EEE4113F - Engineering Design

OppieCop

"The cop that monitors your machine, so you do not have to."

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1 Introduction to the Project

Our group decided to tackle helping small business owners assess whether their machinery was working at optimum performance and making sure the machinery was as eco-friendly as possible. The main issue was that problems within the machine were only seen when it was too late, and repairs or replacement of parts were required, and this proved to be quite a costly affair. Through interviews with a few small business owners, the following was concluded, there was a need for a system that ensured better and regular maintenance and monitoring in businesses that require machinery for daily operation. These businesses needed a way to detect when parts needed to be repaired or replaced as soon as possible as well as to monitor the consumption, output, emissions, etc of the machinery. A machine able to detect issues and fix them earlier would help in reducing the financial strain on the business and maximizing the profits from the goods or services provided. Another thing that helped in making sure machinery worked at the optimum performance was having the machinery serviced frequently. But this proved to also be a financially taxing endeavour.

There was a need for owners to be able to monitor and make sure their machinery was at optimum performance with minimal human supervision required while maintaining eco-friendliness

The solution which the group produced was a system called the OppieCop, a software and hardware machine monitoring system which collects and records real-time and past data regarding the operating efficiency of the machine. This information once gathered by the sensors is reported to the user via a local user interface as well as a remote app. The system will monitor various parameters to ensure the operating efficiency of the machine such as power consumption, the emissions of the machine, vibrations, productivity, visual markers such as rust and grease levels, etc. This information can be used to construct important data regarding when the machine is most efficient. The system will also allow further functionality such as alerting the user when maintenance or new parts are necessary or reducing power or switching off when certain levels of one of the recorded parameters are reached. The proposed solution consists of 5 subsystems (the user interface, air quality sensors, machine operating sensors, power supply, and protective casing). These subsystems are described briefly in section 2.5. Our solution was designed based on the Mac Afric 381. Our solution, the Oppie Cop, aims to improve the operating efficiency of a machine and thereby minimize waste, and repair costs and reduce the emissions and power consumption of a machine.

2 Problem Analysis

2.1 Design School Activities

We spoke about what the challenge statement meant to each of us in module 1. We started making comments to help us understand how each group member interpreted the challenge statement. To find common themes, we sorted our thoughts into categories. Following that, we decoded key terms from the challenge statement and offered our interpretations of what they meant to us. We used divergent thinking when creating our stakeholder map, which represented the people we expected to be involved in the group's creation of the challenge statement. The significance of the stakeholder and our challenge statement, as well as their relationship, were then explored. We completed the module by interviewing the stakeholders, asking them questions about what different components of the challenge statement meant to them, and giving us their perspectives. The points and replies from the interview were then presented to the entire group.

We used divergent thinking while creating our stakeholder map, which reflected the people we expected to be involved in the group's creation of the challenge statement. Out of all the stakeholders we identified, we each picked one to whom we felt we could relate the most. The significance of the stakeholder and our challenge statement, as well as their relationship, were then explored. We finished the lesson by interviewing the stakeholders we chose, asking them guided questions about what the challenge statement's components meant to them, and allowing us to see things from their points of view. The interview's points and responses were then presented to the full group. We completed the model by voting on whose POV diagrams we thought most intriguing, and then creating two POV statements for the two interviewees who the group deemed most fascinating, Lisa, a shop teller, and Sam, a small shop owner.

Module 3 involved ideating and prototyping. We chose a user and added some intriguing details from that user's interview. Sam is a 39-year-old small carpentry business owner. Using that, we produced several "How To" questions in a brainstorming session. As a group, we chose our top four questions and developed as many responses as possible for each one. We then each chose one answer and built on it to produce unique points to add to the concept. We next used a technique called bucketing, in which we blended the possibilities from our earlier brainstorming session into a single unique solution that encompassed all the options. We voted as a group, using a green tick for a clever idea that is easy to implement, a blue tick for a good long-shot idea that would be impactful but difficult to implement, and a yellow tick for the most desirable idea for the user. The results of our voting showed us the preferred idea was 'Sensors detecting air quality in and around the machine.' We decided to adjust this slightly with the help of our coach and suggestions made during the Friday lecture. We decided to add machine operating sensors to make sure the machine is operating optimally. We also provided a picture of what each of us thought a prototype would look like.

The fourth mural is where we put our idea and prototype to the test. We now have a chosen idea, but not everyone in the group will necessarily agree on every element of our prototype concept, therefore the following exercise will address that. We each filled out a separate template to flesh out the specifics and major components of our ideas for putting sensors into a device that will be able to let us monitor the air quality in and around the machine as well as machine operation. We next showed our prototype and idea to outsiders and received comments from each of them. This input was incorporated into a four-sectioned rubric. The first section detailed what the user liked about our proposal, the second section explained what the user disliked about our idea, the third section explored any questions that occurred from the presentation, and the fourth section reviewed any innovative ideas that arose from this approach. Each team member then chose one piece of input from the testing phase, which was then used to build "How To" questions and solutions to fill in the holes in our initial concept.

2.2 Design Choices

2.2.1 Enclosing the moving parts of the machine

The initial solution that we produced was to enclose the moving parts of the machine that is used by the small business owner since the external factors might be causing those specific parts to deteriorate over time. The other issue was that external exposure of the critical parts was an issue because then external objects could damage those parts. This solution had the problem of waste build-up and it being the cause of the machine deteriorating faster. The other issue that was pointed out to us in the interviews we conducted is that not all critical parts can be covered due to the design of the machine, so it means the protection for the machine is extremely limited.

Pros and Cons of enclosing the moving parts of the machine	
Pros	Cons
It ensures that external material (like dust and other small air particles) does not enter the enclosed part.	The build-up of material that manages to make it into the enclosure has to be monitored due to the damage it can create.
When there is a failure at least the damage to the surrounding areas can be protected since the enclosure will take the damage first before damaging others.	Not all parts can be enclosed properly due to their design.
People will not be as exposed to dangerous moving parts.	The ventilation of certain parts cannot be achieved due to the enclosure.
When parts are properly enclosed the parts can last longer due to reduced exposure to air.	The customization of the enclosures is a problem in terms of scaling the solution
There is less need for maintenance because the enclosure produces an optimal operating condition.	Maintenance will take longer since the enclosures have to be removed and put back on.

Table 1: Pros and Cons of moving parts

2.2.2 Measuring air quality to check the health of the machine

The initial solution that we produced was to enclose the moving parts of the machine that is used by the small business owner since the external factors might be causing those specific parts to deteriorate over time. The other issue was that external exposure of the critical parts was an issue because then external objects could damage those parts. This solution had the problem of waste build-up and it being the cause of the machine deteriorating faster. The other issue that was pointed out to us in the interviews we conducted is that not all critical parts can be covered due to the design of the machine, so it means the protection for the machine is extremely limited.

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There is less need for maintenance because the enclosure produces an optimal operating condition.	Maintenance will take longer since the enclosures have to be removed and put back on.

Table 2: Pros and cons of enclosing the moving parts of the machine

2.3 Choosing a Design

We based our design on the Mac Afric 381. We selected the design that measures the air quality and other sensors that will measure the following; the table will be checked for rust using a camera that will then get the video feed being processed to determine if rust on the table is there or not so that the table will have the automotive wax applied on it, the gearbox will have its oil monitored so that whenever oil changes need to be made, they can be done at the first sight of trouble rather than later when it is too late, the drive chain will get a check before it starts running where the grease levels will be checked before it starts operating due to the difficulty of checking the grease levels once it starts operating, the feed roller will be inspected before it starts operating on if oil has been applied to it, so this can work as a reminder before the machine is operated for the first time that day or it can be inspected using a sensor that will communicate if the oil levels are not enough to operate the machine, and The knives must be checked for sharpness so there will be a mechanism to check if the knives are sharp enough to operate.

2.4 Final Design

2.4.1 OPM Diagram

The figure below shows the OPM diagram for the Sensor Monitoring System

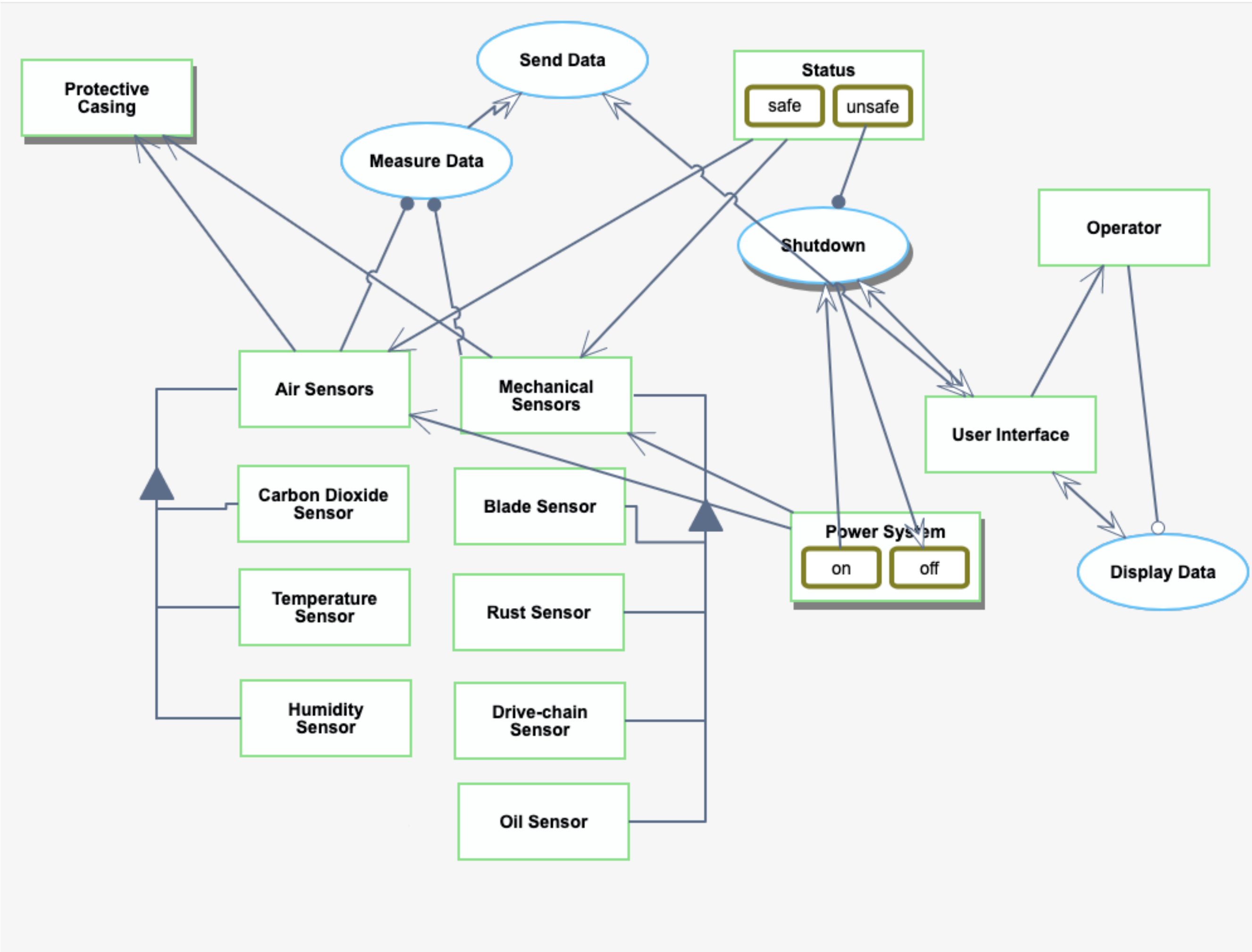

Figure 1: OPM diagram of the system

2.4.2 V-Diagram

The figure below shows the V-diagram for the monitoring system that will be implemented with the possibility of lower the cost on a small business by making sure machinery are in optimum condition for operation by monitoring the air quality, vibration, and mechanical movement.

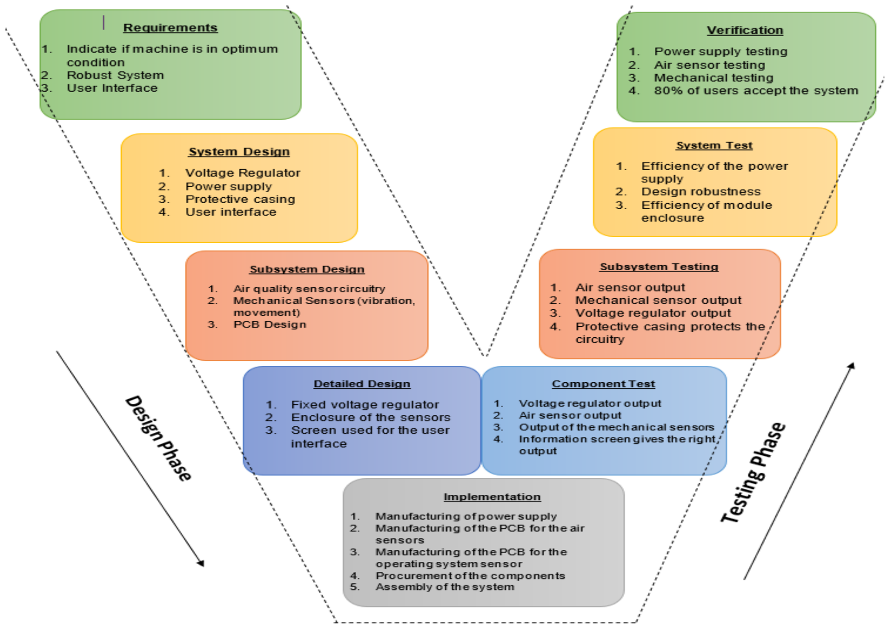

Figure 2: The V-diagram for the system

2.5 Brief Description of the Subsystems

Each subsystem plays an integral role in the operation of the system. This should result in a working device that can determine if a machine is working at its optimum level and indicate to the user if parts need to be replaced and if the machine is eco-friendly or not with its gas emissions.

2.5.1 User Interface

The user interface allows the user to access information as well as change settings and alert actions. The interface consists of 2 components, the first being a physical local interface by the machine which has full functionality and control over the settings and operation of the machine. The second component is a remote interface which can be accessed via an app and allows the user to monitor the machine's operation from any location.t it

2.5.2 Power Supply

This device needs to be robust and thus will need to either have an external power source or connect to existing power sources, as these sources may not be the same. This subsystem needs to take an input voltage of varying sizes and output a DC valued voltage to supply to the rest of the subsystems.

2.5.3 Air Quality Sensors

The Air Sensor subsystem is required to monitor the immediate working environment for both the machine and the machine operator's safety. To assess the quality of the surrounding air, CO2, humidity, and particle count will be measured, as well as temperature. These measurements will be continuously monitored and communicated to the central device.

2.5.4 Machine Operating Sensor

This device will need to sense the most important parts of the machine and they need to collectively indicate the health of the machine.

2.5.5 Protective Casing

The device needs to be able to withstand certain physical conditions. It needs to be able to withstand dust and water and not have any air gaps that would allow insects to enter and damage the sensors inside.

3 User Interface Module (NDXVES002)

3.1 Introduction

The user Interface deals with the data collection, storage and communication between the machine sensors and the user. This module includes the microprocessor, which will orchestrate the functioning of the system; a data storage device; a touch screen interface and a software interface which can be accessed via mobile app. The processor will be programmed to constantly retrieve the data from the various sensors, store this data and process it to generate useful information for the user such as current sensor conditions, historical graphs, efficiency reports, maintenance, repair alerts etc. The user will be able to access this information in 2 ways. The primary interface will be the touch screen of the system which will be located on outsource and thus attached to the Mac Afric 381 Machine. The touch screen interface will display all the current readings or warnings as a home page however allow the user to access historical data, projected graphs, and maintenance schedules as well as set different warning or alert levels through various tabs. The interface will also allow you to export or retrieve the saved data. The interface will be shown in more detail in section 3.2. The mobile interface will be via an app and allow the same basic menu as the local interface however will not include access to the device settings or raw Data.

3.2 User Requirements

The table below the will indicate the requirement from the user for the interface module

Requirement ID	Requirement Text
RID0001	The User Interface must be secure
RID0002	The Information must be accurate
RID0003	Data must be stored regularly and backed up
RID0004	The Remote Interface must show live readings
RID0005	The User must be alerted of any necessary repairs or maintenance
RID0006	The system should alert the user when the emissions from the machine are too high

Table 3: User Requirements for User Interface

3.3 Requirement Analysis:

3.3.1 Analysis of RID003: The user interface must be secure.

The data saved by the machine and its system must not be able to be accessed or retrieved by unwanted parties.

Requirement ID	Requirement Text	Derived From
RT001	The Data and connection must be secured using a secure communication protocol and encryption	RID001

Table 4: Analysis of RID001 for User Interface

Verification:

Ensure the data is encrypted before transmission and the communication protocol is secure

3.3.2 Analysis of RID002: The Information must be accurate.

Requirement ID	Requirement Text	Derived From
RT002	Current Data is accurate to 5% of the current value.	RID002

Table 5: Analysis of RID002 for User Interface

Verification:

Ensure the information saved matches live known sample readings and ensure refresh save and update every minute.

3.3.3 Analysis of RID003: Data must be stored regularly and backed up.

Requirement ID	Requirement Text	Derived From
RT003	Data of the machine must be recorded, saved, and exported to an external backup weekly	RID003

Table 6: Analysis of RID003 for User Interface

Verification:

Ensure the code and system saves the data recorded on an external memory device and that the data can be exported.

3.3.4 Analysis of RID004: The Remote Interface must show live readings.

The information displayed by the system needs to be current to be useful. We allow a buffer period of 2 minutes for information to be processed and reported.

Requirement ID	Requirement Text	Derived From
RT004	The readings reported by the system must be within 2 minutes old.	RID004

Table 7: Analysis of RID004 for User Interface

Verification:

Ensure data is saved and reported every 2 minutes or less and can be seen within these periods.

3.3.5 Analysis of RID005: The User must be alerted of any necessary repairs or maintenance.

The system should be able to detect and report to the user whenever parts of the machine require maintenance or to be replaced.

Requirement ID	Requirement Text	Derived From
RT005	The system detects an early part failure and reports it as soon as discovered.	RID005

Table 8: Analysis of RID005 for User Interface

Verification:

Wear to within 20% of the part life expectancy is detected and reported, and failure of parts is reported within 10 minutes of failure.

3.3.6 Analysis of RID006: The system should alert the user when the emissions from the machine are too high.

Requirement ID	Requirement Text	Derived From
RT006	Whenever the emissions surpass the set value, it should be reported to the user immediately or the set action should occur	RID006

Table 9: Analysis of RID006 for User Interface

Verification:

The Emissions are monitored and recorded constantly, and the system issues the warning to the user and takes appropriate action within 2 minutes of levels surpassing the threshold. Normal live monitoring occurs thereafter.

3.4 Design Choices

The section aims to identify components which meet the design requirements and compare them to choose the best/optimal components for the project. The choice of the solution will be based on various factors such as the cost, testing and implementation and the technical aspects associated with the solution. This subsystem consists of the microcontroller and the User interface System.

3.4.1 Microcontroller Choice

Table 1 below lists the specifications of several readily available microcontrollers to compare them and their ability to meet the specified requirements. Microcontrollers were chosen from ST Microelectronics and Microchip Technologies as they are the most reputable and readily available microcontroller brand and there is a lot are readily available resources when working with them. They also both manufacture microcontrollers based on the ARM Cortex range of microprocessors which are the common design language and will be the easiest to connect to, use and maintain.

The specifications and price for the components were obtained from Digi-Key Electronics' product catalogue dated 23-04-2022.

Microcontroller	ADC Resolution	ADC Voltage Range <5V	GPIO Pins > 8	Temperature Range	Development Board Available	Cost
STM32F4	12 bit	Yes	Yes	-40 to +85 deg	Yes	R24.39
ST10F2	16 bit	Yes	Yes	-40 to +85 deg	Yes	R26.74
STM32F3	32 bit	Yes	Yes	-40 to +85 deg	Yes	R46.49
ATSAMD	16 bit	Yes	Yes	-40 to +85 deg	Yes	R28.17
ATSAML	16 bit	Yes	Yes	-40 to +85 deg	No	R36.65

Table 10: Microprocessor Options

It was found that there are several microcontrollers which meet our specifications as the current technology is beyond our needs. The selection of a microcontroller was narrowed down to 16-bit resolution to meet the requirements then chosen based on cost came down to cost. Thus, the STM32F411E-Disco was chosen as the microcontroller to be used. Below is a picture of the development board to be used:

Figure 3: STM32F411E Microprocessor

3.4.2 User Interface Choices

The design choices for the User Interface will be evaluated and compared below in terms of cost, technical maturity, ease of manufacturing, implementation, ease of testing, reliability and maintenance costs. These comparisons will be used to choose the best solution that meets all requirements.

3.4.2.1 Touch Screen Interface

The first design solution we have is a physical touch screen interface which would be attached to the main system module which is attached to the Mac Afrik 348 Machine. The touch screen is a costlier option than the 2 below however is more compact, has greater function and efficiency and increases the usability and functionality of the system.

Our requirements for the screen specify that we need a screen that is water and dust resistant to an IP67 rating, requires input voltage<5V, fits our device, is bigger than 5 inches and has a resolution above 360p. The final decision was chosen as the cheap touch screen that fits our requirements.

The chosen touch screen for our design was the Seeed Technology 7" 1024X600 CAP TOUCH SCREEN which is shown below:

Figure 4: Seeed Technology 7" Touch Screen

Specifications:

7” capacitive touch display
1024 x 600 Pixels
I2C 16bit
5V @ 2A
Response Time: 10/15 ms
R960.90

3.4.2.2 LCD and Buttons and Dial Interface

A physical LED Screen and interface to navigate the system menu and pages could be implemented as another solution. This solution will also be located on the main system module. This system implementation would be a lot cheaper however has a much larger and more cumbersome form factor, is less efficient, is harder to use and has less functionality and will be slower to use. The following LCD was chosen as it was the cheapest readily accessible option that satified our size and framerate and power requirements.

Figure 5: Newhaven LCD Display

A screen and simple dial interface were chosen were the Newhaven Display NHD LCD and the specifications are shown below:

Specifications:

- 2.4" LCD display
- 128 x 60 Pixels
- SPI
- 3V @ 2A
- R199.90

The control Buttons will be crafted out of 4 tactile buttons (enter, escape, home and settings) which cost R10,90 each and a dial at the cost of R89,67.

3.4.2.3 Mobile Application Interface

The final interface design solution is a mobile application-based interface. This solution would require a wireless module attached to the system whereby it can wirelessly communicate with the user's mobile phone. The interface on the mobile phone will be application-based and uploaded on both android and IOS options. It would allow the user to simply download an app that will act as the interface with our system. This solution removes the need to purchase extra hardware for an interface as just a wireless communication module will be needed. There is an added cost in the designing and development of the application solution and there could be an additional data cost. However, this solution allows for the possibility that a person without a smartphone will not be able to operate the system and raises security concerns for the machine. This solution can also be used in conjunction with one of the previous solutions.

3.4.3 Final Design Solution

It was decided that the STM32F411E-Disco microprocessor was chosen as it satisfies all our requirements for the lowest proper price on a reliable board which has a lot of development tools and assistance as discussed in section 4.4.1. For the user interface the decision was made to use two forms of interface. The secondary interface of a mobile application which can be accessed remotely was decided to be included as it improves the functionality, usability, and capabilities of our system. The decision not to use a mobile application as the primary interface was made to make the design robust to connection or communication errors or delays. Having 2 interfaces allows our system to have remote access, which is a very important and necessary feature, as well as having the reliability of a physical system which can be used for maintenance and to ensure and check the functioning of the system. For our primary interface, the decision was made to use a touch screen interface over an LCD and navigation buttons and dials. Although there is a cost infraction in using this interface, it is believed that the positive advantages such as the form factor, usability, ease of connection and design, maximised space and improved capabilities offset this cost and make this interface the clear choice for our system design.

3.5 Model diagram and possible constraints and limitations

3.5.1 V – Diagram

Figure 6 below indicates the V-diagram for the development and testing of the User Interface submodule.

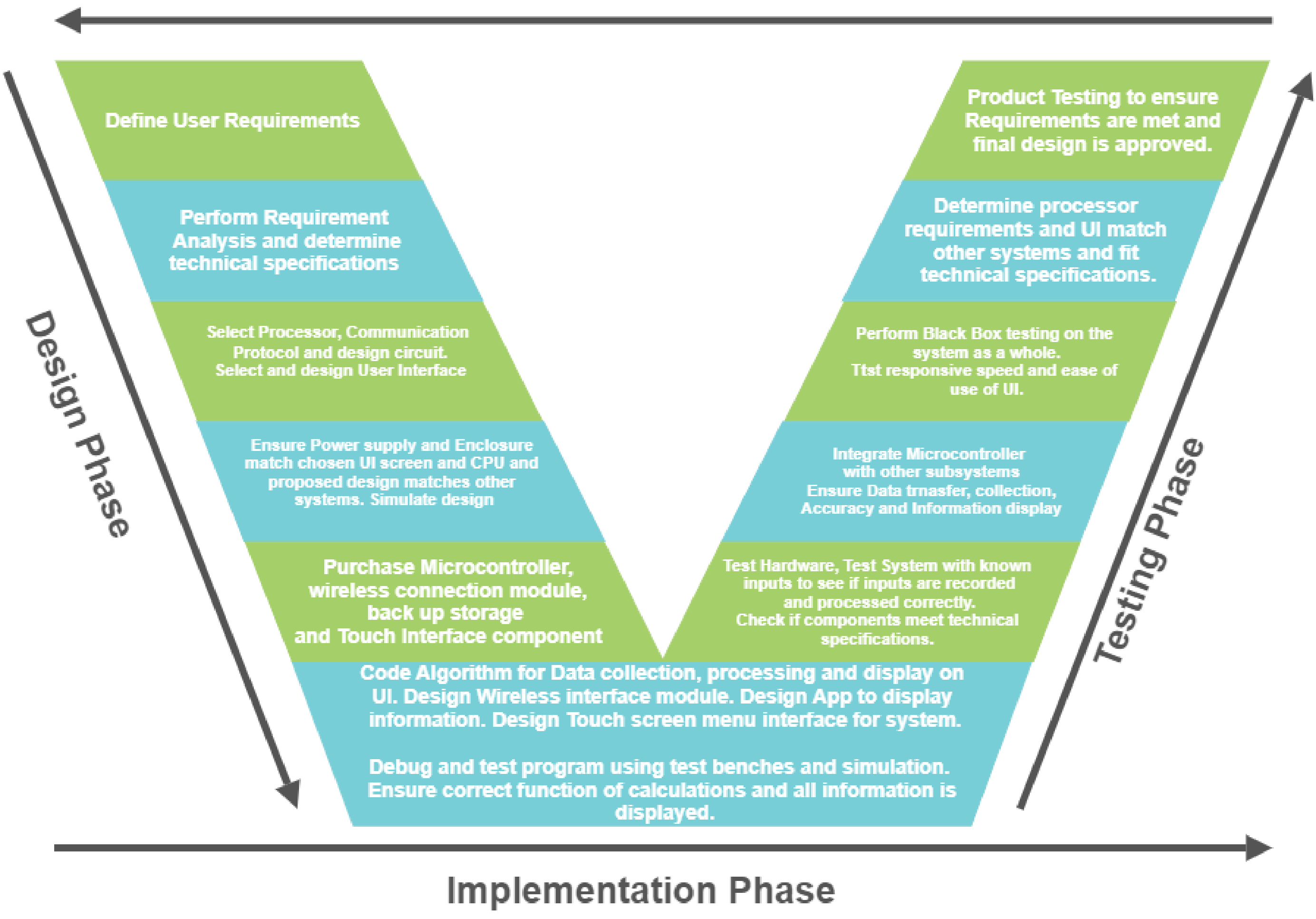

Figure 6: V-diagram for user interface

3.5.2 Constraints and Limitations

3.5.2.1 Regulatory Constraints

According to the Department of Health and Safety Act 85 of 1993, the Machine can only be operated by licensed and qualified individuals, since our system can alter the functioning of the machine, it also needs to only be accessible to authorized individuals. The machine also needs to ensure the protection of the end-user and the then-user and connection with the machine by cyber security regulations.

3.5.2.2 Technical Constraints

There is finite physical backup storage that limits the storage of data and data available for models and processing. The resolution and transfer speed of the connection between the sensors and the processor could limit the accuracy of the sensors' processing time and communications with the mobile applicant provide limitations on data transfer and how up-to-date the information is. The power supply limits the processor and interface to using 5V. The processor and touch screen interface need to fit within the enclosure.

3.5.2.3 Other Constraints

The mobile application has limited settings and these changes can only be made on the physical system. The system needs to be easy to use without the need for training. There is a cost to make our system profitable. The Wi-Fi access is necessary for the system to update the mobile application interface and cloud backup.

3.5.3 STEEPLE Analysis

The STEEPLE analysis below identifies issues that may present themselves as a result of the implemented system. The areas investigated in the analysis are: social, technological, economic, environmental, political, legal, and ethical.

3.5.3.1 Social

The majority of components are manufactured and purchased locally, the efficiency of machines could improve the profits of local businesses and reduce their energy consumption. The system has the potential to create jobs in the manufacturing or maintenance process.

3.5.3.2 Technological

The embedded system is primarily an electronic and software module of the system. The development of our system is a step forward in implementing technology in monitoring factories and plants. Our system increases the information available to operators about their machinery, this could lead to future improvements in efficiency and environmental impact. The interface and processor are based on simple off-the-shelf technology, however, having remote but remote access to monitoring machinery could lead to technological advances.

3.5.3.3 Environmental

Our system has the aim to reduce emissions of a machine as well as ensure efficiency by minimal energy usage and reducing wastage of raw materials. The benefits of the system for the environment are great. There is an environmental cost of manufacturing the microprocessor and the touch screen however this is minimal. Using a mobile application interface allows people to use existing technology they own as an interface.

3.5.3.4 Economic

The system aims to increase the profits of the end-user, the system was initially created for use by small businesses but can be attached to most machines and be used by a variety of companies. The system also aims to reduce power usage and the wastage of raw materials.

3.5.3.5 Political

There is little to no political influence or consideration over the component choices, design, or use of this system.

3.5.3.6 Legal

The development and implementation of the embedded systems module also federationneedizing to be in line with the Occupational Health and Safety Act, No. 85 of 1993 with special attention to electrical installation regulations. This requires an electrical certificate of compliance to be obtained once the installation of the system is completed. The machinery attached must also comply with said acts. Circuitry needs to also meet OSHA standards in corporations.

3.5.3.7 Ethical

The sourcing of components for the system will be done ethically. All design and building processes involved in this project will follow the code of Ethics of the group and all individuals and stakeholders will be treated fairly and ethically

3.6 Design

This module underlines the design of our submodule.

3.6.1 OPM Diagram

The OPM below explains the basic flow of the system, the microcontroller retrieves data from the sensor submodules. This data is stored in memory and processed by the microcontroller to output the graphs, averages and other useful information via the user interface. Trigger levels for the different parameters can be set and the microprocessor will trigger warnings when levels are reached.

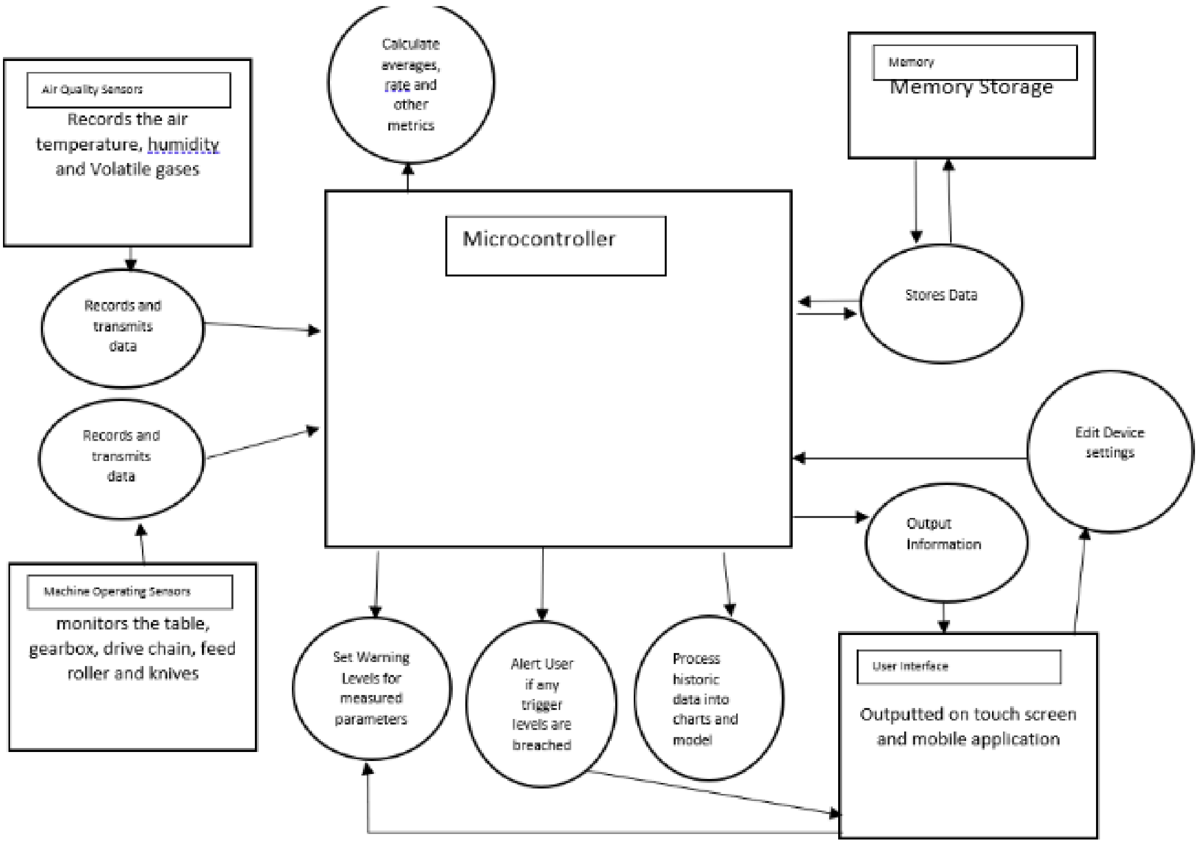

Figure 7: OPM Diagram

3.6.2 System Optimization

The System can be improved if we are able to reduce the need for a physical user interface and thus save space and cost. In order to do such, we need to ensure a stable and reliable power supply and a constant connection to the internet. The code and processing of the can be optimized. Code can be parallelized in order to see runtime gains as well as add further functionality could be added to the system. We can also optimize the protocol used to transfer data around the system

3.6.3 User Interface and Processor UML Class Diagram

The UML Class diagram below explains the basic layout and functioning of the user interfaces and the processes and calculations carried out by the processor. It details the navigation and home menu and the different pages which can be visited such as the graphs, historical data, data metrics etc. The processes and functions of the data manipulation are detailed. The system allows the user to make various settings changes as shown in the settings class. The functions below illustrate the operation and functioning behaviour of the software which controls our system.

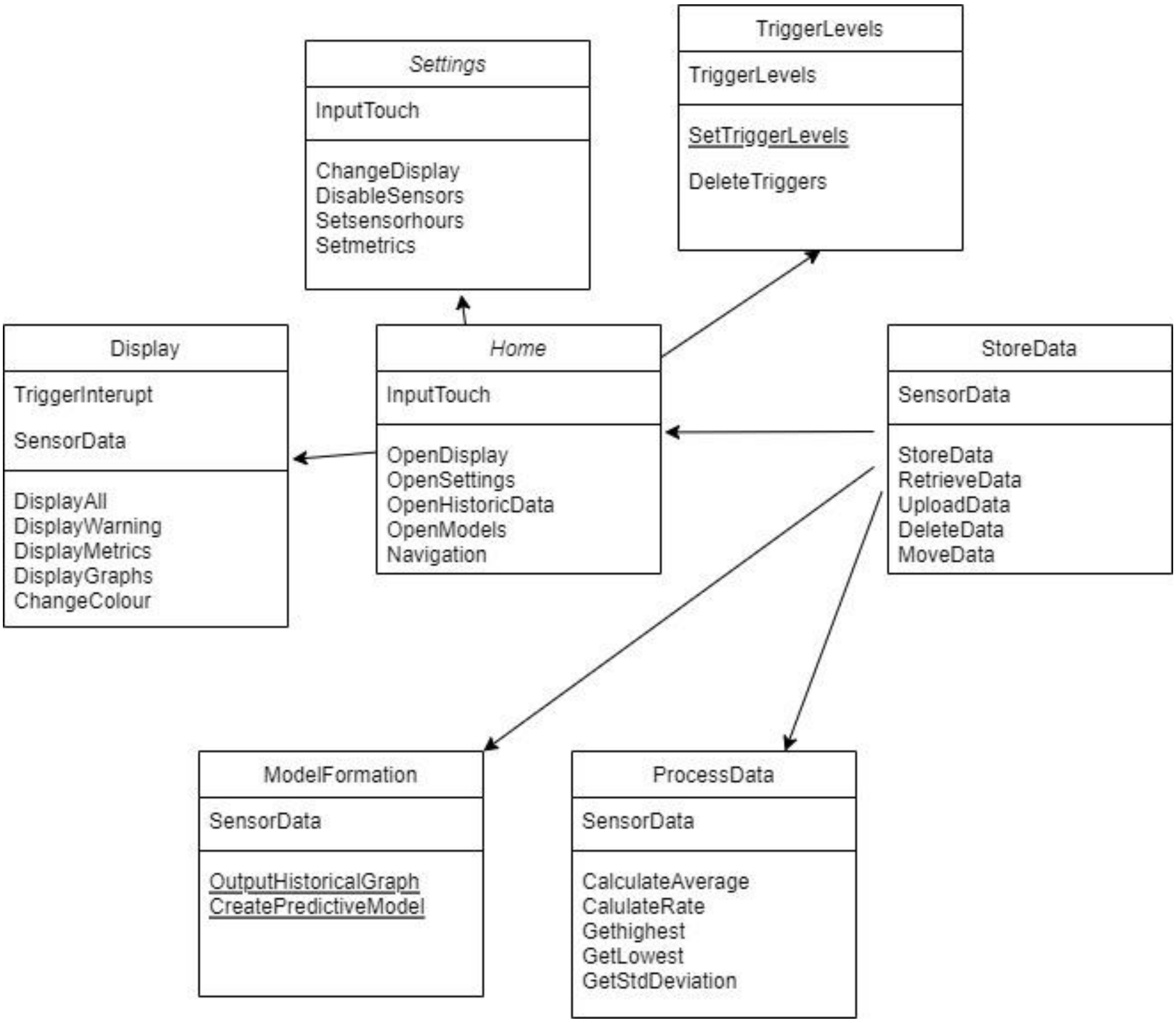

Figure 8: UML Class Diagram

3.6.4 Interface Application design

The design for the User interface can be illustrated in Figures 8 and 9 below. Figure 9 shows the navigation window and options. When any of the options are selected the program will navigate to the relevant tab. An example of such can be seen in Figure 8. It shows the current readings outputted with graphs to illustrate the level in a clear and illustrative manner. The other tabs the program has included:

- Settings
- Historical Data
- Trigger Levels
- Module
- Metrics

Figure 9: Readings Tab

Figure 10:Navigation Window

3.6.5 Sensitivity Analysis

When it comes to sensitivity a problem the UI may find is the format of inputted Data or passwords or readings from the sensors. To overcome this the UI will only accept data in the correct format for example and perform validation checks on all inputted data and confirmation on posts. The sensors may have missing or corrupted readings due to failure or power surges. We have a battery pack to accommodate that and data validation checks to ensure outlying data does not change models or metrics. The system is also reliant on Wi-Fi connection and internet access for the system and the user.

3.6.6 Other Issues

Other concerns for this subsystem are very limited but include issues such as loadshedding and data connection during that period. The design implemented can be improved to update automatically and increase the control over the machine. The development, maintenance and regular updating and improvement of the user interface need to also be taken into consideration.

4 Power Supply (THMNAT011)

4.1 Introduction

The power supply module is responsible for providing power to the entire system. It is this is the "heart" of the OppieCop it provides the necessary power to each component so that the rest of the components can perform the task of checking if the machine is optimal as well as checking the air quality. But the main focus of this module is receiving an input voltage supply whether it be from the main supply (from the machine itself) or an external power source (like a battery). This module will perform the necessary step down of the voltage, so the desired voltage is supplied to the rest of the system. If the voltage going into the rest of the components is too high the power supply will indicate this to the user. In the next section of the document, initialization of the requirements from the user for this module. As well as the limitations for the requirements defined.

4.2 User Requirements

The table below the will indicate the requirement from the user for the power supply module

Requirement ID	Requirement Text
RID001	Regardless of the input power source, the output must provide what is needed for the system
RID002	The power supply (the battery) must be eco-friendly
RID003	The power supply must be durable
RID004	The replacing of the battery must be easy
RID005	The battery must indicate if it needs to be replaced
RID006	The power Supply must last the entire working day

Table 11: User requirements for the power supply

4.3 Requirement Analysis

4.3.1 Analysis of RID001: Regardless of the input power source the output must provide what is needed for the system.

For the system to get power, the power supply module will need to step down the input voltage to a constant voltage so it can supply the other components within the system. The input voltage at the moment is not known it can be varied from 10 V DC to 230V AC (standard in South Africa) and must output 5V DC at the output

Requirement ID	Requirement Text	Derived From
RT001	The power supply will convert 10V - 230V and continuously supply 5V DC to the rest of the system	RID001

Table 12: Analysis of RT001 for the power supply

Verification

This system will be designed to meet the required specifications and will be tested in the operating conditions specified and checked using a multimeter/ oscilloscope to see if the desired output is produced

4.3.2 Analysis of RID002: The power supply (the battery) must be eco-friendly.

When choosing the battery that needs to be used in this system it should be chosen such that it does not negatively affect the environment. For this possible solution is purchasing a rechargeable battery. Or choose a battery from a company that makes sure that their batteries are easy to recycle.

Requirement ID	Requirement Text	Derived From
RT002	When choosing a battery make sure that is rechargeable or a battery that does not harm the environment	RID002

Table 13: Analysis of RT002 for the power supply

Verification

Verification of this will be through comparing specification sheets of the components and running a test not comparing the effect a non-rechargeable vs a rechargeable battery has on the environment.

4.3.3 Analysis of RID003: The power supply must be durable.

As the power supply will be placed by a lot of moving parts it will need to be able to withstand brute forces and sudden movements. Prevent any damages to the power supply module

Requirement ID	Requirement Text	Derived From
RT003	The device must be made strong enough such that it can withstand any physical damage or harsh movements like being dropped or hit. This will be done by choosing components and materials that are durable and strong	RID003

Table 14: Analysis of RT003 for the power supply

Verification

Multiple tests can be done to verify this. One is the drop test which is when the module is dropped from certain heights and then the module is checked to see if it still works. A pressure test can be done to see how much force the power supply system can handle. Check to see if it would be suited for the working environment.

4.3.4 Analysis of RID004: The replacement of the battery must be easy.

Since the device needs to be robust and easy to use for the user so special calls don't need to be made for changes to the device such as battery changes the battery must be placed such that it can be easily accessed

Requirement ID	Requirement Text	Derived From
RT004	When placing the battery/power source within the module make sure that it is placed such that the user has easy access to it	RID004

Table 15: Analysis of RT004 for the power supply

Verification

A test would be having people who have no prior knowledge about the design of the device and ask them to change its power source and access how easy it was for them to complete the task through a questionnaire at the end of the process

4.3.5 Analysis of RID005: The battery must indicate if it needs to be replaced.

As the device would not be on all the time only when the machine is activated the power consumption will not always be the same there needs to be an indicator showing how much power is left in the power source and if it needs recharging or replacing.

Requirement ID	Requirement Text	Derived From
RT005	The device must have an indicator on the power supply module indicating the recharging or replacement of the power source. The most effective way would be through LED light indicators. When there is 50 % or less, shows orange, and then when it is less than 10% the LED changes to red, indicating replacement or recharging	RID005

Table 16: Analysis of RT005 for the power supply

Verification

We can test this by using batteries of known capacitance and attaching them to the module and checking to see if the correct LED colour is shown, for example, if a battery is at 80% capacitance, the LED should be green and a battery that has 40% capacitance the LED should be orange and a dead battery, the LED should be red. This will verify that the module is working as intended.

4.3.6 Analysis of RID006: Power Supply must last the entire working day.

As there is a chance that the machinery will be operating throughout the entire day our device will need to operate then as well. We need to make sure that the power supply can supply power for the entirety of the working day.

Requirement ID	Requirement Text	Derived From
RT006	The power supply must last at least 16 hours. As the device must last the full working day	RID006

Table 17: Analysis of RT006 for the power supply

Verification

The test for this would be running the power source/ battery in standard working conditions and checking that it does last the required time. Checks will be done to see how the battery behaved over time. The check would be to see how long the battery/power source was able to last

4.4 Design choices

In this section, the focus is placed on the possible solutions to solving the requirements defined in the section above. As well as doing a comparison of components that can be and may be best suited for the project. Certain facto be taken into consideration when the components are chosen these factors are monetary cost, will easy the components be easy to manufacture, how difficult the implementation is, how easy it is to test the system, reliability and the cost of maintenance.

4.4.1 Disposable vs Rechargeable Batteries vs Main Power Supply from the machine

There are many possible solutions when it comes to providing power to the entire monitoring device. Three viable options were accessed the first being getting the power from the main machine or power supply, another being using disposable batteries. Lastly, look into the option of using rechargeable batteries.

The first factor that was accessed was the ease of maintenance and implementation and ease of manufacturing as well as costs. The following table below will assess how the factors affect the possible solution.

Factor/ Types	Disposable Battery	Rechargeable Battery	Main supply from machinery
Ease of maintenance	Maintenance is easy, if there are any issues with the battery it just needs to be replaced. Just making sure the battery is not covered in dust or dirt	These are very relatively easy to maintain as all that needs to be checked is that you are using the right charging capacities. Make sure that the contact surfaces and battery compartments are kept clean	This can prove to be exceedingly difficult to maintain if any issue occurs. There are many components involved in the conversion from the mains to the device power.
Ease of manufacturing	Mass-manufactured. Making it easy to get the product as it is easily acquired	Rechargeable batteries are mass-produced and so the acquirement of this product is accessible.	Difficult in manufacturing as it is very product-specific. It is not massed produced.
Technical Maturity	Has been in the industry for an exceptionally long time and faults have been ironed out and it is operation ready.	Has been in the industry for a while and faults are fixed and operation ready	As very case dependant the technical maturity
Ease of implementation	Quite easy to implement disposable battery and the functionality is very straightforward	Easy to implement rechargeable batteries.	Difficult to implement as extremely specific components are required
Cost	R100 [9V single battery] [1]	R 449.95 [24V 3.5AH] [2]	This is dependent on the cost to install the cable to join the machine to the monitoring device
Life span	1 cycle	300+ cycles	Continuous Cycles

Table 18: Comparison of the disposable, rechargeable, and supply from mains as a power source

From the information gathered and costs for the possible power sources, one of the design requirements set out is that the power supply should be an eco-friendlier solution while not being a complex design. For this choice the following things had a heavy influence on the design easy implementation, long life span and environmental impact on the environment. From these requirements specified, a conclusion is drawn that the possible best solution will be a rechargeable battery. The battery does not need to be changed as frequently so the cost will not be as heavy. The rechargeable battery does not require heavy additional circuitry for its implementation.

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4.4.2 Types of Rechargeable batteries

Properties	**Nickel Cadmium**	**Nickel Metal Hydride**	**Lead Acid**	**Lithium-Ion**		
				Cobalt	**Manganese**	**Phosphate**
Energy (Wh/kg)	45-80	60-120	30-50	150-250	100-150	90-120
Internal Resistance	Very Low	Low	Very Low	moderate	low	Very low
Life Span	1000	200-300	200-300	500-1000	500-1000	1000-2000
Time to charge up (hours)	2-4	1-2	8-16	2-4	1-2	1-2
Maintenance	Full discharge every 90 days when in full use	Full discharge every 90 days when in full use	3-6 months	No maintenance required	No maintenance required	No maintenance required
Safety requirements	Thermally stable, fuse protection		Thermally stable	Protection circuitry is required		
Cost	Moderate	Moderate	Low	High		
Technical maturity	The 1950s, been in the industry for a long while	The 1990s have been in the news for a long time so the	In the 1800s, the faults have been ironed out providing a great option	1991s, relatively new to the industry	1996s, relatively new to the industry	1999s, relatively new to the industry
Discharge temperatures (˚C)	-20 to 65		-20 to 50	-20 to 60		

Table 19: Table comparing different types of batteries [3]

For this section, a comparison was done over different types of rechargeable batteries. The main factors that had an influence on the decision on which battery would be chosen where on how low the maintance on the battery would be as well as the charge times on the battery and the biggest influence will be the life span of the battery how many cycles does it have. Cost was not taken in to account as the best battery would be required to do the job. The main types readily available in the market, are nickel-cadmium, nickel-metal hydride, lead-acid, and lithium-Ion. From the table above the following can be seen. Lead-acid batteries were probably the worst decision for our design as they required regular maintenance, and require a long time to charge up. While the lithium-ion battery even though it was the pricy option and is newer to the industry, offered a lot more advantages, there is little to no maintenance required, quick charge time, and a longer life span compared to the other options. It would provide the eco-friendlier option as the battery will not need to be replaced as regularly thus reducing the waste and the cost of disposal of a battery.

4.4.3 Types of regulators

Properties	**Switch Mode**	**Linear regulated**
Efficiency	High	Low
Heat Generation	Low	High
Noise	Increased	Decreased
Circuit complexity	Complicated	Simple
Operations	Boost/buck/negative voltage operation possible	Only step-down buck
Cost	High	Low

Table 20: Properties of switch mode and linear mode voltage regulator [4] [5]

From the analysis of the table above, it was decided that the only necessary operation required for the system was the step down of the voltage. For this reason, the Linear regulated voltage regulator will suffice for the system. As it is also low in cost and complexity in the design these were the factors that played a major role in the decision of the regulator. Made this a more reasonable approach to the problem. Below is shown of the possible circuitry

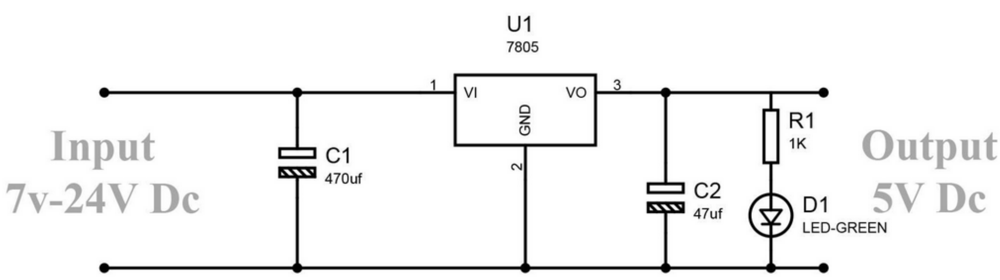

Figure 11: Diagram of the linear regulator to step down a 7V-24V DC to a constant 5V DC [6]

4.4.4 Final Decision

For the power supply module, a possible final decision on the design considered several factors. These considerations were made for the system requirements, these considerations were the system needed to take in varying input voltages and output a constant voltage. Another consideration is that it requires easy maintenance and easy to change the battery. One of the last requirements set about is that the choice of power supply should be able to provide an eco-friendlier solution.

Firstly, looking at the requirement of the eco-friendlier solution. The use of disposable batteries would not be great for the environment. Since these batteries only have one use in them, they would need to dispose of when they have been depleted. As these batteries contain dangerous chemicals which can be detrimental to the environment. As these batteries are disposed of in landfills and take a while to decompose. These chemicals seep into the soil and flow into the rivers and water supplies, meaning this is not the best solution for the environment. [7] Whereas the use of rechargeable batteries compared to disposal won't as often provide an eco-friendlier solution. It was quite evident that the option of drawing the power from the mains would have been the eco-friendlier option but, the complexity of the design would immense. So, this was the reason for the rechargeable being chosen.

Next looking into the option of stepping down the voltage two viable solutions were taken into consideration a linear or a switch-mode linear regulator. As the design only required the voltage to be stepped down the linear voltage regulator. Provided low cost and less complexity in the circuitry design.

Lastly, look at the type of rechargeable battery that would be used in the design. The diverse types provided different properties, and these were described in section 4.4.2 of the report. From the comparison in this section, it was decided that any battery in the lithium-ion range provided the best feasible option for the system design. This range of types of batteries offered the best life span. This entails that the battery does not require to be changed as often. So, this offered an eco-friendlier solution for our design

Looking at all the sub-components together the possible solution that would meet most if not all the requirements set out in this design. The final possible design is a lithium-ion (preferably phosphate) rechargeable battery with the use of a linear voltage regulator.

4.5 Model diagram and possible constraints and limitations

4.5.1 V-diagram

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The diagram below shows the v-diagram of the power supply module that will be used to power the other modules in the device.

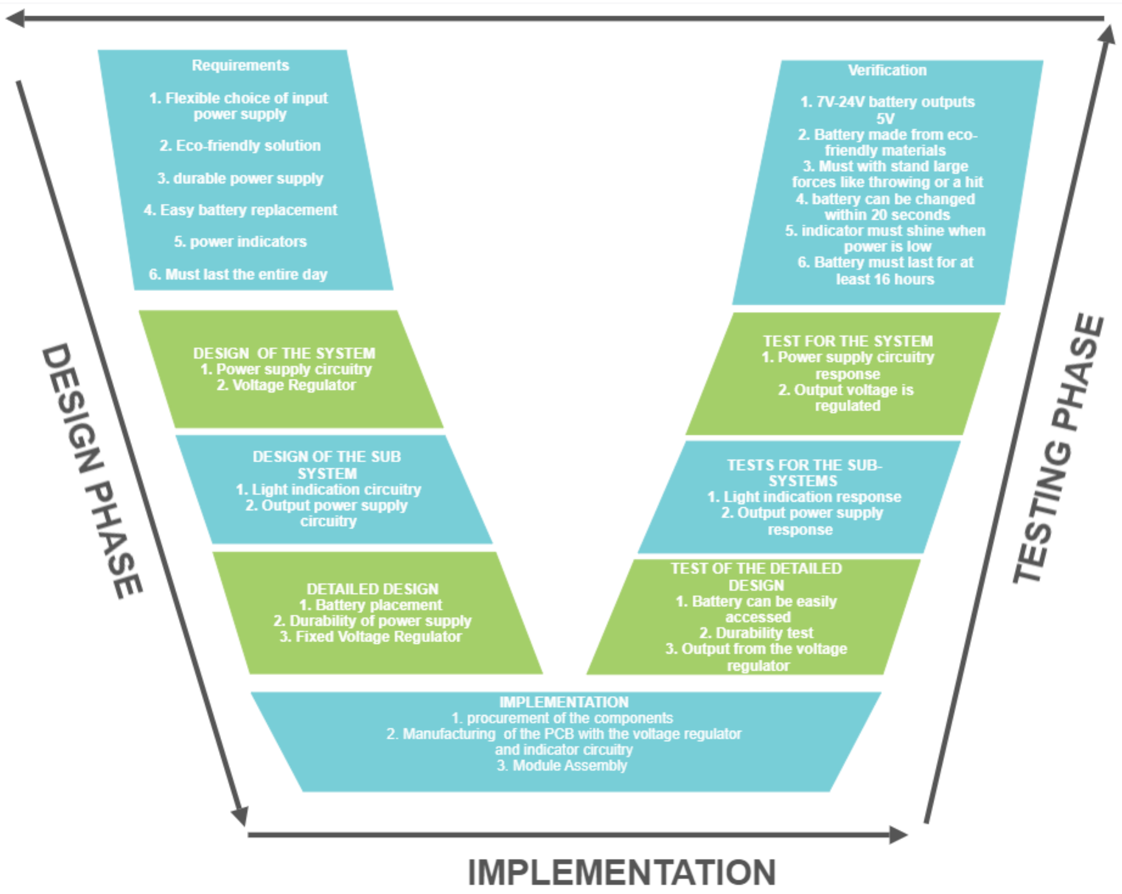

Figure 12:V-diagram for Power supply

4.5.2 Constraints and Limitations

This section will take a further look into the constraints and limitations of the design. The feasibility of the module is determined by the constraints and limitations. This will allow for any issues in the design to be fixed before implementation. Thus allowing for the mitigation of the problem when coming up with the solution.

4.5.2.1 Regulatory Constraints

A regulatory constraint when designing a battery is that whenever a power source is used within a system it is required that there be a protection circuitry to protect the systems from overcharge and discharge. Thus protection circuitry is needed in the power supply module implementation. Public safety regulations must be considered through the implementation. This module should not have any feature that could result in bodily harm such as exposed electric wire or blowing up or causing fires. Steps should be taken into mitigating this problem such as insulating exposed wires and protecting circuitry as stated earlier. There is also the regulation that states in systems containing complex components. The safety of the entire system should be at the same degree as if the components are operated individually. This entails the choice, implementation method, and maintenance of components within the system. Especially with the disposal of batteries when the battery's capacity has been depleted, there are chemicals within the battery that are hazardous, so proper disposal methods should be followed.

4.5.2.2 Technical Constraints

These can be defined as technical issues that prevent the system from performing ideally. [8] For this, a further look will be taken into the effectiveness of component accuracy and battery types.

4.5.2.2.1 Different component types

When calculations are done and simulations run the ideal situations are looked at but unfortunately, this is not the case in the real world. Especially in the manufacturing of components that are massed produced there will be differences in the actual value compared to the ideal value. These changes in values could result in skewed output values So to try and negate this problem when calculations are done and components are selected they will be chosen within a certain uncertainty for example 5% uncertainty. Should be enough not to completely skew output results

4.5.2.2.2 Battery Types

Not all batteries will perform in the same way. They may have the same specification but different brands may use different materials in making the end product. As it is known that batteries can be quite expensive to get high-end quality products. This could result in power failures within the system if a low-end battery quality is chosen or if a battery that has many faults in it is used could damage the system. Ways to negate the effect of the problem stated above, suggesting recommended brands that perform well in tests run to make sure that requirements are met.

4.5.2.3 Possible technical disruptions (Power loss)

Technical disruptions are issues that can occur during operations that could result in the system no longer operating as intended. These are seen as a limitation faced in the design of the module. For this a look into the chances of power loss to the system as the system uses rechargeable batteries there may be instances through negligence where the battery is left in the device and not recharged thus depleting the battery completely. A possible solution to this problem is having two batteries in rotation. Assuring that there is always a charged battery for the device, providing constant power. The second option is integrating the charging module into the power supply so that the charging station is not a separate entity.

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4.5.3 STEEPLE Analysis

Through this analysis the effects this module has on a variety of factors will be seen. While looking into how reasonable and valid the module design is the module will be analysed through the use of the factors set out by STEEPLE

4.5.3.1 Social

This product has no direct effect on the community in which the product operates. Most of the components used in the module will be locally sourced, thus supporting local businesses. The module does assist in helping the user who forms part of the community in the running of their business and thus could benefit the community through upliftment. The module can create jobs as there will be a need for someone to check and do maintenance of the module. If the module with the rest of the system operates well and allows the user's business to operate well and grow could result in job creation for many in the community.

The module does provide occupational safety as it has a protection circuitry set in place. As the module is used commonly amongst many in the community and population in general there should not be religious or cultural objections. Lastly look into the communities attitude to the project, as this is mainly geared towards small business owners who have machinery in their business. It is difficult to assess how the community may perceive this project.

4.5.3.2 Technical

The power supply module forms the heart of the entire system it provides power so the rest of the modules can operate. The use of rechargeable batteries. The life cycle of the module is a relatively simple one to implement as it has been used before quite in many other designs, research will be done in making sure that the best quality and most eco-friendly components are chosen in the design of the device. Issues faced in the life of the project technologies are cost issues as certain components may be expensive due to the quality of the product another issue faced is parts that need to be internationally sourced due to reduced costs this may take a while for the parts to arrive locally.

4.5.3.3 Environmental

Factors that affect the environment are mainly seen in the processes of manufacturing and production of the components and the product. The companies from which the components are sought must follow the environmental rules and regulations and the company that will produce the product must also adhere to these rules and regulations.

The choices of components were made from how recyclable the materials used to make the components were. As well as the carbon footprint the component and companies had on the environment. The development of this module was done such that the effects on the environment are kept to a minimum. As the batteries do contain hazardous chemicals the proper disposal methods will be observed.

4.5.3.4 Economic

The user of this product is intended for a range of businesses but mainly for small business owners who have machinery in use. Thus usually middle to lower-class individuals. When compared to the overall module the cost of this module is relatively low. Thus the entire system will be made affordable for these owners. A module is a viable option and there are no legislation issues that could arise. In the economy now where there are price increases this should not greatly affect the cost of the module. The success of the module and the system as a whole will allow for the branching out into the international market. Strengthening the local market within the global market. There is no short-term economic effect on the community. If successful and through the growth of the small business job may be created through this venture.

4.5.3.5 Political

This module has very low to little incentive or interest from the local governments or political powers. The only thing it may have is meeting safety rules and regulations set out by governments and legislation.

4.5.3.6 Legal

For this module to be implemented it may require that the relevant permits are obtained. As there is electrical work involved certification from a qualified individual is needed. Licencing must be acquired for the operation of the device. All these aspects must be done legally.

4.5.3.7 Ethical

During all the stages of the development of this module, the proper ethical standards will be upheld. All participants partaking in the development will be treated equally. Acquiring all components will be done ethically. No shortcuts will be taken in the development of the module. The development and dealing with producing this module must be done transparently amongst all the stakeholders in the module.

4.6 Subsystem Design

A brief look into the module and its interactions with the rest of the modules as seen in the block diagram below

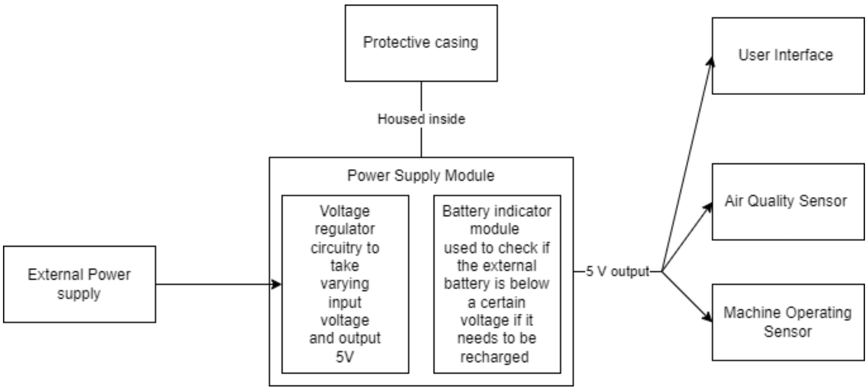


Figure 13: Power supply interface with the other modules in the system

In this section, a closer look will be taken into this module by showing simulations of the module and ways in which the module can be optimised and a better fit for the system as a whole.

4.6.1 OPM Diagram for the module

Below shows the Object Process Methodology or OPM diagram, this shows the method undertaken by the power supply module within the entire system. This to take note of are the processes which are indicated by the oval shapes in our diagram, showing what takes place in this submodule. The rectangles indicate the objects within our module. There is also an agent link that can be seen between the user and the battery this link entails that there needs to be human interaction within the submodule. What the user would need to do is charge the battery when low on charge.

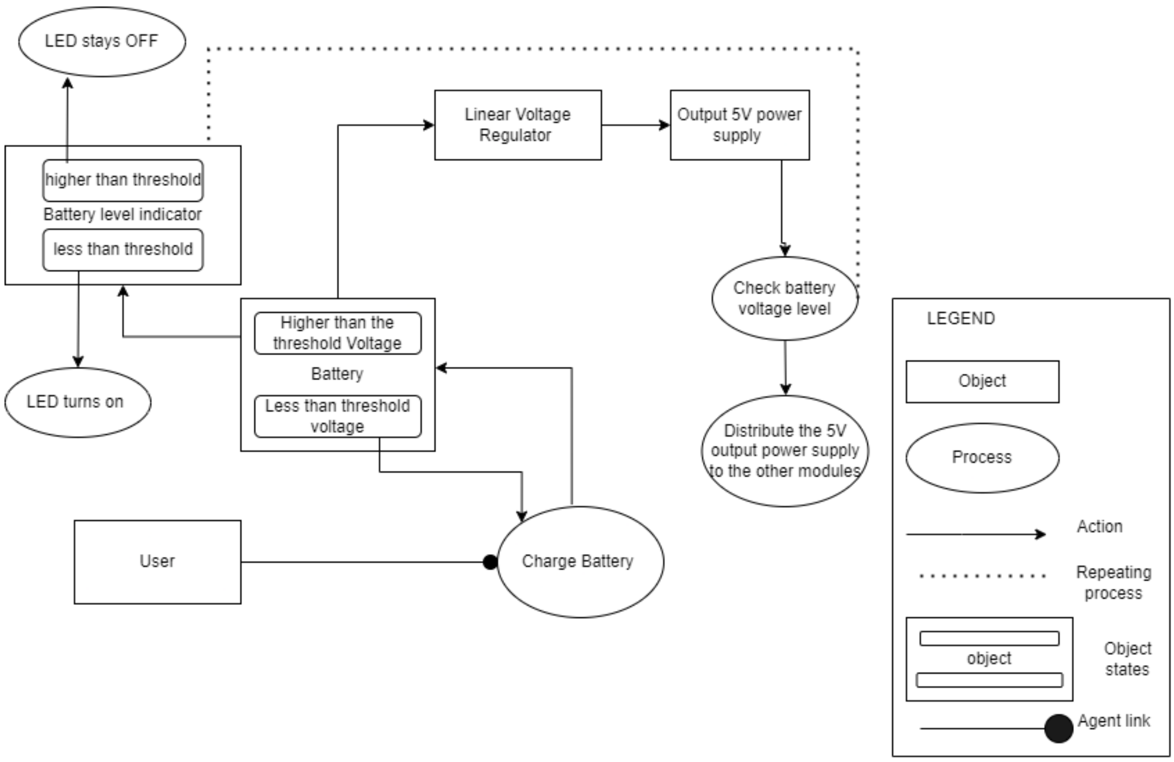


Figure 14: The OPM diagram for the power supply module

4.6.2 Subsystem simulation and prototyping

4.6.2.1 Voltage Regulator submodule circuit and simulations

The voltage regulator circuit takes in varying input voltage and regulates it down to a constant 5V DC output voltage. This circuit was designed to allow the user freedom around the choice of battery they would like to use, taking into account what they can afford. Rather than a set choice of battery, which could prove to be costly and thus detrimental to the user's finances and business. The circuit diagram is shown below.

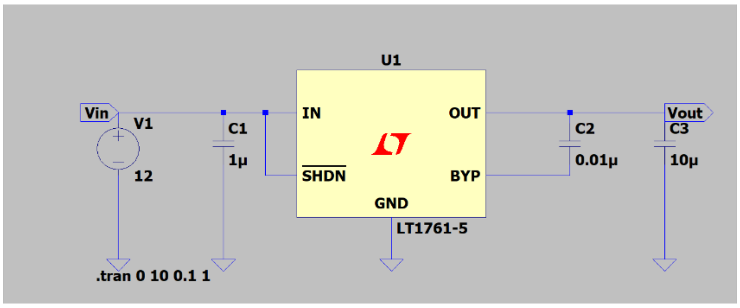


Figure 15: Circuit diagram for the linear voltage regulator

The diagram above will take in an input voltage greater than 5V, and pass it through the IC LT1761-5 which will then output a voltage of 5V. The capacitors are used to filter out high frequencies. Below are the simulations run using LTSpice to verify of the circuit that was designed would meet the requirements set out for the module. The most available battery on the commercial market is the 12V lithium-ion rechargeable battery. So for the first test, we would see if the desired output will be shown when the circuit is in use.

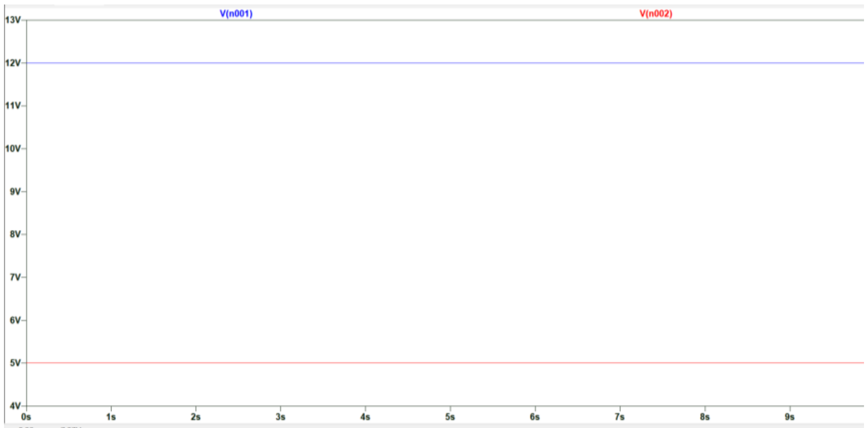


Figure 16: linear voltage regulating standard 12V battery to 5V DC

After simulating the circuit in LTSpice the plot in fig 13 was obtained as can be seen that when fed with 12V the linear voltage regulator would output a constant 5V DC out. This means that the circuit design behaved as expected. After this, the effects of a varying input voltage needed to be analysed. For this simulation, the input voltage was a sinusoid with an amplitude of 23V. As this is what is expected to be one of the bigger commercial readily available batteries.

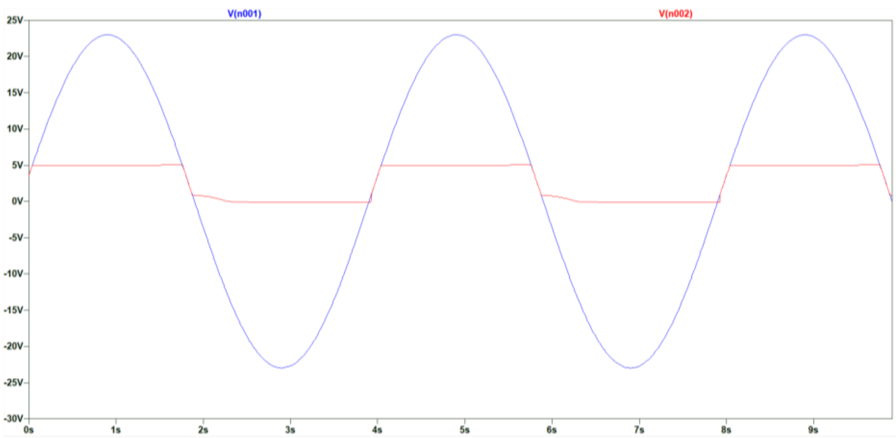


Figure 17: Output of a voltage regulator concerning a varying input voltage

The output of the voltage regulator behaved as expected as can be seen when the input voltage is greater than 5V the linear regulator can regulate the voltage to 5V as desired. But it is also noted that when the voltage is below 5V the resulting output voltage is 0V and unstable as the lines in fig14 are not straight. What this suggests is that the circuit designed I not a boost voltage regulator. To avoid this problem seen in this submodule the next submodule was designed with the battery charge indicator.

4.6.2.2 Battery charge Indicator Module circuit and simulations

The circuit below shows the circuit used to indicate if the battery needs to be recharged or not. This was to assist in the submodule above which would not behave as intended if the input voltage from the battery fell below a certain level of its full charge. This circuit made use of resistors and NPN transistors, as well as Zener diodes and an indicator, LED to tell if the battery needed to be recharged.

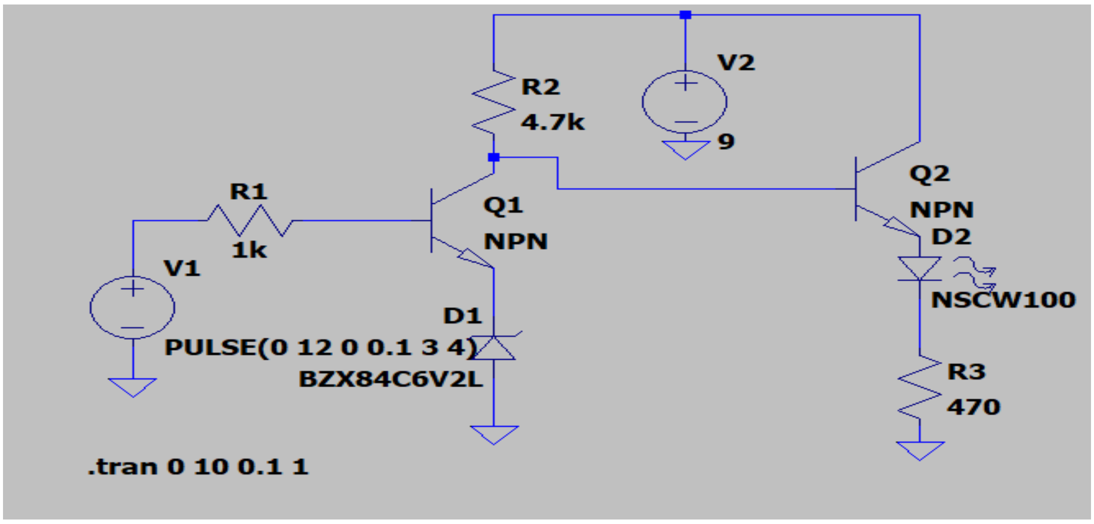


Figure 18: Battery charge level indicator

The way these circuit works is that when the input voltage is to fall below 6.2V the LED will turn on indicating that the battery needs to be recharged. The reason for choosing the indicator voltage to turn on the LED at 6.2V instead of 5V is to avoid a situation where the voltage regulator will not perform as intended as seen in fig 14 when the input voltage dropped below 5V the output voltage is no longer provided with a constant 5V. But rather 0V. Sudden drops in voltages could result in negative effects on the other modules in the system. The circuit in fig 15 was simulated using LTSpice and the results are shown below.

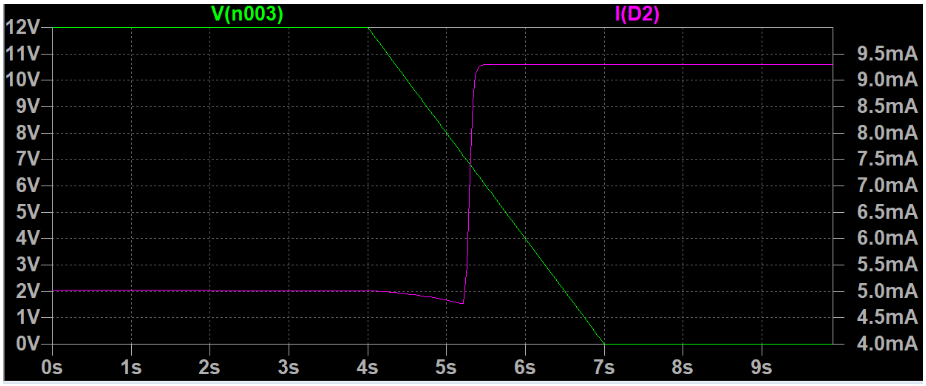


Figure 19: Output of the circuit shown above

The results obtained were positive ones the circuitry performed as expected when the voltage dropped to about 6.6V the LED was turned on this is indicated by the fact that current was now flowing through the component and meaning it would turn on. Indicating that the battery needed to be recharged. When the voltage was greater than the threshold only a little current was flowing through the LED not enough to turn on the LED.

The 3D designs of the module are shown below. Firstly the linear voltage regulator and the battery charge level indicator

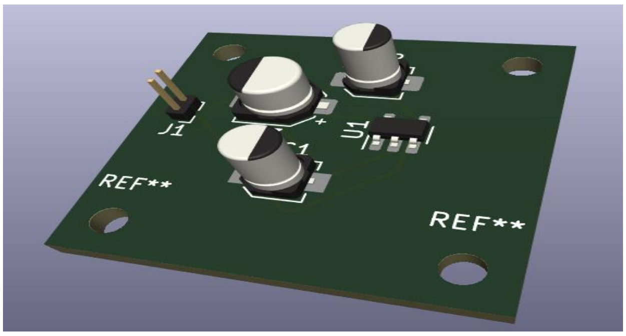


Figure 20:3D model of the PCB design of the linear voltage regulator using KiCAD

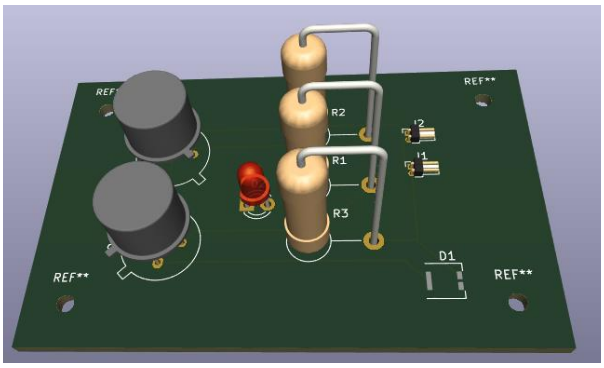


Figure 21:: 3D model of PCB of the LED module

This shows how the PCBs will look after being manufactured.

4.6.3 System Module Optimisation

Even though the module worked as expected there were a few aspects that could be taken into consideration to optimise the module. These aspects are as follows:

4.6.3.1 Redesigning the voltage regulator

The voltage regulator used in the module was a linear voltage regulator that only allowed for the step down of voltages but this in the long run would not allow for the user to get the most use out of the device if they needed to recharge them often. So the more suitable option would be the use of the switch-mode voltage regulator. The benefits of this voltage regulator are more desirable for this type of design. As the switch mode offers advantages as the name suggests the option to switch modes. It offers modes such as boost(step-up), and buck(step-down) as well as the use of negative voltage handling. Whereas the linear voltage regulator only offered the mode of buck to step down. With this type of regulator, if the input voltage was to drop below 5V the regulator would be able to still output a constant 5V supply. But there is a heavy cost around

4.6.3.2 Integrating a charging module into the design

Even though the rechargeable battery offers a more eco-friendlier solution. In the sense of efficiency, it can prove to be quite a hassle to keep having to remove and charge up the battery and then place it back even if you had two batteries in rotation such that having to recharge the battery does not prove to be such a mission. The more effective method would be implementing a charging module onto the system. So the battery does not have to be removed to be charged but rather can remain in the protective casing when it needs to be recharged. Thus the only time the battery needs to be taken out is when the life cycle of the battery has finished.

4.6.3.3 Redesign of the charge indicator submodule

The charge indicator module only gives the user minimal information as the light will turn on when the input voltage goes below a certain value. So a more efficient solution will be iterating this sub-module with the user interface module. Such that information can be fed into the microcontroller and evaluated and then outputted to the screen installed on the system providing the user with more valuable information. Instead of them having to keep on the lookout for a LED to turn on. This would greatly optimise the submodule as it provides more meaningful information to anyone using the system.

4.7 Sensitivity analysis

Lastly looking at the submodule as a whole and how it may perform in the real world. As the simulated values were determined very precisely to give the desired output. Since the real-world implementation will not necessarily perform the same as the simulations it would be desired that it get as close as possible. As it is the main importance of this module to make sure that the output of the module is 5V and not anything higher that could potentially damage the other component and modules like the microcontroller. It is important to include the tolerances present in the values of components. As well as deviations present in the currents and voltages used for references are included. [9]

It then proves to be very vital when selecting components to make this module feasible. The components should be of the highest quality and must work reliably, and perform as intended with little variation. Must also make sure that the components chosen are robust and can be implemented where ever needed. This module must work correctly and the output is exact, as the downfall or error or variation to the output due to variations in the input can negatively affect the rest of the modules. The other modules are dependent on the output from this module in making sure the success of the device.

4.8 Other issues

From the analysis of the design the only other issue that needs to be attended to is, making sure that the disposal of the batteries are done in compliance with the *"National Environmental Management: Waste Act,2008 Act no. 59 of 2008"* [10]. As the batteries that are used in the sub module does contain hazardous chemicals the user must follow proper storage, use and disposal of the batteries. If not disposed properly form a hazard to the environment as these batteries are highly flammable.

The module must comply with the "*Safety, Health, Environment, Risk and Quality requirements and policies of South Africa* " in the designing, installation and in its implementation. This is because the main goal should be to create a safe working environment for all in the workplace.

5 Air Quality Sensors (BRDJAK002)

5.1 Introduction

The air quality monitoring subsystem is required to monitor the working environment surrounding the Mac Afric 381 machine and will be used to ensure that the environment is fit for the human(s) operating the machine and working in the surrounding environment. The air that the machine operator is breathing must be clean and safe, thus the environment needs to be monitored for dangerous gases. Temperature is an important quantity to be measured as it affects both the operator and the machine while it can also be an indicator of potential machine issues or possibly a fire. Humidity should be monitored to confirm that the environment is not extremely uncomfortable for the machine operator, which could lead to poor machine operation and/or a potential accident.

5.2 User Requirements

Requirement ID	Requirement Text
RID001	The sensor unit needs to be able to withstand the machine's working environment.
RID002	The sensors need to be reasonably accurate.
RID003	The sensors need to be powered from the mains.
RID004	The sensors need to report measurements within a reasonable and safe time frame.
RID005	The sensors need to have a safe shutdown routine.

Table 21: User Requirements for Air Quality Sensors

5.3 Requirement Analysis

5.3.1 Analysis of RID001: The sensor unit needs to be able to withstand the machine working environment.

The Mac Afric 381 machine tends to operate in hot, dusty conditions where knocks and bumps to the air quality sensor unit may be frequent. The unit needs to withstand these conditions and continue providing accurate results despite them.

Requirement ID	Requirement text	Derived from
RT001	The sensor unit should not be damaged by regular bumps and knocks due to the working environment.	RID0001
RT002	The sensors' accuracy should not be significantly affected by heat or dust.	RID0001

Table 22: Analysis of RT001 and RT002 for Air Quality Sensors

Verification

The sensor unit will be placed on the machine for a trial period, during which its accuracy will be monitored. This will be done for a variety of periods to ensure there is no predicted drop inaccuracy. At each time interval, the sensor unit will be inspected for damage to ensure the environment will not cause the unit to fail in the future.

5.3.2 Analysis of RID002: The sensors need to be reasonably accurate.

The sensor unit is required to monitor the working environment's suitability for the person(s) operating the machine and surrounding it. A failure to report hazardous working conditions could have significant effects on those that the unit is responsible for protecting. Conversely, if the unit falsely reports hazardous conditions, significant time will be wasted.

Requirement ID	Requirement test text	Derived from
RT003	The sensors for each measured quantity need to report these values accurately.	RID002

Table 23: Analysis of RT003 for Air Quality Sensors

Verification

The sensor unit will be placed in a sealed container, in which, temperature, humidity, and the amount of dangerous gas shall be varied. The reported values will be compared against the actual values to ensure the device is accurate for each quantity it measures.

5.3.3 Analysis of RID003: The sensors need to be powered from the mains.

The most convenient and often available power source will be the mains, as that is how the Mac Afric 381 machine will be powered, thus the sensor unit shall be powered by the same source.

Requirement ID	Requirement test text	Derived from
RT004	The voltage needs to be up to 5 Volts supply taken from the mains (220/230 V)	RID003

Table 24: Analysis of RT004 for Air Quality Sensors

Verification

The voltage supplied shall be measured to ensure that it is not far greater or lesser than 5V.

5.3.4 Analysis of RID004: The sensors need to report measurements within a reasonable and safe time frame.

The air quality sensor unit needs to ensure the working environment is fit for the person(s) in it. A failure to report the temperature and presence of dangerous gases timeously renders the device useless as, by the time they may finally be reported, severe accidents or hazards may have taken place. Furthermore, if the person(s) operating the machine are working in an unfit environment for an extended period, they may cause an accident, thus the humidity needs to be reported within 3 minutes.

Requirement ID	Requirement test text	Derived from
RT005	The temperature and hazardous gas measurements cannot have a longer delay than 30 seconds.	RID004
RT006	The humidity measurement cannot have a longer delay than 3 minutes.	RID004

Table 25: Analysis of RT005 and RT006 for Air Quality Sensors

Verification

The sensor unit will be placed in a sealed container, in which, temperature, humidity, and the amount of dangerous gas shall be varied. The time taken for changes in the temperature, humidity, and the presence of dangerous gases to be reported will be recorded, to be certain, the delay for humidity and dangerous gases is no longer than 30 seconds and the delay for humidity is no longer than 3 minutes.

5.3.5 Analysis of RID005: The sensors need to have a safe shutdown routine.

When power to the sensor unit is turned off, the unit needs to shut down without any damage done to the unit, either electrically or in terms of the software.

Requirement ID	Requirement test text	Derived from
RT007	When their power source is cut, sensors need to gracefully shut down.	RID005

Table 26: Analysis of RT007 for Air Quality Sensors

Verification

Power to the unit will be repeatedly cut, each time the unit will be checked for any electrical faults and the unit will be checked to see whether it continues operating properly after the once powered on again after the shutdown.

5.4 Solution Overviews

5.4.1 Component Solution

The first design solution for the air sensor module consists of two sensor units; one measuring Temperature and Relative Humidity and the other measuring Volatile Gases, a PIC Microcontroller and a Wi-Fi Board to transmit the recorded data to the User Interface

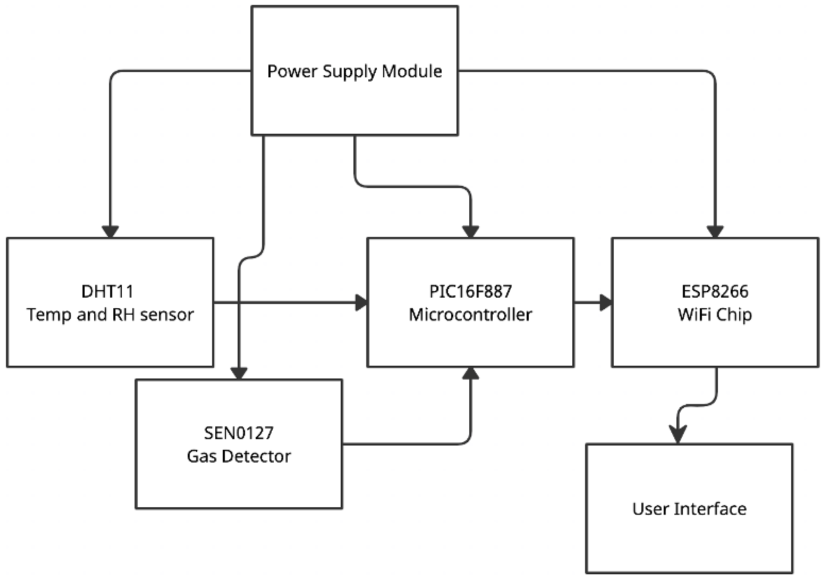


Figure 22: Block Diagram of Component Solution

5.4.2 Module Solution

The second design solution makes use of one sensor unit, which measures Temperature, Relative Humidity, and Volatile gases, this sensor connects to the feather board which communicates the measurements over Wi-Fi, which is already integrated, to the user interface.

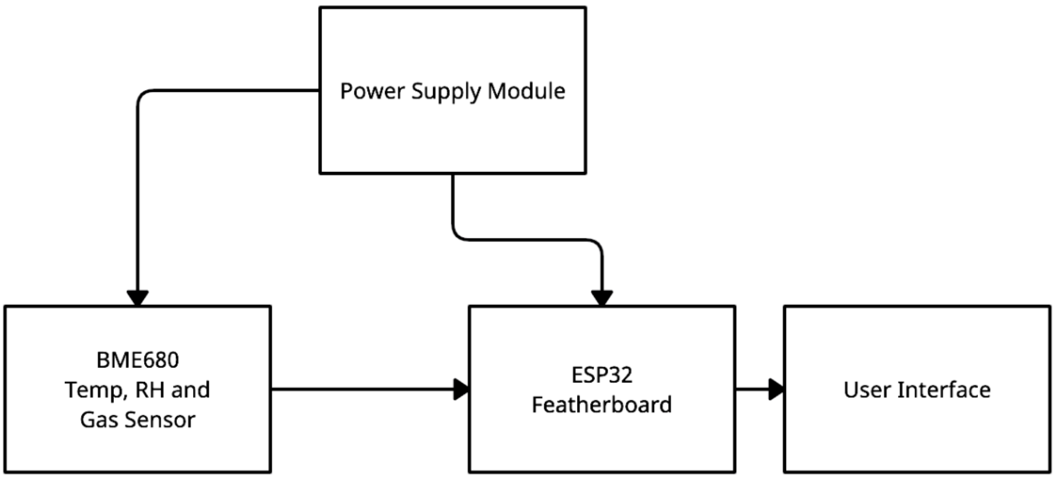


Figure 23: Block Diagram of Module Solution

5.4.3 Solution Comparison

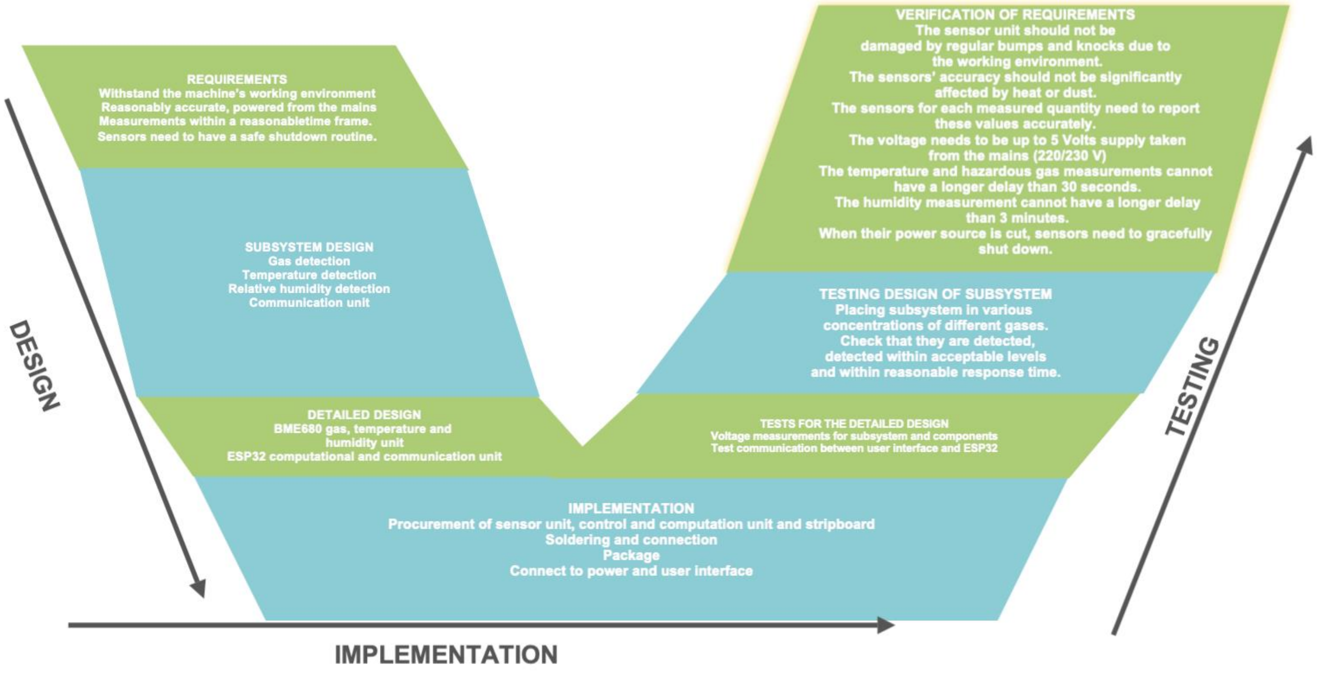
Design Option	Option 1	Option 2
Product List and Cost	• DHT11 Sensor – R57.50 • SEN0127 Sensor – R40.00 • PIC16F887A Microcontroller – R50.19 • ESP8266 – R59.99 • Stripboard – R121.65 • PIC-P40-20MHZ Evaluation Board – R97.34	• BME680 – R191.31 • ESP32 – R189.85 • Stripboard – R121.65
Estimated Total Cost	R426.67	R502.81
Minimum size	80x40x25mm	55x45x15mm
Voltage Range	3 - 5V	3 - 5 V
Component Integration	The PIC165887A microcontroller consists of 8 channels of 10-bit analogue to digital converter (ADC) which is used for the sensors. Serial Peripheral Interface (SPI) is used to interface with the ESP8266 to connect to Wi-Fi.	The BME680 sensor is connected to the ESP32 using an inter-Integrated Circuit (I2C) which is already Wi-Fi enabled.
Sensor Range	Temperature: 0 - 50°C Relative Humidity: 20 - 90%	Temperature: -40 - 85°C Relative Humidity: 0 - 100%
Sensor Accuracy	Temperature: ±2°C Humidity: ±5°C	Temperature: ±1°C Humidity: ±3°C
Application Development	The PIC16F series is a very popular and well-supported microcontroller, with plenty of easily available libraries and coding examples. Tools such as GCC and MPLAB make it easy to program the PIC.	The ESP32 board is easily programmable using the freely available Arduino IDE and which has a large community and plenty of resources. The BME680 is easily interfaced with the ESP32 and the monitoring system can be quickly programmed using freely available packages and code.
Production Ease	Due to the higher number of components, this option requires more complicated wiring, howeverementation due to the simplicity of the parts involved, it is still relatively simple.	Only two components need to be connected in this impl, making its production very simple.
Testing	Testing this setup would require each sensor or component to be tested separately, which would take additional time.	The simplicity of this solution allows for quicker testing.
Reliability	The individual components in this solution are very reliable, thus the reliability of the solution is largely reliant on the correctness of the developed application and the final production of the unit.	The production of this unit leaves little room for error. Similarly, the strength of the provided libraries and code reduces the possibility of errors.
Modifications	Due to the nature of the development of this system, adding sensors or functionality once the system is set up is extremely difficult.	The ESP32 can easily be interfaced with additional sensors allowing for easy future development.

Table 27 Comparison of Air Sensor Solution Options

5.4.4 Final Choice

The first design option is cheaper and allows for more customization in the initial stages, however, developing the system will take more time as well as be more complicated, thus leading to greater overall costs for the unit. The slight increase in price for the second system will drastically save development time, hence further costs, and will improve the overall accuracy of the system. The system will also be easily monitored and maintained and could be customized or altered in the future. The second system also requires only two components to be powered, thus allowing for a simpler power source sub-system. Due to the Second design being made of two pre-packaged modules, there is a far greater support community which would make the design and implementation far simpler. The smaller size of the second design is favourable due to the nature of the working environment.

5.5 V-Diagram



5.6 Constraints

5.6.1 Regulatory Constraints

Although the entire design is based around the Mac Afric 381 Machine, this particular subsystem is only concerned with the machine operating environment, which directly affects the machine, but more importantly, impacts the health and safety of the machine operator(s) and anyone else in the working environment. Thus, this subsystem is required to ensure the working environment can be considered suitable for work under the relevant laws and regulations. The relevant laws for this particular working environment are the Environmental Regulations for Workplaces of 1987 and the Occupational Health and Safety Act of 1993. These laws require the following to be ensured by the subsystem; the air breathed by those in the environment must not endanger their safety, the prescribed exposure limits for airborne substances must not be exceeded and the concentration of any explosive gas must not exceed its lower explosive limit. The subsystem designed thus far ensures that the working environment meets these requirements and thus, that the environment is suitable and safe for its occupants.

5.6.2 Technical Constraints

5.6.2.1 Size

The device only needs to be small enough to not be an obstruction to the machine or any work happening in the environment, thus size is not a particularly important constraint.

5.6.2.2 Durability and Quality

The sensor subsystem needs to be durable enough to withstand the general wear and tear from being placed in a working environment. Thus high-quality components need to be used, which need to be connected and assembled to a high standard.

5.6.2.3 Cost

The device needs to be at a feasible price point as it will be used by small business owners who could not justify an excessive outlay for such a piece of equipment.

5.7 STEEPLE Analysis

5.7.1 Social

The social impact of this particular subsystem is somewhat limited, as it is just one module in a system that is designed for a very specific and limited application. Despite its limited impact, it is worth mentioning that this particular system is responsible for ensuring the health and safety of those operating the Mac Afric 381 machine and in its immediate environment. The subsystem has the potential to protect the lives and well-being of these people which in turn has a significant social impact. The subsystem most importantly will stop the potential loss of life but also the exposure to harmful gases, which may cause long-term sickness. Thus the system can be seen to protect the lives and livelihood of a small number of people which in turn has a far larger social effect on their families and dependents.

5.7.2 Technical

The air sensor subsystem is critical to the system as it completes the monitoring of the machine and its working environment. The system needs to deliver accurate and timely measurements at all times the machine is operating, regardless of other factors. Faults within the sensor unit should immediately be made clear to the user, via the user interface, and should then be fixed before work continues. Due to the importance of subsystem accuracy, high-quality components should be used. Fortunately, due to the advancements in technology, highly accurate sensors and computational devices are relatively cheap.

5.7.3 Environmental

The subsystem detection of hazardous gases has a direct effect on the environment as it can detect a potential leak that would cause ongoing pollution or fire which has devastating effects on the environment. Additionally, the power usage and environmental impact of the production of the components need to be considered. Fortunately, the power usage of the subsystem is low and the components have little impact.

5.7.4 Economic

The subsystem and the entire system are effective low-cost options for managing the maintenance of the Mac Afric 381 machine. The system allows for smaller business owners to optimize the protection and management of their equipment and working environment as well as prevent the drastic economic loss which can arise from a safety issue in the working environment or the machine's damage or failure.

5.7.5 Political

The entire monitoring system and this specific module have very little impact on or influence by any political entity.

5.7.6 Legal

The subsystem is responsible for the health and safety of the people in the working environment of the machine, thus its job is essentially to ensure that the working environment is following the law. A failure of the subsystem to effectively monitor the environment results can easily result in the relevant laws being broken.

5.7.7 Ethical

This subsystem is critical to health and safety, thus the module is designed and maintained ethically. Those working ethically in the implementation of the system should be fairly compensated under a fair and legal contract. Furthermore, the components should be acquired from trustworthy and reputable suppliers, who also conduct ethical business practices and guarantee the quality of their products.

5.8 Technical disruptions

5.8.1 Power outages

Due to electricity not being always given, the device needs to be able to withstand power outages. The device needs to withstand both the power outage and possible electricity surges.

5.8.2 Damaging environment

The device will be placed in an unpredictable working environment which it needs to withstand. Thus the device needs to be physically sturdy and the components need to be of high quality and well assembled.

5.9 Design

5.9.1 Subsystem use case diagram

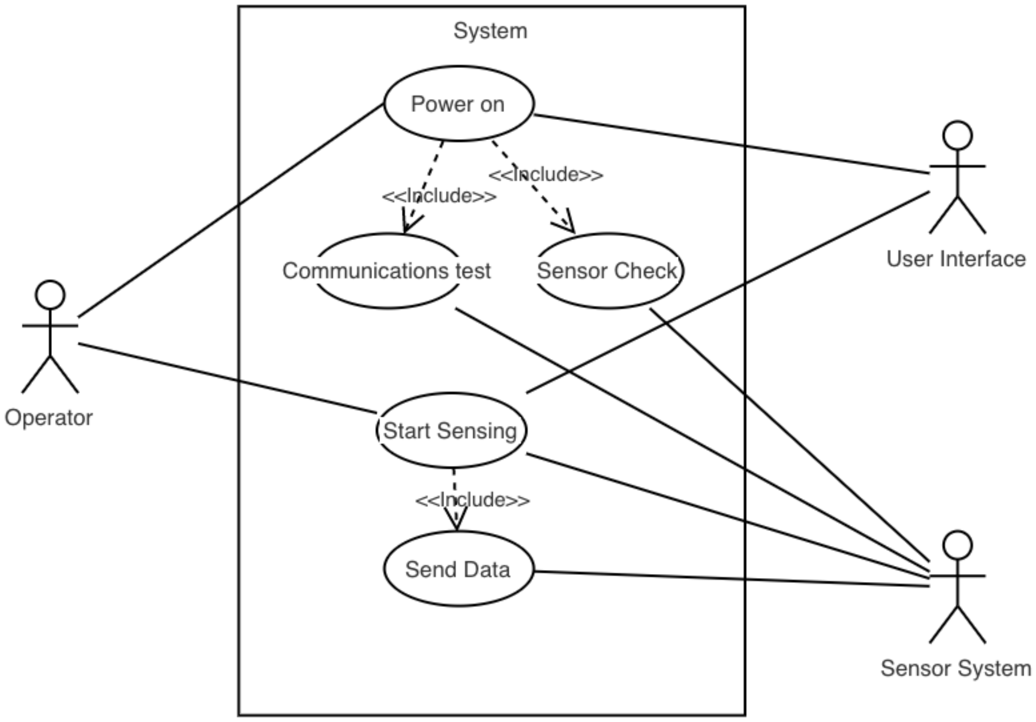


Figure 24 Air Sensor Subsystem Use-case Diagram

5.10 Subsystem schematic

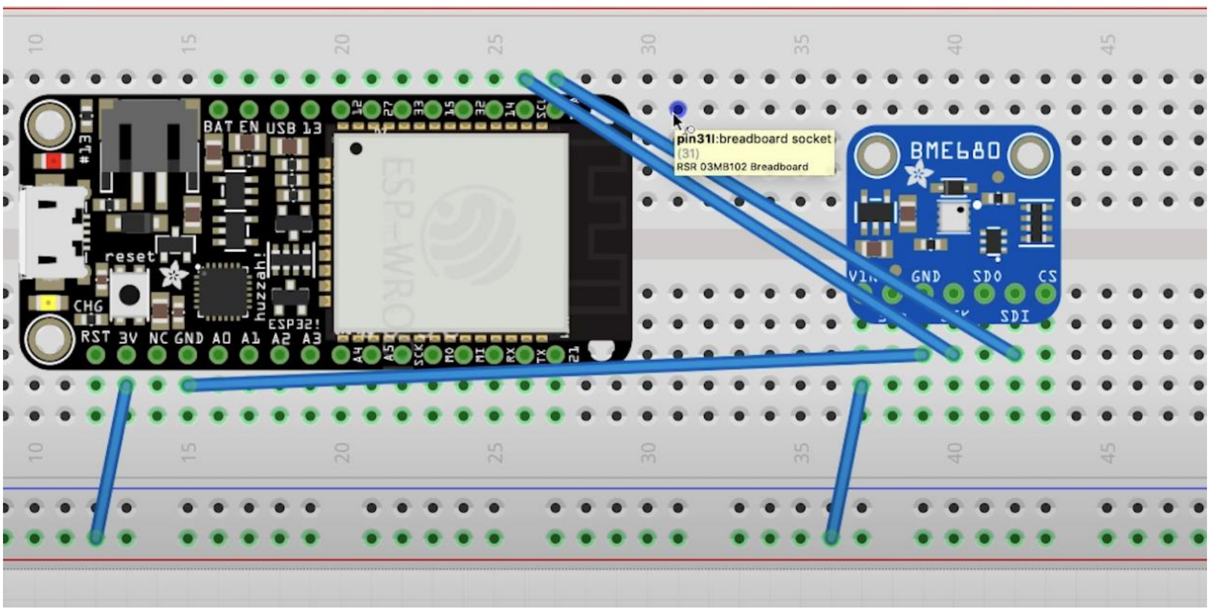


Figure 25 Fritzer connection diagram

5.11 Sensitivity analysis

Sensitivity analysis

The sensitivity of the air monitoring subsystem is entirely based on the sensitivity of the BME680 sensor. This module comes pre-tested and the tolerances are provided. These tolerances indicate that the subsystem is accurate in detection and measurement of the gas, temperature and humidity, however these tolerances could not be verified due to the complexity and cost of such a task. Despite the lack of verification it is fair to assume the tolerances are accurate or if there is any deviation, it would not be significant enough to effect the overall operation or usefulness of the subsystem nor the system as a whole.

Optimizations

The subsystem could be made cheaper and smaller if a PCB style design was used, however this could only be done if the device was to be made on a larger scale, if not it would not yield any cost benefits.

The production of the air sensor subsystem is very important to the quality and feasibility of the final product. Clever production can lead to space being saved. High quality production and assembly is the most important aspect in order to ensure the longevity of the device. However the production quality should be balanced with affordable production.

6 Machine Operating Sensors (MTWYON001)

6.1 Introduction

This module is needed to collect all the information about the essential parts of the Mac Afric 381 machine. The essential parts of the machine are the table, gearbox, drive chain, and feed roller. The table is essential because that is where the wood sits while it will be planned, the issue is that if the table rusts it will cause issues for the wood that is being planned in the machine so it must be kept from rusting. The gearbox needs an oil change as soon as the oil is no longer suitable for use in the machine. The machine continues to operate with oil that is not in good condition will result in the parts that use the oil getting damaged. The drive chain needs to have enough grease to operate well enough with the other parts. However, if the drive chain does not have enough grease it will cause the machine to malfunction due to the drive chain breaking. The feed roller needs to be oiled with machine oil every time before use so that the feed roller is kept up to standard.

6.2 User Requirements

Requirement ID	Requirement Text	Met Requirement (Y/N)
RID001	The sensors need to be able to stay on the machine even at the max speed of the machine and withstand the vibrations created by the machine.	N
RID002	The sensors need to report irregular levels within 5 minutes of them occurring.	Y
RID003	The sensors need to be powered with 5 Volts.	Y
RID004	The sensors need to be able to gracefully power down whether the power is cut.	Y
RID005	The sensors need to report the levels of what they are measuring within a reasonable level.	Y
RID006	The sensors need to indicate whenever they are experiencing irregular events.	Y
RID007	The sensors need to be calibrated to get the highest accuracy they can achieve.	Y

Table 28: User Requirements for Machine Operating Sensors

6.3 Requirement Analysis

6.3.1 Analysis of RID001: The sensors need to be able to stay on the machine even at the max speed of the machine and withstand the vibrations created by the machine

The machine tends to vibrate intensely depending on what the machine is doing at that moment. This is of concern because if the sensors slowly wander off and do not record the appropriate measurements then the machine will not be maintained well due to the inaccuracy caused by the vibration of the machine.

Requirement ID	Requirement text	Derived from
RT001	The sensors should maintain the expected level of accuracy throughout the vibrations.	RID001

Table 29: Analysis of RT001 for Machine Operating Sensors

Verification

The verification of the requirement will be done by checking if the sensors are operating within the expected accuracies from the datasheet, the sensors will be tested after operating 1 hour, 3 hours, a day, and a week to ensure that over time the accuracy is not drastically lost because of the machine operating.

6.3.2 Analysis of RID002: The sensors need to report irregular levels within 5 minutes of them occurring.

Since the sensors need to ensure that the levels seen are not a one-off instead, they are consistent within an interval of time to alert if something wrong has occurred.

Requirement ID	Requirement text	Derived from
RT002	The sensors need to report irregular levels within a 5-minute window of the irregular levels occurring	RID002

Table 30: Analysis of RT002 for Machine Operating Sensors

Verification

The verification of this requirement can be tested by introducing the used oil which is not suitable for the gearbox where the used oil will be 25%, 50%, 75% and 100% of the oil within the gearbox (the oil will not be applied to the gearbox instead it will be applied to a container similar to the gearbox) and seeing if it does report it within the 5-minute window, by introducing a table with low levels of wax, medium levels of wax and high levels of wax and no wax at all to seeing if it does report it within the 5-minute window. The drive chain will be introduced with varying levels of grease where it has no grease, a low amount of grease and well-greased to test if the sensor will be able to alert the low levels and no levels of grease within the 5-minute window. The feed roller will also be tested when it does not have machine oil, low levels of machine oil and the correct amount of machine oil.

6.3.3 Analysis of RID003: The sensors need to be powered with 5 Volts.

Since the machine will be drawing power from the power supply

Requirement ID	**Requirement test text**	**Derived from**
RT003	The voltage needs to be 5 Volts supply taken from the power supply unit	RID003

Table 31: Analysis of RT003 for Machine Operating Sensors

Verification

The verification of this requirement has been discussed in section 4.3.1.

6.3.4 Analysis of RID004: The sensors need to be able to gracefully power down whether the power is cut.

The sensors need to be gracefully shut down because a sudden shutdown could cause problems with the sensors and damage them. To protect the sensors even when there is a power cut there needs to be a graceful shutdown.

Requirement ID	**Requirement test text**	**Derived from**
RT004	The sensors need to gracefully shut down if their main source of power is cut	RID004

Table 32: Analysis of RT004 for Machine Operating Sensors

Verification

The verification of this requirement will be done by cutting the power to the circuit while it is operating to see if it does shut everything down in time before the backup power runs out.

6.3.5 Analysis of RID005: The sensors need to report the levels of what they are measuring within a reasonable margin.

The sensors need to indicate the health of the machine within a timely fashion because an extreme delay could cause irreparable damage to the machine and it would be as if the sensors were not monitoring the critical parts of the machine.

Requirement ID	Requirement test text	Derived from
RT005	The sensors need to report as timely as possible.	RID005

Table 33: Analysis of RT005 for Machine Operating Sensors

Verification

The verification of this requirement will be done by checking how long it takes to report/alert the condition it is supposed to detect when it is introduced to a correctly functioning system

6.3.6 Analysis of RID006: The sensors need to indicate whenever they are experiencing irregular events.

The sensors need to be able to detect the issues we are looking for because if it does not detect them then it will cause problems because it will seem like there is no issue while there is an issue but since it is not detected it will go unnoticed.

Requirement ID	Requirement test text	Derived from
RT006	Report the actual problems we have set it up to detect.	RID006

Table 34: Analysis of RT006 for Machine Operating Sensors

Verification

The verification of this requirement will be done by introducing the condition we would like to detect and the condition where there is nothing to detect. This will be done on at least 10 distinct levels of the condition we would like to detect for the various parts of the machine.

6.3.7 Analysis of RID007: The sensors need to be calibrated to get the highest accuracy they can achieve.

The sensors could lose their accuracy due to many factors in the factory which range from the vibration of the machine, the dust in the air, and other factors in the factory however the sensors need to maintain their accuracy within the conditions they operate in because if the accuracy declines drastically within a short space of time it will be an issue after some time because the sensors will not be capturing the correct information.

Requirement ID	**Requirement test text**	**Derived from**
RT007	The accuracy of the sensors should be kept within a reasonable range of values over a reasonable amount of time.	RID007

Table 35: Analysis of RT007 for Machine Operating Sensors

Verification

This requirement will be verified by letting the sensors operate in similar conditions as when it is in the factory and after 1 hour, 3 hours, 6 hours, a day, and a week. The sensors will be measured just to check if their accuracy has declined because of the environment in, which it is operating.

6.4 OPM diagram and design model

6.4.1 OPM diagram

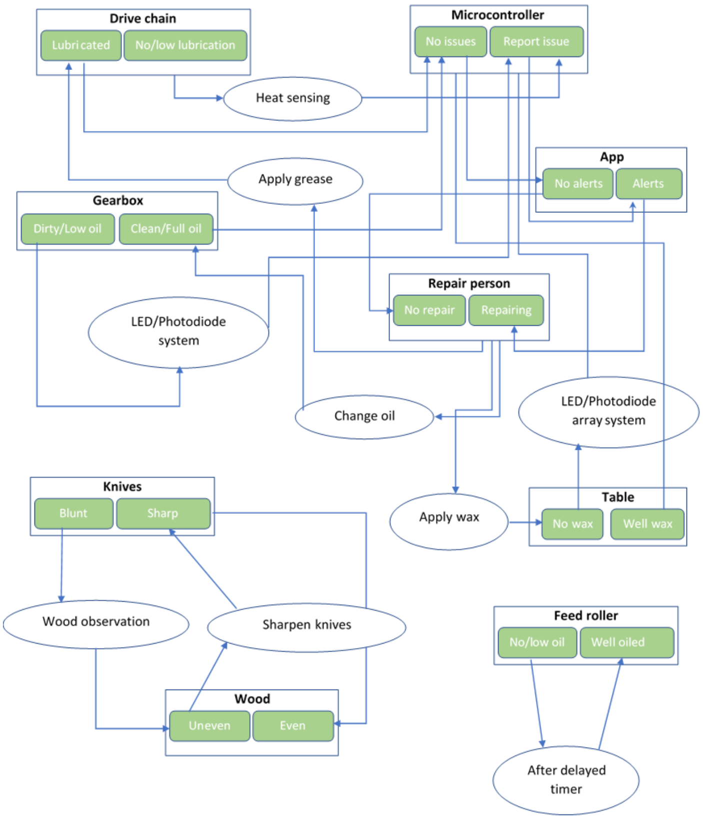


Figure 26: OPM diagram for machine operating sub-system.

6.4.2 Design model

The V-diagram describes the process that will be used to implement the machine operating sensors, at first the user requirements will be collected and these user requirements will be tested using the verification of requirements to check if they do meet the user requirements. Then the design of the subsystem will focus on making sure that the sub-system works according to the expected manner it has been designed for, and the testing for this section will check if the design of the system does what has been specified in the design of the sub-system. The design detail goes deeper in the design and covers the details of the design and the testing of the design will be done by checking if the details specified are met and then the implementation of the design is done only when all the tests have been passed.

Figure 27: V-diagram for machine operating sub-system.

6.5 Design choices

The design choice for monitoring the table, gearbox, drive chain, and feed roller will be determined using the following figures merit, cost, technical maturity, ease of implementation, ease of testing, maintenance costs, life span, and accuracy.

6.5.1 Table – The table needs to be monitored for wax and it needs to be applied to the table so that it is protected from rust.

i. There will be a light shined onto the table at an angle which will bounce back to the photodiode network where it will be determined if there is wax on the table which causes issues to the table there is no wax. When the photodiode detects low levels of light it will send out an alert indicating that there isn't enough wax on the table that should not be there since the table has to be shining the light back in normal operating circumstances.

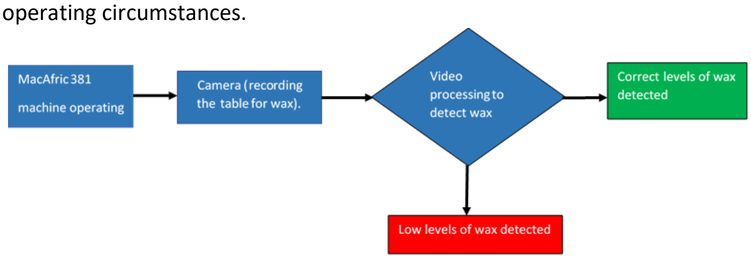


Figure 28: Block diagram of design (i) table wax detection.

ii. The table could be monitored using a powerful camera that can pick up low levels of wax, the video feed will be processed through image processing to determine if there is there are low levels of wax or not on the table. Once the wax levels has been detected then it will send out an alert.

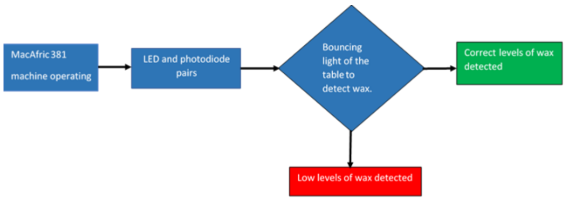


Figure 29: Block diagram of design (ii) table wax detection.

Figures of merit	Design choice (i) - weights	Design choice (ii) - weights	Weight explanation
Cost	4	1	1 (high) – 5 (low)
Technical maturity	5	2	1 (immature) – 5 (mature)
Ease of implementation	5	2	1 (hard) – 5 (very easy)
Ease of testing	4	1	1 (Very hard) – 5 (Very easy)
Maintenance costs	5	2	1 (high) – 5 (low)
Life span	4	3	1 (short) – 5 (long)
Accuracy	2	5	1 (low) – 5 (high)
Total of figure of merits weight	29	16	

Table 36: Figures of merit for table design choice (i) and (ii)

6.5.2 Gearbox – The oil in the gearbox needs to be checked if it is still at the right levels and if the oil does not have impurities

i. The gearbox oil container will have a light on one end and a photodiode on the other end. The amount of light captured by the photodiode will determine if there are the right levels of oil and if the oil has impurities which will be detected if the light levels are low. If the light levels are high that would mean that the oil levels are running low since the oil will not be covering the light and that means more light can reach the photodiode.

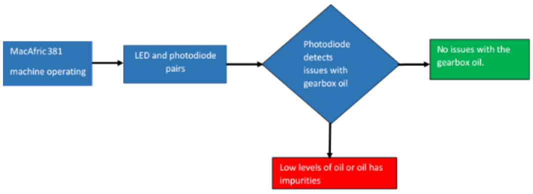


Figure 30: Block diagram of design (i) gearbox oil detection.

ii. The other option is to put 2 electrical rods into the oil and if the rods conduct electricity then that means there are impurities in the oil which makes it not usable for the gearbox. Since the levels of voltage will be low to not cause issues where sparks will be created.

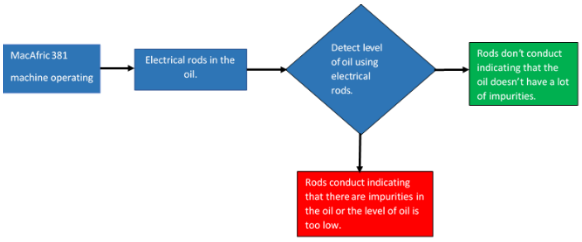


Figure 31: Block diagram of design (ii) gearbox oil detection.

Figures of merit	Design choice (i)	Design choice (ii)	Weight explanation
Cost	4	2	1 (high) – 5 (low)
Technical maturity	4	4	1 (immature) – 5 (mature)
Ease of implementation	4	4	1 (hard) – 5 (very easy)
Ease of testing	4	4	1 (Very hard) – 5 (Very easy)
Maintenance costs	5	5	1 (high) – 5 (low)
Life span	4	4	1 (short) – 5 (long)
Accuracy	1	3	1 (low) – 5 (high)
Total of figure of merits weight	26	26	

Table 37: Figures of merit gearbox oil detection design choice (i) and (ii)

6.5.3 Drive chain – The drive chain needs to be greased well so that it can continue working properly at driving the motor.

i. Detecting the speed of the gear that is linked by the drive chain will ensure that if the drive chain is running low in grease then the speed will be slower so then it can send out an alert to grease up the drive chain since it is operating at low levels.

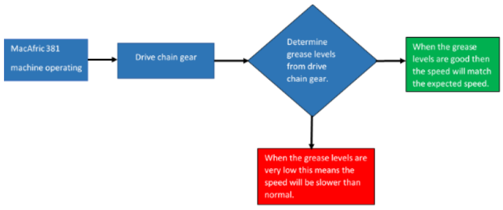


Figure 32: Block diagram of design (i) drive chain grease detection.

ii. Detecting the air quality of the drive chain can allow for the drive chain to be monitored on if it is working properly. This means when the drive chain does not have enough grease it will put out a certain odour which can be detected and once it is detected it can send out an alert indicating that the drive chain needs grease. When the drive chain does not need grease the odour will be in normal conditions. The grease should not trigger the odour detector.

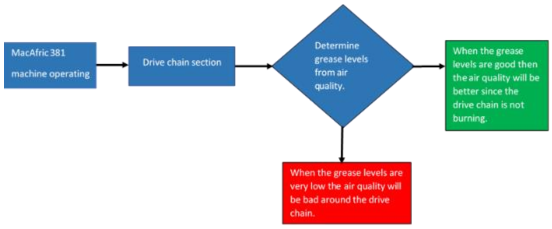


Figure 33: Block diagram of design (ii) drive chain grease detection.

iii. The other option for detecting the grease on the drive chain is using a temperature sensor to detect the heat that comes from the drive chain. When the drive chain is not greased well the drive chain will emit more heat due to the friction it will have with the gear however if the drive chain is greased out properly the drive chain will not emit as much heat because it has reduced the level of friction between the gear and the drive chain.

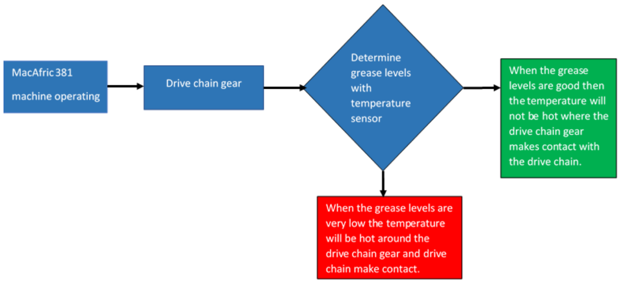


Figure 34: Block diagram of design (iii) drive chain grease detection.

Figures of merit	Design choice (i)	Design choice (ii)	Design choice (iii)	Weight explanation
Cost	5	2	4	1 (high) – 5 (low)
Technical maturity	4	2	4	1 (immature) – 5 (mature)
Ease of implementation	5	3	3	1 (hard) – 5 (very easy)
Ease of testing	5	1	3	1 (Very hard) – 5 (Very easy)
Maintenance costs	4	3	3	1 (high) – 5 (low)
Life span	5	3	3	1 (short) – 5 (long)
Accuracy	2	3	4	1 (low) – 5 (high)
Total of figure of merits weight	30	17	24	

Table 38: Figures of merit drive chain design choice (i), (ii), and (iii)

6.5.4 Feed roller – The feed roller needs to be lubricated using machine oil to continue operating properly.

i. The solution to this is by detecting the amount of machine oil on the tension screws of both the infeed and outfeed rollers. Since the application of the oil is done on the tension screws the level of oil that is there on the tension screws indicates the level of oil that is there. The level of oil can be detected by placing 2 electrical strips on the screws and if the electrical strips complete the circuit then the level of machine oil is too low and it needs to be applied again but if the circuit doesn't complete then there is enough machine oil.

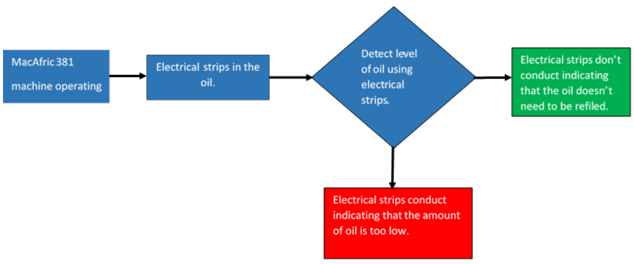


Figure 35: Block diagram of design (i) feed roller mechanism.

ii. The other method to ensure that the level of oil is maintained properly is to have a timer that will reset every time oil is applied to the tension screws and that timer will wait a certain amount of time depending on the amount of work done by the machine and then after that time, it will send out an alert to replenish the oil.

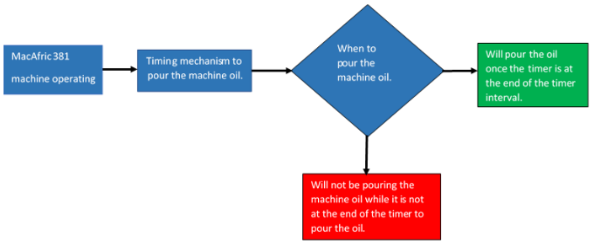


Figure 36: Block diagram of design (ii) feed roller mechanism.

Figures of merit	Design choice (i)	Design choice (ii)	Weight explanation
Cost	4	5	1 (high) – 5 (low)
Technical maturity	4	5	1 (immature) – 5 (mature)
Ease of implementation	3	4	1 (hard) – 5 (very easy)
Ease of testing	4	4	1 (Very hard) – 5 (Very easy)
Maintenance costs	4	4	1 (high) – 5 (low)
Life span	5	5	1 (short) – 5 (long)
Accuracy	2	2	1 (low) – 5 (high)
Total of figure of merits weight	26	29	

Table 39: Figures of merit feed roller design choice (i) and (ii)

6.5.5 Final solution

i. Table

The solution that will be selected to detect wax will be design choice (i) this is due to the fact that the design met the figures of merit with exceptional performance on the cost, technical maturity, ease of implementation/testing, maintenance costs and life span. As much as it didn't perform that well on accuracy the accuracy is not that crucial in detecting the levels of wax on the table.

ii. Gearbox

The solution that will be selected to detect the amount of oil in the gearbox and the level of impurities in the oil will be design choice (i). Both designs were equal in the total of the figures of merit however the lower cost of design choice (i) made it much better even at the cost of accuracy.

iii. Drive chain

The solution selected to detect the level of grease on the drive chain is design choice (iii), the reason as much as it is lower than design choice (i) the accuracy needs to be high for the drive chain since extended use of the drive chain on the drive gear can damage the drive chain to irreparable conditions.

iv. Feed roller

The solution that will be selected here is design choice (ii) this is due to the fact that there already exists a microcontroller and all that is needed is to notify anyone around the machine to apply the machine oil and since the amount of the machine oil that requires to be applied is so small it doesn't need to be very accurate and it doesn't need to be monitored all the time so that is why design choice (ii) has been selected.

6.6 STEEPLE analysis with possible constraints and limitations

6.6.1 STEEPLE Analysis

STEEPLE term	Description
Social	The social aspect of this product will be making sure that the safety of the employees is taken care of when it comes to the emission of gases that are odourless but deadly over time. The project will ensure that the machines people are working with are in top condition so that the likelihood of them being catastrophic is reduced.
Technical	The product has to survive for a long time since it is the product used to extend the lifespan of the Mac Afric 381 machine. This is important because if the product we designing doesn't last for a long period then it means the costs of maintaining/replacing it will be as great as repairing the machines if they are damaged. Judging by the warranty that the Mac Afric 381 has of 1 year, then the product we designing needs to last at least 2 years so that it can make sure that the Mac Afric is pushed further than what the warranty expects and it will need to ensure that it gives the machine an extra year or several so that the business can make more money rather than making losses.
Environmental	Since the product will ensure that the machine is maintained with early indications in place instead of scheduled maintenance being implemented it will allow the machine to work in conditions where it emits less pollution than if it had been maintained on a schedule because the schedule miss early warning signs that could help to resolve the matter earlier than later when the damage is beyond repair. The usage of resources for this product is very limited to using the electricity and the components used to make the sensor circuits and the container for all the circuitry. The manufacturing costs of the various sensors do not cost above R500 each. The various components used for this project are components that are cheap and common. When it comes to the environmental costs the costs are the metal that has been used to create the components used for the electronics plus the transportation of the various components that will be used in this product doesn't add a positive impact. When the product reaches its end of life it needs to be sent to an e-waste recycling location where the various metals will be recouped from the electronics that made up the product. Rehabilitation will not be cost-effective in this instance because the various components will have to be checked for their condition if they are still in a functional state then they can be rehabilitated however the time it takes to process whether it is worth rehabilitation or not is too long. The other issue with rehabilitation is that there are components that can't be rehabilitated due to the size of the product we are creating.
Economic	The product reduces repair costs that are experienced by the owner because since fewer machines are being repaired due to the product sending out alerts for when there is a sign of problems building due to a faulty part and then it will be attended to by not necessarily replacing it because it was spotted early so what happens is that the maintenance task will be adding wax, or adding oil to a certain part. Unlike when working with a scheduled maintenance plan the issues are only detected when something catastrophic happens or the damage is big enough to be visible to anyone operating or around the machine. The users of OppieCop are small business owners who want to ensure that they are more sustainable and ensure that they grow as a business while doing that. They cannot afford very fancy machinery and equipment that will monitor and ensure that whenever there is a small sign of trouble it can just alert them and they can attend to it. The small business owner is looking for a cheap easy solution to ensure that they are sustainable and they can grow their business as well.
Political	The political party that decides to endorse the OppieCop for the small businesses that use these machines would ensure that the pollution in the area they are running for would be below if they are concerned about climate change. They could also ensure that the business of the place they run will thrive since the costs of repairing their machines have been reduced because of the monitoring done by the OppieCop.
Legal	The issue with legal is that if the company that made the product doesn't allow attachments then it might violate a warranty which would mean the owner would be risking losing the warranty for the product we develop.
Ethical	The OppieCop does not act unethically when it comes to the small business owner however it does change the expected dates for the supplier because the machines monitored by the OppieCop last longer than the small business owner won't have to buy new machines as frequently.

Table 40: Steeple analysis for machine operating sensors

6.6.2 Constraints and limitations

Size	The size of the sensors needs to be small and fit within the already existing machine because too much alteration would cause issues for the maintenance of both the machine and OppieCop.
Amount of light	The amount of light shone onto the machine or next to the machine will need to be limited otherwise the detection of the rust on the table will cause issues like false readings from the light that is produced and not the light that should be referred. An alternative could be ensuring that is used to detect the rust is limited to a specific spectrum so that it can pick up the right values with low levels of noise.
Nothing should be protruding	Similar to the size however this constraint covers having nothing stick out due to the occupational safety hazard it can cause, which may lead to drastic issues later on.
The colour of the oil needs to be reasonably consistent	The colour of the oil more so for the gearbox oil needs to maintain a reasonably similar because it will not be able to operate as well if the colour has changed. The oil will need to be recalibrated for the different colours of oil since OppieCop has a specific colour of oil that it is expecting.
The temperature sensor needs to be able flexible	The temperature sensor that will be capturing the temperature of the drive chain from the gear that is driving the drive chain will need to be flexible since it will be rotating and during rotation, the cable will be moved as fast as the gear is moving. The cable also needs to be strong on its connection points because if it can easily snap off then it will cause issues for the operation. It will also be a problem since parts will be able to just drop and damage some of the other parts in the machine.

Table 41: Constraints of machine operating sensors

6.6.3 Technical disruptions

i. The vibration of the machine

Due to the vibration of the Mac Afric 381 machine when it is operational the sensors need to be able to withstand such an environment because it might cause false positives that will send out alerts when it is not supposed to. The detection of rust on the table can be hard if the machine keeps vibrating at a rate where the photodiode cannot capture the light that is bounced onto the table.

The gearbox oil container will be an issue if the vibrations cause the gearbox oil to move in such a way that the oil level is not maintained most of the time. After all, if either the LED or the photodiode are not contained within the oil then they will send out alerts when they shouldn't send alerts out because there could be enough gearbox oil for the gearbox to function properly.

The temperature sensor might need to be recalibrated due to the different temperatures the machine might experience during different seasons. So in summer, the environment temperature might be warmer causing the sensor to be able to register the temperature at a higher level when compared to winter where the machine will be cooler overall so the temperature for the trigger will be lower due to the environmental temperature.

ii. Having to run long thin cables to the different sensor locations

The issue with this is that the different sensor units have wires that go from the sensor unit to the processing unit and the issue is that If any of those wire cables is cut then the sensor unit might not be functional which will cause issues to the processing unit and if that happens it might damage the processing unit which will be an issue for the other sensor units.

iii. Damage to the photodiode network might cause the whole network to not work.

The issue with building the photodiode network in such a way that makes the whole network non-operational when there is an issue with one or more photodiodes causes real issues where the product is so sensitive to issues that it will be repaired most of the time because having to search and finding exactly which photodiode caused the problem will be a difficult task.

iv. Eskom power outages.

This issue is caused by having an unreliable power provider which means at a moment's notice they can switch off the electricity which means we have to design the OppieCop in a way that ensures it can survive electrical surges and that it has enough power to gracefully shutdown because a sudden shutdown might cause data corruption or damage the electronics.

v. Falling sensors when they fall apart.

This issue is dealing with when things fail from the sensor side of things whereas when the sensor itself fails what will occur. The issue is that the failing sensor might damage certain parts of the Mac Afric 381 machine because it is falling while the machine is working which is an issue for the parts the sensors cover. The ability to gracefully stop the whole machine if there is a sensor part that falls or to abruptly stop the machine if the failure of the sensor will cause catastrophic damage.

vi. Light from the surrounding environment.

This issue deals with the photodiode reading the light from the factory floor where the machine is used instead of reading the values from the light that bounces on the table produced by the LED to detect the wax on the table. The way to solve this issue is by enclosing the LED and the photodiodes in such a way that the environmental light won't interrupt the light from the LED to the photodiode. This can be done by creating a rectangular hood for the machine table so that the wood can pass and the light source in the hood is the LED only.

6.7 Subsystem design

6.7.1 Subsystem schematic

The following schematics show the design of the circuits that should be implemented to perform the requirements as laid out above. The following circuits are

Table wax detection circuit

The simulation of the above circuit could not be done due to the fact that the reflectance is unknown when the wax is applied and the wax is not applied. The simulation of the light being emitted by the LEDs and for that light to bounce of the table of the machine to the photodiodes is highly difficult to simulate. The next best thing to test the performance is to build a prototype and testing out the design as it would have been done if there was simulation software. The light emitting diode and photodiode pair has its own +5 volts line due to the fact that resilience is built by having each pair having its own 5 volts due to the fact if they were connect in series then if one of the LEDs was damaged when the whole line of LEDs/photodiodes won't work which is an issue since the sensitivity will be high because if one part gets damaged then the whole system for sensing wax will be out of order.

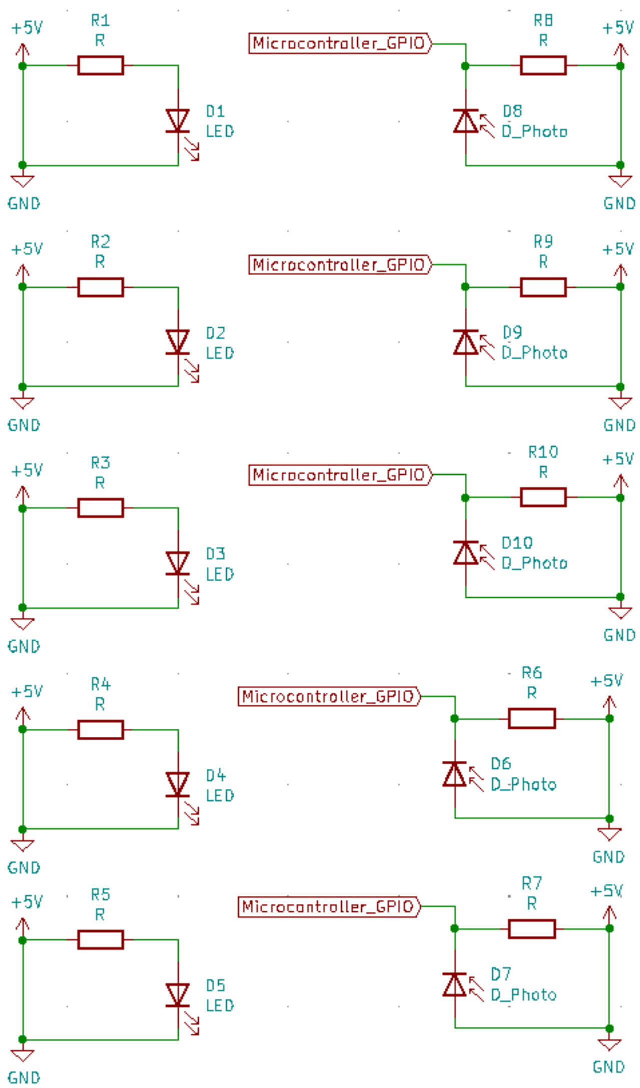


Figure 37: Circuit schematic of the table wax detection circuit.

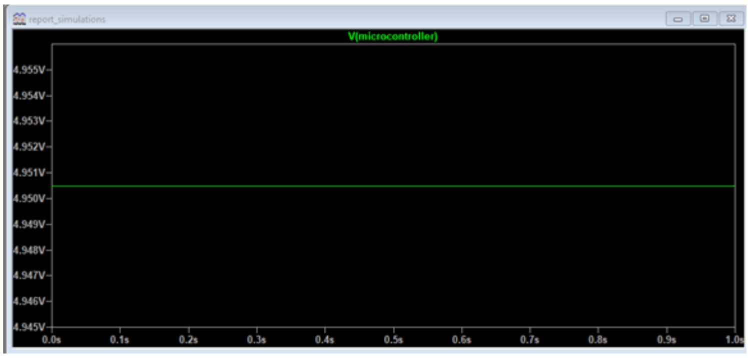


Figure 39: Voltage level when there is no wax on the table.

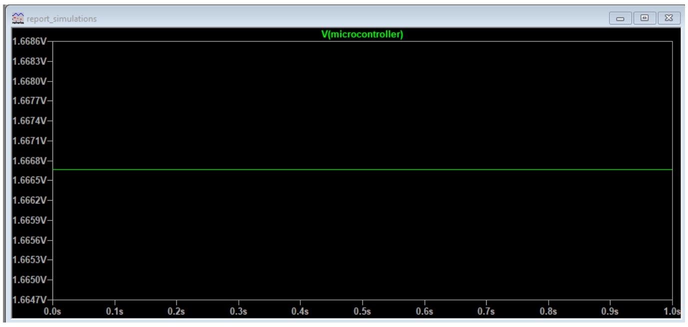


Figure 38: Voltage level when there is the correct amount of wax on the table

Gearbox oil detection circuit

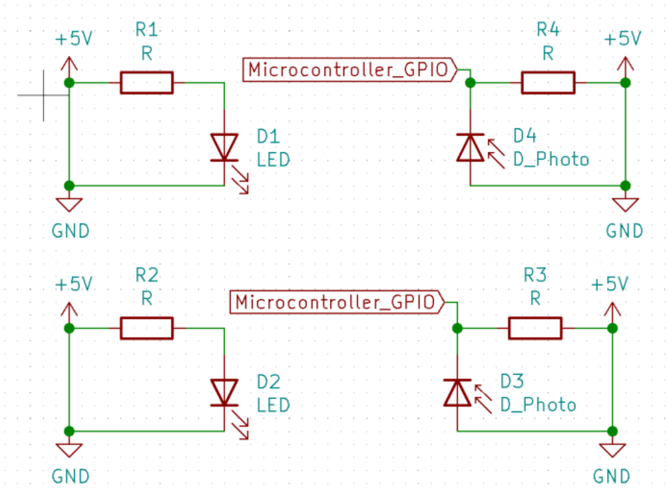


Figure 40: Circuit schematic of the gearbox oil detection circuit

The simulation of the above circuit of testing the design for detecting the gearbox oil could not be implemented due to the fact that there isn't a software that can simulate the light being emitted from the LEDs to the photodiodes and displaying the voltages that the photodiode would create due to the design. The circuit has to be prototyped to be tested if there are any issues with the design. The refraction of the oil is known but the simulation to determine if the photodiode will be able to detect the changes in the oil is not there.

The simulation of the above circuit of testing the design for detecting the gearbox oil could not be implemented due to the fact that there isn't a software that can simulate the light being emitted from the LEDs to the photodiodes and displaying the voltages that the photodiode would create due to the design. The circuit has to be prototyped to be tested if there are any issues with the design. The refraction of the oil is known but the simulation to determine if the photodiode will be able to detect the changes in the oil is not there.

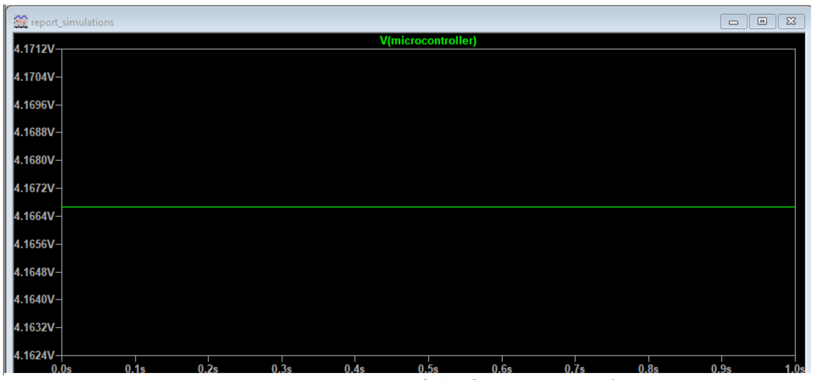


Figure 42: Voltage when the gearbox is full of oil and doesn't have impurities.

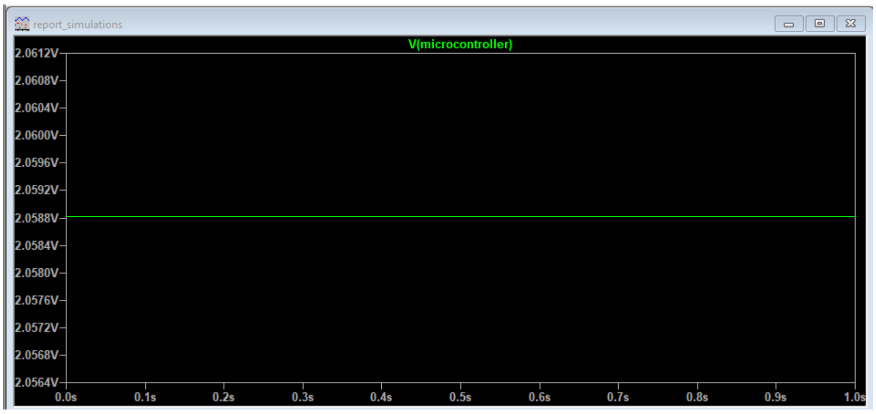


Figure 41: Voltage when the gearbox has low/no oil and it has impurities.

Drive chain detection circuit

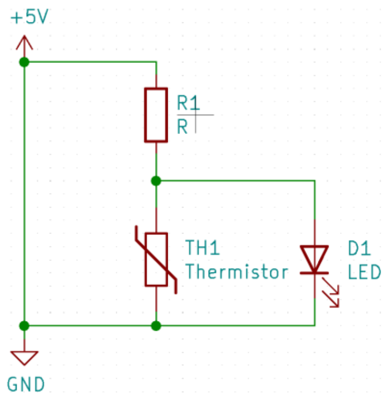


Figure 43: Circuit schematic of the drive chain grease detection circuit.

The simulation of the above circuit is not there due to the fact that the material composition of the gear used to drive the drive chain is not given through the manual book. The other issue is that the thermal conductivity is unknown since it is not made available in the user manual of the machine. The situation that would have been simulated was the detection of heat that is caused by the drive chain when it has little to no grease on the drive chain however to simulate the interaction between the gear and the thermistor is difficult due to the fact there is currently no software that simulates that set up.

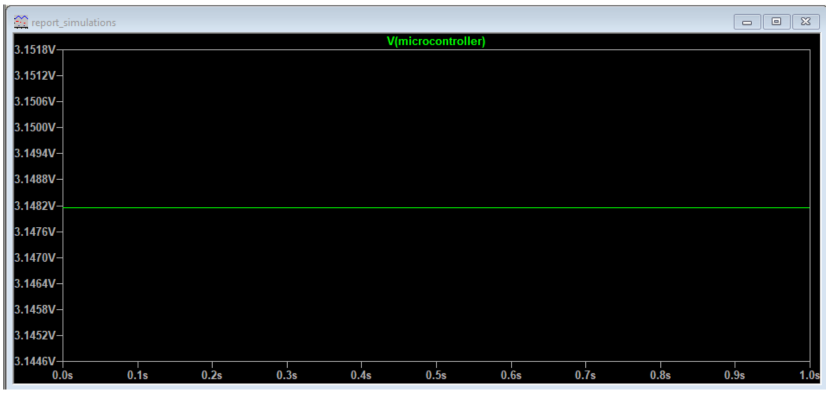


Figure 45: Voltage when the drive chain grease is enough

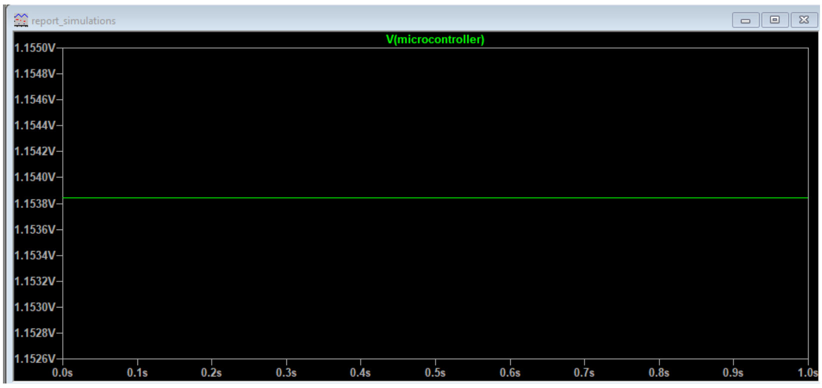


Figure 44: Voltage when drive chain grease is low.

Feed roller

Due to the fact that the timing mechanism will be implemented from the microcontroller there is no schematic that can be drawn of the circuit that will be doing the timing due to the fact that it will be all software base.

6.7.2 Sensitivity analysis and optimizations

Sensitivity analysis

The sensitivity of the circuits is not very high due to the fact that they have reasonable tolerances that will ensure that the circuits still function as expected. Since the simulations could not be done the sensitivity of the components is taken from the datasheets of each component instead of it being tested.

The table wax detection circuit has a sensitivity issue when it comes to the angle at which the circuit will be placed so that the photodiodes can pick up the light from the LEDs. Although the sensitivity is there it is not so high that it will make the manufacturing cause less yield when manufacturing the parts due to the fact that the sensitive is reduced by having the circuit covered in a protective casing which will ensure that external light doesn't temper with the light received by the photodiodes.

Optimizations

All the circuits can be ran as independent units where they have their own power supply and should emit the data wirelessly. The reason this would be better is so that the different parts of the machine are detected independently and it is modular and decentralized in such a manner that whenever there is a cable issue it is in one circuit board which will not affect the other circuits that are implemented. The other optimization is to instead coat the table with a material that is highly unlikely to rust, such as plastic so that there is no need to detect the rust on the table of the machine.

The wax on the table could be detected using a better method that doesn't involve building a unit that covers the table so that the machine table can still be observable and the machine can be used as per normal with out having to get used to the fact that the machine is covered where the wood comes out.

The sensors for the different parts could be made to be modular and they use wireless communication to send all the information that is needed from them. This would ensure that Oppiecop is versatile and can work on other machines that are built differently but can hold the specific sensor instead of having to customize for every single machine.

Detect the heat from the drive chain by not needing to have direct contact with the gear that drives the drive chain so that the heat sensing unit doesn't need any alterations and it won't disturb the operation of the machine.

6.8 Other issues

Legal

The issue of the machine warranty being voided due to the alteration that will done by adding the components to monitor the table, drive chain, gearbox oil container and the timing mechanism for the feed roller. This can be an issue because whenever there is an issue with the machine caused by the company machine being faulty when it was sold will not be replaced because the alteration of the machine has voided the warranty. The solution to this is to ensure that the alterations do not void the warranty instead they are add-ons instead of the Oppiecop needing to alter certain parts of the machine.

The responsibility will be hard to determine if the machine malfunctions in a way that causes irreplaceable damage or causes loss of life. The alteration will cause the responsibility to fall on the people who implemented the alteration so the alteration has to be done in a manner that ensures that it lowers the odds of the malfunction to not occur to a point that it is highly unlikely to occur.

Health & safety

The alteration of the different parts so that the monitoring of the table, drive chain, gearbox and the timing mechanism of the feed roller might cause issues with the design of the machine where safety has been built-in. So it is our responsibility to ensure that the safety mechanism built into the system are not altered to the point where it will be a significant risk for the machine to be used.

The OppieCop has to reduce the number of exposed wires due to the fact that the machine is mostly metallic which will conduct if a wire is exposed and might cause a malfunction which might cause irreplaceable damage.

7 Protective Casing (JCBAKH001)

7.1 Introduction

This subsystem deals with the design of a protective case for all the sensors and components needed for the OppieCop Device. Aesthetics, function, and protection are the three aspects to consider when designing a case for any device. Designers must strike a balance between these aspects to develop cases that provide value rather than detract from a costly investment. The device needs to be enclosed in a protective casing made from a light but strong material. The device should be able to easily attach to and connected to the Mac Afric 381 machine. The protective casing needs to be IP68 rated for dust resistance, and water resistance, and not have any air gaps that would allow insects to enter and damage the sensors and other components inside. The case must also be designed in such a way that it can be easily manufactured and not require too much time to assemble.

7.2 User Requirements

The table below shows the User Requirements for the Protective Casing

Requirement ID	Requirement Text
RID001	Water Resistance
RID002	Dust resistance
RID003	No Air Gaps
RID004	Durable Material
RID005	Adequate Ventilation

Table 42: User Requirements for Protective Casing

7.3 Requirements Analysis

7.3.1 Analysis of RID001: Water Resistance

The working environment is not always predictable therefore the device needs to be able to protect the components inside the protective casing from being damaged when wet.

Requirement ID	Requirement Text	Derived From
RT001	The device must be able to withstand a certain amount of water and be water-res if dropped into a body of water.	RID001

Table 43: Analysis of RID001 for Protective Casing

Verification:

This can be tested by submerging the protective casing in up to 3m of water for several minutes and checking whether the inside got wet.

7.3.2 Analysis of RID002: Dust Resistance

The working environment is not always predictable therefore the device needs to be able to protect the components inside the protective casing from being damaged when surrounded by dust.

Requirement ID	Requirement Text	Derived From
RT002	The device must be able to withstand a certain amount of dust	RID002

Table 44: Analysis of RID002 for Protective Casing

Verification:

This can be tested by applying a vacuum to force large amounts of dust into the protective casing for several minutes and checking whether any dust got inside.

7.3.3 Analysis of RID003: No Air Gaps

Often the machines run hot and attract insects and bugs. There need to be no air gaps in the casing that would allow even the smallest of insects to get inside and damage the sensors and components inside the protective casing.

Requirement ID	Requirement Text	Derived From
RT003	The device must not have any air gaps that would allow insects to get in and damage the device	RID003

Table 45: Analysis of RID003 for Protective Casing

Verification:

This can be tested by applying a high-grade air seal inside the protective casing not allowing for anything to get inside the casing to affect the device's components.

7.3.4 Analysis of RID004: Durable Material

Our device should be able to protect the components from being damaged in the unlikely event that it falls off the machine or something hits it.

Requirement ID	Requirement Text	Derived From
RT004	The device must be made from strong enough material such that it can withstand physical damage if dropped or something falls on it.	RID004

Table 46: Analysis of RID004 for Protective Casing

Verification:

This can be tested by doing a series of drop tests from different heights. The durability of the device's protective casing can also be tested by dropping a series of objects found in the working environment from different heights and ensuring the case is not damaged.

7.3.5 Analysis of RID005: Adequate Ventilation

The components inside should be able to "breathe" in a sense and this is achieved through ventilation. Without proper ventilation, the components inside could overheat and begin to malfunction.

Requirement ID	Requirement Text	Derived From
RT005	The device must allow for an adequate amount of airflow inside to keep components cool.	RID005

Table 47: Analysis of RID002 for Protective Casing

Verification:

This can be tested by placing a high grade temperature sensor inside the device and monitoring the readings throughout the day and making sure the levels don't rise to concerning level. There will be a very fine mesh inside the casing to protect the components from water droplets, dust particles and insects.

7.4 Design Choices

Deciding how our device will be protected is a major step in its functional success and ensuring the longevity of the product's lifespan. As stated before, the casing must be IP68 water and dust-resistant. This can be achieved by minimizing the number of places water and dust can enter the casing by minimizing the number of parts used to assemble the protective casing. Ideally, if we can limit the protective casing to made of 2 pieces through an efficient yet aesthetic design, we can achieve all the requirements laid out by the user. Below is an assessment of two methods that can be used to meet all the user requirements and the most effective solution will be selected

7.4.1 Using Acrylonitrile Butadiene Styrene

ABS, or acrylonitrile butadiene styrene, is a thermoplastic that is commonly used to manufacture light, stiff moulded goods including tubes, automobile body components, wheel covers, enclosures, and protective headgear. Many electrical devices are enclosed in ABS for several reasons such as its notable ability to resistant against corrosive substances as well as physical forces [11]. It's easy to machine and has a low melting temperature, making it ideal for injection moulding and 3D printing. ABS is also very reasonably priced at around R45.00 per kg. The material has a water absorption rate of 0,2% - 0,45% making it ideal for our protective casing. 3D printing allows us to design an enclosure with high accuracy thus controlling the number of air gaps that would let insects in and ultimately damage the device [12].

Requirements met

The table below shows which user requirements acrylonitrile butadiene styrene meets.

Requirement ID	Requirement Text	Met (✓) / Not Met (X)
RID001	Water Resistance	✓
RID002	Dust resistance	✓
RID003	No Air Gaps	N/A
RID004	Durable Material	✓
RID005	Adequate Ventilation	N/A

Table 48: Shows which requirements ABS meet.

Advantages

ABS plastic has several advantages, ranging from low production costs to a robust, aesthetically pleasing structure. Its capacity to survive many heating and cooling cycles make it ideal for recycling. ABS has a wide range of colour and surface texture possibilities and may be produced to a high-quality finish. It's small and versatile, and it may be used for a variety of tasks. Finally, ABS has a low heat and electricity conductivity, making it ideal for items that require electrical insulation. It also has good impact resistance and can efficiently and consistently absorb shock [13].

Disadvantages

Some downsides of ABS plastic exist to counteract these benefits. Because of its low melting point, it is not suitable for high-temperature applications or medical implants. It also has low solvent and fatigue resistance, and unless adequately covered, it is susceptible to UV exposure and weathering. Because of its poor conductivity, it can't always be employed in instances where it would be inconvenient for the overall design. When the ABS material is burnt, it produces a bit of smoke, which may raise issues about air pollution. While these drawbacks exist, ABS may be a cost-effective, beautiful, and high-performing thermoplastic with a broad range of advantages when utilized in situations where it is not subject to the limits stated above.

7.4.2 Using Polycarbonate

Polycarbonate is a strong plastic that can be moulded into a variety of forms and is exceedingly durable. It stands out for its ability to withstand a wide range of environmental variables, including dust, water, and corrosion. Polycarbonate is one of the most adaptable enclosure materials available, being durable enough to withstand even the harshest outside circumstances while yet being aesthetically beautiful enough to fit into virtually any workplace. It's a versatile enclosure material that may be utilized for a variety of purposes. It's widely utilized for anything from industrial control panels to electrical wire junction boxes. Because of its durability, it's ideal for outdoor enclosures, and its diversity of appealing designs also makes it a wonderful choice for inside enclosures. The material is also very cost-efficient at approximate efficient at approximately R55.00 per kg [14].

Requirements met

The table below shows which user requirements polycarbonate meets.

Requirement ID	Requirement Text	Met (✓) / Not Met (X)
RID001	Water Resistance	✓
RID002	Dust resistance	✓
RID003	No Air Gaps	N/A
RID004	Durable Material	✓
RID005	Adequate Ventilation	N/A

Table 49: Shows which requirements Polycarbonate meet.

Advantages

Polycarbonates have excellent heat resistance and may be used with flame retardant materials without degrading the latter. Polycarbonates, as noted above, are thermoplastics, which means they do not burn when heated. Instead, at their melting point (155° C), they turn into liquids. This feature aids in the melting, cooling, and reheating of polycarbonates without deterioration, allowing them to be readily injection moulded and then recycled [15] Polycarbonate is 250 times tougher than glass and nearly unbreakable. Polycarbonate is a good choice for protecting against harsh weather, flying debris, and vandalism because of its impact resilience. Solid or multiwall polycarbonate sheets are routinely offered in conventional widths and thicknesses ranging from 4mm to 32mm. Following the manufacturer's directions, the material may be sculpted or bent at room temperature using conventional equipment [16].

Disadvantages

The main disadvantage of polycarbonate is that it isn’t resistant to scratches. For example, if something should happen to fall on a protective casing made of polycarbonate, it may be scratched. This problem can be solved by polishing the polycarbonate. Polycarbonate also expands at a rate of 0.065 mm per meter per degree Celsius [15]; [17]. It shouldn't be an issue as long as we keep this information in mind when processing. In our case, it shouldn’t be an issue as even if the components inside over-heat, it will still be within the limits of what polycarbonate can withstand.

7.4.3 Comparing Acrylonitrile Butadiene Styrene to Polycarbonate

Below is a table showing the comparison between ABS and Polycarbonate against a list of properties.

Criteria	Acrylonitrile Butadiene Styrene	Polycarbonate
Production Cost	Cheap at R45/kg	Slightly more expensive at R55/kg
Technical maturity	High technical maturity as ABS is a commonly used plastic for protective enclosures.	Although Polycarbonate is a highly technically mature material, it isn't mainly used for protective enclosures
Ease of manufacturing	Easier to manufacture once all the chemicals have been sourced. Required chemicals are usually readily available as they are quite common	Fewer ingredients are needed to make polycarbonate, but extreme heat is required in the manufacturing process
Implementation	Using ABS will be easy as mentioned before it is commonly used for appliance and instrument housings, therefore satisfactory results are expected	Usually, polycarbonate is used for objects needing transparent casings even though adding colour or a design will not be difficult. Cutting and moulding the pieces into the shape required is possible without much effort
Ease of testing	Both materials undergo the same form of testing. Stress testing is a common and useful way to observe the levels of strain the material can handle.	Both materials undergo the same form of testing. Stress testing is a common and useful way to observe the levels of strain the material can handle.
Reliability	Very reliable, provided the conditions are not extreme. It can be reliable enough for indoor use.	Very reliable and used in extreme conditions. It can confidently be used in most conditions either inside or outside.
Maintenance costs	Maintaining a protective casing made of ABS is incredibly easy. A quick wipe with a damp cloth to keep it clean is more than enough, as the material is durable enough to not succumb to corrosion and physical damage	Polycarbonate is also easy to maintain but slightly more effort is required in the frequency of cleaning as the material tends to fade in colour making the protective casing look much older even though it is as durable as ABS in our operating conditions.

Table 50:ABS vs Polycarbonate

7.4.4 Final Choice

When manufacturers need a tough, translucent plastic that can readily combine colours and patterns, polycarbonate is the material of choice. When it comes to patterns and colours, polycarbonate always wins when compared to ABS. Polycarbonate is also heat resistant and flame retardant to some extent.

Acrylonitrile, Butadiene, and Styrene are the three plastic ingredients that make up ABS. The ABS plastic mix, when combined, creates a great impact-resistant material that can be readily processed into various forms and has a beautiful shine. Acrylonitrile Butadiene Styrene plastic is also significantly less costly than polycarbonate sheet material. The chemical and hardness component in ABS plastic is provided by Acrylonitrile, while the impact resistance characteristics are enhanced by Butadiene, and the heat resistance and good property upgrades are provided by Styrene [18].

For our protective casing, we believe Acrylonitrile Butadiene Styrene is a better choice as the material to be used. It meets all the user requirements and is easier to manufacture and implement. It is also the more favourable option as costs for production and maintenance are also lower and prove to be more reliable in the long run.

7.5 Model diagram and possible constraints and limitations

7.5.1 V-diagram

The V diagram below depicts the design process for the protective case and the testing phase. The planning and thought process behind the sort of protective casing are discussed in the design phase. The system was designed to meet the needs of the users, which dictated the type of mock system that was created. System implementation describes what materials will be used, what sort of adhesive or air seal will be used, and what overall shape the casing will take. The testing phase includes the vigorous tests that the system needs to pass. The casing will be subjected to harsh physical tests and many water and dust resistance tests. Only once the protective casing has passed all the tests with flying colours, will it be released to the public.

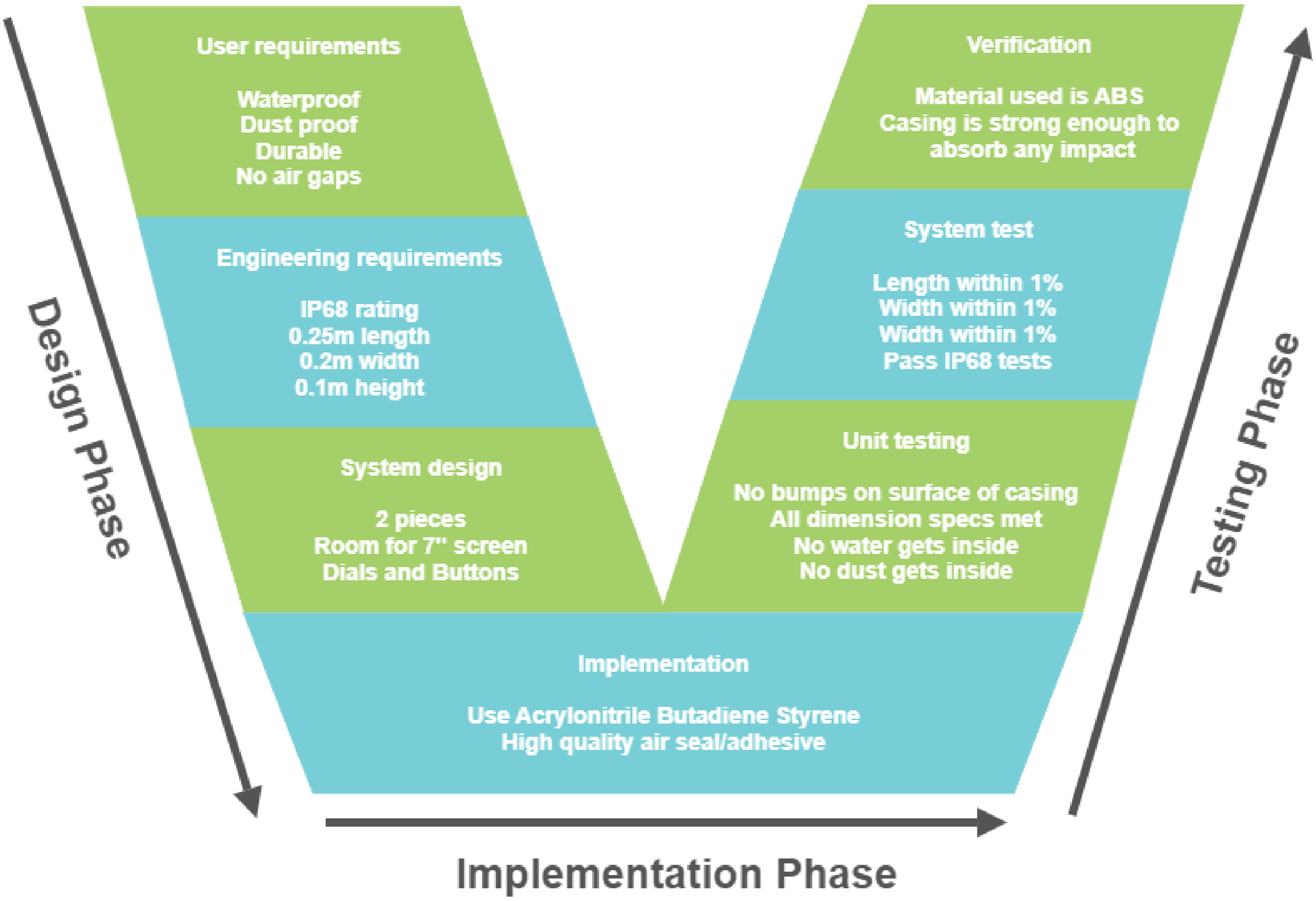


Figure 46: V-diagram for Protective casing

7.5.2 Constraints and Limitations

This section will go further into the design's constraints and limitations. The constraints and limitations of the module influence its viability. This will allow any design flaws to be addressed before implementation.

7.5.2.1 Temperature Constraints

The temperature is one of the most important factors to keep under control in electronic enclosures: the heat produced by the components inside the enclosure combined with the external temperature means that there is a need to control to avoid jamming the instruments and components it contains. We need to reduce the temperature inside the structure through ventilation to fix the problem. [19]

7.5.2.2 Dust and Insects entering through air gaps

While proper ventilation is needed, it must not be an entry point for dust and insects as this would mean the casing has not met a fundamental user requirement and can easily damage the components inside the casing. This could be solved by using a fine mesh to stop foreign particles from entering the device [19].

7.5.2.3 Waterproofing constraints

Having a protective casing with ventilation is key to its success, but this ventilation, although having a fine mesh to protect from dust particles and insects, is susceptible to water entering inside and damaging the components. This is why having the casing be IP68 rated is vital to its success in the workplace.

7.5.2.4 Material production issues

We have chosen ABS as the main material for the protective casing. There could be issues while mass-producing ABS, causing its structural integrity to be a concern. Since ABS is mass-produced, a large batch of protective casings made may suffer from poor structural integrity if anything goes wrong in the manufacturing phase of the material.

7.5.3 STEEPLE Analysis

7.5.3.1 Social

Using locally sourced chemicals to make ABS and then South African companies to manufacture the casing will help the local community grow. The product is not designed/manufactured/advertised in a way that would offend any cultural/religious or racial groups

7.5.3.2 Technical

The casing is not necessarily an advanced piece of technology. However, the product must be manufactured with incredible accuracy as any inconsistencies may cause the device to not function as intended. The main function is to protect what is inside.

7.5.3.3 Economic

The manufacturing of this product will be done by local businesses, thereby helping our south African economy grow and creating more job opportunities for many people which would not occur if manufacturing was outsourced.

7.5.3.4 Environmental

We should all aim to decrease our carbon footprint. The production of the materials should be done with clean energy and with recycled materials where possible. All waste products should be disposed of in an environmentally friendly manner.

7.5.3.5 Political

The manufacturing of the protective casings is not funded by any political party or does not align with the agenda of any political party or political group.

7.5.3.6 Legal

All ingredients used to manufacture the materials that have the potential to offend any social group need to be disclosed to avoid liability. All safety regulations are met, and the manufacturing process is well documented

7.5.3.7 Ethical

The right ethical standards will be observed during the production of the protective casing. Everyone involved in the development would be treated equally. There will be systems in place to allow workers to report any instances of unethical behaviour and or treatment by anyone else. These systems will hold the accused parties accountable for their behaviour ensuring that the work environment is transparent and not toxic [20].

7.5.4 Other Issues to consider

7.5.4.1 Health and safety

Injection moulding involves heating and cooling substances rapidly and repeatedly therefore, every part of the injection moulding process will be performed with all the necessary protective gear and all safety regulations must be adhered to so as to keep all workers safe. This ensures no damages to machinery and no harm to any worker in the work place.

7.6 Subsystem design

7.6.1 OPM Diagram

The injection moulding process involves regularly and rapidly filling strong metal moulds with molten polymers, allowing for the mass manufacture of identical parts in enormous quantities. Simple enclosures made of rigid or non-rigid plastics, such as those used in gaming controllers, electronic keys, kiosk displays, and a variety of other items, are frequently made using this technology.
Injection-moulded enclosures have a longer lead time and higher initial overhead due to tooling costs, but when manufactured in large quantities, parts become extremely cost-efficient [21].

Below is an OPM diagram of the Injection moulding process.

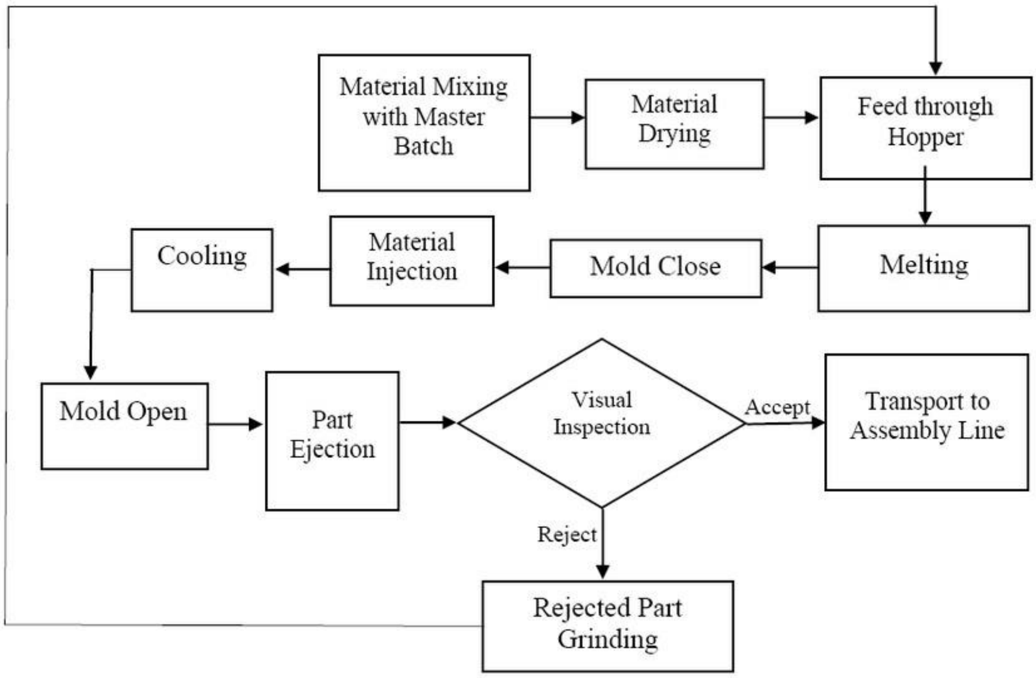


Figure 47: OPM diagram of injection moulding process

7.6.2 Simulated design

Below is a figure showing an initial sketch of what the device enclosed in the protective casing could look like from all six views.

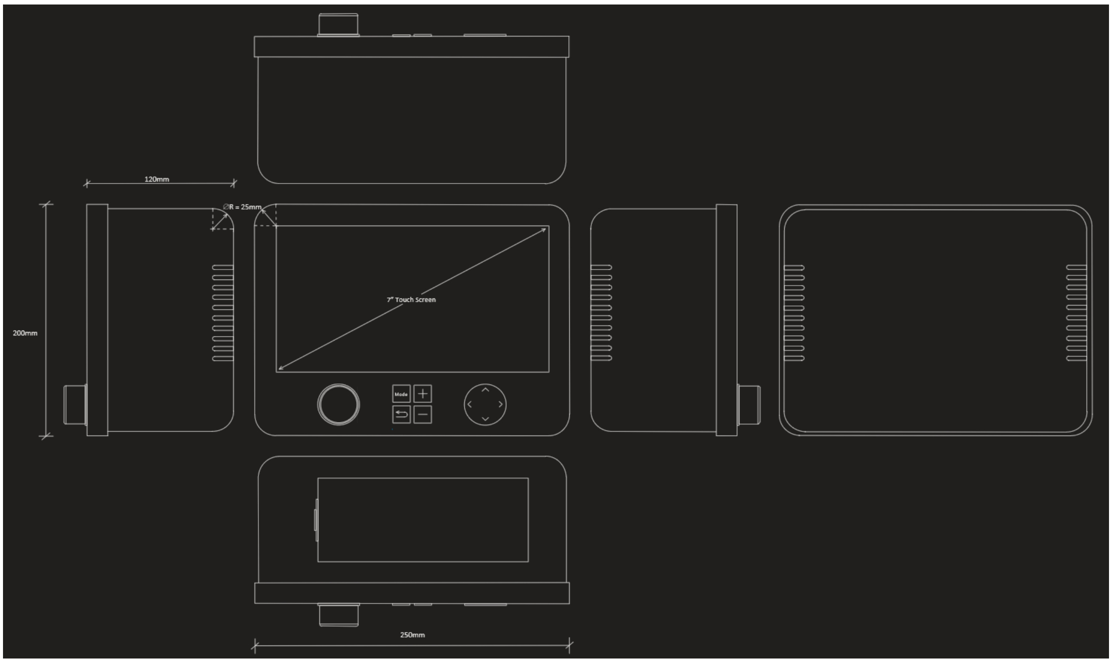


Figure 48: Initial schematic of protective casing

Once a general idea was formed and agreed upon, with the aid of AutoCAD, a more accurate representation of all six sides were generated.

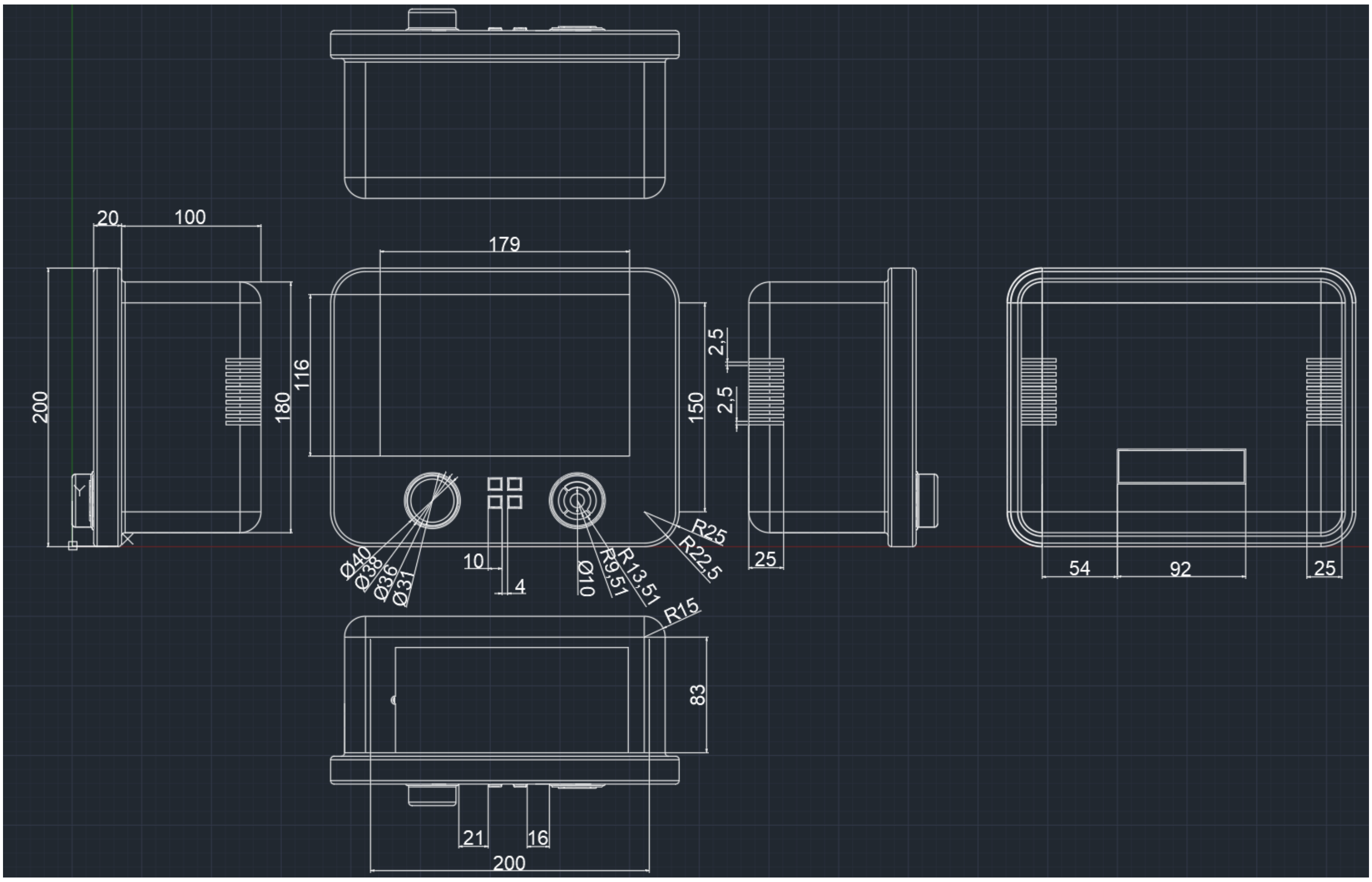


Figure 49: Detailed schematic of protective casing

Once the schematic above was finalised, we began a 3D modelling process using Shapr3D to be able to better visualise what the casing would look like. Below is the 3D model of the protective casing with the 7'' screen detailed above in the user interface subsystem.

Figure 50: 3D model of Protective Casing

Some more angles to see the rear of the device in the protective casing are below.

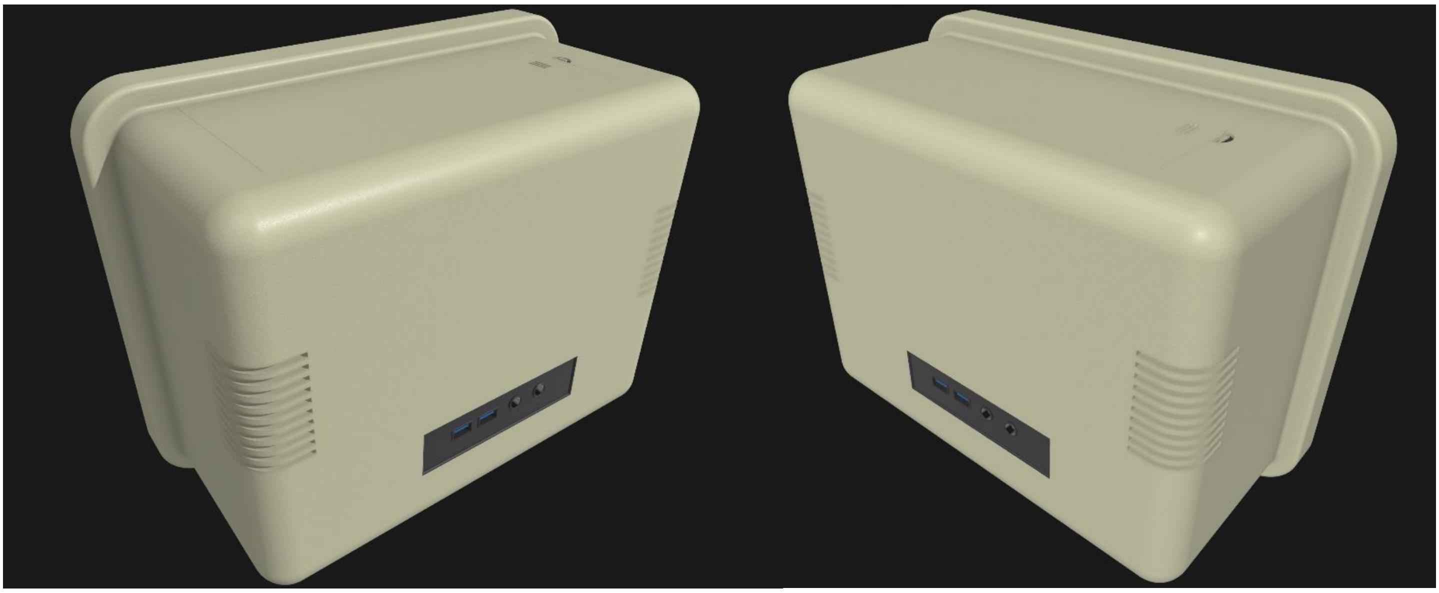


Figure 51: More angles of the protective casing

7.6.3 Sensitivity analysis

The injection moulding process has a lot of moving elements, but that doesn't mean you can't optimize how you do it and ensure the quality of your end product. Professionalism, optimization, and attention to detail, among other things, are all valuable assets. Below is how to make the most of each to improve the injection moulding process [22].

Optimization of the injection moulding process

Both small and large manufacturing processes need a keen eye for detail and optimization. For example, the process should allow the machines to run as long as possible without interruption. Standards for loading and unloading moulds predictably and efficiently should be in place wherever possible. If the work requires you to keep to a certain production schedule or produce a certain number of products per hour, optimization might be the key. Effective staff training is another key to optimization. The people in charge of the machines should be able to keep focused without having to second-guess themselves. How to cool the products is another issue to optimize and keep in mind. Optimize the process so that it runs smoothly throughout the whole manufacturing process [22].

Monitoring production rates

Part two of optimization is keeping track of the manufacturing efforts at all times. It involves holding people accountable but simultaneously recognizing achievement. It's crucial to have a well-trained and passionate staff, but one should also have checks in place to detect bottlenecks in the production processes or places where their training may have fallen short. Making rewards available for team members who continuously surpass objectives or maintain safe work practices without losing efficiency is typically a demonstrable advantage. Manufacturing companies have reported significant labour cost reductions just by rewarding safe and high-quality work [22].

Efficient material use

Another important tip for optimizing the injection moulding process and the quality of our end product is to use resources wisely and efficiently. One option is to reduce the shot size. Experts say that reducing the shot size by 10% of the machine's maximum capacity will enable the application nozzle to extract more colour and completely work the check ring. Both procedures make cleanup easier in the future and assist to decrease waste. Another technique to guarantee that our materials budget is stretched as far as possible is to use suitable thermoplastic for our application. ABS plastics strike a great balance between cost and durability [22].

Preventative Maintenance

One item that should not be forgotten is preventive maintenance. When it comes to preventative maintenance, make cleaning the equipment a high priority. Spend some time drafting a repeatable cleaning procedure for the hopper and conveyor sections to ensure they're clear of debris. Taking this seriously can help prevent cross-contamination by ensuring no colours are seeping in from the previous cycle [22].

The above are just a few suggestions to improve the injection moulding process. Improving this process ensures the protective casing we want to build is built with the highest accuracy and efficiency.

8 Conclusion

For this project, the main goal was to develop a system that would be able to monitor the machinery used in the business. This system would assist in monitoring the machinery in the business, by making sure the machine's operating parts worked at optimum conditions, and the machine was not harming the environment by dispersing harmful gases or chemicals. This information would be related to the owner of the machinery through a user interface. The system was to be housed in a protective case along with an independent power source making the entire system robust.

Initially what was done through the design process was identifying the issues around operating machinery in a business and the effects it had on the environment and the owner. From this, we were able to set out goals for the design and began planning how we were going to achieve these goals. One of the main issues that came out from the investigation was that machinery that was out of commission due to it being broken or needing repair affect the businesses using machinery, especially small businesses. Another issue that arose was that when not properly monitored the machine may be releasing harmful chemicals and gases into the air, which increases the carbon footprint of the business. One of the requirements set out by the user was that they wanted to make sure their business is doing its part for the environment. After deliberating about the problems stated above the following conclusion was drawn to make sure that the machine is working at optimal conditions while providing an eco-friendly solution, this could be achieved by addressing the monitoring of operating parts and the air quality around the machine.

Through investigation and discussion held amongst the team, a viable solution was initialised and broken down into submodules that were accessed and designed by the members of the group. The design entailed a monitoring system that would make use of sensors to monitor different aspects of the machine and display the information to the user on a screen. As the system needs to be able to be moved around and placed on machinery that had movement it required a casing that would be able to protect the system and a power source that would allow for the system to be moved around. From this, the system was broken down into the following subsystems user interface, power supply, air quality sensors, machine operating sensors and protective casing.

Once the subsystems were identified, the user requirements were analysed and accessing different design choices, the best solution for each subsystem was chosen. With the use of the STEEPLE analysis, each solution for subsystems was analysed. The limitation and constraints of each design were considered as well as any technical disruption that could occur where accessed. The functionality of the designs was accessed through the use of simulations. Once all of this was completed we were able to determine if our system worked as predicted and was a viable and functional solution to the problem that was faced.

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Appendix A: ELO Requirements

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	2.5 Brief Description of the Subsystems	12
	3.1 Introduction	13
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	3.3 Requirement analysis	13-14
	3.4 Design choices	15-17
	3.6 Subsystem design	20
	3.6.1 OPM Diagram for the module	20
	3.6.2 Subsystem simulation and prototyping	22
	3.6.3 System Module Optimisation	22
	3.7 Sensitivity Analysis	22
ELO 7	3.5 Design model, STEEPLE analysis with possible constraints and limitations	18-22
	3.5.1 V diagram	18
	3.5.2 Constraints and limitations	19
	3.5.3 STEEPLE Analysis	19
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ELO 8	Met on teams, worked on subsection (machine operating sensors) and group sections	Can be found on Microsoft teams, as well as WhatsApp chat found in the files section
ELO 10	3.5 Design model, STEEPLE analysis with possible constraints and lmitations	18-19
	3.5.1 V diagram	18
	3.5.2 Constraints and limitations	19
	3.5.3 STEEPLE Analysis	19
	3.7 Other issues	22
	Report presentation (whole report)	Whole Report

Name: Nathanael Thomas Student Number: THMNAT011 Task: Subsystem 2 – Power Supply (Section 4 of the report)		
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ELO 8	Met on teams, worked on subsection (machine operating sensors) and group sections	Can be found on Microsoft teams, as well as WhatsApp chat found in the files section
ELO 10	4.5 Design model, STEEPLE analysis with possible constraints and limitations	27-29
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	Report presentation (whole report)	Whole Report

Name: Jake Burditt Student Number: BRDJAK001 Task: Subsystem 3 – Air Quality Sensors (Section 5 of the report)		
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ELO 3	1 Introduction to the project	9
	2.1 Design School Activities	9 -10
	2.2 Design Choices	10
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ELO 7	5.5 Design model, STEEPLE analysis with possible constraints and limitations	
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	5.5.3 STEEPLE Analysis	40
	5.8 Other issues	40
ELO 8	Met on teams, worked on subsection (machine operating sensors) and group sections	Can be found on Microsoft teams, as well as WhatsApp chat found in the files section
ELO 10	5.5 Design model, STEEPLE analysis with possible constraints and limitations	
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	Report presentation (whole report)	Whole Report

Name: Yondela Matwele
Student Number: MTWYON001
Task: Subsystem 4 – Machine Operating Sensor (Section 6 of the report)

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ELO 8	Met on teams, worked on subsection (machine operating sensors) and group sections	Can be found on Microsoft teams, as well as WhatsApp chat found in the files section
ELO 10	6.6 STEEPLE analysis with possible constraints and limitations	51-53
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	Report presentation (whole report)	Whole Report

Name: Akhil Jacob Student Number: JCBAKH001 Task: Subsystem 5 Protective casing (Section 7 of the report)		
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ELO 3	1 Introduction to the project	9
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