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by Thomas Grennan

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Name: Thomas Grennan

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1. Executive Summary

Summary is too long

The proposed Ingredient Dosing System project for a Small to medium enterprise (SME) customer within the bakery industry has been successfully researched, evaluated and planned resulting in a clear implementation plan being developed for 2023. The current method of weighing and layering ingredients is labour intensive and time consuming, requiring operators to manually weigh and load the ingredients into a mixing bowl in layers. Due to new contracts the customer must scale up production and ensure that the tray bake ingredient mix is highly accurate to the recipe due to quality concerns from the end-user's customer. Therefore, a flexible fully automated dosing and weighing system with traceability features must be commissioned by 17/04/2023 in line with the new contract start dates.

Initially, the project constraints were researched to outline any issues that would affect the project early on. The first constraint found was that dust clouds can occur when flour is dispensed, potentially causing explosions if ignited by a spark. Extensive research found that the ATEX directive 2014/34/EU must be followed to ensure that the constructed system is designed in a manner to operate in this environment. The second main constraint is due to the system dosing food products, requiring care and consideration in the design and manufacturing stage to ensure no contamination can occur, FDA guidelines, case studies and UK legislation will be followed during the design and implementation phase. Other constraints included the requirement to conform to the machinery directive to achieve UKCA conformity. Ethical, Sustainability, Environmental and Intellectual Property and Risk constraints were also outlined.

too much detail for a summary

A functional design specification (FDS) was developed with the end-user to outline key requirements and deliverables that must be achieved to ensure the project is successful. Ranging from customer specification, applicable standards and the author's requirements. A test plan was then developed and divided to allow for conformity and functional testing, providing a clear method of testing to ensure that all of the FDS' criteria is achieved.

Three solutions were researched and developed in line with the FDS to automate the ingredient dosing system. All solutions were similar, only changing in control philosophy. Solution 1 utilises a Siemens S7-1500 PLC as a stand-alone system, Solution 2 requires the system to operate as a slave to another production line in the end-user's factory through an ET200SP Remote IO CPU and Solution 3 implements a Raspberry Pi microcontroller to control the process. 10 criteria points were used to compare each solution, it was found that Solution 1 is the most achievable option within the timeframe, also offering the lowest overall cost.

Never start a sentence with a number

Project management techniques were developed to create Work Breakdown Structure (WBS), Gantt chart and resource plan to develop a clear implementation plan commencing on January 3rd 2023 to be delivered and installed by April 2023.

2. Introduction

The proposed project is an automated ingredient dosing system for a customer in the baking industry requiring a production increase due to new contracts. The project aim is to improve quality, consistency and speed of dosing the tray bake mix due to concerns of inconsistency and variance in the end product. The project is justified to reduce the waste of raw materials and remove a highly-frequent labour-intensive operation. Currently, the process requires 6 ingredients (Plain Flour, Self-Raising Flour, Caster Sugar, Light Brown Sugar, Scone Mix and Oats) to be manually weighed and loaded into a mixing bowl in layers, where human-error is frequent requiring product to be scrapped.

The project proposes a fully automated system with 6 bulk hoppers to accurately dose and weigh ingredients into a mixing bowl within ATEX zones 20, 21 & 22. The control system must be flexible and designed to allow users to create, modify and store 'recipes', whilst providing traceability features to trace and re-call products if required.

The authors company will design, manufacture, commission and install the system. The budget for electrical and software tasks is £110,000 and must be completed by April 2023.

3. Project Background and Problem Definition and Constraints

3.1 Project Background

The project is based within a special purpose machinery company who designs, manufactures and installs automated machines for a wide range of sectors. The company has been awarded a project to develop a system that accurately dispenses and weighs ingredients for tray bake products for a customer within the baking industry. The project is part of "Ffatri 4.0" with the aim of proving that productivity and sustainability targets in manufacturing can be achieved through digital manufacturing technologies (gov.wales, 2022).

An overall layout diagram (with labels) of the system would have been useful for your reader

3.2 Problem Definition

The customer has concerns that there is a variance of consistency and quality of their product. As the company is producing vast quantities of products for the same customers, it is vital that each product tastes and looks the same.

The current method of measuring the ingredients is labour-intensive and time-consuming requiring operators to manually weigh and load over 100kg of ingredients into a mixing bowl up to 20 times per day during peak periods. The process relies on the operator's accuracy when loading the correct ingredient type and quantity, making the process susceptible to human error, often resulting in large quantities of product being scrapped causing revenue losses of up to £3300. An automated dispensing and weighing system is required to accurately dispense and weigh the exact amount of ingredients every time increasing consistency, enabling labour to be used elsewhere within the bakery.

Due to the nature of flour causing dust clouds when it is dispensed which can be ignited by a spark, the system must be designed in line with ATEX directive 2014/34/EU for Zones 20, 21 and 22.

Classification of explosive atmospheres ATEX / IEC		
Definition	ATEX and IEC	
	Gas	Dust
An area in which an explosive atmosphere is continually present	Zone 0	Zone 20
An area where an explosive atmosphere is likely to occur in normal operation	Zone 1	Zone 21
An area where an explosive atmosphere is not likely to occur in normal operation, but may occur for short periods	Zone 2	Zone 22

Figure 1 - Classification of ATEX Explosive Atmospheres (Electronics, 2020)

3.3 Constraints

3.3.1 Professional Conduct, Ethics & Legality

This section on ethics was worth 5 marks. One paragraph is limited

The author is registered with the Institution of Engineering and Technology (IET); therefore, their 34 rules of conduct are followed. Members must observe the current provisions of the Engineering Council and Royal Academy of Engineering's Statement of Ethical Principles, upholding the institutions reputation and ensuring that members do not undertake professional tasks and responsibilities that they are not competent to discharge (IET, 2019).

As the system is processing food product, great care is to be ensured during design to ensure consumer safety. The legal requirements for hygienic design of food machinery outlined in the Supply of Machinery (Safety) Regulations 2008 must be abided by, these are outlined in table 1. (HSE, 2017).

Key Regulations in the Design of Hygienic Machines	
Rule	Regulation
1	Materials coming into contact with food satisfy certain conditions as to suitability and surfaces in contact with food are smooth, have minimum edges & recesses.
2	The machine can be cleaned before each use and can be easily dismantled for cleaning
3	Machine Lubricants cannot come into contact with foods product
4	Cleaning or disinfecting chemicals can be completely discharged from the machine
5	Organic matter cannot accumulate in areas that cannot be cleaned
6	Food safe materials must be used where it is in contact with food products
7	Instructions must be provided to indicate recommended cleaning methods and products

Table 1 - Key Regulations in the Design of Hygienic Machines (HSE, 2017)

To comply with UK legislation, 178/2002 'General Food Law' Article 18 must be followed requiring food and food substances to be traceable, allowing product to be traced and recalled if required (FSA, 2020). The project must be capable of storing batch codes of the ingredients stored in the hopper, it must also create a batch code for the final dosed product, this enables the "one step back, one step forward" supply-chain rule to be followed, required by 178/2002 (epicor, 2020). Along with batch codes, dates, times and personnel information will be stored to aid traceability.

A legal contract will be drawn up and signed by both parties, this sets in stone project deliverables, timelines, expectations and information required to successfully complete the project, this will include any repercussions such as fines due to late delivery. The project will

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Spelling

follow the companies 14 stage plan, ensuring all project milestones and machinery directive compliance are achieved (Automation, 2020).

Automated equipment is often associated with redundancies and loss of jobs, however, the current operators will be trained to operate and maintain the ingredient dosing system, finishing line and other equipment introduced as a part of Ffatri 4.0, ensuring their jobs are secure. This application utilises automation as an assistant, not a replacement and so is used in an ethical way (thinkautomation, 2021).

3.3.2 Machine Safety Requirements

It is essential that the operator and wider community can safely operate the machine. To ensure safety of the author and colleagues, the Health and Safety at Work Act 1974, The Electricity at Work Regulations 1989 and Provision and Use of Work Equipment Regulations 1998 (PUWER) will be abided by at all times as a legality within the UK.

The machine will be installed in 2023 in the UK market requiring UKCA conformity. As the system will only be placed within the UK market CE conformity is not required (HSE, 2022). The authors company self-declares compliance, requiring a technical file to be created, this contains information about the means used to ensure that the product meets essential requirements of the machinery directive (gov.uk, 2022).

The project must meet the machinery directive as the product falls under the category stated as *gov.uk states that "....." (2022)* *"an assembly, fitted with or intended to be fitted with a drive system other than directly applied human or animal effort, consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application"* (gov.uk, 2022). It is essential that these regulations are followed as gov.uk states *"it is an offence for a 'responsible person' to supply machinery unless they comply with the 2008 Regulations"* (gov.uk, 2022). *source already stated*

To comply with the machinery directive an "Essential Health and Safety Requirement" report must be compiled to determine which requirements outlined in annexe 1 of the directive apply to the machine including machine ergonomics, noise, external radiation and energy sources. This document outlines potential hazards operators may face when in the machine danger zone (safe:machine, 2020).

A risk assessment will be undertaken to determine the machine performance level from an industry standard Severity, Frequency and Possibility matrix seen in Figure 2. The performance level (PL) is a value used to define the safety-related parts of a control systems ability to perform a safety function under foreseeable conditions. The required performance level (PLr) sets a guideline to achieve the required risk reduction for each safety function, thus

requiring the PL to be higher or equal to the PLr (Keyence, 2019). A SISTEMA report will be compiled using manufacturers data to ensure that the machine safety function is reliable through statistical reliability analysis of the functional safety system, also confirming the control systems performance level as per EN ISO 13849-1:2015 (IFA, 2011).

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What PL rating are you working towards?

Required performance level (PLr) according to ISO 13849-1

This standard also uses a risk graph to determine the required safety level. The parameters S, F and P are used to determine the magnitude of the risk.

The result of the procedure is a "required performance level" (PLr).

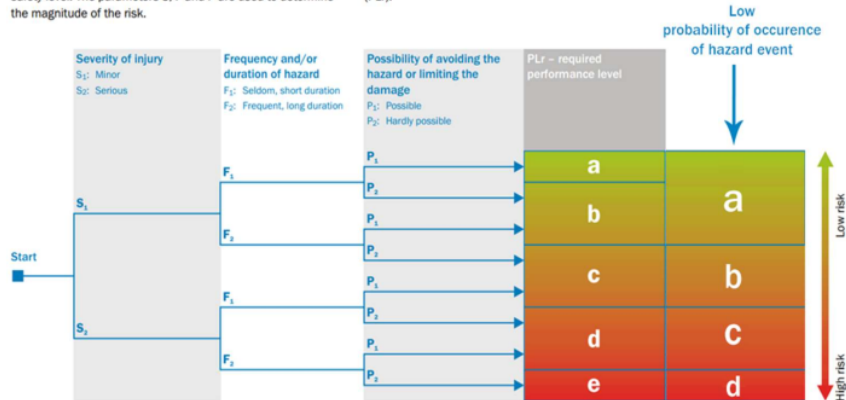


Figure 2 - Performance Level Graph (Barr-Thorp, 2021)

The ingredients dosed are susceptible to creating dust clouds. The Equipment and Protective Systems Intended for use in Potentially Explosive Atmospheres Regulations 2016 must be followed, formally known as ATEX - Directive 2014/34/EU. This regulation covers equipment intended to be used in potentially explosive atmospheres that are capable of causing an explosion through their own source of ignition (gov.uk, 2022).

All control systems will be designed following BS EN 60204 - Safety of Machinery Electrical Equipment of Machines, covering a wide range of clauses from cable colours, pushbutton colours, isolation devices and IP ratings. An engineer not associated with the project will undertake a "60204 Checklist" to ensure that the system is compliant.

The Electromagnetic Compatibility Regulations 2016 will be followed, ensuring all best practices are followed to minimise Electromagnetic Interference on equipment within the same electromagnetic environment.*how will this be checked?*

3.3.3 Environmental and Sustainable

The machine design will have environmental considerations. "Air-Saver" functionality will be incorporated to remove air from the system if no machine actions have been made within 10 minutes, preventing the waste of compressed air. Energy sources will be monitored, in order for the system to be sustainable it must be cost effective to run to meet the return on investment (ROI), this equipment will allow for the running costs to be determined. Technologies like PROFlenergy will be implemented where viable to reduce energy consumption (Profibus, 2021).

The system will be designed to ensure power consumption is low as possible, all control equipment will be 24VDC powered from a 230VAC-24VDC Power Supply Unit (PSU) which is the only mains device, operating at a low power of 460W resulting in a low yearly cost of £375.36 to run the system seen from the calculations in appendix 9.3.

The system will be designed so that it not only complies with legislation, it will be designed to minimise the adverse impact to the environment by striving to go beyond the minimum requirements. Resources will be used efficiently and effectively, the system is designed in a manner where ingredients other than the current 6 can be processed through the system through software modifications, this allows for the system to be re-usable if certain ingredients are no longer required.

The project as a whole will seek multiple views in order to solve sustainability challenges, engaging with project engineers and stakeholders to understand the requirements and perspective of those involved.

3.3.4 Intellectual Property

Intellectual Property such as PLC programs and drawings are property of the Original Equipment Manufacturer (OEM). A machine manual including drawings is supplied to the customer to aid with operation, fault finding and general reference. PLC programs will be available for monitoring but must be password protected to ensure no modifications are made unless authorised by the company, modifications made to the system will void the warranty as per manufacturers discretion (Manufacturing, 2018). In compliance with UKCA marking, a technical file must be available for 10 years after the machine is manufactured, this belongs to the manufacturer and only the enforcement authorities have the right to request it under reasonable grounds (Spiers, 2022).

3.3.5 Risks

As a result of COVID-19 and Brexit, the World is suffering from supply-chain issues, coupled with the shortage of Integrated Circuit (IC) Chips have resulted in mass shortages of control equipment (Montague, 2021). Suppliers are unable to give accurate delivery dates on components, which is a major risk having the potential to put the project on hold, preventing it from meeting the deadline.

What is your strategy to deal with this issue?

4. Functional Design Specification and Test Plan

4.1 Functional Design Specification

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The Functional Design Specification (FDS) comprises of customer specification's (CS) and standards that must be followed. The specification is broken down into 8 different types of deliverables that must be achieved, outlined below:

P - Performance

S – Safety

D – Diagnostics

A – Aesthetics

T – Technical

F – Financial

E – Environmental

G - Ergonomics

Functional Design Specification		
Ref.	Requirement	Standard
P.0	4-off 375 Litre capacity stainless steel hopper for Caster Sugar, Light Brown Sugar, Buttery Scone Mix and Rolled Jumbo Oats	Customer Specification
P.1	2-off 500 Litre capacity stainless steel hopper for Plain & Self-Raising Flour	Customer Specification
P.2	System must detect if a hopper is empty	Customer Specification
P.3	System must allow for 'Recipes' to be added	Customer Specification
P.4	System includes function to add external product to mixing bowl	Customer Specification
P.5	System includes function to empty each hopper for cleaning	Customer Specification
P.6	Weigh Scale must allow for weights up to 320Kg	Customer Specification
P.7	Weigh Scale must be accurate to 20g (0.02Kg)	Customer Specification
P.8	GUI must have 12" Display	Customer Specification
P.9	System must be supplied by Single Phase 230V 50Hz	Customer Specification
P.10	System must include connection to a Siemens IOT2050	Customer Specification

P.11	System must include IFM DF2101 IO-Link fuse modules	Customer Specification
S.0	System Performance Level (PL) must be greater than or equal to the Performance Level Required (PLr)	ISO 13849-1:2015
S.1	All protective conductor connecting points must be marked or labelled with IEC 60417-5019:2006-08 symbol.	BS EN 60204-1:2018 8.2.4
S.2	All equipment within the ATEX zone must be adequately rated i.e., Equipment in Zone 22 must be rated to minimum Zone 22	Equipment and Protective Systems Intended for use in Potentially Explosive Atmosphere Regulations 2016
S.3	Air Service unit must have a shut-off valve of the lockable type	ISO 13849-1:2015
S.4	Main Electrical Panel must have an isolator of the lockable type	BS EN 60204-1:2018 5.3.3
S.5	Signals between the safe and ATEX zone must be connected through barriers	Equipment and Protective Systems Intended for use in Potentially Explosive Atmosphere Regulations 2016
S.6	The system must be designed following the best EMC practices	The Electrical Equipment (Safety) Regulations 2016
S.7	Live parts shall be located inside enclosures that provide protection against contact with live parts, and can only be opened with a proprietary key	BS EN 60204-1:2018 6.2.2
D.0	The system must display the status of Inputs, Outputs and Alarms	Manufacturers Specification
D.1	The system must display information on the current sequence step	Manufacturers Specification
D.2	The system must detect a loss of air pressure	Manufacturers Specification
A.0	Machine Frame Powder coated to RAL7035	Manufacturer Specification
A.1	Control Panels outside of ATEX zone to be Mild Steel minimum IP54, finished in RAL7035	Manufacturers Specification
A.2	Control Panels in ATEX zone to be Stainless Steel minimum IP66, unfinished	Manufacturers Specification
A.3	Actuator colours will be designed in accordance with BS EN 60204-1	BS EN 60204-1 10.2.1
T.0	Technical File must be compiled including System Overview, Drawings, Calculations, Risk Assessment, Conformity Documentation, Instructions and Manufacturers declaration	Supply of Machinery (Safety) Regulations 2008
F.0	Project must be delivered within budget	Manufacturers Specification
E.0	Must incorporate "Air-Saver" mode after 15 minutes of inactivity	Customer Specification
E.1	System must monitor Electricity consumption	Customer Specification

E.2	System must monitor Air consumption	Customer Specification
G.0	GUI must be mounted 1.5m from the floor to the centre	Customer Specification
G.1	Main electrical isolator must be mounted between 0.6m and 1.7m	BS EN 60204-1:2018 5.3.4
G.2	The system and equipment must be ergonomically designed to allow maintenance to be performed easily	BS EN 60204-1:2018 11.2.1

Table 2 – Functional Design Specification

4.2 Test Plan

A test plan based upon the deliverables set out in the FDS is compiled in table 3, these tests are carried out as part of the Factory Acceptance Test (FAT) by an engineer not associated with the project, ensuring no conflict of interest. Other test documents include a BS EN 60204-1:2018 Checklist and an EMC Checklist to ensure the system is designed in accordance with these standards. The test plan is divided into two test methods, conformity testing and functional testing.

4.2.1 Conformity Testing

Conformity, or 'Compliance' testing is a method used to ensure that FDS items that cannot be functionally tested conform to the FDS, it tests to ensure the implementation meets the requirements of the functional design specification (nist.gov, 2021).

Conformity Tests				
Ref.	Test Description	Expected Outcome	Actual Outcome	Evidence
P.0	Check the Hopper Capacity for Caster Sugar, Light Brown Sugar, Buttery Scone Mix and Rolled Jumbo Oats Hoppers	4-off 375 Litre capacity stainless steel hoppers are fitted for Caster Sugar, Light Brown Sugar, Buttery Scone Mix and Rolled Jumbo Oats		
P.1	Check the Hopper Capacity for Plain & Self-Raising Flour	2-off 500 Litre capacity stainless steel hoppers fitted for Plain & Self-Raising Flour		
P.8	Check the screen size of the GUI	GUI has a 12" Screen		
P.10	Check PLC network	System is connected to a Siemens IOT2050 Gateway		
P.11	Check 24V Circuit Protection	IFM DF2101 IO-Link Module Wired		
S.0	Compare the PL rating to the PLr rating	SISTEMA report confirms that the PL is greater than or equal to the PLr		

S.1	Inspect all protective conductor bonding points	All protective conductor bonding points are labelled in accordance with IEC 60417-5019:2006-08			
S.2	Check the ATEX rating of electrical components in the ATEX zone	All equipment within the ATEX zone is rated suitably to the risk assessment.			
S.5	Confirm that all electrical signals between the safe zone and ATEX zone are connected through barriers, or are suitably rated to allow for no barrier	Signals between the safe zone and ATEX zones are connected through intrinsic barriers, or are suitably rated to require no barrier			
S.6	Confirm EMC checklist has been completed	EMC Checklist is completed and passed			
S.7	Ensure that all mains live parts are protected against contact	All mains live parts are located in enclosures that provide protection against contact, which can only be opened by a proprietary key.			
S.3	Turn the main shut-off valve off and lock with padlock	Air Service unit is locked and cannot be reinstated, pressure switch indicates <0.5 Bar			
S.4	Turn the panel isolator off and lock with padlock	Electrical Isolator is locked and cannot be reinstated			
A.0	Check machine frame RAL colour	Machine Frame is powder coated to RAL7035			
A.1	Check the specification of control panels in the safe zone	Control Panels outside of ATEX zone are Mild Steel IP54, finished in RAL7035			
A.2	Check the specification of control panels in the ATEX zone	Control Panels in ATEX zone are Stainless Steel IP66, unfinished			
A.3	Check actuator colours	Actuator Colours conform with BS EN 60204-1:2018			
T.0	Check that the technical file is compiled	Technical File is compiled and saved in the project folder			

F.0	Check that the project budget has not been exceeded	Project budget has not been exceeded			
G.0	Measure the distance between the floor and centre of the GUI	GUI is measured at 1.5m from the centre to the floor			
G.1	Measure the distance between the floor and centre of the main panel isolator	Main electrical isolator is measured between 0.6m and 1.7m from the floor			
G.2	Ensure all maintenance activities can be undertaken	All maintenance activities can be suitably undertaken			

Table 3 – Test Plan: Conformity Tests

4.2.2 Functional Testing

The second test method is functional testing seen in table 4, these tests validate the software system against the functional requirements of the FDS. This section ensures that the system and sequences operate as intended (Hamilton, 2022).

Functional Tests				
Ref.	Test Description	Expected Outcome	Actual Outcome	Evidence
P.2	When the hoppers are empty, start a dosing cycle	After 10 seconds, the system indicates that the hopper is empty		
P.3	On the GUI recipe screen, add a new recipe and press save.	In the controller software, the new recipe is saved		
P.4	During a cycle that requires external product, add a product and enter the product weight	System acknowledges addition of external product, carries on with sequence		
P.5	Run a "Empty Sequence"	System runs an empty sequence, removes all product from the selected hopper.		
P.6	Load the scale with 320Kg	Scale indicates a weight of 320Kg, Weight displayed on GUI		
P.7	Dose 10 different recipes into the mixing bowl on the scale	Each recipe is manually weighed and is accurate to +/- 20g		
P.9	Test the incoming supply voltage	Incoming voltage is tested at 230V +/- 10%, All panel equipment is powered on		
D.0	Check GUI 'Diagnostics' screen	Diagnostics screen displays the status of the system Inputs & Outputs		
D.1	During a sequence, check the 'Auto' screen	Auto screen displays current sequence step number		
D.2	In any mode, shut off the main air isolation valve	System detects loss of air pressure and flags an alarm		
E.0	In any mode, do not control any machine functions	After 15 minutes of no operator action, the system removes power		

		to the dump valve, removing air from the system.			
E.1	Check 'System Info' Screen	System Info screen displays Electricity consumption information			
E.2	Check 'System Info' Screen	System Info screen displays Air consumption information			

Table 4 – Test Plan: Functional Tests

5. Literature Review

Three solutions have been researched and considered, all with the ability to automate the ingredient dosing system utilising the required hardware outlined in the FDS.

5.1 Solution 1

Solution 1 utilises a Siemens S7-1500 PLC to control the dispensing of ingredients using an ATEX rated two-stage proportional valve. The initial stage proportionally opens the valve between 0% & 100% in linear response to an analog signal between 4 & 20mA, allowing large amounts of ingredient to dose, as the target weight is approached it slowly closes. When the target weight is close, the fine-dosing stage takes over, dosing 10 grams per move utilising a two-position rotary valve, the process is repeated for the next required ingredients in the recipe, dosing in layers to aid with mixing (Mastrolonardo, 2022).

The analog signal from the PLC is input into a SMART Current Driver, which repeats the input signal on its output through an isolated DC/DC converter at a power level where sparks cannot be generated for use in ATEX zones (Pepperl+Fuchs, 2022) . The rotary valve will be controlled by PLC Outputs, the manifold will be situated in the ATEX zone. Therefore, it is rated to 'Ex n' where under normal operating conditions it cannot generate a spark (Derrick, 2020).

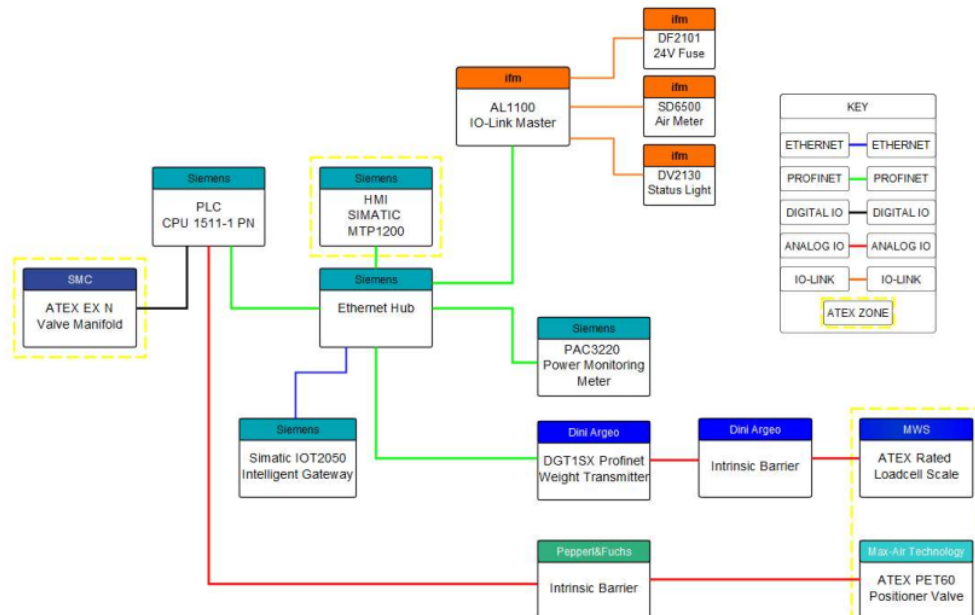


Figure 3 - Solution 1 Network Overview

An Ethernet Hub connects the PLC to field devices through PROFINET industrial ethernet. This includes an MTP1200 Siemens 12.1" Human Machine Interface (HMI) for operator control of the process and recipes.

An ATEX rated floor scale will initially tare the mixing bowl and weigh the ingredients dispensed through the valves. This is in the ATEX zone and will be connected using a load cell rated Zener Barrier to protect the excitation, signal and sense lines. The loadcell signals will be connected to a PROFINET weight transmitter to send the PLC an absolute weight in grams with a resolution of 0.01 $\mu\text{V/d}$ (Argeo, 2022) .

Environmental and financial assets will be monitored, incorporating a Siemens PAC3220 to monitor electricity consumption and IFM SD5600 to monitor compressed air consumption. The PAC3220 will communicate with the PLC via PROFINET (Siemens, 2021), whereas the SD5600 will be a 'Slave' to an IO-Link PROFINET master allowing real values to be read by the PLC (ifm, 2022). Both the PAC3220 and IO-Link master will seamlessly communicate with the PLC via General Station Description (GSD) files. The IO-Link master will also control a 1-segment lamp and buzzer to notify and display the machine status to the operator.

Solution 1 offers connection to Siemens MindSphere through a Simatic IOT2050 (Siemens, 2022), giving the customer the ability to store and display data on dashboards, enabling the process to be viewed and analysed. Solution 1 has component cost of £59,353.59 and a labour cost of £38,080.00.

5.2 Solution 2

Solution 2 is similar to Solution 1; however, this solution is controlled by the finishing 'Tray Bake Line' that is being installed in the same factory by the author. This line is controlled by a Siemens 1515 PLC. Utilising PROFINET, the S7-1511 PLC in Solution 1 is replaced by a more cost-effective Siemens ET200SP Remote IO CPU (Siemens, 2021), this CPU will be controlled by the Tray Bake Line PLC in TIA Portal, making this system a slave reducing CPU costs by £455 (Graham, 2022).

PROFINET cables can be connected between devices up to 100m (PROFINET, 2009), enabling a single communication cable to connect between the line PLC and ET200SP. This solution removes the requirement for an IFM IO-Link Master, instead enabling a cheaper ET200SP CM IO-Link card to be used on the ET200SP rack, maximising panel space (Graham, 2022) . The finishing line already has a SIMATIC IOT2050, thus allowing the hopper system data to be collected through the finishing line over PROFINET saving £360 and

maximising panel space (Siemens, 2021). All other hardware remains the same, Solution 2 has cheaper component costs, saving £807.59 compared to solution 1. However, overall, it is more expensive at £1,012.41 more than Solution 1, due to the extra labour hours required.

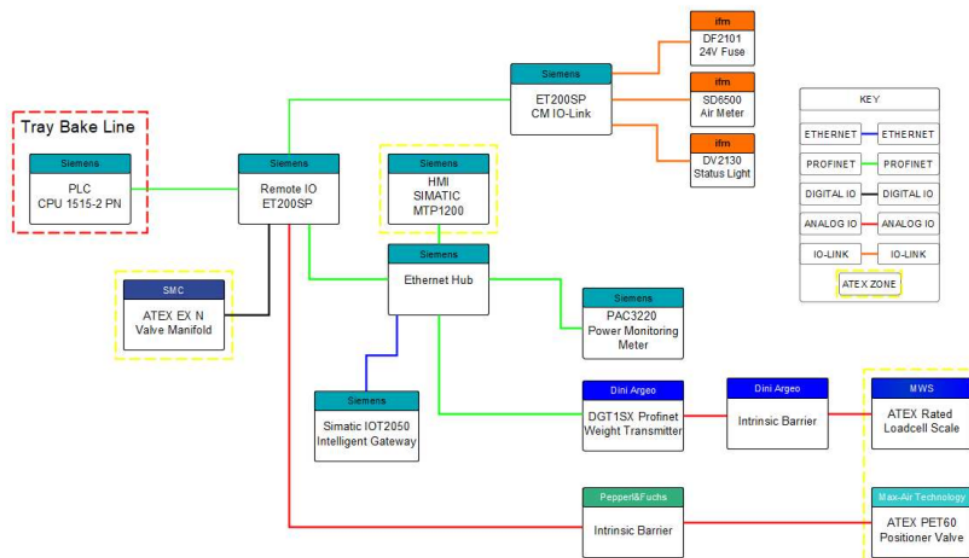


Figure 4 - Solution 2 Network Overview

5.3 Solution 3

Solution 3 utilises a Raspberry Pi Model 4 Microcontroller to control the system through Modbus-TCP, communicating with the field devices through an Ethernet Hub (MathWorks, 2020). The network architecture is similar to the previous solutions; however, the PROFINET devices are different, instead using Modbus-TCP.

The Raspberry PI is an economical controller, at a fraction of the price of a PLC, the largest capacity model costs £85, offering a multitude of free Integrated Development Areas (IDE) to program in (ThePiHut, 2022). The Raspberry Pi's General Purpose Input Outputs (GPIO) operates at 3.3Vdc adding complications integrating with the 24Vdc & Analog valves, requiring extra hardware (Pounder, 2020). Digital IO will require Interface Relays to control 24vdc equipment with the 3.3vdc GPIO, and the PET60 Positioner Valves require a 3rd party 4-20mA current loop transmitter module to be incorporated due to the lack of built-in analog outputs in the model 4 (ncd.io, 2022).

Sifam Tinsley's Modbus-TCP Power Monitor replaces the PAC3220 for monitoring of electricity consumption (Tinsley, 2021). Air consumption is monitored over IO-Link using a

Modbus-TCP master, also controlling the status light and buzzer (IFM, 2020). Dini Argeo offer a Modbus-TCP alternative to the Profinet Weight Transmitter used in Solutions 1 and 2, allowing for the same ATEX Loadcell scale and barrier to be used (Argeo, 2022). An ATEX zone 22 HMI from Weintek provides an interface between the operator and control system over Modbus-TCP (plcdirect, 2021), Implementation to MindSphere is also executed through Modbus-TCP (Siemens, 2022).

Solution 3 is the cheapest hardware solution at £56,012, £3341.59 cheaper than Solution 1 and £2534.00 cheaper than Solution 2. However, it is more expensive than both for labour at £42,840.00.

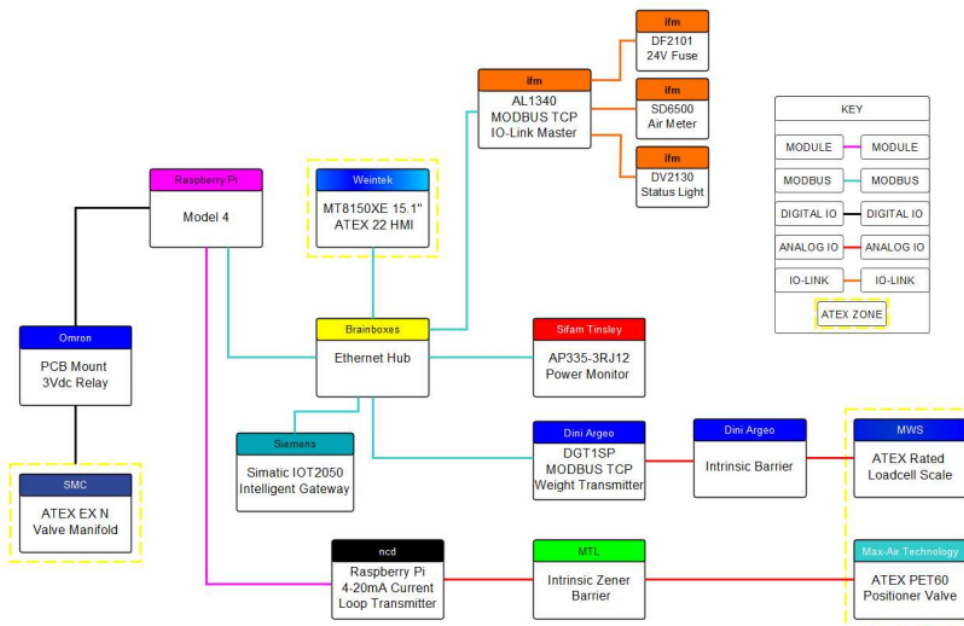


Figure 5 - Solution 3 Network Overview

5.4 Solution Comparison & Choice

A 3 to 1 scoring method produced the radar graph in Figure 6, this compares 10 criteria below, where the best solution for that criteria is scored at 3, the worst is scored at 1. For example, the cheapest solution is scored at 3 and the most expensive at 1, the solution that is easiest to deliver is scored 3, the most difficult is scored 1, the scoring table is seen in appendix 9.5.

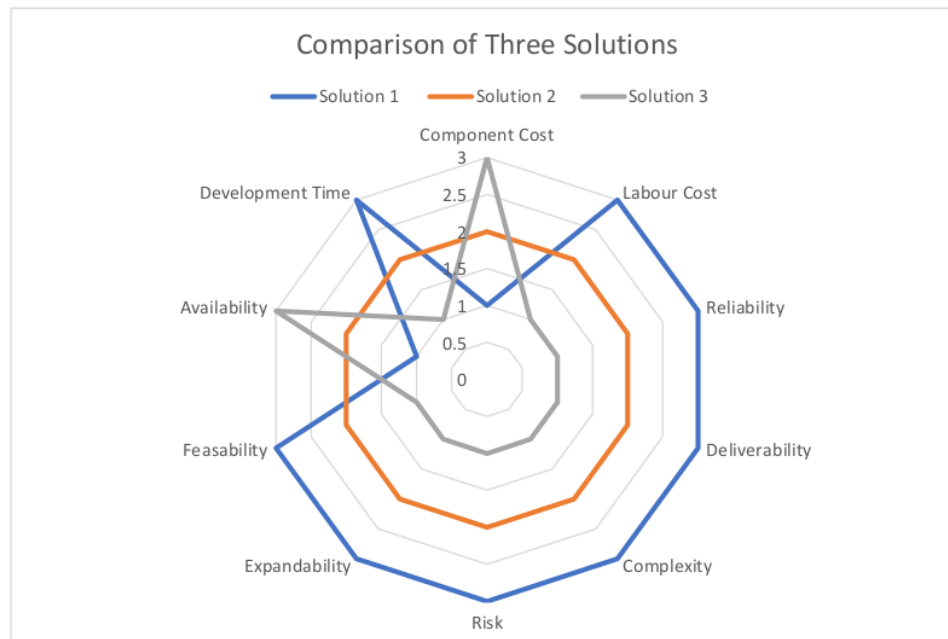


Figure 6 - Solution Radar Graph

It is clear from Figure 6 that Solution 1 is the strongest solution, scoring the best in 8 out of 10 criteria, only scoring lower in component cost and availability due to the current supply bottlenecks Siemens are facing due to the global chip shortage (Revill, 2021).

Solution 2 scored well throughout, offering lower component costs and better availability compared to solution 1. Simple PROFINET connection to the tray bake line PLC is far simpler than utilising Modbus-TCP required by solution 3

Punctuation Error

Solution 3 scores low compared to Solutions 1 & 2 due to the authors lack of experience with the equipment, thus driving the low scores for complexity, deliverability, feasibility, development time and risk, along with its limited IO amount.

Both Solutions 2 & 3 are suitable options, however both have aspects which are less favourable compared to Solution 1. Solution 2 requires the system to work as a slave to the tray bake line, therefore any PLC modifications or faults would stop the operation of the ingredient dosing system impacting two production stages, and other than a reduction in bought-out materials it has no advantage over Solution 1. Solution 3 requires far greater development and manufacturing time due to limited familiarity with the Raspberry-Pi platform and Modbus-TCP resulting in £4,760 increase in labour costs over Solution 1. However, all solutions fall below the £110,000 budget.

In order for the project to be delivered on time and to budget, Solution 1 is the best option.

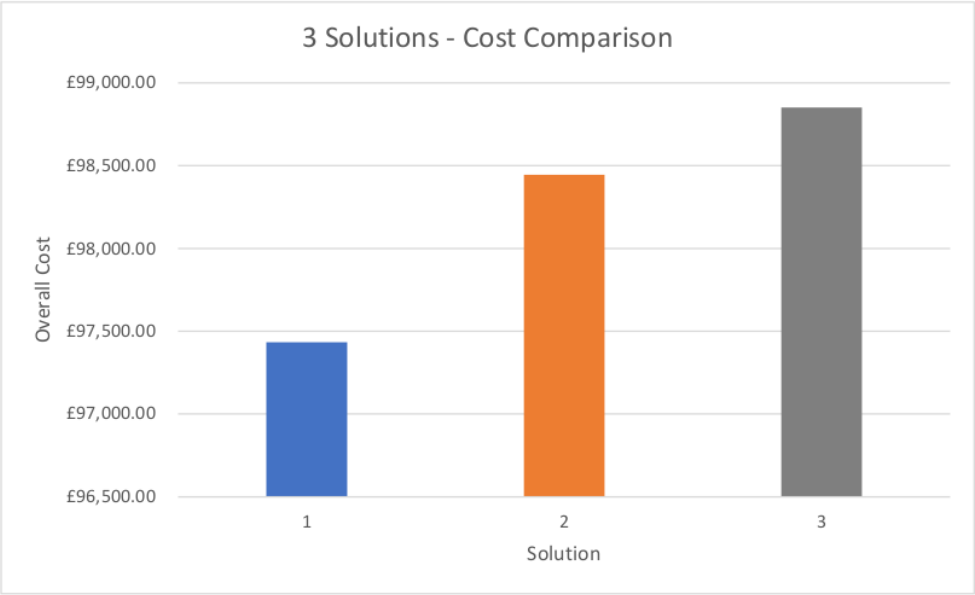


Figure 7 - Cost Comparison of 3 Solutions

6. Project Planning, Work breakdown and Management Techniques

6.1 Work Breakdown Structure

A work breakdown structure (WBS) is developed to break the project scope down into manageable tasks required to complete the project (ProjectManager, 2020), outlined in appendix 9.7. The WBS divides the project into three sections – Electrical, Mechanical and Software, further dividing it into design, manufacturing and documentation tasks with sub-tasks. Tasks highlighted in red are the responsibility of the author, green are the responsibility of the mechanical engineer and purple the responsibility of the workshop department but managed by the author.

6.2 Gantt Chart

Utilising the WBS, the second management technique is developed – the Gantt chart. This management technique assists in planning and scheduling all tasks required to complete the project displayed in a horizontal bar-chart with start and end dates, creating a visual graph to manage schedules and deadlines, allowing for progress and discrepancies to be monitored (APM, 2019).

Appendix 9.8 displays the Gantt chart, starting January 2nd, and expected to finish April 7th if no issues arise. The Gantt chart allows for two weeks of slippage as a contingency for potential supply-chain, labour or technical issues to be resolved. Weekly meetings will take place with the project team to discuss the Gantt chart and project progress.

6.3 Resource Plan

The goal of a resource plan is to identify and assign the resources necessary to execute the project tasks. While largely focused on personnel resources and time, it also involves equipment, tools and supplies. The resource plan is developed along with the Gantt chart to ensure that the resources needed are available in line with the chart dates. Appendix 9.9 displays and explains the resource plan.

6.4 Costing Spreadsheet

Materials and labour costs will be tracked using the cost breakdown spreadsheet seen in appendix 9.10. Each week the hours spent on the project will be logged and compared to the budgeted hours to determine the remaining hours, likewise, each requisition form will be added to the spreadsheet to monitor that the materials budget is not exceeded. This management technique allows for the projects finances to be kept on track on a weekly basis.

6.5 Log Books

Log books written to record weekly activity, events and achievements in a systematic order for the duration of the project cycle. This document is useful in capturing thoughts, notes, as well as the sequence of project activities. Appendix 9.12 displays the project log books so far.

7. Conclusions and Recommendations

The project definition, research and quality plan section has been successful allowing the project to be at a clear state to begin the implementation phase in January 2023, providing the customer with a solution that meets their requirements in terms of deliverables and timescales.

You could have stated the PL rating here and refer to your determination method in the appendix

The project risks and constraints outlined areas that are risks to the project success. The dosing of food products and the care and consideration required during the design and implementation stages is a substantial constraint, along with flour being considered a “dangerous goods” by the HSE due to the potential of dust clouds igniting from a spark (HSE, 2017). Outlining these constraints was highly useful in determining regulations and standards applicable to the project, allowing plans to be implemented to minimise the risks, including the safety regulations required to meet the machinery directive to achieve UKCA conformity.

The Functional Design Specification (FDS) outlined key deliverables and project outcomes from customer specification to British standards, enabling clear overarching project definition to exist which can be monitored during implementation (Cleanrooms, 2019). The FDS detailed performance, safety, diagnostics, aesthetics deliverables and more. It has been signed by the author and the customer, allowing both parties to have a mutual agreement on the project deliverables. A test plan has been produced based on the FDS, to enable the required deliverables to be tested to confirm conformity at the end of the implementation.

Solution 1 is best suited to the project, scoring the best in 8 out of 10 criteria seen from its widest coverage in the radar graph. Solution 1 utilises PROFINET GSDML files imported into TIA Portal enabling seamless connection to control devices with reduced software development, allowing the weigh-scale loadcell analog signals to be converted into Real values to be read by the PLC without internal scaling, Energy consumption will be constantly monitored through the PAC meter and data on DC current, Compressed Air usage and process status is obtained through the PROFINET IO-Link Master.

The Unified Comfort Panel HMI offers elementary implementation and high-security in TIA Portal allowing for full user flexibility in creating and storing recipes into the PLC with enhanced security, protecting valuable process data. Control of the bulk-dosing and fine-dosing valves will be implemented utilising analog and digital outputs respectively within the PLC sequence, allowing initially for large bulk dosing from the proportional valve. Once the target weight is closely approached the fine-dosing phase will change over to accurately achieve the desired weight. All equipment within the danger zone will be suitably rated to the required ATEX level.

The project management techniques developed will enable a successful project to be delivered on time and to budget. The work breakdown structure allows for each individual task to be broken down and managed by assigned personnel. The Gantt chart has been developed to enable the project milestones to be monitored and controlled by assigning tasks on specific dates avoiding resource overload and enhancing time management whilst allowing for two weeks slippage. The cost breakdown spreadsheet will be monitored and updated weekly to allow for costs and labour to be controlled, helping forecast if the budget will suffice before it is too late.

The project definition, research and quality plan will ensure that the implementation phase can be undertaken and achieved in every aspect. The author is fully aware of the constraints and regulations that must be followed in the implementation phase to ensure the system conforms to the machinery directive. The system expectations are clearly outlined in the FDS, along with a test plan to ensure all deliverables are achieved at the project end.

The main recommendation is to follow the timing plans weekly ensuring that all tasks are achieved within the budget and to ensure all resources are available. A current concern is the global supply chain issues which could affect component delivery, a two-week slippage has been included to resolve any issues that arise due to this, whether that is re-design or sourcing from other suppliers. Currently the HMI is longest lead-time component, however, Siemens' View of Things can be used to simulate the HMI screen to allow the machine to be commissioned while waiting for delivery (Siemens, 2021).

You could have included more simulation for proving your algorithms if there is any delay in other hardware or mechanical delays

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9. Appendix

9.1 Project Proposal

SGEL6000 INDEPENDENT PROJECT

PROJECT PROPOSAL DOCUMENT

Student Name: Thomas Grennan
Project Title: Ingredient Dosing System
Date: 07/10/2022
Budget: £110,000

Description of Project

The project is based in Flint, North Wales for an artisan bakery, which has requested a fully automated ingredient dosing system for their existing and future products to improve the consistency and quality of the product. Design, manufacturing and initial commissioning will be undertaken at the manufacturer's site, final commissioning and sign off will be undertaken at the customer's site.

The current process of dosing ingredients is labour intensive and requires operators to manually load around 100kg of ingredients from bulk storage sacks. The customer also has quality concerns as the ingredients are weighed by operators, this makes the process susceptible to the wrong quantities of product being mixed, thus decreasing the quality of the product. The customer wishes to automate the manufacturing process which includes a cell where the product ingredients will be automatically dispensed from bulk hoppers into a mixing bowl and the ingredients accurately weighed. The ingredients dosed and their quantity will be dependent on the recipe selected by the operator. The cell must be designed for ATEX zone 20, 21 & 22 due to the nature of the ingredients.

All Electrical controls will be undertaken by the author, this includes project management, electrical design, build and commissioning. Software design and commissioning will also be undertaken by the author with support from the company's Lead Control and Systems Engineer James Bevan when required. Electrical installation and acceptance testing will also be undertaken by the author. All mechanical design aspects of the project will be undertaken by the mechanical engineer Wojciech Milkowski, Mechanical build will be undertaken by EBS mechanical technicians.

The total project budget for the control system labour and parts has been calculated as £110,000 to allow for contingencies. The project must be installed, fully commissioned and signed-off by the customer by April 2023.

Agreement for project proposal

Student Signature: _____ Date: _____

Industrial Supervisor Signature: _____ Date: _____

Academic Tutor Signature: _____ Date: _____

9.2 Risk Assessment

9.2.1 Key to Risk Tables

Key to Risk Estimation tables

(LO) Likelihood of occurrence

0.033	---	Almost impossible	only in extreme circumstances
1	---	Highly unlikely	though conceivable
1.5	---	Unlikely	but could occur
2	---	Possible	but unusual
5	---	Even chance	could happen
8	---	Probable	not surprising
10	---	Likely	to be expected
15	---	Certain	no doubt

(FE) Frequency of exposure

0.5	---	Annually
1	---	Monthly
1.5	---	Weekly
2.5	---	Daily
4	---	Hourly
5	---	Constant

(DPH) Degree of possible harm

0.1	---	Scratch or bruise
0.5	---	Laceration or mild ill health effect
2	---	Break of minor bone or minor illness (temporary)
4	---	Break of major bone or minor illness (temporary)
6	---	Loss of 1 limb, eye, hearing (permanent)
10	---	Loss of 2 limbs or eyes (Permanent)
15	---	Fatality

(NP) Number of persons at risk

1	---	1 - 2 persons
2	---	3 - 7 persons
4	---	8 - 15 persons
8	---	16 - 50 persons
12	---	50+ persons

(HRN) Hazard Rating Number - $HRN = LO \times FE \times DPH \times NP$

0 - 5	---	Negligible Risk
6 - 50	---	Low, significant risk
51 - 500	---	High Risk
over 500	---	Unacceptable Risk

Figure 8 - Key to Risk Estimation Table (Pilz, 2022)

9.2.2 Risk Assessment Table

Type or group of hazard	Origin	Potential consequences	Comments	Initial assessment							Action required	Re-assessment after taking action							Action required																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																										
				LO	FE	DPH	NP	HSN	Risk level	LO		FE	DPH	NP	HSN	Risk level																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																													
Electrical hazards	Stored energy (gravity)	Being run over	1: Mixing bowl rolling down the ramp	1.5	5	4	1	30	Low, significant																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				

Figure 9 - Risk Assessment Part 1

Type or group of hazard	Origin	Potential consequences	Comments	Initial assessment						Action required	Re-assessment after taking action						Action required
				LO	FE	DPH	NP	HRN	Risk level		LO	FE	DPH	NP	HRN	Risk level	
		Shock	11. Potential exposure to live electrical components.	2	5	2	1	20	Low, significant	All electrical components to be contained within an earthed metal enclosure, which can only be opened with a panel key. Warnings labels to be fitted inside and outside of cabinet.	0.033	5	2	1	0.033	Negligible	Hazard to be documented in Machine Manual
	Parts becoming live under fault conditions	Burn	12. All electrical components contained within earthed metal enclosure. Can only be opened with panel key.	2	5	0.5	1	8	Negligible	All electrical components to be contained within an earthed metal enclosure, which can only be opened with a panel key. Use proven components and best practice design. Warnings labels to be fitted inside and outside of cabinet.	0.033	5	0.5	1	0.0025	Negligible	Hazard to be documented in Machine Manual
		Electrocution	13. All electrical components contained within earthed metal enclosure. Can only be opened with panel key.	2	5	15	1	150	High	All electrical components to be contained within an earthed metal enclosure, which can only be opened with a panel key. Use proven components and best practice design. Warnings labels to be fitted inside and outside of cabinet.	0.033	5	15	1	2.475	Negligible	Hazard to be documented in Machine Manual
		Shock	14. All electrical components contained within earthed metal enclosure. Can only be opened with panel key.	2	5	2	1	20	Low, significant	All electrical components to be contained within an earthed metal enclosure, which can only be opened with a panel key. Use proven components and best practice design. Warnings labels to be fitted inside and outside of cabinet.	0.033	5	2	1	0.033	Negligible	Hazard to be documented in Machine Manual
	Short-circuit	Burn	15. All electrical components contained within earthed metal enclosure. Can only be opened with panel key.	2	5	0.5	1	8	Negligible	All electrical components to be contained within an earthed metal enclosure, which can only be opened with a panel key. Use proven components and best practice design. Warnings labels to be fitted inside and outside of cabinet.	0.033	5	0.5	1	0.0025	Negligible	Hazard to be documented in Machine Manual

Figure 10 - Risk Assessment Part 2

Type or group of hazard	Origin	Potential consequences	Comments	Initial assessment						Re-assessment after taking action						Action required
				LO	FE	DPH	NP	NRN	Risk level	LO	FE	DPH	NP	NRN	Risk level	
Noise hazards		Electrocution	116. All electrical components contained within earthed metal enclosure. Can only be opened with panel key.	2	5	15	1	150	High	0.033	5	15	1	2.475	Negligible	Hazard to be documented in Machine Manual
		Shock	117. All electrical components contained within earthed metal enclosure. Can only be opened with panel key.	2	5	2	1	25	Low, significant	0.033	5	2	1	0.33	Negligible	Hazard to be documented in Machine Manual
	Exhaust system	Discomfort	24. Pneumatic exhausts noise	5	5	0.5	2	25	Low, significant	1	5	0.5	2	5	Negligible	Note in Machine Manual - Recommended that Ear protection is worn and warning labels are attached to machine if noise levels are above 85db's, if noise levels are above 85db's then it is mandatory.
	Moving parts	Discomfort	25. Noise hazard from equipment	1.5	5	0.5	2	7.5	Low, significant					0	Negligible	
Material/substance hazards	Dust	Breathing difficulties, suffocation	15. Dust from ingredients being inhaled	2	5	6	2	120	High	1	4	6	1	24	Low, significant	Note in Machine Manual - PPE to be worn and dust mask to be used to prevent create health risk.

Figure 11 - Risk Assessment Part 3

Type or group of hazard	Origin	Potential consequences	Comments	Initial assessment						Action required	Re-assessment after taking action						Action required
				LO	FE	DPCH	NP	REN	Risk level		LO	FE	DPCH	NP	REN	Risk level	
	Unloading	29: Machine falling, risk of crushing	Machine becomes unstable whilst unloading. Unqualified or unauthorised personnel unloading machine.	8	0.5	1.5	1	60	High	Machine to be lifted by forklift truck, by authorised personnel only. This is to be stated in the machine manual, along with the approximate size and weight of the machine. Machine design to incorporate lifting facilities where necessary.	1	0.5	1.5	1	7.5	Low, significant	
Assembly, installation and commissioning	Assembly of the machine	30: Risk of falling from heights	Assembly and commissioning requires working at heights	1.5	0.5	1.5	1	11.25	Low, significant	Only qualified personnel using proper equipment to work at heights.	1	0.5	1.5	1	7.5	Low, significant	
	Connection to energy supplies (eg electricity, compressed air)	31: Risk of electric shock.	Services connected incorrectly by unqualified personnel.	2	0.5	1.5	1	15	Low, significant	Machine to be connected by qualified personnel only. Energy supplies to be stated in machine manual.	1	0.5	1.5	1	7.5	Low, significant	
Cleaning and maintenance	Adjustments	32: Hazards from electrical and pneumatic energy and actuators movement.	Machine running during intervention	2	2.5	1.5	1	75	High	Ensure machine is isolated before undertaken any cleaning or maintenance work. If manual movements are required this is to be done only by qualified and competent personnel. This to be stated in machine manual.	0.033	2.5	1.5	1	1.2375	Negligible	
	Cleaning, disinfection	33: Hazards from electrical and pneumatic energy and actuators movement.	Machine running during intervention	2	2.5	1.5	1	75	High	Ensure machine is isolated before undertaken any cleaning or maintenance work. This to be stated in machine manual.	0.033	2.5	1.5	1	1.2375	Negligible	
	Dismantling/removal of parts, components, device of the machine	34: Potential for wrongly re-fitted parts.	No dismantling/removal of parts, components, devices of the machine are to be carried out without the written consent of the manufacturer. Bottom pipes might be removed for cleaning. This is stated in the machine manual.	1	2.5	4	1	10	Low, significant	Ensure all pipes are isolated before enabling power to the machine. Pipe removal for cleaning must be done by competent and qualified personnel.	0.033	2.5	4	1	0.33	Negligible	
Decommissioning and dismantling	Disconnection and energy dissipation	35: Risk of electric shock.	Services disconnected incorrectly by unqualified personnel.	2	0.5	1.5	1	15	Low, significant	Machine to be disconnected by qualified personnel only.	1	0.5	1.5	1	7.5	Low, significant	

Figure 13 - Risk Assessment Part 5

Type or group of hazard	Origin	Potential consequences	Comments	Initial assessment						Re-assessment after taking action						Action required
				LO	FE	DPH	NP	HRN	Risk level	LO	FE	DPH	NP	HRN	Risk level	
	Lifting	36. Machine falling, risk of crushing	Machine becomes unstable whilst lifting. Unqualified or unauthorised personnel lifting machine.	8	0.5	15	1	60	High	1	0.5	15	1	7.5	Low, significant	
	Loading	37. Machine falling, risk of crushing	Machine becomes unstable whilst loading. Unqualified or unauthorised personnel loading machine.	8	0.5	15	1	60	High	1	0.5	15	1	7.5	Low, significant	
	Transportation	38. Machine falling, risk of crushing	Machine becomes unstable during transportation	8	0.5	15	1	60	High	1	0.5	15	1	7.5	Low, significant	
	Unloading	39. Machine falling, risk of crushing	Machine becomes unstable whilst unloading. Unqualified or unauthorised personnel unloading machine.	8	0.5	15	1	60	High	1	0.5	15	1	7.5	Low, significant	

Figure 14 - Risk Assessment Part 6

9.3 Estimated Electricity Costs

The system will utilise a Siemens 6EP1334-1LB00 power supply, as seen from the datasheet in figure 15 at 230V the power supply draws 2A.

Input	
type of the power supply network	1-phase AC
supply voltage at AC	Set by means of selector switch on the device
• initial value	
supply voltage	
• 1 at AC rated value	120 V
• 2 at AC rated value	230 V
input voltage	
• 1 at AC	93 ... 132 V
• 2 at AC	187 ... 264 V
design of input wide range input	No
overvoltage overload capability	2.3 × Vin rated, 1.3 ms
operating condition of the mains buffering	at Vin = 93/187 V
buffering time for rated value of the output current in the event of power failure minimum	20 ms
operating condition of the mains buffering	at Vin = 93/187 V
line frequency	
• 1 rated value	50 Hz
• 2 rated value	60 Hz
line frequency	47 ... 63 Hz
input current	
• at rated input voltage 120 V	4.1 A
• at rated input voltage 230 V	2 A
current limitation of inrush current at 25 °C maximum	65 A
duration of inrush current limiting at 25 °C	
• typical	3 ms
I2t value maximum	3.3 A²·s
fuse protection type	T 6.3 A/250 V (not accessible)
• in the feeder	Recommended miniature circuit breaker: from 10 A characteristic C

Figure 15 – Siemens 10A Power Supply Data sheet (Siemens, 2022)

Therefore, the power consumption is calculated as:

$$Power\ Consumption = I \times V = 2A \times 230V = 460W$$

According to EDF Energy, the current cost per kilowatt hour (kWh) is £0.34 (2022), the customer operates 8 hours per day, and is expected to work 300 days in 2023 therefore the yearly electricity cost is calculated below:

$$Yearly\ Electricity\ Costs = \frac{Power \times Hours}{1000} \times \text{£kWh} \times Days\ per\ year$$

$$Yearly\ Electricity\ Costs = \frac{460 \times 8}{1000} \times 0.34 \times 300 = \text{£}375.36$$

9.4 Solutions Cost Breakdown

Table 5 displays the cost breakdown for each solution. Solution 1 is the cheapest overall solution but is the most expensive in terms of component costs. Solution 1 contains hardware that the author is most familiar with therefore design and manufacture hours are lower which drives the overall cost down. Due to the authors lack of experience with Solution 3's hardware, this has driven the overall cost to be the most expensive out of the three, even though the component costs are the cheapest.

Cost Breakdown							
Solution 1			Solution 2			Solution 3	
Department	Budget Hours		Department	Budget Hours		Department	Budget Hours
Design	232		Design	250		Design	300
Manufacture	200		Manufacture	208		Manufacture	200
Documentation	112		Documentation	112		Documentation	112
Hours	544		Hours	570		Hours	612
Labour Cost	£ 38,080.00		Labour Cost	£ 39,900.00		Labour Cost	£ 42,840.00
Component Cost	£ 59,353.59		Component Cost	£ 58,546.00		Component Cost	£ 56,012.00
Solution 1 Total Cost	£ 97,433.59		Solution 2 Total Cost	£ 98,446.00		Solution 3 Total Cost	£ 98,852.00

Table 5 – 3 Solutions Cost Breakdown Table

Figures 16 & 17 display comparisons of labour and component costs respectively, it is clear that Solution 1 has the lowest labour costs but the highest component costs, this is inverted for Solution 3 which has the highest labour costs but has far cheaper component costs, whereas Solution 2 is in the middle for both costs.

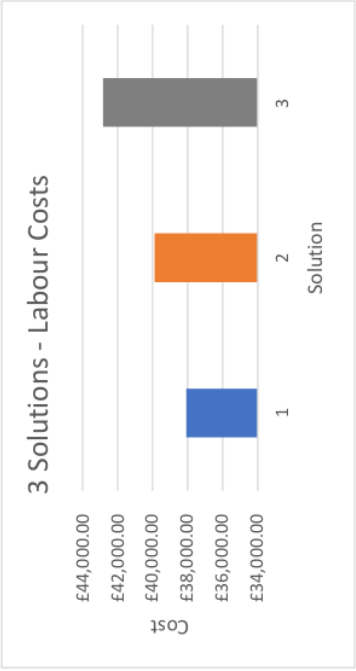


Figure 17 – 3 Solutions: Labour Costs

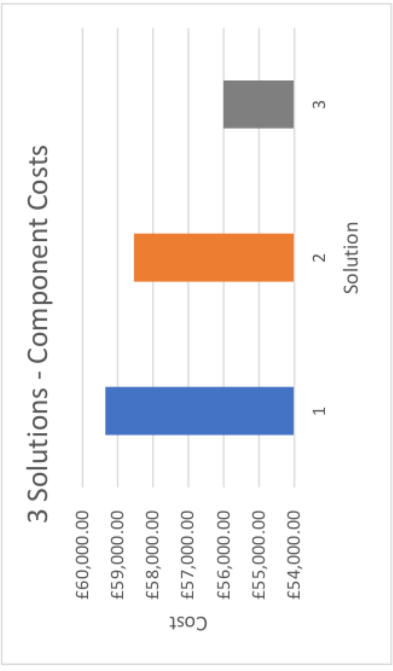


Figure 16 - 3 Solutions: Component Costs

9.5 Scoring Matrix for Solutions

Table 6 displays the scoring matrix developed to compare the three solutions. 10 project criteria are compared between the three solutions utilising a 3 to 1 scoring method, where the solution which best meets the criteria scores 3, whereas the solution which worst meets the criteria scores 1.

Comparison of Three Solutions			
Criteria	Solution 1	Solution 2	Solution 3
Component Cost	1	2	3
Labour Cost	3	2	1
Reliability	3	2	1
Deliverability	3	2	1
Complexity	3	2	1
Risk	3	2	1
Expandability	3	2	1
Feasibility	3	2	1
Availability	1	2	3
Development Time	3	2	1
Total	26	20	14

Table 6 – Comparison of Three Solutions

9.6 Performance Level Required

The ingredient dosing system Performance Level Required (PLr) is calculated using the risk graph seen below in Figure 18. This is determined referencing BS EN ISO 13849-1: 2015 (ISO, 2015).

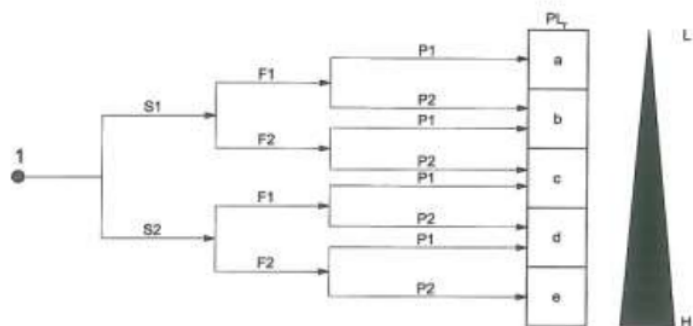


Figure 18 - Risk Graph (ISO, 2015)

Table 7 explains the risk parameters seen in the risk graph.

Risk Graph Parameters	
S	Severity of injury
S1	Slight (normally reversible injury)
S2	Serious (normally irreversible injury or death)
F	Frequency and/or exposure to hazard
F1	Seldom-to-less-often and/or exposure time is short
F2	Frequent-to-continuous and/or exposure time is long
P	Possibility of avoiding hazard or limiting harm
P1	Possible under specific conditions
P2	Scarcely possible

Table 7 – Risk Graph Parameters

The authors company follows BS EN ISO 13849-1:2015 as it is better suited to individual machines. Another method of categorising machine safety levels is EN 62061 Safety Integrity Levels (SIL), however, Dirk Meyer states that “SIL is more suited to complex facilities with multiple machines such as refineries” (2021).

Table 8 displays the relationship between performance level (PL) and safety integrity level (SIL). PL a has no correspondence on the SIL scale and is mainly used to reduce the risk of slight, normally reversible injury. Since SIL 4 is dedicated to catastrophic events possible in the process industry, this range is not relevant for risks at machines. Thus, PL e corresponding to SIL 3 is defined as the highest level.

PL	SIL
a	No correspondence
b	1
c	1
d	2
e	3

Table 8 - Relationship between performance level (PL) and safety integrity level (SIL)

Figure 19 displays the risk graph developed for the ingredient dosing system. It has been assessed and decided that the injuries that can be sustained from operating the machine are slight (normally reversible injury), the exposure to the hazards are frequent and the possibility of avoiding the hazards are possible under specific conditions.

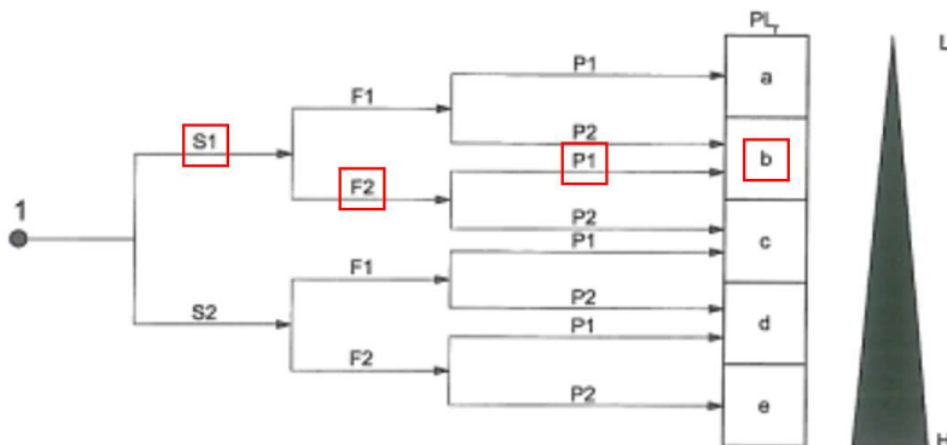


Figure 19 - Ingredient Dosing System Risk Graph

This should have been stated clearly in the main body of the report

From the graph seen in Figure 19, the assessed PLr for the ingredient dosing system is B.

S	F	P	Performance level
1	2	1	b

Table 9 – Ingredient Dosing System Performance Level Required.

9.7 WBS Chart

Figure 20 displays the higher-level architecture of the Work Breakdown Structure, the system tasks are sub-categorised into design, manufacture and design for each engineering discipline.

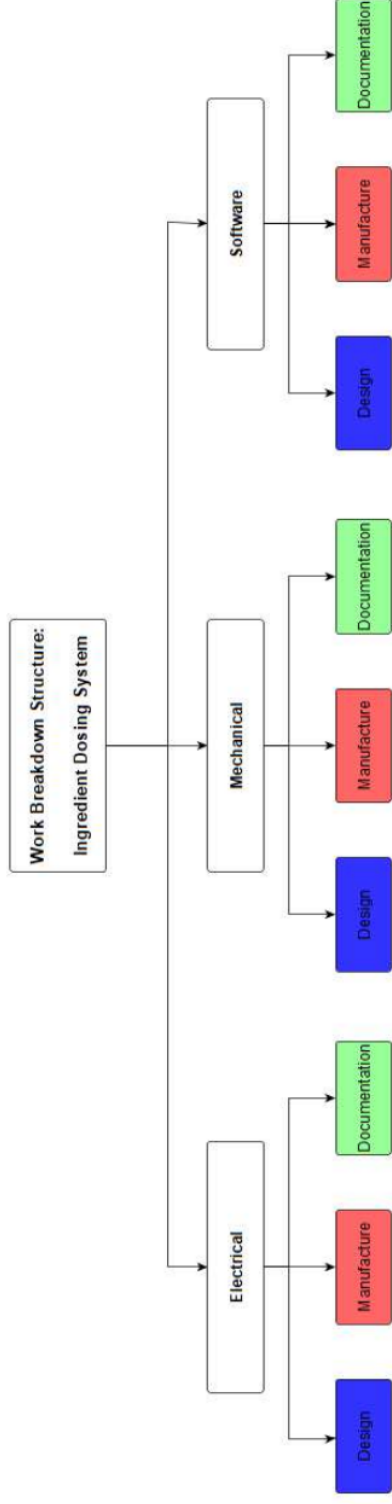


Figure 20 - Work Breakdown Structure High-Level Architecture

Figure 21 displays the lower-level architecture of the electrical tasks of the work breakdown structure.

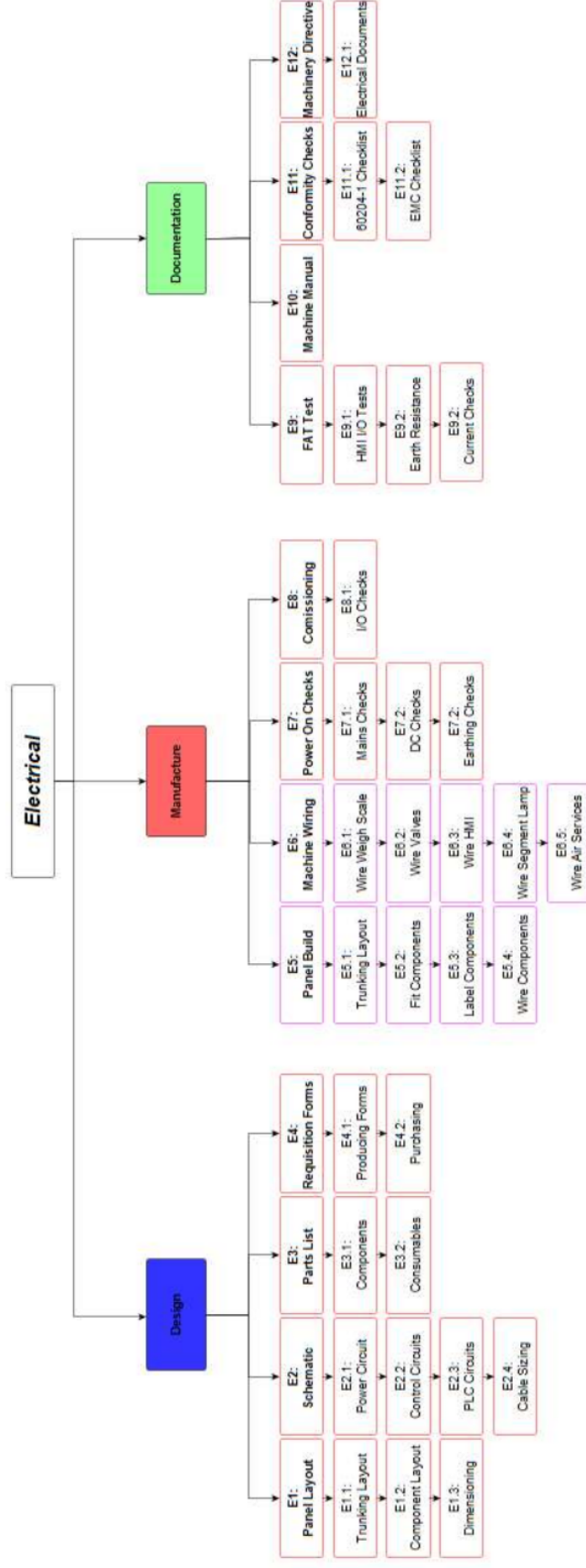


Figure 21 – Electrical Work Breakdown Structure

Figure 22 displays the lower-level architecture of the mechanical tasks of the work breakdown structure.

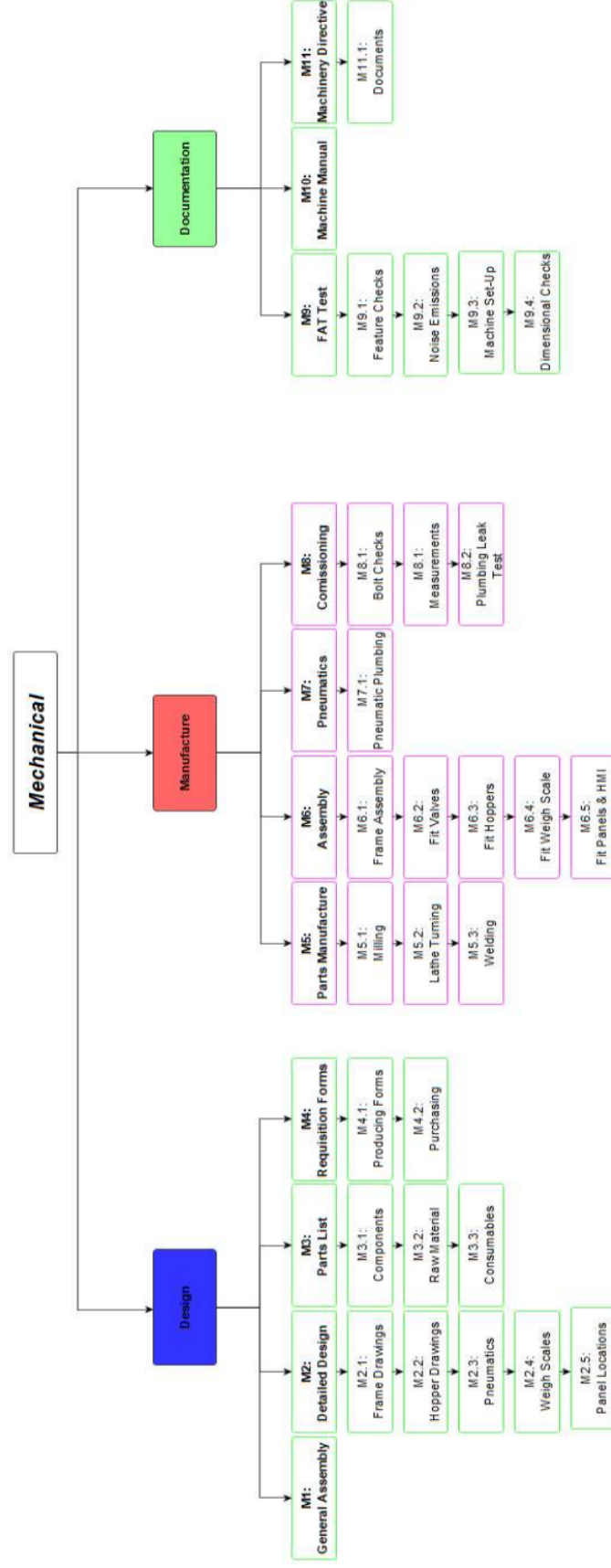


Figure 22 - Mechanical Work Breakdown Structure

Figure 23 displays the lower-level architecture of the software tasks of the work breakdown structure.

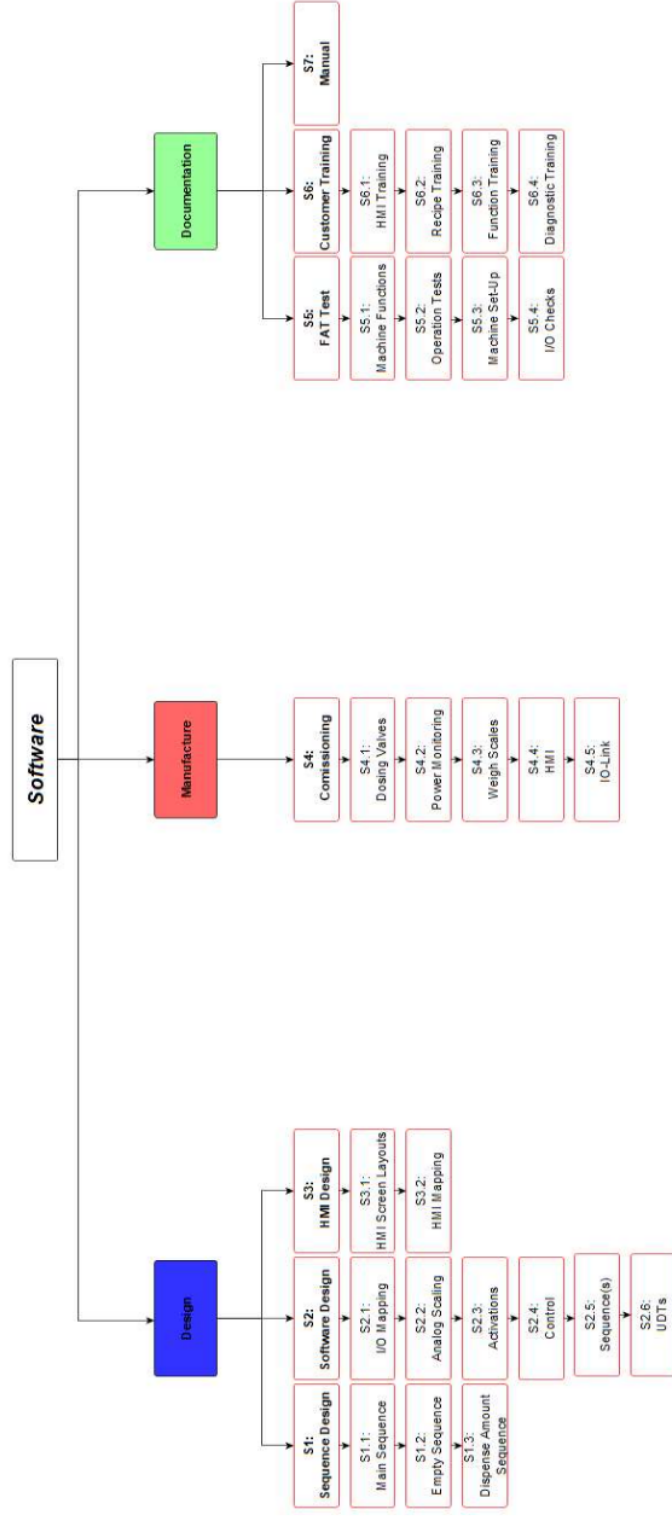


Figure 23 - Software Work Breakdown Structure

9.8 Gantt Chart

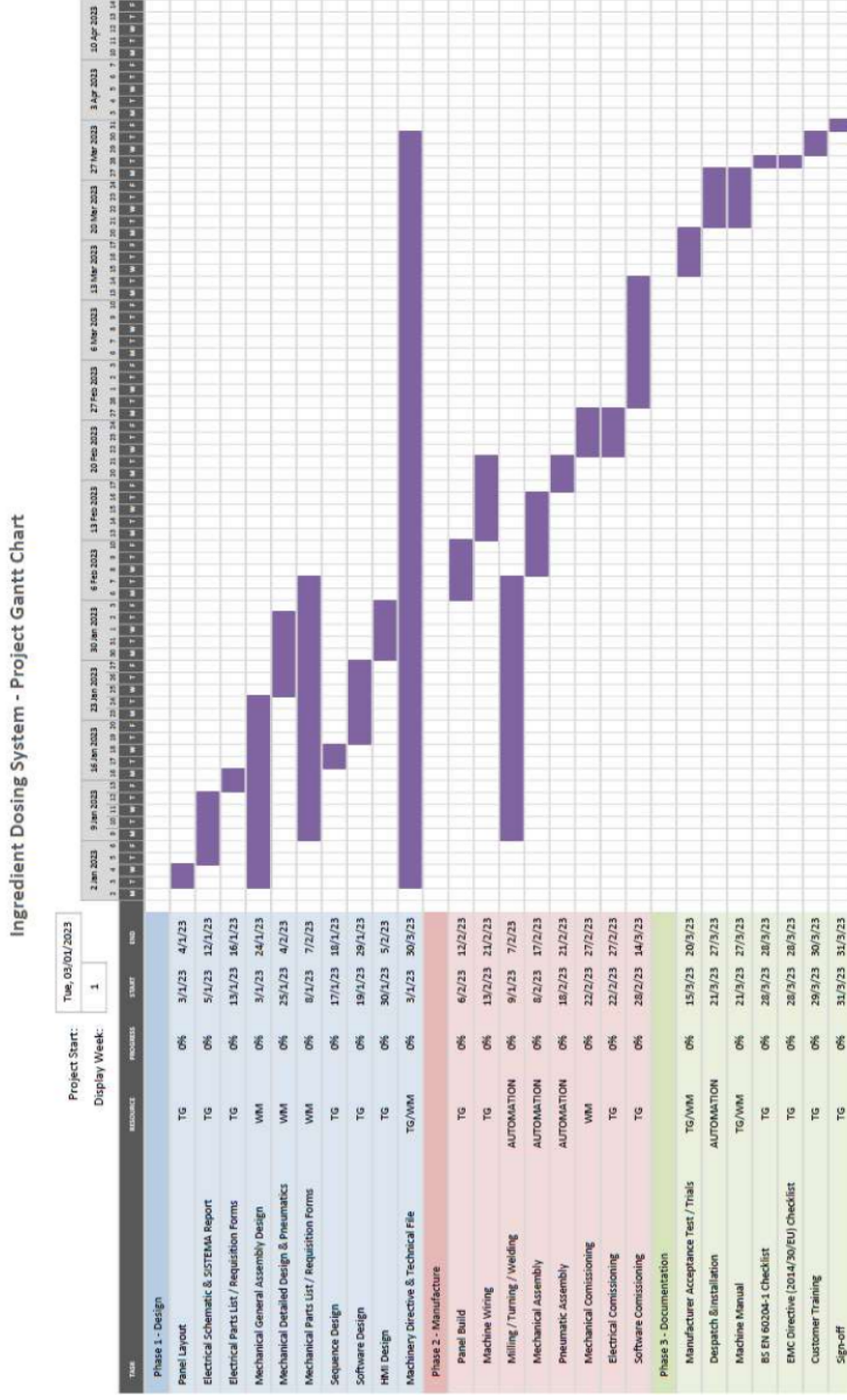


Figure 24 – Project Gantt Chart

9.9 Resource Plan

Figure 25 displays the Ingredient Dosing System resource plan. This plan is issued to all labour resources to ensure that the resource is available on the required dates. The workshop supervisor will receive a copy to ensure that the workshop personnel and equipment resources are available on the required dates. This management technique provides an effective way of allocating personnel to projects, this document is linked to a personnel sheet which displays all projects and assigned personnel to ensure no double booking occurs.

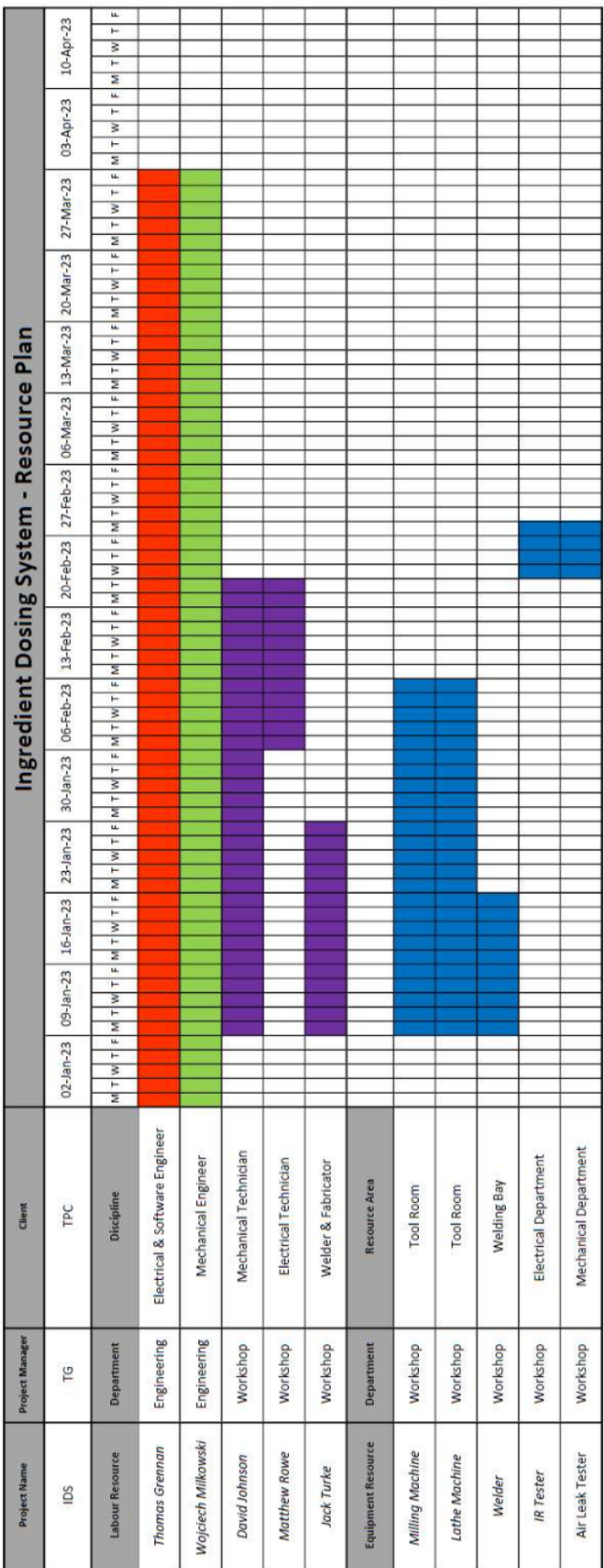


Figure 25 – Project Resource Plan

9.10 Costing Spreadsheet

Electrical Material				
Supplier	Cost	Order Date	Date Required by	Delivery Date
Applied Automation				
BPX				
ICOTEK				
ifm				
Parmley Graham				
R&M				
Routecco				
RS				
Underwoods				
Western Automation				
Actual Cost	£0.00			
Budget	£65,000.00			

Labour				
Department	Budget Hours	Actual Hours	Remaining Hours	Last Updated On:
Design	232	0	0	03/12/2022
Manufacture	200	0	0	
Documentation	112	0	0	
Hours	544	0	0	
Cost	£ 45,000.00	£ -	£ -	

Cost Tracker - Budget vs Actual	
Budget	£110,000.00
Actual Cost	£0.00

Table 10 - Costing Spreadsheet

9.11 Glossary of Terms

Acronym / Term	Definition
PLC	Programmable Logic Controller - An industrial computer control system that monitors the state of input devices to make decisions based on a user defined program to control output devices.
GUI	Graphical User Interface – A computer program that enables an operator to communicate with a PLC/PC through symbols, pointing devices and visual metaphors displayed on a screen.
HMI	Human Machine Interface – Hardware & Software which an operator uses to interact with a controller, ranging from a touchscreen panel running HMI software to a control panel with pushbuttons and pilot lights.
PSU	Power Supply Unit – A unit used to convert Alternating Current into Direct Current for use in control systems.
SW	Software – A set of instructions, data and programs used to execute user defined tasks in Programmable Logic Controllers and Microcontrollers.
HW	Hardware – The external and internal devices & equipment that enables major functions to be performed including inputs, outputs, storage, communication, processing and more.
Recipe	A recipe defines a series of parameters that can be entered into a HMI and stored in the PLCs memory in the form of Data Blocks or User Defined Data Type in order to maximise code reusability.
HSE	Health and Safety Executive – The United Kingdom national regulator for workplace health and safety.
OEM	Original Equipment Manufacturer – An OEM designs and constructs systems and components used in another company's end product or process.
GPIO	General Purpose Input Output – An uncommitted digital signal pin used in integrated circuits, may be used as an input or an output as defined by the software.
PL	Performance Level – The value used to define the safety-related parts of a control systems ability to perform safety functions under foreseeable conditions.
PLr	Performance Level Required – The mandatory performance level of a machine to reduce the risk outlined in the risk assessment.
SIL	Safety Integrity Level – The measure of safety system performance in machines and processes, in terms of the probability of failure on demand (PFD).
SISTEMA	Safety Integrity Software Tool for the Evaluation of Machine Applications – A tool used by engineers to confirm if the safety related parts of a control system meet the performance level required (PLr).
WBS	Work Breakdown Structure – A planning tool used to help a project team plan, define and organize the scope of a project, breaking down large tasks into sub-tasks.
FAT	Factory Acceptance Test – Internal testing to verify that manufactured systems and machines meet their intended purpose in terms of safety, operation and functional design specification.
EMC	Electromagnetic Compatibility – The characteristic of electrical and electronic equipment to permit its operation within the same electromagnetic environment as other.

IO-Link	Short Distance Digital Point-to-Point industrial networking communication standard used to connect digital sensors and actuators to an industrial fieldbus.
IoT	Internet of Things – Physical objects with sensors, software and processing ability that connect and exchange data with other devices and systems over the internet.
IIoT	Industrial Internet of Things – Interconnected sensors, instrumentation, actuators and other devices networked together within a computerised industrial application. This connectivity allows for data capture, analysis and exchange vastly improving production and manufacturing processes.
MindSphere	Industrial IoT service solution developed by Siemens for Internet of Things applications where operational data is stored in cloud-based applications, this data is accessible through digital applications to allow customers to make decisions based on factual data.
Profinet	Industry technical standard fieldbus for data communication over industrial ethernet, designed to collect and send data to control equipment in industrial systems.
Modbus-TCP	Data communication protocol developed by Modicon for use with its PLCs, utilised in connecting industrial electronic device using the Ethernet transport layer.

Table 11 – Glossary of Terms

SGEL6000
Independent Project
Log Book

Thomas Grennan
Ingredient Dosing System
2022-2023

Summary of Entries

Log Entry	Date	Brief Description of Activity	Duration (hrs)	Accumulated time (hrs)
1	30/09/22	Customer Meeting	3	3
2	07/10/22	Initial Concept Meeting	6	9
3	14/10/22	ATEX Research	2	11
4	21/10/22	Research / Supplier Visit	10	21
5	28/10/22	Project Scope Development	6	27
6	04/11/22	On-site	0	27
7	11/11/22	Concept Review / Project Scope Review	12	39
8	18/11/22	Literature Review	20	59
9	25/11/22	Comparison of 3 Solutions	6	65
10	02/12/22	Contacting Suppliers	9	74
11	09/12/22	Work Breakdown Structure & Gantt Chart	16	90
12	16/12/22	Resource Plan & Costing Spreadsheet	10	100
13	23/12/22	Report Writing	9	109

Log Entry Sheet

Log Number	1
Date	30/09/2022
Duration (hrs)	3
Accumulated time (hrs)	3

Record of activities and achievements

An initial meeting took place with the customer to understand the problem that they need to overcome. The customer explained that the current method of preparing and weighing the ingredients is labour intensive and requires the operator to manually load the mixing bowl multiple times per day, weighing the individual ingredients which makes it susceptible for the wrong quantities to be mixed, this is a concern for the customer as the quality of the product can greatly be reduced.

The customer requested an automated system which will accurately dispense ingredients into the mixing bowl from bulk storage containers.

Plans for next week

The plan for the following week is to start looking into the initial mechanical concept with Mechanical Engineer, Wojciech Milkowski.

Signed _____

Signed _____

Log Entry Sheet

Log Number	2
Date	07/10/2022
Duration (hrs)	6
Accumulated time (hrs)	9

Record of activities and achievements

Internal meetings took place with Mechanical Engineer, Wojciech Milkowski. The initial mechanical non-detailed draft concept was developed. The concept included 6 bulk storage containers which hold the ingredients required, the ingredients will be dispensed from these containers into a mixing bowl.

The concept was reviewed with the Engineering department. The author has concerns of the constraints due to the flour being dispensed being vulnerable to igniting due to it having a larger surface area exposed to oxygen per unit weight, as the flour grains are so small, they burn instantly, igniting the other grains near it which could cause an explosion. It was also suggested that a mezzanine floor with stairs is built around the bulk containers to allow operators to easily fill them.

The concept is due to be reviewed with the customer on 20/10/2022.

Plans for next week

Before the customer review due to the concerns of the nature of the product being dispensed, the plan for the following week is to look into ATEX regulations.

Signed _____

Signed _____

Log Entry Sheet

Log Number	3
Date	14/10/2022
Duration (hrs)	2
Accumulated time (hrs)	11

Record of activities and achievements

Initial research was undertaken into ATEX regulations to understand the requirements of ATEX as a standard, and ATEX within the food industry. It was found that the system is likely to fall under ATEX zones 20 (area in which an explosive mixture is continuously present or present for long periods), 21 (area in which an explosive mixture is likely to occur in normal operation) & 22 (an area in which an explosive mixture is not likely to occur in normal operation and if it occurs it will exist only for a short time) .

Plans for next week

The plan for the following week is to further research ATEX regulations, focused on the electrical requirements. A mechanical concept review with the customer will also take place.

Signed _____

Signed _____

Log Entry Sheet

Log Number	4
Date	21/10/2022
Duration (hrs)	10
Accumulated time (hrs)	21

Record of activities and achievements

Week 4 saw further research undertaken on ATEX directives, particularly Directive 99/92/EC and Directive 2014/34/EU.

Sales Engineers from Parmley Graham visited the authors workplace to demonstrate the Pepperl + Fuchs Intrinsic Barrier and other ATEX rated control equipment that can be utilised within the project.

Due to a customer breakdown, the planned customer concept review has been delayed until the 26th of October.

Time has also been spent on a draft of Assignment 1 Task 4.

Plans for next week

The plan for the coming week is to develop the project scope statement with the project team.

Signed _____

Signed _____

Log Entry Sheet

Log Number	5
Date	28/10/2022
Duration (hrs)	6
Accumulated time (hrs)	27

Record of activities and achievements

This week, Wojciech Milkowski and I developed the project scope statement, this document outlines:

- Project Justification
- Problem to be solved
- Mission objectives inc. Business Objectives & Project Objectives
- Scope of what is included and is not included within the quote i.e, Delivery, Installation etc.
- Project success criteria
- Summary of deliverables

This is an essential document that must be accurately compiled to ensure that both the manufacturer and supplier are on the same page of what is expected from the project. The document was then sent to internal stakeholders to review.

Plans for next week

The author is working away on-site for the duration of week 6, no progress is expected to be made.

Signed _____

Signed _____

Log Entry Sheet

Log Number	6
Date	04/11/2022
Duration (hrs)	0
Accumulated time (hrs)	27

Record of activities and achievements

The author worked away at a customer site for the duration of week 6, no progress has been made on the project.

Plans for next week

The plan for week 6 is to review the project scope and mechanical concept with the customer, it is planned that both the scope and concept will be signed off by the customer. This is stage 1 of the company's 14 stage project management plan.

Signed _____

Signed _____

Log Entry Sheet

Log Number	7
Date	11/11/2022
Duration (hrs)	12
Accumulated time (hrs)	39

Record of activities and achievements

This week a mechanical concept review was held with the customer, this enables the customer to visually view the CAD model and how it would fit within their production environment. The customer was happy with the initial concept and signed it off.

The internal stakeholders approved the project scope, this document was also reviewed with the customer who agreed and signed the statement.

The author also spent time on the FDS and Testing Plan for task 5 & 6 of assignment 1.

Plans for next week

The plan for the forthcoming week is to research electrical concepts that provide a solution to the problem, this is in line with the literature review.

Signed _____

Signed _____

Log Entry Sheet

Log Number	8
Date	18/11/2022
Duration (hrs)	20
Accumulated time (hrs)	59

Record of activities and achievements

Week 8 saw extensive research into the 3 possible solutions to solve the project requirements. Research was undertaken in the form of Journals, Articles, Websites, speaking to suppliers at Parmley Graham and through YouTube videos.

3 solutions and hardware overviews were developed, as per the FDS, the ATEX rated two-stage proportional valve and weigh scale must be incorporated, along with the SIMATIC IOT2050 gateway.

Solution 1 utilises a Siemens S7-1511 PLC to control the system, Analog outputs from the PLC will send a 4-20mA signal through an intrinsically safe barrier to the proportional valve to linearly open it between 0% and 100% allowing for the bulk dosing phase to occur, once the target weight is approached the valves second stage finely doses the remaining ingredient to accurately dose the required weight. Electricity is monitored through a Siemens PAC3220 meter, Air is monitored through an IFM SD6500 compressed air meter through IO-Link. The weigh scale will be controlled over PROFINET by a Dini Argeo Weight Transmitter, connected to the weigh scale by an intrinsic barrier. The operator interface is a Siemens Unified Comfort Panel HMI which communicates with the PLC via PROFINET.

Solution 2 incorporates control from the "Tray Bake Line" that the authors company are designing that will be installed before the ingredient dosing system, the Tray Bake PLC will control the dosing system over PROFINET, with the dosing system IO wired to an ET200SP Remote IO module, vastly reducing the costs of hardware compared to the S7-1511, also enabling connection to Siemens MindSphere through the tray bake line Simatic IOT2050. All other hardware is identical.

Solution 3 utilises control of the system through a Raspberry Pi Model 4 Microcontroller using Modbus-TCP to communicate with the field devices through an Ethernet Hub. The network architecture is similar to the previous solutions; however, devices have been changed to allow for Modbus-TCP communication. The Raspberry Pi's General Purpose Input Outputs (GPIO) operate at 3.3Vdc adding complications when integrating with the 24Vdc & Analog valves, requiring extra hardware. Digital IO will require Interface Relays to control 24vdc equipment with 3.3vdc, and the PET60 Positioner Valves are controlled by a 4-20mA current loop transmitter module.

Sifam Tinsley's Modbus-TCP Power Monitor is utilised for power monitoring of electricity (Tinsley, 2021), Air consumption is monitored over IO-Link using a Modbus-TCP master, the IO-Link master also controls the status light and buzzer to alert operators on process

events. Dini Argeo offers a Modbus-TCP alternative to the PROFINET Weight Transmitter used in solutions 1 and 2, allowing for the same ATEX Loadcell scale and barrier to be used. An ATEX zone 22 HMI from Weintek provides an interface between the operator and control system over Modbus-TCP, Implementation to MindSphere is executed through Modbus-TCP.

Plans for next week

The plan for the following week is to develop a comparison between the three solutions.

Signed _____

Signed _____

Log Entry Sheet

Log Number	9
Date	25/11/22
Duration (hrs)	6
Accumulated time (hrs)	65

Record of activities and achievements

This week a radar graph was developed to compare the three solutions.

It was found that solution 1 is the strongest solution for the project, scoring the best in 7 out of 9 criteria. Solution 1 only scored lower in cost due to the low price of Raspberry Pi's and their associated equipment and availability due to the current supply bottlenecks Siemens are facing due to the global chip shortage.

Solution 2 is a viable option scoring in the middle throughout offering cheaper costs and better availability of components compared to solution 1, offering a simple connection to the tray bake line PLC through a single PROFINET cable, however, if the line is down due to a breakdown it will cause the dosing system to cease operation impacting two production stages.

Solution 3 scores low compared to solutions 1 & 2. due to the authors lack of experience with the equipment, thus driving the low scores for complexity, deliverability, feasibility, development time and risk, and compared to a PLC it is not as expandable due to the fixed IO amount or as reliable.

Plans for next week

The plan for the following week is to obtain quotes from suppliers to find a true component cost for each solution, along with lead times.

Signed _____

Signed _____

Log Entry Sheet

Log Number	10
Date	02/12/2022
Duration (hrs)	9
Accumulated time (hrs)	74

Record of activities and achievements

This week suppliers have been contacted to obtain availability quotes for bought out materials. Currently the HMI and Analog Output Module are on the longest lead time with dates expected at Week 6 of 2023, all other components are on a shorter lead time up to 3 weeks.

This will be monitored weekly to ensure that any changes in the supply chain are captured early to limit delay on the delivery date.

Plans for next week

The plan for next week is to develop the Work Breakdown Structure (WBS) & Gantt chart.

Signed _____

Signed _____

Log Entry Sheet

Log Number	11
Date	09/12/2022
Duration (hrs)	16
Accumulated time (hrs)	90

Record of activities and achievements

Week 11 saw the author develop the Work Breakdown Structure, to break down the project scope into the tasks required to complete the project. The WBS divides the project into three sections – Electrical, Mechanical and Software, and further divides it into design, manufacturing and documentation tasks with sub-tasks allocated to personnel

Utilising the WBS, the second management technique is developed – the Gantt chart. This is a project management tool to assist in planning and scheduling all tasks required to complete the project in a horizontal bar-chart with start and end dates, creating a visual graph to manage schedules, deadlines allowing for progress and discrepancies to be monitored.

Time was also spent writing the report

Plans for next week

The plan for the following week is to develop a resource plan and costing spreadsheet to monitor personnel requirements and finances.

Signed _____

Signed

Log Entry Sheet

Log Number	12
Date	16/12/2022
Duration (hrs)	10
Accumulated time (hrs)	100

Record of activities and achievements

In Week 12, the resource plan was developed with the aim to identify and assign the resources necessary to execute the project tasks focused on human resources and time, it also involves equipment, tools and supplies. The resource plan is developed along with the Gantt chart to ensure that the resources needed are available in line with the chart dates.

A costing spreadsheet is also created to monitor the hours spent on the project, and the cost spent on bought out material to ensure that the project budget is not exceeded

Plans for next week

The plan for the following week is to finish the conclusion of the first project report.

Signed _____

Signed

Log Entry Sheet

Log Number	13
Date	23/12/2022
Duration (hrs)	9
Accumulated time (hrs)	109

Record of activities and achievements

This week time was spent writing the report.

Plans for next week

There are no plans for the next week due to the Christmas break, the next entry will be for the first week of the implementation phase.

Signed _____

Signed _____

FINAL GRADE

GENERAL COMMENTS

Instructor

79/100

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5



Summary is too long

No more that 300 words for a summary

Text Comment. too much detail for a summary

Text Comment. Never start a sentence with a number

PAGE 6

PAGE 7

Text Comment. An overall layout diagram (with labels) of the system would have been useful for your reader

PAGE 8

Text Comment. This section on ehics was worth 5 marks. One paragraph is limited

PAGE 9

QM

Punctuation Error

Punctuation error

QM

Spelling

Spelling error

QM

Punctuation Error

Punctuation error

Text Comment. gov.uk states that "....." (2022)

QM

Incorrectly cited, this is not the Harvard Method

Text Comment. source already stated

PAGE 10

QM

Punctuation Error

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Text Comment. What PL rating are you working towards?

Text Comment. how will this be checked?

PAGE 11

QM

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PAGE 12

Text Comment. What is your strategy to deal with this issue?

PAGE 13

QM

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Punctuation Error

Punctuation error

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PAGE 29

Text Comment. You could have stated the PL rating here and refer to your determination method in the appendix

PAGE 30

Text Comment. Is a 2 week slippage reasonable?

Text Comment. You could have included more simulation for proving your algorithms if there is any delay in other hardware or mechanical delays

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Text Comment. This should have been stated clearly in the main body of the report

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GRADING FORM: NEW CSG-RUBRIC

THOMAS GRENNAN

1. ENGAGEMENT WITH LITERATURE

 An excellent and extensive range of sources consulted and cited correctly using the Harvard method. (8/10) Listed correctly and mostly correctly cited except for quotations. (6/10) total = 14/20

14

2. KNOWLEDGE AND UNDERSTANDING

 Section 3: Project background and problem definition Clear explanations given though an overall diagram would have helped the reader visualise the system. (3/5) Section 3: Project constraints: Ethical. Limited consideration by reference to membership of the IET (2/5) Section 3: Project constraints: Sustainability Some consideration given (3/5) Section 3: Project constraints: Legal/Commercial Very good considerations given in most areas. PL rating not stated in main report but found in appendix. (4/5) Total = 12/20

12

3. COGNITIVE AND INTELLECTUAL

 Section 4: Functional Design Specification An excellent section, very comprehensive analysis

19

presented (5/5) Section 4: Test planning Excellent method presented (5/5) Section 5: Evaluation of solutions and justification of final solution Excellent analysis of solutions (4/5) Section 7: Conclusions and Recommendations A very good section that paves the way forward (5/5) Total = 19/20

4. PRACTICAL APPLICATION



Section 6: Project Plan Very good evidence of planning though a contingency of 2 weeks is probably not enough (4/5) Section 6: Working breakdown structure, costing exercise and management techniques Detailed evidence provided for all aspects (5/5) Appendix: Risk assessment for implementation phase Excellent assessment of all aspects of risk (5/5) Appendix: Planning phase log-book entries. Good evidence of management of project through the log-book (4/5) Total = 18/20

18

5. TRANSFERABLE SKILLS



Section 1: Executive summary Good overview but far too long, too much detail. (3/5) All Sections: Presentation quality of the report, diagrams, charts, tables, figure numbering, page and section numbering etc Excellent structure and presentation (5/5) All Sections: Quality of the writing style, use of punctuation and grammar Generally well written but contains some punctuation errors such as parentheses and the use of apostrophe "s" for possession. (3/5) Word

16

count limit not exceeded Total words declared as
3953 within 10% over the 3600 limit (5/5) Total =
16/20