood of explosive atmospheres and implementing appropriate control measures.
- **ATEX Directives (2014/34/EU and 1999/92/EC)**
Requirements for equipment and protective systems intended for use in explosive atmospheres, ensuring that gas detection equipment is suitable for hazardous environments.

Duomo (n.d.) SG895 – ATEX Gas Sensor (Detection of 10+ Gases). [online] Available at: <https://duomo.co.uk/product/sg895-atex-gas-sensor-detection-of-10-gases/>

FLIR Systems (n.d.) Leaders of the steel industry use FLIR GF346 gas detection cameras to detect harmful carbon monoxide gas. [online] Available at:

<https://www.flir.co.uk/discover/instruments/gas-detection/leaders-of-the-steel-industry-use-flir-gf346-gas-detection-cameras-to-detect-harmful-carbon-monoxide-gas/>

Health and Safety International (n.d.) Detecting deadly gases in industrial settings. [online] Available at: <https://www.healthandsafetyinternational.com/article/1842480/detecting-deadly-gases> (Health and safety internaional , n.d.)

Sensitron (n.d.) Steel industry and gas detection. [online] Available at: <https://www.sensitron.it/en/steel-industry-and-gas-detection/> [Accessed 2 May 2025].

6.4.4 Compliance (RP - 2220260)

To help ensure employees are working in a safe it environment, it is important that they adhere to certain contractual requirements and for the employer to also adhere to them.

- **Training and Competence**
All personnel should be trained to use the equipment for emergency procedures.
- **Regular Calibration and Maintenance**
Gas equipment should be regularly maintained according to manufacturing guidelines and regularly calibrated.
- **Documentation**
All inspections and maintenance reports should be well documented and easily accessible to show compliance.
- **Emergency Procedures**
Establish and communicate clear procedures for responding to gas detection alarms, including evacuation plans and first-aid measures.
Health and Safety Executive (HSE) (2013) ATEX and explosive atmospheres - hazardous area classification. [online] Available at: <https://www.hse.gov.uk/fireandexplosion/atex.htm> [Accessed 2 May 2025].

International Gas Detectors (IGD) (n.d.) Why You Need Gas Detection: The Legal Requirements. [online] Available at: <https://www.internationalgasdetectors.com/why-you-need-gas-detection-the-legal-requirements/>

Sensitron (n.d.) Steel industry and gas detection. [online] Available at: <https://www.sensitron.it/en/steel-industry-and-gas-detection/>

Duomo (n.d.) SG895 – ATEX Gas Sensor (Detection of 10+ Gases). [online] Available at: <https://duomo.co.uk/product/sg895-atex-gas-sensor-detection-of-10-gases/>

FLIR Systems (n.d.) Leaders of the Steel Industry use FLIR GF346 Gas Detection Cameras to Detect Harmful Carbon Monoxide Gas. [online] Available at: <https://www.flir.co.uk/discover/instruments/gas-detection/leaders-of-the-steel-industry-use-flir-gf346-gas-detection-cameras-to-detect-harmful-carbon-monoxide-gas/>

Heating and Process (n.d.) In-Situ Gas Analysers Zone 1 Zone 2 ATEX Hazardous Areas. [online] Available at: <https://www.heatingandprocess.com/product/product-category/gas-analyzers-in-situ-fixed-gas-analysis-measurement/>

Health and Safety Executive (HSE) (n.d.) The legal framework. [online] Available at: <https://www.hse.gov.uk/gas/lpg/legalframework.htm>

British Standards Institution (BSI) (2014) BS EN 60079-29-3:2014 Explosive atmospheres - Gas detectors - Guidance on functional safety of fixed gas detection systems. [online] Available at: <https://shop.bsigroup.com/ProductDetail/?pid=000000000030294045>

6.4.5 Summary of SAR Environmental Report (RP - 2220260)

As this section of the report shows, the SAR will be utilised in very harsh environments and potentially dangerous. Whether it is treacherous environments such as the steel works where combustion is a real potential threat, noise pollution and hearing loss or literal toxic environments, which have greater effects on the surrounding environment.

If it all possible it would be extremely beneficial to subtract as much human interaction as possible. It cannot be done totally as there will always be a need for some human interaction such as maintenance on the SAR, or maintenance at the plant itself but it can check to ensure that there.

The SAR should incorporate the tools mentioned such as gas detection and flammable gases, as it would be easier to have one device that could do most if not all the jobs, in order to be more efficient, cost effective in the long run and, most importantly, keeping employees safe as reasonably practicable.

7 Design Specialist – Jospeh Garnish (2221724)

7.1 Design Overview (JG – 2221724)

The requirement is to create a design specification for a multi-purpose safety analysis robot. This will include a final design for the robot's structure, primarily focusing on the monocoque, but also the auxiliary components & sub assembly. The manufacturing design is focusing on creating a product which is robust and reliable, suitable for withstanding environmental challenges in construction sites. The design prioritizes ease of manufacture, a modular design for assembly and component standardisation.

This specification aims to balance performance, durability, and manufacturability. A key focus is placed on the practical design of the monocoque, including the use of large-format additive manufacturing (LFAM) to create bespoke tooling. This approach enables low-volume, cost-effective production without compromising quality. It also enables faster prototyping cycles, allowing the design to be revised efficiently during development.

7.2 Design Objectives (JG – 2221724)

The primary goal of the project is to design a reliable and robust robot capable of operating in the tough environmental conditions typical of a construction site. Specific objectives include:

- Creating a lightweight but structurally strong chassis
- Ensuring modularity for easy repair and upgrades
- Simplifying manufacturing and assembly
- Supporting a range of safety and environmental sensors
- Reducing production costs for small-volume manufacturing
- Allowing adaptability to different environments and use cases

These objectives were achieved through the selection of materials, design of subassemblies, and the overall system layout. The design also considers scalability for potential future applications beyond the construction sector, ensuring that the platform remains flexible and relevant.

7.3 Structural Design Overview (JG – 2221724)

The core structure of the robot consists of a monocoque fabricated from carbon fibre-reinforced polymer (CFRP). This will consist of using a pre-impregnated material, meaning the resin is already infused into the fabric during the manufacturing process, ensuring a proportionate resin flow throughout the material during curing. This will help to guarantee strength and structural integrity in the monocoque.

A monocoque structure integrates the load-bearing capabilities into the external shell itself, this means the need for a separate internal frame is redundant. Using this design method means it achieves a more compact and lighter design, which will also improve the handling and power efficiency of the robot during drive.

The chosen monocoque shape is a compact rectangular shell with curved edges. The use of large radii was necessary due to the nature of design for additive manufacturing (sharp corners and edges are often not viable for 3D printing). However, this design approach for the tooling (moulds) means that this geometry translates over to the component itself. Therefore, the curves on the monocoque will minimise any stress concentrations upon impact.

Internally, the shell is divided into compartments for subsystems including power, sensors, and computing hardware. CFRP was chosen for its excellent strength-to-weight ratio, corrosion resistance, and fatigue durability. These are all qualities essential for a robot expected to withstand vibration, impact, and rough handling in the field (Mallick, 2007).

Carbon fibre also provides additional benefits in thermal stability, helping to reduce warping due to temperature fluctuations on outdoor job sites. The shell thickness is optimised using finite element analysis (FEA) to withstand anticipated loading scenarios. A structural safety factor of 2.5 was applied to account for unexpected stress events, such as drops or impacts from falling debris.

7.4 Tooling and Manufacturing of the Monocoque (JG – 2221724)

One of the key aspects of the project is the method used to manufacture the carbon fibre monocoque. Traditional composite tooling methods, such as CNC-machined aluminium moulds, can be costly and time-consuming, especially for small production runs. To overcome this, we have opted for large-format additive manufacturing (LFAM) to produce the moulds used in lay-up.

The tooling is printed using a high-temperature thermoplastic, such as carbon fibre-filled PEI (e.g., ULTEM), which can withstand the high pressures and temperatures of autoclave curing (Ngo et al., 2018).

However, it is important to consider the risks associated with using large format additive manufacturing materials rather than conventional tooling methods such as Base 978 or glass fibre. PEI, the chosen material, is anisotropic, meaning that under heat during curing, the mould tools will expand approximately 10x more in the Z direction (local printing direction) than the X and Y. This means during the design stage it is imperative that an appropriate scaling factor is applied, in order to allow the part to expand and cure at the correct nominal dimensions.

After printing, the moulds are machined to a smooth finish to ensure part accuracy. Prepreg carbon fibre fabric is laid onto the mould following a specific ply orientation schedule to achieve the desired mechanical performance. Once the lay-up is complete, the part is vacuum-bagged and cured in an autoclave. The curing process ensures full resin cross-linking, resulting in a part with optimal mechanical properties.

This method enables rapid iteration of tooling designs, shortens lead times, and significantly reduces costs compared to metal tooling (Gardiner, 2015). It also allows for design changes to be implemented quickly, which is particularly beneficial during early development stages. Embedded inserts for mounting brackets are incorporated into the lay-up, which avoids post-machining and further enhances structural integrity.

Additionally, the 3D-printed moulds can be reused for multiple cycles if handled correctly. This approach supports a semi-automated production process with fewer bottlenecks and opens the possibility for localised or on-demand manufacturing in the field. As well as this, the nature of 3D printed moulds allows for modification of the tooling after the manufacture of a first off component, providing the change is material off (a female feature on the tool). This is because the additive manufactured tooling has additional stock, so it can simply be re-machined and re-prepared for lamination.

7.5 Auxiliary Components and Sub-Assemblies (JG – 2221724)

To maintain serviceability and upgrade potential, the robot is built from a set of modular subassemblies. These subassemblies are designed to be independently tested and replaced, reducing repair times and supporting rapid deployment.

7.5.1 Mobility System (JG – 2221724)

Preliminary design explores the option of the robot using a four-wheel-drive system, powered by 24V brushless DC motors with planetary gearboxes. Each wheel is independently suspended with a trailing-arm suspension system, improving traction on uneven terrain. The tyres are designed to be puncture-resistant and have a self-sealing inner layer to avoid downtime from debris.

7.5.2 Sensor Array (JG – 2221724)

The robot is equipped with a range of sensors, including gas sensors (for CO, CH₄, and H₂S), a thermal camera, stereo vision system, night vision IR LEDs, and a 360° LIDAR scanner. These sensors feed data to the onboard processor and are mounted on a retractable mast. The mast can be manually adjusted or automatically lowered when navigating low-clearance zones.

All subassemblies are using quick-connect fittings and labelled interfaces, improving ease of maintenance.

7.6 Manufacturing Design Strategy (JG – 2221724)

The design has been optimised not just for performance, but also for ease of manufacture and assembly. Standardised components, including fasteners and electrical connectors, are used throughout. This reduces inventory complexity and improves repair turnaround times.

One of the critical design features for this analysis robot is the use of a desktop 3D printed interchangeable adaptor for a range of sensor types. The 3D printed modular design effectively allows the manufacturer to tweak the design of the 3D printed adaptor to fit the need of the customer. The adaptors design in principle will remain the same with standard features, then customisable features can be added/removed to fit a bespoke sensor as per the customers' requirements. Using the desktop 3D printing technology has several benefits, such as flexibility in design, rapid prototyping and testing, low cost and a more sustainable option than metallic alternatives.

- Most structural parts can be produced using established manufacturing techniques:
- Plastic covers and mounts are produced via injection moulding using ABS or polycarbonate for their impact resistance and UV stability.
- Metal brackets and internal supports are fabricated from stainless steel or anodised aluminium, chosen for their corrosion resistance and weight.
- Wiring harnesses are preassembled and tested offsite before integration.

Sub-assemblies are manufactured in parallel and undergo bench testing before integration. Final assembly takes place in a flow-line format, with quality checks at each station. This modular production line can be scaled up or down depending on demand.

Custom jigs and fixtures, which can also be 3D-printed, are used during assembly to ensure precise alignment of key components such as sensor mounts and motor housings. The robot can be assembled using standard hand tools in under two hours, a critical factor for service operations.

Desktop 3D printing as a manufacturing method for the adaptors as well as the custom jigs and fixtures has several benefits. Including material selection and profiling. The Bambu studios 3D printer is the proposed specification of machine to be used for this work, this printer has a very large range of material options for various applications. The adaptor components should be manufactured using a carbon fibre reinforced polymer such as PETG-CF to increase strength and durability. Whereas the jigs and fixtures which may be used to manufacture a

first off component can utilise a polymer such as PLA, as it is very low cost and strength is not critical for a one time use jig.

7.7 Environmental and Safety Considerations (JG – 2221724)

Given its intended environment, the robot has been designed to meet IP67 standards, offering complete protection against dust and limited water immersion (IEC, 2013). The monocoque shell is reinforced with external rubber and polycarbonate bumpers to absorb shocks and impacts.

All electronics are enclosed and shielded to reduce interference, and passive cooling fins dissipate heat without relying on fans, which are susceptible to clogging in dusty environments. The robot operates on a low-voltage system (<50V DC), complying with international safety standards (BSI, 2018).

- For safety during operation and handling, several redundant systems are included:
- Emergency stop buttons located on the top and rear panels
- Current and thermal limiters within the power system
- Independent sensor watchdog timers to flag anomalies in critical systems

Each component is rated for a minimum operating lifespan of 10,000 hours. The carbon fibre shell will undergo lifecycle testing using simulated drop and pressure conditions to ensure structural integrity. All adhesives and coatings are compliant with REACH and RoHS regulations.

7.8 Testing and Validation (JG – 2221724)

To ensure it meets its design goals, the robot will undergo a comprehensive validation process. These tests are divided into laboratory, field, and environmental categories:

Drop and Impact Tests. The robot will be dropped from various heights onto concrete and compacted gravel to test the strength of the monocoque and internal shock absorption systems.

Ingress Protection (IP) Testing. Performed in accordance with IEC 60529 to verify dust and water resistance.

Thermal Cycling. Subjected to temperature fluctuations from -20°C to +60°C to assess material expansion and battery performance.

Electromagnetic Compatibility (EMC). Ensures the robot's electronics will not interfere with nearby devices.

Field Trials. Carried out on an active construction site, assessing navigation, sensor accuracy, and durability over extended use.

Test results will inform any necessary design revisions prior to production scaling. Performance metrics such as uptime, error rates, and sensor calibration drift will be monitored using onboard diagnostics and logged to the cloud.

7.9 Future Developments (JG – 2221724)

Although this specification is tailored to construction sites, the design is intended to be flexible. With minor adjustments, the robot could be adapted for use in agriculture, mining, disaster response, or infrastructure inspection. Potential future enhancements include:

- Fully autonomous navigation using SLAM algorithms
- Integration with drones for aerial inspection
- Real-time integration with Building Information Modelling (BIM) platforms
- Swappable sensor bays for specific industry use cases
- Upgraded AI modules for hazard recognition and real-time alerting

The use of LFAM for tooling makes design updates more agile, allowing for continuous development without significant cost increases. With a digital archive of tooling files, production can be resumed or replicated across locations without the need for physical tool storage.

7.10 Design Summary (JG – 2221724)

This report outlines a practical, robust, and scalable design for a safety analysis robot suited for construction environments. The use of a carbon fibre monocoque created using LFAM tooling provides an efficient solution to the challenge of building a lightweight but tough robot that can withstand harsh field conditions. The design places equal emphasis on performance, manufacturability, and long-term usability.

With modular subassemblies, robust environmental protection, and modern electronics, the robot offers a comprehensive platform for real-time safety monitoring and can be readily upgraded for a range of future applications. It exhibits modern engineering practices that prioritise efficiency, adaptability, and sustainability.

8 Analytics and Performance Specialist – Garon Williams (2320123)

8.1 Performance Metrics (GW – 2320123)

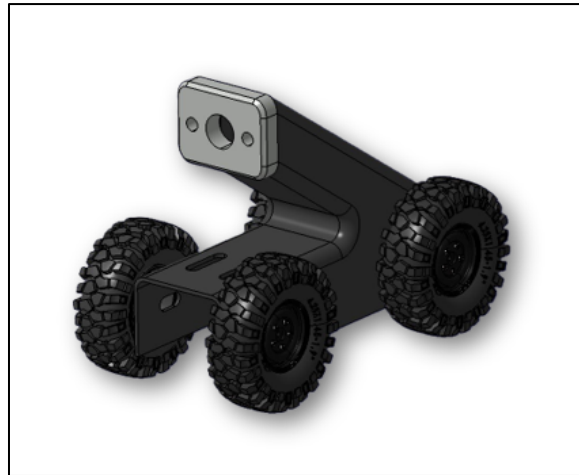


Figure 6 - Crawler Design

8.1.1 Objectives (GW – 2320123)

CASE STUDY:

On November 8th, 2001, there was a disaster in Port talbot steelworks, at around 5pm. A huge blast tore through the foundations of blast furnace no.5, this then caused the 5000-tonne blast furnace to lift approximately 0.75m from the base. This led to 15 employees being injured with three whom passed away. The newspaper article included a report from the health and safety executive published in 2008 (Turner, P. and Williams, N. (2019). The health and safety report found that the previous owners, torus, have breached health and safety standards, this resulting in a fine of 1.33million and ordered to pay costs of 1.74 million in Swansea crown court (Wales Online (2013).

In all companies with a workforce, it is vital that the company monitors the environment of which these employees are working. The case study is an example of what we aim to prevent with the environmental crawler inspection drone. Inspection drones exist but are industry focused and not applicable for all. For example, there is a crawler which is made by a company called Jireh, this crawler sole purpose is to monitor welding standards and quality. Our main aim for this product is to combine several environmental hazards in common manufacturing company's facilities, for one crawler. These environmental hazards are:

- Gas Leaks
- Harmful Chemical emissions
- Fires
- CO2 levels

Currently the crawler will have detachable payloads for each of the environmental hazards, this allows for designated GPS routes for each instrument. Some areas in workplaces will only have certain environmental hazards. This would optimise inspection time as the crawler is only monitoring certain environments depending on which instrument is attached.

Our aim is to create a crawler with low latency, immediate and accurate data collection system. The crawler will use real time monitoring for the data collection system. The system is known for having a low latency which makes it ideal for this product to provide live readings. The crawler will optimise this data to aid inspection routes, inspection time and hazard response time. We also aim for a GPS routing system which will calculate the most efficient route for an optimised inspection time. The GPS system will also allow the crawler to report any findings in specified zones. This will enable management to proceed with the evacuation procedure and prevent the use of the zone. A reliable and accurate GPS routing system will optimise the battery consumption. With time, the crawler will be proven, and insurance companies will see the crawler as a safety feature which could have an impact on the insurance prices for these large companies. With having a detachable payload system for different instruments to monitor the environment, the crawler must be able to recognise which payload is attached as it may have a different inspection area. For now, the detachable payload must be done manually, the same goes for charging but we aim to improve these in the future.

8.2 Analytics (GW – 2320123)

8.2.1 Data Collection (GW – 2320123)

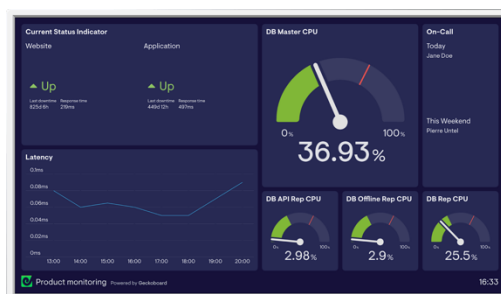


Figure 7 - Real time monitoring example

For an efficient and reliable method of data collection, we believe that real time monitoring is the best method for this crawler. The real time monitoring will consist of continuously updated data on the system, process and events (Barney, N. (2023)). Real-time data collection is a process that allows administrators to monitor and evaluate the data collected by the crawler

(Symestic, 2025). Real time monitoring has a low latency, meaning information can be transmitted with minimal delay. This will enable the crawler to supply an immediate and efficient data collection system for the consumer. Due to real time monitoring having an immediate response time, it'll benefit the response time for administration to be made aware of the hazardous environment (Symestic, 2025).

Data collected

- Payload detection levels
- Which payload is attached
- Performance data
- Battery consumption

This data will allow administrators and technicians to analyse the data collected, performance data, battery consumption and which payload is attached. Technicians will be able to analyse the data and detect any inefficiencies. If detected, the technician will schedule an appointment to inspect the drone visually.

8.2.2 Performance Review (GW – 2320123)

To monitor the performance of the crawler, real time data will allow us to determine if some of the components are functioning as they should. Components such as, the motor, battery, and electronic speed controller (ESC) will all be monitored. Based off the data collected, it can give us an idea of why the crawler is not functioning at its optimum. The administrators will have to monitor the performance of the crawler. We will monitor the crawler every quarterly and perform maintenance checks and service the crawler. If administrators detect inefficiencies, they can request a technician to monitor the crawler. The crawler will use a basic flowchart for the system, asking questions repeatedly until satisfied.

8.2.3 Flowchart (GW – 2320123)

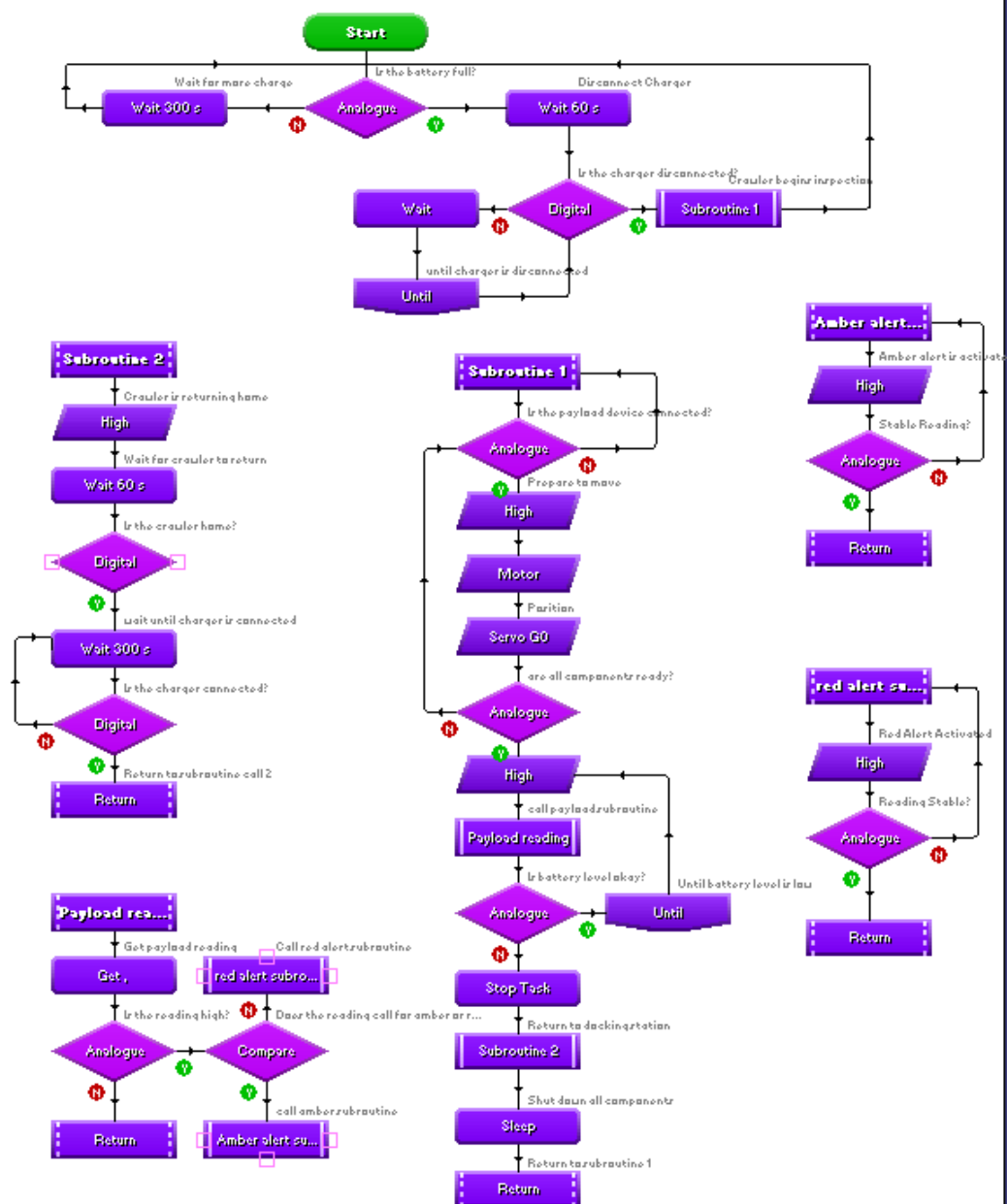


Figure 8 - Electronic Flowchart

The electronic flowchart shown in figure 8, is the basic process of which the crawler will operate. As the crawler is charging, the system will ask whether the battery level is at a satisfactory level, if not, there is a pause for three hundred seconds. It will then repeat the question until the battery is full. The system will then pause for 60 seconds before asking if the charging lead has been disconnected. The system would continue asking the question until the charging cable is manually disconnected. Once satisfied, a subroutine is called, this is the main inspection cycle. The electronics will then power up and prepare to begin the inspection route. Once all the electronics have prepared for the inspection route, it will call and repeat the payload reading subroutine, until a low battery level has been detected. The payload reading subroutine tests if the value of the payload has exceeded the safe limit. If readings have, then the system will compare the reading and decide whether the breach was amber or red. The system would then call either amber or red subroutines, it would then continue to monitor the payload reading until the reading has fallen back to normal levels. The alerts will be easily identified in the excel spreadsheet by colour coding the alerts. If the reading is low, the subroutine will then return and continue monitoring the readings until the battery level is low. Once the battery has been detected as low, the crawler would stop the task and be redirected back to the docking station. The system will then reset and wait for the battery level to return to a satisfactory level, repeating the system once full.

8.2.4 Reporting (GW – 2320123)

The real time data will be collected and stored into an excel spreadsheet showing all data. The excel spreadsheet can be accessed by both the administrators and the technicians, this will enable the technician to detect any inefficiencies without being on site. The system will also continuously add data as the crawler is inspecting with date and time stamps.

The system will also continuously add data as the crawler is inspecting with date and time stamps as shown in figure 7. The table also includes several columns all containing the crucial data required for the analysis. The real time monitoring will be able to identify different

Timestamp	Payload Device fitted	Crawler Speed	Environmental Hazards	Gas Level (ppm)	Safety Level	Device Power Consumed	CO2 Levels (ppm)	Battery Level	Location (Zones)	Motor efficiency
11/05/2025 22:19	Gas Level Detector	1.2 m/s	ALERT!!!	75 ppm	RISK	200W	n/a	85.00%	Zone 1	97%
11/05/2025 23:20	Live Ground	1.2 m/s	None	n/a	Stable	220W	n/a	50.00%	Zone 4	93%
12/05/2025 12:07	CO2 Level Detector	1.2 m/s	None	n/a	Stable	350W	423 ppm	33.00%	Zone 2	84%
13/05/2025 13:20	Gas Level Detector	1.2 m/s	None	5 ppm	Stable	150W	n/a	18.00%	Zone 6	90%
12/05/2025 22:19	Offline	Offline	Offline	Offline	Offline	Offline	Offline	Recharging	Offline	Offline
13/05/2025 09:19	Gas Level Detector	1.2 m/s	RED ALERT!!!	200 ppm	Risk	200W	n/a	95%	Zone 3	100%

Figure 9 - Excel Spreadsheet for real time monitoring

Real time monitoring would allow administrators to monitor the surrounding area for any environmental hazards whilst also monitoring the performance of the crawler. The system will also identify which zone the reading has been detected. The spreadsheet will use a colour coded system for easy identification.

System Stable	Green
Battery Level Low	Blue
Amber Alert	Yellow
Red Alert	Red
Offline	Grey

Figure 10 - Colour coded system for real time monitoring.

The colour coding system shown in figure 10 outlines the alerts, stable levels and when the crawler is offline. The battery level has been detected as low at 13:20, the crawler would stop the task and proceed back to the docking station for charging. There has been an amber alert warning due to the crawler identifying a high gas level reading, this will result in the evacuation of the facility, whilst the crawler monitors the reading. There is also a red alert warning, this is a risk to life warning and requires immediate evacuation for the facility. The authorities would also be notified that there is a code red for the facility. Once the red alert is in place, the crawler will remain in the zone and monitor the safety levels. Depending on the payloads attached to the crawler, the data will be inputted into the desired columns and ignore the ones that are not applicable. There is also live battery level and crawler power consumption reading shown in real time. The crawler will detect when it needs to recharge at the docking station. The crawler power consumption is more for the technician, they can see whether the circuit is functioning properly. Any spikes or dips in the power consumption will indicate there is an issue within the circuit board. The system will also create a quarterly metric diagram which would use the data collected. This can aid the root cause analysis process to help understand why a fault or inefficiency has occurred.

8.3 Future Improvements (GW – 2320123)

8.3.1 Mobile App (GW – 2320123)

The main future improvement for real time monitoring, is the app for real time data collection. In this app you will be able to view the data collected, crawler components efficiency, map of the premises, technician help desk and schedule servicing. We can add a safety feature for the business by getting the employees to download the app and register as an employee. This will then allow employees to opt into allowing notifications from the app, for alerts on hazardous environments. This is to ensure the employees understand that there is a safety breach in a specified zone and proceed with evacuation procedure. The employees will also be able to access the map, specifying zones and evacuation procedure in the app. Creating a

crawler which has integrated sensors and payload into the circuit board. This will remove the need for human involvement. It will also enable the crawler to monitor several environments at the same time. For the larger facilities with several buildings, we can add more docking stations for the crawler to dock and charge. This will be routed into the GPS route so the crawler is aware there are several docking stations where it can charge before continuing the inspection.

8.3.2 Ai powered camera (GW – 2320123)

Another improvement for the crawler would be, adding a camera with integrated ai. It allows for detection of employees in the surrounding area and redirects the path live to avoid them, it would also use a safe variable speed whilst manoeuvring around employees and obstacles. The camera can also scan the surrounding area for any safety breaches, this can be obstacles in a high trafficked area. The ai camera would also be able to spot activities and behaviours that could become safety problems (Selko, A. (2022). Analysing the surrounding areas and capturing images can enable management to modify processes and layouts to ensure the safety standard in detected areas increase.

Ai powered Camera:

- Object Localization
- Image classification
- Object verification
- Object Tracking
- Object recognition
- Object detection
- Semantic segmentation
- Monitor employee safety whilst working.

The AI camera can then monitor the employees whilst they work, capture images of employees disobeying the safety protocols. With future improvements, the ai camera would be able to map out the building size and route the best GPS route for the facility.

8.3.3 Optimising the battery (GW – 2320123)

With future improvements, we can integrate new components into the system which would allow an elongated battery life. Adding laser sensors into the system will allow the crawler to avoid moving obstacles. We can then look to convert the breaking power into energy for the battery. If the crawler needs to monitor an external zone, we can integrate a solar panel into the monocoque of the crawler. This would allow the crawler to recharge using a renewable source of energy.

8.3.4 Upgraded Battery (GW – 2320123)

The battery currently used for the crawler is a lithium ion. These batteries performance is affected with low temperature, it reduces the performance around 25%. They are also known to explode with high temperatures. Due to the Crawler being a safety inspection device, we will research into a reliable and better performance batteries available in the future market. There are solid-state batteries being developed which can improve the batteries performance and efficiency whilst significantly reducing fire risks. It would potentially offer an ultra-fast charging. These batteries are due to be released commercially around twenty twenty-six/seven (Laserax (2025)).

8.3.5 Maintenance and Services (GW – 2320123)

Within the mobile app, administrators would be able to request a service or maintenance appointment, and we would send a trained technician. We would recommend companies to schedule the crawler maintenance into their overall operations effectiveness (OOE) and total effective equipment performance (TEEP). These processes are used for defining the availability; by requesting these appointments, you can schedule downtime in these processes for the duration of the appointment. Regular planned maintenance and servicing is recommended for optimum performance.

8.4 Summary (GW – 2320123)

The crawler has a large consumer market, with its innovative technology, the crawler can become an industry standard. The real time monitoring system which the crawler is using will be a great selling point for the target market. If used correctly, it will positively impact the crawler's performance. The system will allow administrators to monitor crucial data from the desk, allowing earlier identification of hazards or decreased crawler performance. The crawler has the basic function for quick and reliable data collection and hazard identification. With future development, an app will replace the excel spreadsheet and contain everything needed. There is also the possibility of integrating the use of an ai camera which analysis the surrounding areas and capture any images for future improvement to safety. If the ai camera is optimised, it can transform the safety level of both the facility and the employees. Integrating laser sensors for early detection of obstacle collision can be integrated into the system using the electronic speed controller for a variable speed to aid the prevention of collision. We will aim to continuously improve the crawler with new innovative technology which will bolster the performance and reliability of the crawler.

9 Materials, Manufacturing Process & Sustainability Specialist – Shay Quinn (2319936)

9.1 Materials (SQ – 2319936)

The chassis of the Safety Analysis Robot (SAR) is the backbone of the robotic system. The Robot will operate in hazardous, industrial, DSEAR classified, high and low temperature environments, the selection of the material is a critical design decision. The material must be strong, lightweight, corrosion resistant, heat-tolerant, and capable of withstanding mechanical stress, all while remaining cost-effective and sustainable.

The following materials were shortlisted for analysis:

- Aluminium 6061,
- Stainless Steel 304
- Titanium Grade 2
- ABS
- Nylon 6
- Polycarbonate
- Carbon Fibre

Material	Type	Density (g/cm ³)	Tensile Strength (MPa)	Heat Resistance	Corrosion Resistance	Cost (\$/kg)	Machinability	Remarks
METAL								
Aluminum 6061	Metal	2.7	310	Up to 150°C	Good	2.5 – 3.0	Excellent	Lightweight, widely used
Stainless Steel 304	Metal	8	505	Up to 870°C	Excellent	3.0 – 4.0	Moderate	Heavy but corrosion-proof
Titanium Grade 2	Metal	4.5	344	Up to 400°C	Excellent	30 – 50	Difficult	Very strong, costly
Plastic								
ABS Plastic	Plastic	1.04	40	Up to 80°C	Moderate	1.5 – 2.0	Excellent	Inexpensive, easy to form
Nylon 6	Plastic	1.13	75	Up to 120°C	Moderate	2.0 – 3.0	Good	Flexible, absorbs moisture
Polycarbonate	Plastic	1.2	65	Up to 135°C	Good	2.5 – 3.5	Good	Impact resistant
Other								
Carbon Fibre (CFRP)	Composite	1.6	600–1000+	Up to 250°C	Excellent	20 – 30	Difficult	Ultra-strong, lightweight, chosen material

Figure 11 - Material Value Table

Carbon Fibre Reinforced Polymer (CFRP)

CFRP consists of woven carbon strands set in a polymer resin. It is extremely rigid, lightweight, and has a high fatigue life. This composite resists corrosion, thermal degradation, and chemical attack, making it ideal for extreme environments the SAR may encounter. It's especially suited for precision-engineered component where weight and strength are critical.

The main drawbacks are high manufacturing costs, difficulty in post-processing, and the need for specialist fabrication such as vacuum forming.

Aluminium 6061

This is a popular engineering metal due to its ease of machining, corrosion resistance, and low density. It's a good candidate for general purpose robots and is widely used in aerospace and automotive applications. Its thermal tolerance is moderate however, can be enhanced with surface treatments to the metal, such as anodizing. It is very cheap to buy and easy to manufacture in most workshops.

Stainless Steel 304

Stainless steel is known for its exceptional corrosion resistance and mechanical strength. It's used where durability and exposure to moisture, chemicals, or heat are concerns. However, its high density makes it unsuitable for lightweight robotic designs. The weight significantly reduces mobility and energy efficiency, which is critical due to the robot being battery powered and would need to be as light as possible to ensure efficiency from the batteries.

Titanium Grade 2

Titanium offers a strong balance between corrosion resistance, heat tolerance, and mechanical performance. It's lighter than steel but stronger than aluminium. Despite these advantages, its cost and difficulty to machine make it impractical for most prototypes or mid-scale production unless operating in extreme environments.

ABS Plastic

ABS is a low-cost, easily mouldable plastic used widely in enclosures and structural housings. It performs well in light-duty environments but lacks the mechanical and thermal durability for use in DSEAR or industrial zones. It's a great choice for rapid prototyping, but not for long-term deployment in harsh conditions.

Nylon 6

Nylon is tougher than ABS and performs well in repetitive mechanical motion systems. Its semi-flexible nature absorbs impact. However, it absorbs moisture, which affects its dimensional stability and reduces performance in humid or chemically active zones.

Polycarbonate

Polycarbonate offers a good mix of impact resistance and transparency. It is used in enclosures and parts that may experience mechanical shocks. However, it scratches easily

and, like other thermoplastics, can deform under high heat, making it secondary candidate for high temperature environments.

Material Choice

After comprehensive evaluation of seven potential chassis materials, including three metals (Aluminium 6061, Stainless Steel 304, Titanium Grade 2), three plastics (ABS, Nylon 6, Polycarbonate), and the composite Carbon Fibre Reinforced Polymer (CFRP). CFRP emerged as the most suitable material for the Safety Analysis Robot. This choice is based on its superior balance of mechanical performance, thermal resistance, environmental durability, and manufacturing feasibility.

Although CFRP is not as easily manufactured as some of the other materials, it makes up for this with its characteristics. CFRP outperforms metals in several critical aspects for this application. While the metals like titanium and stainless steel offer high strength and temperature resistance, they come with high weight and/or aren't cost effective. Aluminium is lightweight and corrosion-resistant but lacks the tensile strength and rigidity needed for high-stress environment the SAR will encounter. CFRP, by contrast, offers high tensile strength, exceptional stiffness, and weight reduction of up to 60% compared to aluminium (the lightest metal of the 3), all of these can be shown in figure 1, paired with the epoxy resin allows it to have a higher working temperature then as well. Combining all these characteristics make this material ideal for the robot's chassis, allowing great mobility, lightweight allowing it to easily traverse the harsh environments whilst also being energy efficient, and load bearing performance in hazardous settings.

Compared to high performance plastics such as ABS, Nylon 6, & Polycarbonate, CFRP significantly exceeds in structural integrity and thermal resistance. While plastics are easily fabricated and cost effective, they typically degrade at lower temperatures, deform underload, and lack mechanical robustness required in safety critical industrial settings.

9.2 Sustainability (SQ – 2319936)

As the Safety Analysis Robot (SAR) is designed for use in demanding, harsh, industrial environments, including engineering facilities, hazardous safety zones, and DSEAR – regulated areas, ensuring its sustainability is not only environmentally responsible, it is also a legal and practical requirement for market readiness within the UK, to ensure compliance with several UK sustainability regulations and framework.

In compliance with the UK Eco-design and Energy Labelling Regulations, the robot must be developed with energy efficiency, repairability, and durability in mind. This is particularly important in DSEAR zones, and high impact areas, where equipment failure due to poor design or thermal efficiency can have severe safety consequences. A modular, maintainable design supports long-term use including regular maintenance plans, reducing the environmental impact of frequent replacements and ensuring compliance with Eco-design standards.

Under Extended Producer Responsibility (EPR) and WEEE regulations, manufacturers of electronic and electrical equipment must take responsibility for the end-of-life recovery of products. Designing the robot with recyclable materials, and ensuring it is easy to disassemble, directly supports obligations. Moreover, it aligns with circular economy goals set out in Environment Act 2021, which targets reduced waste and increased resource efficiency across industries.

The robot will include coatings, sensors and circuit components, it must also comply with UK REACH chemical safety standards. Using non-toxic, compliant materials ensuring that the robot can operate safely in sensitive safety zones and be manufactured without breaching chemical use regulations.

Furthermore, in alignment with the Green Claims Code, any claims regarding the robot's environmental benefits, such as durability, recyclability, or energy efficiency, must be verifiable and evidence-based.

Finally, incorporating sustainability is a strategic benefit. Many engineering and safety-critical industries are under pressure to decarbonize. Offering a robot that supports long-term use, low environmental impact, and safe disposal or reuse increases its appeal and adoption potential across sectors facing Environmental, Social & Governance scrutiny.

Material & Manufacturing Sustainability

Carbon fibre itself is energy-intensive to produce, especially during the pyrolysis phase of converting it into carbon filaments. However, when viewed over the full life cycle, CFRP contributes to sustainability in several ways.

It is highly efficient due to its extremely low density and high strength-to-weight ratio, CFRP reduces overall weight of the robot. This leads to lower energy consumption during use.

CFRP has a very long-life cycle durability, this is due to CFRP being corrosion resistant, high fatigue, and high thermal degradation, being much better than most materials. This results in

less frequent replacements, and lower maintenance costs and needs, in turn reducing material turnover.

Process Sustainability

The hybrid method of using 3D printed tooling for CFRP Lay-Up maximizes resources efficiency during fabrication.

3D printed moulds generate very little waste, these tools are also reusable for small batch runs, reducing the need for high-impact tooling materials.

The Lay-Up process, particularly when vacuum bagged, ensures optimal resin to fibre ratio, minimal excess, and consistent part quality.

The Carbon Lay-Up technique can be performed at room temperature or low temperature curing as well as being manually placed in, consuming less energy than other manufacturing processes.

9.3 Manufacturing Process (SQ – 2319936)

Carbon Fibre Reinforced Polymer (CFRP) is chosen as the primary material for the chassis of the Safety Analysis Robot due to its exceptional strength-to-weight ratio, chemical and heat resistance, as well as its exceptional structural rigidity. However, CFRP is not a homogenous material like plastics or metals, it is a composite composed of carbon fibre reinforcements embedded in a polymer resin matrix, which is typically epoxy and what will be used for the SAR. As such, its manufacturing process differs significantly and requires careful planning to ensure strength, durability and dimensional accuracy, this will be done using a 3D printed tooling part to help in ensuring this criteria is met. By creating this tooling part using a 3D printer it ensures we can manufacture CFRP parts effectively and affordably especially in this phase of the project's life. This approach reduces lead time, lowers costs, and allows rapid design iterations.

Overview of the Hybrid Manufacturing Process

The manufacturing process follows a multi-stage workflow that combines additive manufacturing with composite fabrication. A 3D printed mould or tooling part was first created based on the Robot's CAD geometry, providing a precisely shaped surface for the Carbon Fibre. The CFRP is then layered onto this mould using resin-impregnated fibres, followed by vacuum bagging and curing to consolidate the structure. This hybrid approach allows for high-accuracy fabrication with minimal waste and rapid iteration, ideal for both prototyping and functional production. With the tooling being manufactured using 3D printing, the tooling part

is easily manufactured, easily replaceable, and quick to manufacture together if it were to break.

3D Printing

To create the tooling, A 3D model is made using 3D software such as SolidWorks to produce this, the 3D printer is used to then print it using common plastic filaments such as PETG, to further increase dimensional accuracy.

Carbon Fibre Lay-Up

After preparing the 3D printed mould, the carbon fibre lay-up process begins, sheets of woven carbon fibre fabric are to be cut to size and laid into the tooling surface in multiple orientations, alternating between 0, 45 and 90 degrees to ensure strength in all loading directions. Each ply is then impregnated with epoxy resin manually during this phase of the project, ensuring each ply was fully saturated. The process was completed with care to avoid wrinkles, air bubbles, or fibre misalignment, all of which can compromise mechanical performance.

Once completed, the chassis can be placed in a vacuum bag, under negative pressure, the laminate, was compacted tightly against the mould, allowing excess resin and air to be removed. This result in composite structure with an optimal fibre-to-resin ratio, improved strength, and minimal voids to avoid a weakened structural integrity.

Advantages of Hybrid Manufacturing

The hybrid manufacturing method offers significant advantages over traditional metal forming or high-cost composite manufacturing routes. First, the use of 3D printed tooling reduces overall production costs, especially during prototyping or low-volume runs. Tooling can be rapidly redesigned to accommodate design changes without requiring re-machining or outsourcing. The precision of additive manufacturing ensures tight tolerances and repeatable geometries, which is critical for mechanical assemblies.

In terms of structural performance, CFRP provides exceptional strength-to-weight ratio, which enhances the robot's mobility, efficiency, and resistance to operational stresses. The use of vacuum bagging techniques ensures the final component is lightweight, rigid, and has minimal surface defects, all of which contribute to both functional and aesthetic qualities.

Sustainability Considerations

Sustainability is a key concern in modern engineering, especially for products intended for industrial and public safety use. The hybrid manufacturing method used here supports

sustainability goals in multiple ways. Firstly, the use of 3D printed tooling drastically reduces material waste compared to subtractive manufacturing methods. Since only the material required for the mould is printed, there is minimal excess, and any failed prints can be often recycled or repurposed.

CFRP, although not traditionally biodegradable, offers long-term durability that reduces the need for replacement parts, contributing to a lower lifetime environmental footprint. Moreover, as recycling methods for composites improve, CFRP waste can increasingly be reused in secondary applications. The precision enabled by additive manufacturing also reduces the chance of design errors and remanufacturing, leading to further resource savings.

The use of hybrid manufacturing process also aligns with UK Sustainability regulations and design for environment guidelines. By improving material efficiency, enable in house tooling production, and extending product lifespan, the process contributes to reduced energy consumption and lower embedded carbon key targets in the UK's environmental strategy for industrial innovation.

10 Maintenance Manager – Connor Griffiths (2216420)

10.1 Introduction (CG - 2216420)

Our group project aims to design and implement a Safety Analysis Robot. The robot is designed to operate remotely in hazardous environments while navigating challenging terrain. To provide maximum efficiency and safety, it's important that the robot has design implementations, such as snap-fit fittings, to provide safe and easy access to internal components and sensors to provide real-time monitoring.

In my role as the maintenance and safety specialist, I have focused on efficient maintenance checks that adhere to strict safety standards. A key objective is to focus on a modular design, such as interchangeable wheels to suit all work environments and emergency stop functions to protect workers and the surrounding environment. This approach aligns with the research by Zwicker, Zesch, and Moser (2010) in their examination of inspection robots for power plants, highlighting the practical benefits of a modular, “safety-first design in high-risk environments”.

10.2 Maintainability implementation (CG - 2216420)

10.2.1 Modular design and component standardisation (CG - 2216420)

The Safety Analysis Robot has a modular design utilising interchangeable components. The robot is equipped with four quick-release, interchangeable wheels designed to adapt to different terrain conditions. The wheels are secured with snap-fit fittings, which remove the necessity for complex tools when disassembling or reassembling. This approach significantly decreases the Mean Time to Repair (MTTR) (*see Equ. 1*). According to Levin and Kalal (2003), Mean Time to Repair is the most used method to display the maintainability of a product.

Standardising components allows maintenance engineers to use a more efficient stock management system and simpler repair processes. All modules, such as the sensors, power supply units, and motors are engineered for snap-fit integration with the main chassis. This design allows for the immediate replacement of components without the need for complex calibration procedures or tools, drastically reducing potential down time. Our approach is supported by the research of ‘Modular Designs’ by Upendra Kachru (2007).

$$MTTR = \frac{\text{Time Required to Fix All Failiures}}{\text{Total Number of Failiures}}$$

Equation 1- MTTR (Levin and Kalal, 2003)

10.2.2 Preventative and Predictive Maintenance (CG - 2216420)

Preventative and Predictive maintenance will be used together to ensure the robot operates at optimal performance.

10.2.2.1 Planned Preventative Maintenance (PPM) (CG - 2216420)

A scheduled maintenance checklist is essential to reducing potential breakdowns. To ensure maximum safety and efficiency PPM schedules will be implemented, alongside visual inspections of the robot performed by the operator. Depending on the usage of the robot required by the customer, a PPM schedule can be tailored to run on work hours [10hrs,100hrs,1000hrs and 10Khrs] or annual frequency [daily, weekly, monthly and yearly]. The maintenance procedure includes inspection of component wear, calibration of sensors and electrical connection testing. (see 'Appendix B' for SAR PPM schedule)

10.2.2.2 Predictive Maintenance (CG - 2216420)

By applying an integrated sensor network, the safety analysis robot (SAR) measures all its own internal operational functions, readings are then forwarded to a system called 'Omni-trend' created by PRUFTECHNIK. This system acts as a central location for vibration measurement and analysis which can indicate wear of components and “*diagnose problems before they become severe*” (Mohan, 2025). The use of Omni-trend has proven successful in the bearing analysis findings of Hemati and Shooshtari (2023). By applying a predictive maintenance approach, we can aim to increase the Mean Time Between Failures (MTBF) (see Equ.2), therefore increasing the robot's availability (see Equ.3).

$$MTBF = \frac{\text{Total Operating Time}}{\text{Number Of Failures}}$$

Equation 2 – MTBF (IBM, 2023)

$$\text{Availability} = \frac{MTBF}{(MTBF + MTTR)}$$

Equation 3 – Availability (Torell and Avelar, 2017)

10.2.2.3 Training and Documentation (CG - 2216420)

To ensure each operator is confident and competent in their ability to function the SAR, standard operating procedures (SOPs) will be provided to the customer and due to the modular design of the robot, the SOPs will be tailored to the specific work environment.

The Standard Operating Procedures will include required routinely inspections, part replacements, emergency repair and how to tailor the robot to different environments. Standard Operating Procedures are essential for consistency and repeatability in maintenance

and repair tasks. They reduce downtime by reducing human error, leading to a shorter mean time to repair (MTTR) once failures occur (Akyar, 2012).

10.2.3 Diagnostic Readings (CG - 2216420)

To ensure safe and efficient operation of the Safety Analysis Robot (SAR), constant diagnostic readings are taken by a network of sensors which relay critical operating data to the remote operator.

10.2.3.1 Thermal Sensors (CG - 2216420)

Thermal sensors within the robot take interval measurements of the temperatures of critical components such as batteries, motors and circuit boards. These sensors provide real time monitoring which alert the system to issues prior to component failure. For example, when the thermal sensors detect high temperature from the motor, load will be decreased until the motor returns to optimal working temperature, this ensures the robot can still function in all conditions. A similar approach was recently taken by Suhail, Guangul and Nazeer (2024) in examining how advanced diagnostic systems and tools have become for problem mitigation.

10.2.3.2 Vibration Sensor (CG - 2216420)

Vibration sensors play a crucial role in assessing the mechanical integrity of the Safety Analysis Robot, these sensors are installed on critical components such as wheel actuators and the chassis elements where unusual oscillations could indicate issues like imbalance, misalignment or wear. Thorough vibration analysis allows proactive maintenance. The vibration sensor examines real-time vibration patterns against baseline profiles to identify early defects. Bond (2010) highlights that analysis of vibration signals can notify maintenance teams to implement corrective actions before any significant degradation of components occurs.

10.2.3.3 Gas and Environmental sensors (CG - 2216420)

Considering the dangerous environments where the SAR is applied, it is essential to keep track of the surrounding conditions. Gas sensors are designed to identify harmful substances, whereas environmental sensors monitor factors like humidity, dust levels, and surrounding temperature. These sensors serve two purposes. They provide crucial information for planning maintenance by pinpointing environmental stress levels that could speed up component wear and trigger safety measures when hazardous gas levels or other dangerous situations are detected. An engineering study conducted by Cruz, Oliveira and Correia (2024), shows the importance of continuous monitoring and how it aids in reducing critical component failure. Therefore, increasing the MTBF (Mean Time Between Failure).

10.3 Externally Mounted Battery System (CG - 2216420)

The Safety Analysis Robot features an externally mounted battery system, which improves operational uptime and maintenance efficiency. This design allows operators to quickly remove an empty battery and replace it with a fully charged battery, ensuring the system stays operational almost 24/7 and minimising downtime for recharging.

The externally mounted setup guarantees that battery units are managed only when the system is correctly isolated, reducing the risk of contact with live electrical circuits during maintenance procedures. By outsourcing the battery supply, we can avoid the difficulties of custom battery development and guaranteeing that the battery meets all legal requirements. This approach allows for quick integration into the robot's modular design, which not only simplifies the battery replacement process but also minimises the mean time to repair (MTTR). Battery swapping significantly reduces system downtime. A recent online “Battery Swap Study” (Closer Lindholmen Science Park, 2025) shows that replacing batteries can reduce downtime by more than 70% when compared to conventional recharging methods.

10.4 Safety Analysis and Risk Mitigation (CG - 2216420)

In addition to enhancing maintainability, the Safety Analysis Robot (SAR) has features to ensure the protection of the operators and the surrounding environment. This section details our method for identifying, analysing and mitigating risks.

10.4.1 Risk identification and analysis (CG - 2216420)

To manage risks effectively, it is essential to have a thorough awareness of all potential hazards that could impact the SAR. It is essential to identify and analyse factors like environmental conditions, component failures, and human error to effectively and efficiently reduce risk. It is essential to ensure that our assessments and mitigation procedures align with standards such as ISO 12100 (International Organization for Standardization (ISO), 2025b) for risk assessment and ISO 10218-1 (International Organization for Standardization, 2025) for the safety of industrial robots. Adherence to the UK ATEX Regulations (HSE, 2019) ensures that equipment designed for explosive atmospheres undergoes rigorous testing and certification.

A Failure Modes and Effects Analysis (FMEA) was performed to systematically identify and prioritise potential failures for the SAR. This approach allowed for a thorough assessment of each essential component, including environmental sensors, modular fittings, and power and safety systems, by applying scores for occurrence, severity, and detection. The resulting Risk Priority Numbers (RPNs) were useful in identifying our most essential risk mitigation actions.

Failure Mode & Effect Analysis (FMEA) - Safety Analysis Robot (SAR)							
Potential Failure Mode	Likelihood of Occurrence	Severity	Likelihood of Detection	Risk Priority Number (RPN)	Mitigating Actions Recommended	Potential Failure Causes	Potential Effect(s) of Failure
Loose attachment or detachment of wheels	4	8	5	160	Enhance snap-fit design; improve quality control and inspection frequency; retrain personnel on secure mounting	Snap-fit fitting wear, manufacturing defects, improper installation	Loss of mobility & stability; potential accidents during operation or maintenance
Inaccurate readings or sensor failure	3	9	6	162	Increase calibration frequency; add additional sensor redundancy; implement sensor health validation measures	Calibration drift, sensor aging, exposure to extreme temperatures	Overheating undetected, leading to component damage or fire risk
Failure to detect abnormal vibration signals	4	7	5	140	Improve sensor mounting and signal filtering techniques; enhance maintenance diagnostics	Sensor degradation, misalignment, signal interference	Missed early warnings of mechanical issues; delayed maintenance may lead to severe breakdown
Failure to detect toxic or combustible gases	5	9	4	180	Install dual/robust sensors; upgrade calibration protocols; consider protective housings against environmental interference	Sensor failure, environmental interference (dust, humidity), contamination	Undetected hazardous conditions exposing operators; risk of explosions
Poor battery connection or battery swap failure	3	8	4	96	Increase connector durability; adopt sensor-based connection verification; additional training and periodic checks	Connector wear, mishandling during swaps, improper integration of battery interlock	Loss of power; operational downtime; potential hazards during maintenance with live connections
Interlock malfunction, failure to isolate when panels or guards are removed	3	10	3	90	Reinforce interlock mechanisms; implement redundant circuits; conduct periodic re-certification and inspections	Mechanical failure, wiring issues, improper installation, wear over time	Exposed live electrical components; increased risk to operator safety during maintenance
Delay or failure in emergency shutdown	2	10	4	80	Update detection and shutdown software; increase frequency of emergency drills; add additional fail-safe checks	Software/hardware failures, communication delays in control system	Prolonged exposure to hazardous conditions; severe equipment damage; risk of injury

Figure 12 - FMEA for SAR (created by Connor Griffiths, see appx)

10.4.1.1 Environmental Hazards (CG - 2216420)

The SAR is designed to function in environments that may include extreme temperatures, toxic gas releases, and explosive conditions. ISO 12100 (International Organization for Standardization (ISO), 2025b) outlines that a thorough risk assessment should help to mitigate each hazard by recognising environmental factors and establishing suitable risk reduction procedures (International Organization for Standardization, 2010). In addition, the design complies with the UK and EU ATEX Directive (EU-OSHA, 2022), which regulates explosive atmosphere equipment and safety systems. To guarantee safe operation in unpredictable environments, this guideline requires comprehensive evaluation and certification of equipment used in hazardous areas.

10.4.1.2 Component Failures (CG - 2216420)

Failure to address component issues such as mechanical issues, sensor malfunctions, and electrical faults can lead to major operational hazards. ISO 10218-1 (International Organization for Standardization (ISO), 2025) outlines design requirements that allow industrial robots to incorporate safety features to isolate errors and minimise the risk of failure. Pérez Alvarez (2020), in his research discusses how downtime and hazards can be reduced by detecting component failures before they fail. With the implementation of real-time monitoring and modular components, when failure occurs, the damaged component is replaced with the new. By implementing this, the need for downtime for repairs is drastically reduced.

10.4.1.3 Human Factors (CG - 2216420)

Human error poses a considerable risk, given the complexity of the maintenance repair processes and emergency procedures. Insufficient training or poorly outlined Standard

Operating Procedures (SOPs) can result in maintenance delays, incorrect repairs, and an increased chance of accidents. Manufacturers must create thorough training manuals and maintenance procedures to remain in accordance with industrial standards and regulations such as PUWER (the Provision and Use of Work Equipment Regulations 1998) and the HASAWA (Health and Safety at Work Act 1974). The research on HEA (Human Error Analysis) by Null et al. (2020) shows that implementing a structured approach to human error analysis, along with thorough documentation and systematic training, allows engineers to identify vulnerabilities and potential errors at an early stage. This approach minimises the chances of mistakes and improves overall system safety.

10.5 Risk Mitigation Strategies (CG - 2216420)

The mitigation strategy for identified risks involves the implementation of the following procedures.

10.5.1 Redundant systems and fail-safe measures (CG - 2216420)

Critical components such as sensor arrays and emergency stop systems incorporate redundancy and fail safes to prevent a single point of failure from risking overall safety. Following UK regulatory guidance as set by the HSE and PUWER, redundant systems are considered good practice in high-risk environments (SHP Online, 2015). For example, our redundancy system works by having multiple of the same sensor but only one of the same sensors is active at one time. In the event of an emergency the safety analysis robot has implemented fail-safe measures to isolate the failing component, if possible, a redundant component will be activated in its place.

10.5.2 Enhanced Maintenance Procedures (CG - 2216420)

Our approach to reducing risk includes both Planned Preventative Maintenance (PPM) and real-time predictive maintenance monitoring. By undertaking regular scheduled maintenance procedures, following the guidelines set by R Keith Mobley (2002) and Rausand (2011) is essential for maintaining components and preventing faults from occurring. This integrated approach, combined with condition-based monitoring via our sensor network, greatly reduces unexpected downtime and enhances overall system reliability.

10.5.3 Comprehensive training and documentation (CG - 2216420)

To reduce risks related to human factors, the use of clear and detailed Standard Operating Procedures (SOPs) that comply with the UK's PUWER and Health and Safety Executive (HSE) standards are used. In line with the guidelines from the Health and Safety Executive (HSE) (1999), 'HSG48: Reducing Error and Influencing Behaviour', we implement regular training and refresher courses to guarantee that operators are competent in routine

maintenance and emergency procedures. The findings in HSG48 show that thorough procedures and training programs play a crucial role in mitigating human error, therefore improving safety in the workplace.

10.5.4 Safety Interlocks (CG - 2216420)

Safety interlocks are integrated into the Safety Analysis Robot to further mitigate risk. The interlocks work to automatically interrupt the operation of the Robot when critical maintenance panels, guards or component modules are removed. For example, when an engineer is performing a maintenance procedure, and removes a panel, the interlock comes out and the circuit is open. The loss in continuity activates a full isolation of the robot, therefore drastically reducing risk to the operator. According to ISO 14119, interlocking devices must be designed and selected according to rigorous criteria so that machinery remains in a safe state when access panels or protective guards are not in place (Vomiero, 2022).

Considering current industry standards and reliability research, the Pilz PNOZ X2 safety relay system suits the safety analysis robots needs. This system is highly regarded in the field of industrial automation due to its high reliability and straightforward integration into modular safety circuits. Adhering to ISO 14119 (Vomiero, 2022), the design ensures quick and reliable isolation of the machine when the interlock conditions are not met (Pilz, 2025).



Figure 13 (Pilz, 2025) - Pilz PNOZ X2 Safety Relay System

10.5.5 Emergency isolation procedures (CG - 2216420)

In the event of an emergency, the safety analysis robot has integrated isolation procedures. It's programmed to execute an immediate emergency shutdown of the failed components to further protect the remaining components. Implementing emergency stop systems allow for maximum operating safety whilst also mitigating risk to the operator. When maintenance tasks are preformed, an isolation of the entire Safety Analysis Robot ensures there are no electrically live components and there are no moving parts to cause entrapment of body parts. The emergency procedures adhere to the highest and recommendations from Post (2024) as well

as the Robotics Safety Requirements Standard, ISO 10218-1:2025 (International Organization for Standardization, 2025).

10.6 Section Summary (CG - 2216420)

Through my contributions as maintenance and safety specialist, this section has highlighted a thorough approach to enhancing system reliability and minimising downtime. Our design incorporates interchangeable components, quick-release snap-fit fittings, and advanced diagnostic sensors, effectively reducing the Mean Time to Repair (MTTR) and extending the Mean Time Between Failures (MTBF). These measures help keep the robot functioning effectively even in extreme conditions.

Additionally, the addition of, swappable batteries reduce downtime by allowing for quick power replacement. Safety interlocks and redundant fail-safe systems also help reduce risks during maintenance and operation. The risk assessment we conducted, which aligns with essential standards like ISO 12100:2010 and ISO 10218-1:2025, as well as UK regulations such as PUWER and the Health and Safety at Work Act 1974, shows that we are effectively managing both environmental hazards and human factors. Ultimately, thorough training and detailed standard operating procedures (SOPs) guarantee that maintenance tasks are executed consistently and safely, therefore minimising the risk of human error.

11 Achievement and Progress Relative to Initial Project Plan (Group)

At the start of the project, the project team set out a goal to complete the project to a high standard with a goal of a comprehensive design at the end for the Safety Analysis Robot (SAR). The project manager established a detailed project plan, alongside inputs from the team to support this goal. The plan was structured in two phases with key milestones as mentioned in section 6.1. The progress and achievements relating to these milestones and goals are summarised below.

11.1 Interim Viva Presentation (Group)

Planned:

The plan was to have a concept idea/design by this point to present to the board members as it was midway through the project. The aim was to have a good depth of knowledge from a wide range of research undertaken by the group to this point.

Achieved:

This was achieved on time with respect to the project plan. Through good in-depth research undertaken by the team, there was a good basis for concept design. The presentation was delivered on time to the group of board members with positive feedback on aspects of the project so far with areas identified for improvement.

11.2 Final Design (Group)

Planned:

It was set out that the project team would have a final design by 30th April. This would give plenty of time to ensure the rest of the disciplines could confirm their areas for the project, meaning any additional features could be incorporated into the design before the deadline. It would also provide some time to be able to write up the report.

Minor time extension:

Due to the risk outlined in section 6.3, there was some compromise that had to be done with the design as the robot was becoming more complex than the time frame allowed. For this reason, the design slipped by a few days. Regardless of this, the team still sees this section as an achievement as the risk was mitigated and there was potential for the slip to be up to 2 weeks without mitigating it. Therefore, the final design with respect to the project plan was achieved.

11.3 Report and Presentation Completion (Group)

Planned:

It was set out for the project report and presentation to meet the deadline of the project. However, as it was intended for there not to be a rush at the end of the project, the project manager asked for the reports to be completed a week prior to allow time to put them together.

Achieved:

This was achieved on-time with all members of the group handing in the reports to the project manager prior to the deadline to give time to put them together. The reports as outlined in this included in-depth research from the team for the final design.

12 Successes and Failures of the Project (Group)

12.1 Succeses

13 Conclusion

14 Bibliography

ahmed, saad (2024). *Pruftechnik*. [online] Pruftechnik Blog. Available at: <https://www.pruftechnik.com> [Accessed 20 May 2025].

Anonymous (2016). *Equipment for Potentially Explosive Atmospheres (ATEX)*. [online] Internal Market, Industry, Entrepreneurship and SMEs - European Commission. Available at: https://ec.europa.eu/growth/sectors/mechanical-engineering/atex_en.

Barney, N. (2023). *What is real-time monitoring?* [online] WhatIs.com. Available at: <https://www.techtarget.com/whatis/definition/real-time-monitoring>.

Bower, D.C. and Walker, D.H.T. (2007). Planning Knowledge for Phased Rollout Projects. *Project Management Journal*, [online] 38(3), pp.45–60. doi:<https://doi.org/10.1002/pmj.20005>.

British Standards Institute (2014). *BS EN 60079-29-3:2014 Explosive Atmospheres*. [online] Gas Detectors - Guidance on Functional Safety of Fixed Gas Detection systems. Available at: <https://shop.bsigroup.com/ProductDetail/?pid=000000000030294045>.

BSI (2018). *BS EN 60204-1:2018 - Safety of Machinery - Electrical Equipment of Machines*.

Campbell, F.C. (2010). *Structural Composite Materials*. Materials Park: Asm.

Clarke, P. (2018). *OEE, TEEP, and OOE – What is the Difference? - SL Controls*. [online] SL Controls. Available at: <https://slcontrols.com/en/oe-teep-and-ooe-what-is-the-difference/> [Accessed 20 May 2025].

Closer Lindholmen Science Park (2025). *BATTERY SWAP STUDY a BEV VEHICLE EVOLUTION*. [online] Available at: <https://closer.lindholmen.s/sites/default/files/2025-02/Bilaga%206.4.2%20BATT%20SWAP%20STUDY.pdf>.

Cruz, E.M.G.N.V., Oliveira, S. and Correia, A. (2024). Robotics Applications in the Hospital Domain: a Literature Review. *Applied System Innovation*, 7(6), p.125.

Dalcher, D. (2020). *Leading the Project Revolution : Reframing the Human Dynamics of Successful Projects*. London: Routledge.

Doyle, J.C., Francis, B.A. and Tannenbaum, A.R. (1992). *Feedback Control Theory*. Dover Publications.

Duomo (UK) Ltd. (2025). *SG895 - ATEX Gas Sensor (Detection of 10+ Gases)*. [online] Available at: <https://duomo.co.uk/product/sg95-atex-gas-sensor-detection-of-10-gases/> [Accessed 20 May 2025].

Eaton (2022). *ATEX and Explosive Atmospheres*. [online] ATEX and Explosive Atmospheres. Available at: <https://www.eaton.com/gb/en-gb/catalog/lighting/atex-and-explosive-atmospheres..>

Europa.eu. (2018). *Legislation | Safety and Health at Work EU-OSHA*. [online] Available at: <https://osha.europa.eu/en/legislation/guidelines/guidelines-directive-201434-eu-atex-product-directive>. [Accessed 20 May 2025].

Eze, T. (2024). *Why You Need Gas Detection: the Legal Requirements*. [online] IGD. Available at: <https://www.internationalgasdetectors.com/why-you-need-gas-detection-the-legal-requirements/> [Accessed 20 May 2025].

Flir.co.uk. (2022). *Leaders of the Steel Industry Use FLIR GF346 Gas Detection Cameras to Detect Harmful Carbon Monoxide Gas*. [online] Available at: <https://www.flir.co.uk/discover/instruments/gas-detection/leaders-of-the-steel-industry-use-flir-gf346-gas-detection-cameras-to-detect-harmful-carbon-monoxide-gas/> [Accessed 20 May 2025].

Gardiner, G. (2015). *Additive Manufacturing for Composite Tooling*.

GOV.UK (2013). *The Waste Electrical and Electronic Equipment Regulations 2013*. [online] Legislation.gov.uk. Available at: <https://www.legislation.gov.uk/ukxi/2013/3113/contents>.

GOV.UK (2019). *The REACH etc. (Amendment etc.) (EU Exit) Regulations 2019*. [online] Legislation.gov.uk. Available at: <https://www.legislation.gov.uk/ukdsi/2019/9780111178034>.

GOV.UK (2021). *Environment Act 2021*. [online] Legislation.gov.uk. Available at: <https://www.legislation.gov.uk/ukpga/2021/30/contents>.

Gustavo Pérez Alvarez (2020). Real-Time Fault Detection and Diagnosis Using Intelligent Monitoring and Supervision Systems. *IntechOpen eBooks*.
doi:<https://doi.org/10.5772/intechopen.90158>.

Health and Safety Executive (2019). *The Dangerous Substances and Explosive Atmospheres Regulations 2002 - Fire and Explosion*. [online] Hse.gov.uk. Available at:
<https://www.hse.gov.uk/fireandexplosion/dsear.htm>.

Heating and Process. (2023). *In-Situ Gas Analysers & Analysis Measurement (Zone 1 Zone 2 Hazardous Areas)*. [online] Available at:
<https://www.heatingandprocess.com/product/product-category/gas-analyzers-insitu-fixed-gas-analysis-measurement/> [Accessed 20 May 2025].

Hemati, A. and Shooshtari, A. (2023). Bearing Failure Analysis Using Vibration Analysis and Natural Frequency Excitation. *Journal of Failure Analysis and Prevention*, 23(4), pp.1431–1437. doi:<https://doi.org/10.1007/s11668-023-01700-0>.

HM Government (2021). Green Claims Code. [online] greenclaims.campaign.gov.uk. Available at: <https://greenclaims.campaign.gov.uk/>.

HSE (1999). Reducing Error and Influencing Behaviour. *Structural Survey*, [online] 17(3). doi:<https://doi.org/10.1108/ss.1999.11017cae.007>.

HSE (2019a). *ATEX and Explosive Atmospheres - Fire and Explosion*. [online] Hse.gov.uk. Available at: <https://www.hse.gov.uk/fireandexplosion/atex.htm>.

HSE (2019b). *ATEX and Explosive Atmospheres - Fire and Explosion*. [online] ATEX and Explosive Atmospheres . Available at: <https://www.hse.gov.uk/fireandexplosion/atex.htm..>

Ibm.com. (2024). *Think Topics | IBM*. [online] Available at:
<https://www.ibm.com/think/topics/mtbf> [Accessed 20 May 2025].

IEC (2013). IEC 60529: Degrees of Protection Provided by Enclosures . *International Electrotechnical Commission*.

International Organization for Standardization (2010). Safety of Machinery — General Principles for Design — Risk assessment and risk reduction.
doi:<https://doi.org/10.5555/iso12100:2010>.

International Organization for Standardization (2025). *ISO/DIS 12100*. [online] ISO. Available at: <https://www.iso.org/standard/88578.html>.

International Organization for Standardization (2025). Safety Requirements Part 1: Industrial Robots. *ISO 10218-1:2025 Robotics*.

Isin Akyar (2012). *Latest Research into Quality Control*. [online] *InTech eBooks*. doi:<https://doi.org/10.5772/45955>.

Karim, M.A. (2016). *Detecting Deadly Gases*. [online] [Healthandsafetyinternational.com](https://www.healthandsafetyinternational.com). Available at: <https://www.healthandsafetyinternational.com/article/1842480/detecting-deadly-gases/> [Accessed 20 May 2025].

Kerzner, H. (2017). *Project management: a Systems Approach to planning, scheduling, and Controlling*. 13th ed. John Wiley & Sons, Inc.

Kutsch, E. and Hall, M. (2005). Intervening Conditions on the Management of Project risk: Dealing with Uncertainty in Information Technology Projects. *International Journal of Project Management*, 23(8), pp.591–599. doi:<https://doi.org/10.1016/j.ijproman.2005.06.009>.

Laserax (2025). *Solid State Batteries Vs. Lithium-Ion: Which One Is Better?* [online] Laserax. Available at: <https://www.laserax.com/blog/solid-state-vs-lithium-ion-batteries>.

Levin, M.A. and Kalal, T.T. (2003). *Improving Product Reliability*. John Wiley & Sons.

Mallick, P.K. (2007). *Fiber-Reinforced Composites: Materials, Manufacturing, and Design*. CRC Press.

Matweb.com. (2025a). ASM Material Data Sheet. [online] Available at: <https://asm.matweb.com/search/specificmaterial.asp?bassnum=mq304a&utm>.

Matweb.com. (2025b). ASM Material Data Sheet. [online] Available at: <https://asm.matweb.com/search/specificmaterial.asp?bassnum=ma6061t6&utm>.

Matweb.com. (2025c). ASM Material Data Sheet. [online] Available at: <https://asm.matweb.com/search/specificmaterial.asp?bassnum=mtu020&utm> [Accessed 22 May 2025].

Matweb.com. (2025d). Overview of materials for Acrylonitrile Butadiene Styrene (ABS), Extruded. [online] Available at: <https://www.matweb.com/search/datasheet.aspx?MatGUID=3a8afcddac864d4b8f58d40570d2e5aa&utm> [Accessed 23 May 2025].

Matweb.com. (2025f). Overview of materials for Thermoplastic Polyimide, Carbon Fiber. [online] Available at: <https://matweb.com/search/DataSheet.aspx?MatGUID=d855dd38134049348725465233f82542&utm> [Accessed 23 May 2025].

Mobley, R.K. (2002). *An Introduction to Predictive Maintenance*. Elsevier.

Mohan, A. (2025). *Why It's Time to Consider Condition-Based Maintenance* | *Pruftechnik*. [online] Pruftechnik Blog. Available at: <https://www.pruftechnik.com/time-for-condition-based-maintenance/>.

Ngo, T.D., Kashani, A., Imbalzano, G. and Nguyen, K.T.Q. (n.d.). Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. *Composites Part B: Engineering*, 143, pp.172–196.

Novachem-uk.co.uk. (2015). High Temperature Epoxies. [online] Available at: https://www.novachem-uk.co.uk/products/category.html?id=252&gad_source=1&gad_campaignid=121481625&gbr aid=0AAAAADm_Eu9Io7JjN6Pv30Q8TVMIPercv&gclid=Cj0KCQjwucDBBhDxARIsANqFdr0b9PW2Q8Mi-BdqcNLm6Kxz8n_Wb3TXAMUhZmOz_9V1JWWMQb68YwAaAuuSEALw_wcB [Accessed 23 May 2025].

Null, C.H., Hobbs, A., O'Hara, J. and Dischinger, C. (2020). *Guidance for Human Error Analysis (HEA)*. National Aeronautics and Space Administration (NASA).

PILZ (2025). *PNOZ X2 24VAC/DC 2n/o | Monitoring of E-STOP, safety gates, light barriers | PNOZ X - safety relays | Safety relays / protection relays | Relay modules | Product view | Pilz Site*. [online] Pilz.com. Available at: <https://www.pilz.com/en-INT/eshop/Relay-modules/Safety-relays-protection-relays/PNOZ-X-safety-relays/Monitoring-of-E-STOP-safety-gates-light-barriers/PNOZ-X2-24VAC-DC-2-o/p/774303>.

Post, H. (2024). *Industrial robot safety considerations, standards and best practices to consider - Control Engineering*. [online] Control Engineering. Available at: <https://www.controleng.com/industrial-robot-safety-considerations-standards-and-best-practices-to-consider> [Accessed 20 May 2025].

Project Management Institute (2023). *Project Management Institute*. [online] Pmi.org. Available at: <https://www.pmi.org/>.

Protoxyz.com. (2024). ProtoXYZ |. [online] Available at: https://protoxyz.com/materials/Plastic/Nylon_6?utm [Accessed 22 May 2025].

Pugh, S. (1991). *Total design*. Addison-Wesley.

Rausand, M. and Haugen, S. (2011). *Risk assessment : theory, methods, and applications*. Hoboken, Nj: John Wiley & Sons.

Robert Bond Randall (2011). *Vibration-based Condition Monitoring : industrial, Aerospace and Automotive Applications*. Chichester: A John Wiley and Sons, Ltd., Publication, Cop.

Selko, A. (2022). *Using AI-Driven Cameras to Increase Safety at Facilities*. [online] EHS Today. Available at: <https://www.ehstoday.com/safety-technology/article/21252541/using-ai-driven-cameras-to-increase-safety-at-facilities>.

Sensitron (n.d.). *Steel Industry and Gas Detection*. [online] Available at: <https://www.sensitron.it/en/steel-industry-and-gas-detection/>.

SHP Online (2015). *PUWER: Provision and Use of Work Equipment Regulations | SHP - Health and Safety News, Legislation, PPE, CPD and Resources*. [online] SHP - Health and Safety News, Legislation, PPE, CPD and Resources. Available at: <https://www.shponline.co.uk/legislation-and-guidance/puwer-regulation-18-control-systems> [Accessed 20 May 2025].

Strong, A.B. (2008). *Fundamentals of Composites Manufacturing: Materials, Methods and Applications*. SME.

Suhail, A.H., Guangul, F.M. and Nazeer, A. (2024). *Advanced System Diagnostics Tools: Innovations and Applications*. *IntechOpen eBooks*.
doi:<https://doi.org/10.5772/intechopen.114378>.

Symestic (2025). *Real-Time Data Monitoring (RTDM)*. [online] Symestic.com. Available at: <https://www.symestic.com/en-us/what-is/rtdm>.

The Guardian. (2000). *Poor Air Quality Puts Steelworks in Bad Odour with Locals*. [online] Available at: <https://www.theguardian.com/uk/2000/sep/04/geoffreygibbs>.

Torell, W. and Avelar, V. (2017). *Mean Time between Failure: Explanation and Standards Revision I*.

Turner, P. and Williams, N. (2019). *The Port Talbot Steelworks Disaster of 2001 Which Is Still Fresh in the town's Mind*. [online] Wales Online. Available at: <https://www.walesonline.co.uk/news/wales-news/port-talbot-steelworks-disaster-2001-16184749> [Accessed 20 May 2025].

Uppendra Kachru (2007). *Production and Operations Management*. New Delhi: Excel Books.

UK GOV (2021). The Ecodesign for Energy-Related Products and Energy Information Regulations 2021. [online] Legislation.gov.uk. Available at: <https://www.legislation.gov.uk/ukxi/2021/745/contents/made>.

Vomiero, R. (n.d.). *ISO 14119 -Understanding Different Types of Interlocks Specialized Practice Lead (Machine & Robotics Safety) Workplace Safety and Prevention Services*. [online] Available at: https://www.safe-machines-at-work.org/fileadmin/user_upload/pdf/control_devices/Seminars_Functional_Safety_and_Validation/ISO_14119_-_Understanding_Different_Types_of_Interlocking_Devices.pdf.

WalesOnline (2013). *Steelworks Explosion Report Published*. [online] Wales Online. Available at: <https://www.walesonline.co.uk/news/wales-news/steelworks-explosion-report-published-2148122> [Accessed 20 May 2025].

World Steel Association (2020). *Explosive Atmospheres (ATEX)*. [online] Explosive Atmospheres. Available at: <https://worldsteel.org/steel-by-topic/sustainability/safety-health>.

Zhang, Y. and Li, D. (2024). Enhancing Project Performance through Effective Team Communication: a Comprehensive Study Integrating Project Management Quotient, Trust, and Management Information Systems. *Journal of Information Systems Engineering and Management*, 9(1), p.25574. doi:<https://doi.org/10.55267/iadt.07.14317>.

Zwicker, E., Zesch, W. and Moser, R. (2010). A Modular Inspection Robot Platform for Power Plant Applications. [online] pp.1–6. doi:<https://doi.org/10.1109/carpi.2010.5624429>.

15 Appendix 'A'

Group Project 1 Meeting Minutes

Project	Group Project - To be Confirmed	Date	07/02/25
Attendees	BGH, GW, JG, CG, RP, SQ		
Apologies			

Weekly catch-up meeting	
Item	Summary
1. Actions	- Decide on a project to do - Group - Initial Idea – Drone for inspection or other site operation. - Research ideas to be considered - Group - Project Plan to be created – BGH
2. Technical	Engineering Progress: No engineering Progress so far.
3. Risks	n/a
4. AOB	

Week 1

Group Project 1 Meeting Minutes



Project	Group Project – Safety Analysis Robot	Date	14/02/25
Attendees	BGH, GW, JG, CG, RP, SQ		
Apologies			

Weekly catch-up meeting	
Item	Summary
1. Actions	- Decide on a project to do – Group - Completed - Research ideas to be considered – Group - Completed - Project Plan to be created – BGH – Draft Completed - Members to review proj plan - Draft PDS to be created - BGH - Research to begin - Group
2. Technical	Engineering Progress: Decided on project idea – a drone/crawler used for inspection. This isn't set as we will do some research to see if it's possible for it to be multipurpose – Gas monitoring etc. Initial roles have been decided with individuals of the group putting themselves forward for a specific role. These are based on their skills and roles in their organisation. Draft project plan has been set-up for the first phase of the project. – Group members to review and reply with and queries or updates.
3. Risks	n/a
4. AOB	

Week 2

Group Project 1 Meeting Minutes



Project	Group Project – Safety Analysis Robot	Date	14/02/25
Attendees			
Apologies	Meeting cancelled due to members being away.		

Weekly catch-up meeting	
Item	Summary
1. Actions	- Decide on a project to do – Group - Completed - Research ideas to be considered – Group - Completed - Project Plan to be created – BGH – Draft Completed - Members to review proj plan - Draft PDS to be created - BGH - Research to begin - Group
2. Technical	Engineering Progress: Decided on project idea – a drone/crawler used for inspection. This isn't set as we will do some research to see if it's possible for it to be multipurpose – Gas monitoring etc. Initial roles have been decided with individuals of the group putting themselves forward for a specific role. These are based on their skills and roles in their organisation. Draft project plan has been set-up for the first phase of the project. – Group members to review and reply with and queries or updates.
3. Risks	n/a
4. AOB	

Week 3

Group Project 1 Meeting Minutes



Project	Group Project – Safety Analysis Robot	Date	28/02/25
Attendees	BGH, GW, JG, CG, RP, SQ		
Apologies			

Weekly catch-up meeting	
Item	Summary
1. Actions	- Members to review <u>proj plan</u> - Complete - Draft PDS to be created – BGH - complete - Research to begin – Group – Started - Start preparing slides for Viva presentation - Continue research and develop PDS
2. Technical	Engineering Progress: Project idea refined with multipurpose robot confirmed. Confirmed to be a crawler rather than drone. Draft PDS completed. Members to add and refine as research is undertaken. Research underway on safety, materials, and initial concept designs. Not much more to report as it is just research being continued.
3. Risks	n/a
4. AOB	No issues within the group, meetings to go on as planned with availability being monitored.

Week 4

Group Project 1 Meeting Minutes

Project	Group Project – Safety Analysis Robot	Date	07/03/25
Attendees			
Apologies	Meeting cancelled – Research to carry on as planned.		



Weekly catch-up meeting	
Item	Summary
1. Actions	- Members to review <u>proj</u> plan - Complete - Draft PDS to be created – BGH - complete - Research to begin – Group – Started - Start preparing slides for Viva presentation - Continue research and develop PDS
2. Technical	Engineering Progress: Project idea refined with multipurpose robot confirmed. Confirmed to be a crawler rather than drone. Draft PDS completed. Members to add and refine as research is undertaken. Research underway on safety, materials, and initial concept designs. Not much more to report as it is just research being continued.
3. Risks	n/a
4. AOB	No issues within the group, meetings to go on as planned with availability being monitored.

Week 5

Group Project 1 Meeting Minutes



Project	Group Project – Safety Analysis Robot	Date	14/03/25
Attendees	BGH, CG, RP, SQ		
Apologies	JG, GW		



Weekly catch-up meeting	
Item	Summary
1. Actions	- Draft PDS to be created – BGH – complete - QFD to be Completed (CG Prepared)- Group - Slides for Interim Viva to be sent to BGH – Group - BGH to add slides to PPT for VIVA – BGH - Phase 2 Project plan to be developed – BGH - Concept design to be created - JG - Continue research and develop PDS - Group
2. Technical	Engineering Progress: Project idea refined with multipurpose robot confirmed. Confirmed to be a crawler rather than drone. Draft PDS completed. Members to add and refine as research is undertaken. Research underway on safety, materials, and initial concept designs. CG added QFD to folder. Group to fill this out as appropriate. JG has started looking at a concept design and manufacturing process. To have Concept design for Interim viva
3. Risks	There is a slight risk we are adding too much to the robot to be completed in time for the project completion date.
4. AOB	No issues within the group, meetings to go on as planned with availability being monitored.

Week 6

Group Project 1 Meeting Minutes



Project	Group Project – Safety Analysis Robot	Date	21/03/25
Attendees	BGH, CG, RP, SQ, JG, GW		
Apologies			

Weekly catch-up meeting	
Item	Summary
1. Actions	- Draft PDS to be created – BGH – complete - QFD to be Completed (CG Prepared)- Group - Slides for Interim Viva to be sent to BGH – complete - BGH to add slides to PPT for VIVA – complete - Phase 2 Project plan to be developed – complete - Concept design to be created - complet - Continue research and develop PDS – Group - Upload PowerPoint to Moodle - BGH Interim viva presentation today.
2. Technical	Engineering Progress: Project idea refined with multipurpose robot confirmed. Confirmed to be a crawler rather than drone. Draft PDS completed. Members to add and refine as research is undertaken. Research underway on safety, materials, and initial concept designs. CG added QFD to folder. Group to fill this out as appropriate. JG has started looking at a concept design and manufacturing process. To have Concept design for Interim viva
3. Risks	There is a slight risk we are adding too much to the robot to be completed in time for the project completion date.
4. AOB	No issues within the group, meetings to go on as planned with availability being monitored. Phase 2 to start next week

Week 7

Group Project 1 Meeting Minutes

Project	Group Project – Safety Analysis Robot	Date	21/03/25
Attendees	Cancelled		
Apologies			

Weekly catch-up meeting	
Item	Summary
1. Actions	- Draft PDS to be created – BGH – complete - QFD to be Completed (CG Prepared)- Group - Slides for Interim Viva to be sent to BGH – complete - BGH to add slides to PPT for VIVA – complete - Phase 2 Project plan to be developed – complete - Concept design to be created - complet - Continue research and develop PDS – Group - Upload PowerPoint to Moodle - BGH Interim viva presentation today.
2. Technical	Engineering Progress: Project idea refined with multipurpose robot confirmed. Confirmed to be a crawler rather than drone. Draft PDS completed. Members to add and refine as research is undertaken. Research underway on safety, materials, and initial concept designs. CG added QFD to folder. Group to fill this out as appropriate. JG has started looking at a concept design and manufacturing process. To have Concept design for Interim viva
3. Risks	There is a slight risk we are adding too much to the robot to be completed in time for the project completion date.
4. AOB	No issues within the group, meetings to go on as planned with availability being monitored. Phase 2 to start next week

Week 8

Group Project 1 Meeting Minutes



Project	Group Project – Safety Analysis Robot	Date	05/04/25
Attendees	BGH, CG, JG, SQ,		
Apologies	RP, GW		

Weekly catch-up meeting	
Item	Summary
1. Actions	• QFD to be Completed (CG Prepared)- Group • Phase 2 Project plan to be developed – complete • Continue research and develop PDS – Group • Interim viva presentation today. – complete • Develop power source for robot – GW, CG • Further research to be carried out – Group • Design development based on research - JG
2. Technical	• Engineering Progress: Draft PDS completed. Members to add and refine as research is undertaken. Research carried on: safety, materials, and initial concept designs. CG added QFD to folder. Group to fill this out as appropriate. JG has completed a concept design. This will be developed further using the teams research. Materials, power source etc. Team to start looking at the end goal and bringing all the research together for a final design
3. Risks	There is a slight risk we are adding too much to the robot to be completed in time for the project completion date. Deadline is fast approaching, need to be aware of time management.
4. AOB	No issues within the group, meetings to go on as planned with availability being monitored. Phase 2 to started last week. Meeting was cancelled due to numbers low on site.

Week 9

Group Project 1 Meeting Minutes



Project	Group Project – Safety Analysis Robot	Date	12/04/25
Attendees	Cancelled		
Apologies			

Weekly catch-up meeting	
Item	Summary
1. Actions	- QFD to be Completed (CG Prepared)- Group - Phase 2 Project plan to be developed – complete - Continue research and develop PDS – Group - Interim viva presentation today. – complete - Develop power source for robot – GW, CG - Further research to be carried out – Group - Design development based on research - JG
2. Technical	• Engineering Progress: Draft PDS completed. Members to add and refine as research is undertaken. Research carried on: safety, materials, and initial concept designs. CG added QFD to folder. Group to fill this out as appropriate. JG has completed a concept design. This will be developed further using the <u>teams</u> research. Materials, power source etc. Team to start looking at the end goal and bringing all the research together for a final design
3. Risks	There is a slight risk we are adding too much to the robot to be completed in time for the project completion date. Deadline is fast approaching, need to be aware of time management.
4. AOB	No issues within the group, meetings to go on as planned with availability being monitored. Phase 2 to started last week. Meeting was cancelled due to numbers low on site.

Week 10

Group Project 1 Meeting Minutes

Project	Group Project – Safety Analysis Robot	Date	19/04/25
Attendees	Cancelled - Easter		
Apologies			

Weekly catch-up meeting	
Item	Summary
1. Actions	• QFD to be Completed (CG Prepared)- Group • Phase 2 Project plan to be developed – complete • Continue research and develop PDS – Group • Interim viva presentation today. – complete • Develop power source for robot – GW, CG • Further research to be carried out – Group • Design development based on research - JG
2. Technical	• Engineering Progress: Draft PDS completed. Members to add and refine as research is undertaken. Research carried on: safety, materials, and initial concept designs. CG added QFD to folder. Group to fill this out as appropriate. JG has completed a concept design. This will be developed further using the <u>teams</u> research. Materials, power source etc. Team to start looking at the end goal and bringing all the research together for a final design
3. Risks	There is a slight risk we are adding too much to the robot to be completed in time for the project completion date. Deadline is fast approaching, need to be aware of time management.
4. AOB	No issues within the group, meetings to go on as planned with availability being monitored. Phase 2 to started last week. Meeting was cancelled due to numbers low on site. Easter holidays. Meeting cancelled. Communication within the team on the WhatsApp group about progress.

Week 11

Group Project 1 Meeting Minutes



Project	Group Project – Safety Analysis Robot	Date	25/04/25
Attendees	BG, CG, GW, RP, SQ, JG		
Apologies			

Weekly catch-up meeting	
Item	Summary
1. Actions	- QFD to be Completed (CG Prepared)- Group - Continue research and develop PDS – Group - Develop power source for robot – GW, CG - Design development based on research – JG - Finalise maintenance plan – CG - Confirm ATEX restrictions for design development – RP - Finalise material to be used – SQ - Start finalising research and development to bring into final report. - Group
2. Technical	Engineering Progress: PDS Progressed, to be finalised. Research carried on: safety, materials, Sustainability. QFD Progressed. JG to further the design incorporating materials and maintainability. Team to start looking at the end goal and bringing all the research together for a final design Members to start thinking about the report and writing their sections in time for the deadline. Feedback from VIVA received. Team to review and look for improvements for next presentation and report.
3. Risks	There is a slight risk we are adding too much to the robot to be completed in time for the project completion date. Deadline is fast approaching, need to be aware of time management.
4. AOB	No issues within the group, meetings to go on as planned with availability being monitored. Next couple meetings decided as not essential to attend. We as a team understand what we need to do from now. Communication will be carried on through our communication source of whatsapp. After easter bank holiday, team to refocus on bringing the project forward.

Week 12

Group Project 1 Meeting Minutes



Project	Group Project – Safety Analysis Robot	Date	02/05/25
Attendees	BG, CG, GW, RP, SQ, JG – Final Meeting (Report to be finalised)		
Apologies			

Weekly catch-up meeting	
Item	Summary
1. Actions	- QFD to be Completed (CG Prepared)- Group - Continue research and develop PDS – Group - Develop power source for robot – GW, CG - Design development based on research – JG - Finalise maintenance plan – CG - Confirm ATEX restrictions for design development – RP - Finalise material to be used – SQ - Start finalising research and development to bring into final report. - Group
2. Technical	Engineering Progress: PDS Progressed, to be finalised. Research carried on: safety, materials, Sustainability. QFD Progressed. JG to further the design ~~incorporating~~ materials and maintainability. Team to start looking at the end goal and bringing all the research together for a final design Members to start thinking about the report and writing their sections in time for the deadline. Feedback from VIVA received. Team to review and look for improvements for next presentation and report.
3. Risks	There is a slight risk we are adding too much to the robot to be completed in time for the project completion date. Deadline is fast approaching, need to be aware of time management.
4. AOB	No issues within the group, meetings to go on as planned with availability being monitored. Next couple meetings decided as not essential to attend. We as a team understand what we need to do from now. Communication will be carried on through our communication source of ~~whatsapp~~. After easter bank holiday, team to refocus on bringing the project forward.

Week 13 – Final Meeting

Planned Preventative Maintenance (PPM) Schedule for the Safety Analysis Robot

Daily:

Visual Inspection of External Components:

Perform a thorough visual check of the robot's external surfaces, enclosures, and accessible critical components. Look for any signs of damage, discoloration, or misalignment that might indicate wear or the onset of a fault.

Battery System Visual Check:

Inspect the quick-swap battery system to ensure that connections are secure, the battery is free of visible defects, and there are no signs of physical damage.

Log Maintenance:

After each daily inspection, update the maintenance log with observations and any corrective actions taken. This ensures traceability and helps detect recurring issues early.

Author: Connor Griffiths
Date Created: 10/05/2025
Issue: 01
SAR Planned Preventative Maintenance Schedule

Monthly:

Electrical Connections & Wiring Check:

Conduct a detailed inspection of all wiring and electrical connections. Verify that connectors are tightly secured, check for any corrosion or signs of overheating, and ensure that insulation remains intact. Correct any deficiencies before they lead to more significant issues.

Sensor Calibration and Diagnostic Check:

Perform comprehensive calibration on all diagnostic sensors (thermal, vibration, gas, and environmental). Use precisely calibrated instruments to verify that sensor outputs match expected baseline values. Recalibrate any sensors that deviate from their normal range.

Modular Component Inspection:

Examine all snap-fit fittings and modular components—including wheels, sensors, and control panels—for signs of wear, looseness, or damage. Confirm that the modular design maintains ease of replacement, ensuring that the Mean Time to Repair (MTTR) is minimized.

Safety Systems Test:

Test all safety interlocks and emergency isolation mechanisms. Simulate scenarios such as the removal of a maintenance panel or guard to ensure that the system automatically isolates critical functions to protect the operator. Verify that the emergency shutdown procedures are fully functional.

Full Battery System Test:

Conduct a complete test of the battery system. This includes checking the performance, secure connections, and integration with the robot's control circuitry during battery swap operations. Ensure that the recharging cycle is functioning effectively.

Documentation Update:

Update all maintenance logs and records with the results from the monthly checks. Document any corrective actions and note any trends that may indicate a developing issue.

6th Monthly (Biannual):

System Diagnostic & FMEA Review:

Run an integrated diagnostic test on the entire robot system. Utilize the results of the test to review and update the Failure Modes and Effects Analysis (FMEA), reassessing risk ratings, and verifying that all mitigation measures remain effective. Use this review to drive long-term maintenance planning.

Detailed Electrical System Inspection:

Conduct a more in-depth examination of the internal wiring and electrical systems. This inspection should detect issues that may not be obvious during regular monthly checks, such as subtle insulation breakdowns or internal corrosion.

Performance Evaluation:

Evaluate the overall performance of both the maintenance procedures and safety systems. Look for any recurring issues or trends and adjust the maintenance schedule or procedures accordingly to optimize future performance.

Yearly (Annual):

In-Depth Overall System Inspection:

Perform a complete, detailed inspection of the entire robot, covering all internal and external components, wiring, sensor arrays, safety mechanisms, and power systems. This helps ensure that the design remains robust and that no critical areas have been overlooked.

Compliance and Certification Audit:

Verify that all maintenance activities and safety measures comply with relevant industry standards and legal requirements. This includes ensuring adherence to ISO 12100, ISO 10218-1, UK ATEX regulations, and PUWER guidelines. Arrange for any necessary audits or certification renewals.

Review and Update Maintenance Procedures:

Analyse maintenance records and system performance data from the entire year. Based on this analysis, update maintenance procedures and PPM schedules to address any areas for improvement. This process should incorporate lessons learned and align with evolving industry best practices.

Long-Term Planning:

Develop plans for significant component replacements, upgrades, or redesigns based on the accumulated performance data. Ensure that future maintenance strategies are informed by historical trends and anticipated operational demands.

Author: Connor Griffiths

Date Created: 10/05/2025

Issue: 01

SAR Planned Preventative Maintenance Schedule