



The Design, Construction and Analysis of the Enhancement of an Electrical Locking System for Access Control in Eastman.

by

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This project was submitted as part of the requirements for the award of

BEng (Hons) Electrical and Electronic Engineering

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Declaration Form and Form of Consent

DECLARATION

I, Jack Rees Spillett, declare that I am the sole author of this Project; that all references cited have been consulted; that I have conducted all work of which this is a record, and that the finished work lies within the prescribed word limits.

This work has not previously been accepted as part of any other degree submission.

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Abstract

This report outlines the design, development, and implementation of an access control system at Eastman Chemical Company, Newport, an Upper Tier COMAH Chemical Manufacturing Site. The system, which uses a keypad, LED indicators, and a PIC microcontroller, was developed to replace an existing keycard access system following an incident that necessitated enhanced security measures.

The primary objective was to create a secure, user-friendly access control solution for a D.C.S. Server Room. The solution was required to be efficiently installed, incorporate itself into a preexisting system, feature a customisable PIN, and have an uninterruptible power supply (UPS) lasting over twelve hours. The total budget for the project needed to remain under £115 and be completed before May 2025.

The project encompassed the design and simulation of the system using Proteus 8, programming the PIC microcontroller with MikroC, and prototyping, construction, analysis, and final installation of the system following the relevant procedures required on-site. Testing revealed the advantages of using Proteus 8 for design verification and the discrepancies between simulated and real-world performance. The real-world analysis showed issues with testing equipment that temporarily indicated flaws with the system itself. The design stage was carried out in phases to ensure correct operation.

For each stage of this project, a waterfall development methodology was followed. While the project was successful, several challenges were encountered. These challenges resulted in recommendations for future iterations, including using alternative components, the benefits of calibrated equipment and reassessing the feasibility of preexisting systems.

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Table of Contents

1.0 Introduction	9
1.1 Project Context	9
1.2 Project Aim and Objectives	10
1.3 Report Structure	11
2.0 Literature Review	12
2.1 Literature Review Introduction	12
2.2 Eastman Chemical Company	12
2.3 Traditional and Modern Access Control Systems	13
2.4 Security Concerns in Existing Access Control Systems	14
2.5 Microcontrollers in Access Control Systems	14
2.6 Power Backup Considerations in Access Control Systems	15
2.7 Relevance to the Project	15
2.7 Conclusion	16
3.0 Background Research	17
3.1 Existing Access Control Systems	17
3.3 Battery Considerations	18
3.4 Ethical and Environmental Considerations	19
3.4 Legal Considerations	20
3.5 Tools and Software	20
4.0 Component Research	22
4.1 Component Research Introduction	22
4.2 Microcontroller	22
4.3 Keypad	23
4.4 Enclosures	24
4.5 Power Supply	25
4.6 Battery	26
4.7 Relay	27
4.8 LEDs	28
5.0 System Design	30
5.1 System Design Introduction	30
5.1.1 Simulation and System Modelling in Proteus	30
5.1.2 Program Development in MikroC	30
5.1.3 Prototyping and Assembly	31
5.2 System Design Iterations on Proteus	32
5.3 System Design Iterations on MikroC	34
5.4 Design Iterations on MikroC Conclusion	44
6.0 System Design Prototyping	45

6.1 Introduction	45
6.2 User Interface Board	46
6.3 Control Board	47
6.4 PIC Programming	48
6.5 Enclosure and Assembly	52
6.6 Prototype Verification	53
7.0 Final System Summary	55
8.0 Pre-Implementation Testing and Analysis	56
8.1 Introduction	56
8.2 Practical and Simulated Results Figures	56
8.3 Comparison of Practical and Simulated Results for Voltage	59
8.4 Comparison of Practical and Simulated Results for Resistance	60
9.0 Implementation Analysis	61
9.1 Introduction	61
9.2 Modification of Change Permit	62
9.3 Exposure Permit	65
9.4 Implementation	67
10.0 Post-Implementation Analysis and Evaluation	70
10.1 Keypad Functionality and System Operation	70
10.2 Installation Time	70
10.3 PIN Customisation	71
10.4 Power Supply and Battery Backup Duration	71
10.5 Cost Evaluation	72
10. 6 Timeframe and Project Deadline	73
10.7 GANTT Chart	74
11.0 Conclusion	75
12.0 Recommendations	77
13.0 Reflection	79
14.0 References	81
15.0 Bibliography	88
Appendices	89
Appendix One: Final Program	89

List of Tables and Figures

Table / Figure	Page
Table 1 - Comparison of Existing Access Control Systems	17
Table 2 - Battery Comparison [23]	18
Table 3 - Keypad Comparison	23
Table 4 - Enclosure Comparison	24
Table 5 - Transformer Comparison	25
Table 6 - Battery Comparison	26
Table 7 - Relay Comparison	27
Table 8 - Green LED Comparison	28
Table 9 - Red LED Comparison	29
Table 10 - Comparison of Practical and Simulated Results for Voltage	59
Table 11 - Comparison of Practical and Simulated Results for Resistance	60
Table 12 - Assumed Costings Compared to Total Costings	72
Figure 1 - Existing Technology Example One [20]	17
Figure 2 - Existing Technology Example Two [21]	17
Figure 3 - Existing Technology Example Three [22]	17
Figure 4 - Access Control Systems Examples [4]	13
Figure 5 - PIC16F877A Specification	22
Figure 6 - Keypad One [40]	23
Figure 7 - Keypad Two [41]	23
Figure 8 - Keypad Three [42]	23
Figure 9 - Enclosure One [43]	24
Figure 10 - Enclosure Two [44]	24
Figure 11 - Enclosure Three [45]	24
Figure 12 - Transformer One [46]	25
Figure 13 - Transformer Two [47]	25
Figure 14 - Transformer Three[48]	25
Figure 15 - Battery One [49]	26
Figure 16 - Battery Two [50]	26
Figure 17 - Battery Three [51]	26
Figure 18 - Relay One [52]	27
Figure 19 - Relay Two [53]	27
Figure 20 - Relay Three [54]	27
Figure 21 - Green LED One [55]	28
Figure 22 - Green LED Two [56]	28
Figure 23 - Green LED Three [57]	28
Figure 24 - Red LED One [58]	29
Figure 25 - Red LED Two [59]	29
Figure 26 - Red LED Three [60]	29
Figure 27 - Proteus Final Design	33
Figure 28 - Program Flow Chart	35

Figure 29 - Program Draft One Snip	36
Figure 30 - Program Draft Two Snip	37
Figure 31 - Program Draft Three Snip	38
Figure 32 - Program Draft Four Snip	39
Figure 33 - Program Draft Five Snip	40
Figure 34 - Program Draft Six Snip	41
Figure 35 - Program Draft Seven Snip	42
Figure 36 - Program Final Draft Snip	43
Figure 37 - User Interface Board Picture One	46
Figure 38 - User Interface Board Picture Two	46
Figure 39 - Control Board Picture One	47
Figure 40 - Control Board Picture Two	47
Figure 41 - PICKit3 Pinout [61]	48
Figure 42 - PIC16F877A Pinout [62]	48
Figure 43 - Programming Hardware Evidence One	49
Figure 44 - Programming Hardware Evidence Two	49
Figure 45 - Programming Hardware Evidence Three	50
Figure 46 - Programming Hardware Evidence Four	50
Figure 47 - Programming Hardware Evidence Five	51
Figure 49 - Enclosure and Assembly Evidence One	52
Figure 50 - Enclosure and Assembly Evidence Two	52
Figure 51 - Enclosure and Assembly Evidence Three	52
Figure 52 - Enclosure and Assembly Evidence Four	52
Figure 53 - Prototype Verification Evidence One	53
Figure 54 - Prototype Verification Evidence Two	53
Figure 55 - Prototype Verification Evidence Three	54
Figure 56 - Prototype Verification Evidence Four	54
Figure 57 - Pre-Implementation Testing and Analysis Evidence One	57
Figure 58 - Pre-Implementation Testing and Analysis Evidence Two	57
Figure 59 - Pre-Implementation Testing and Analysis Evidence Three	57
Figure 60 - Pre-Implementation Testing and Analysis Evidence Four	57
Figure 61 - Pre-Implementation Testing and Analysis of Proteus Evidence One	58
Figure 62 - Pre-Implementation Testing and Analysis of Proteus Evidence Two	58
Figure 63 - Pre-Implementation Testing and Analysis of Proteus Evidence Three	58
Figure 64 - Modification of Change Permit Snip One	62
Figure 65 - Modification of Change Permit Snip Two	63
Figure 66 - Modification of Change Permit Snip Three	63
Figure 67 - PSSR	64
Figure 68 - Exposure Permit	66
Figure 69 - Survey of Work Area	67
Figure 70 - Final Installation Front	68
Figure 71 - Final Installation Back	69
Figure 72 - PIN Customisation Evidence	73
Figure 73 - GANTT Chart	74

1.0 Introduction

1.1 Project Context

Access control systems are critical in maintaining security and restricting unauthorised access in various environments, whether domestic, industrial or corporate environments. Traditional key-based and keycard systems, while widely used, pose certain security risks. An incident at Eastman Chemical Company, Newport, highlighted vulnerabilities in the existing keycard system, so a need arose to develop a more reliable alternative.

This project focused on designing, developing and implementing an access control system that enhances security using a keypad, LED indication, and a PIC microcontroller. The system was required to replace a keycard access control system, to provide a more robust solution for securing a D.C.S. (Digital Control Systems) Server Room.

1.2 Project Aim and Objectives

An access control system is a security system designed to limit and control access to certain areas or resources, typically within a commercial or industrial setting. Access control systems can authenticate users using multiple identification methods, ranging from mechanical keys to keycards, biometrics or keypads.

The primary aim of this project was to design and implement a secure, reliable, and cost-effective access control system to replace the existing keycard access control system at Eastman Chemical Company, Newport. The project was required to address identified security concerns while ensuring ease of use. To achieve this aim, the following objectives were set:

Keypad Operation – On successful pin entry, the system needed to switch a contact, releasing the preexisting electromagnetic lock, and opening the door.

Quick Installation – The system should be installed within one hour to minimise disruption.

Customisable PIN – The system must allow for the PIN to be changed.

Power Supply and Battery Backup – The system must operate primarily on mains power but feature battery backup (UPS) to ensure continued functionality if power is lost.

Battery Backup Duration – The battery backup power source was required to last for over 12 hours in the event of power failure.

Cost – The total project cost needed to remain below £115 to meet budget constraints.

Time Constraints – To align with the predefined deadlines of the University of Wales Trinity Saint David, it was vital that the project was completed before May 2025

1.3 Report Structure

This report is structured into several chapters to provide a comprehensive analysis of the project. These include a literature review examining existing literature on access control technologies, similar systems on the market, and relevant security considerations. A system design and implementation, which discusses hardware and software decisions. The testing and evaluation chapter presents the findings of the project, notably comparing the real-world differences to the simulated results. Finally, the conclusion and recommendations chapter, which summarises the challenges encountered and makes recommendations for future improvements.

2.0 Literature Review

2.1 Literature Review Introduction

This chapter provides a comprehensive review of relevant literature on access control systems and the methodologies and technologies they employ. This chapter is structured into sections covering traditional and modern access control systems, security concerns with existing solutions, the use of microcontrollers in security systems and UPS considerations. Analysing existing literature has provided insight into how this project has built upon existing work while addressing the specific security needs at Eastman Chemical Company, Newport.

2.2 Eastman Chemical Company

Eastman Chemical Company operates a significant facility in Newport, South Wales, encompassing both a sales office and an Upper Tier COMAH manufacturing site. The sales office, Eastman Company UK Limited, serves as a hub for commercial operations in the UK.

Adjacent to the sales office is the manufacturing site operated by Solutia UK Limited, a subsidiary of Eastman. Acquired in 2012, this facility produces speciality chemicals, including Therminol heat transfer fluids and Saflex plasticisers. The site adheres to stringent environmental and energy management standards, holding ISO 14001:2015 and ISO 50001:2018 certifications. Demonstrating a commitment to sustainability, the Newport site installed two industrial-scale wind turbines in 2009, generating a portion of its electricity needs [1].

Eastman's Newport operations play a crucial role in the company's UK presence, combining commercial activities with advanced manufacturing and a strong emphasis on environmental responsibility.

2.3 Traditional and Modern Access Control Systems

Access control systems have evolved from simple mechanical locks to sophisticated electronic systems. Early security systems relied on mechanical locks and keys, which presented challenges such as unauthorised key duplication and the general inconvenience of managing multiple keys [2]. To overcome these limitations, keycard systems became widely adopted in corporate and industrial environments. However, research by A. Williamson et al. highlights vulnerabilities in keycard systems, such as susceptibility to cloning and more complicated hacking techniques [3]. Examples of Access Control Systems can be seen in Figure 4.



Figure 4 - Access Control Systems Examples [4].

Modern access control systems integrate electronic components such as biometric authentication, RFID technology, and keypad-based security mechanisms. Studies by R.S. Sandhu et al. demonstrate that electronic keypad systems offer a balance between security and cost-effectiveness, making them suitable for environments requiring moderate security measures [5]. Further research conducted by D. A. Adams et al. agrees with the premise, however, presents that there is a major issue with the use of PIN or password based on the theory that a brief search of associative memory can be used to anticipate what subjects will choose for passwords or personal identification numbers (PIN) [6]. S. Mohammed et al. designed and implemented a system which used both RFID and a PIN to account for this; however, they state that this increase in cost and system complexity greatly affects accessibility and ease of use [7].

2.4 Security Concerns in Existing Access Control Systems

Despite technological advancements, access control systems remain susceptible to security breaches, often from multiple sources. Research by F. Farahmand highlights common threats, including brute-force attacks, replay attacks, and vulnerabilities in outdated encryption methods [8]. Similarly, a case study by V. Thangavel analysed the failure of a keycard system due to credential skimming, reinforcing the need for alternatives with higher security measures [9]. 60% of organisations use keycard access control, which, although convenient, 66% of organisations would prioritise security over convenience [10].

A project with similar objectives was undertaken by researchers at San Juan de Letran, automating room access. The scope included access control to a room housing utility controls. Their results found that the use of both a keycard system to control access to the facility and a localised keypad offered a convenient yet secure solution, without suffering the issues which were faced by S. Mohammed et al. However, it still accounts for the security concerns raised by D. A. Adams et al [6], [7], [11].

2.5 Microcontrollers in Access Control Systems

The global microcontroller market was valued at \$32.37 billion in 2023 and is projected to expand at an annual growth rate of 11.7% from 2024 to 2030 [12]. Microcontrollers are widely used in access control systems and have been widely studied. Research by D. Strobel et al. highlights the advantages of using PIC microcontrollers due to their low power consumption, cost-effectiveness, and ease of programming [13]. Additionally, studies by I. Ungurean compare different microcontroller platforms, concluding that PIC microcontrollers provide efficient real-time processing for security applications [14].

MikroC is a programming language designed for microcontroller applications, which has been widely adopted for embedded system development [15]. The effectiveness of MikroC in managing secure access control functions has been demonstrated in multiple projects, some integrating real-time feedback mechanisms such as LED indicators and alarms, or integration with a wider system [16].

2.6 Power Backup Considerations in Access Control Systems

A Uninterruptible Power Supply (UPS) is a backup power source that provides electricity to devices during a power outage. UPS solutions are crucial in security systems to ensure continuous operation during power failures. Multiple studies have been conducted by researchers considering the use of UPS systems in access control systems, the majority of which present their benefits, including research by M. Amir, which states considerations which need to be made to effectively implement a UPS into an access control system. Further research by F. Pasqualetti et. al. states in great detail that security systems relying solely on mains power are at risk of downtime, potentially compromising restricted areas [17]. This simple concept is essential in providing a reliable security solution.

2.7 Relevance to the Project

Within Eastman, access control is employed to control access to critical areas, where major incidents could occur if the equipment is tampered with i.e. Safety Instrumented Systems (SIS), CCTV, etc. Solely keycard systems were used before this project began, restricting access to certain individuals at certain levels. Similarly to the research conducted by F. Farahmand and V. Thangavel, the worry of a keycard being skimmed or stolen arose at Eastman. To mitigate these risks, suggestions were made to integrate multi-layer authentication, i.e. use of a PIN, to add complexity [18],[19]. As a result, this project incorporated a PIN authentication system, addressing these concerns while maintaining usability and allowing access to the D.C.S. Server Room to be issued in the event of an incident quickly.

The research by D. Strobel et al. and I. Ungurean present the benefits of using a PIC Microcontroller for access control systems [13], [14]. This, in combination with their low cost and accessibility, is why a PIC microcontroller, programmed with MikroC, was used to control access for the project. Similarly, the use of a UPS system was a result of the findings by M. Amir. The objective requiring the UPS to be capable of supporting the system for over 12 hours was a result of primary research conducted at Eastman Chemical Company. The longest power outage was found to be 11 hours. Although unlikely to happen again, as it hasn't occurred since 1984, a UPS capable of 12 hours was thus required.

2.7 Conclusion

This literature review has examined various aspects of access control systems, including their vulnerabilities, the use of microcontrollers and power backup strategies. Findings indicate that traditional keycard systems pose security risks, while PIN-based electronic locks provide an effective alternative in some applications. PIC microcontrollers have been widely supported in research due to their efficiency, common use and cost-effectiveness. Additionally, the integration of a UPS solution enhances system reliability. These insights validate the approach taken in this project and demonstrate its relevance and impact in improving security at Eastman Chemical Company, Newport.

3.0 Background Research

3.1 Existing Access Control Systems

As covered previously, Electronic access control systems are widely used in domestic, commercial, and industrial settings. They incorporate various technologies, such as keypad locks, biometric authentication, and smart access systems. These systems commonly feature user programmability, multiple access modes (e.g., PIN codes, RFID or biometric recognition), and remote-control capabilities [20]. Below shown in Table 1 is a selection of existing access control solutions.

Table 1 - Comparison of Existing Access Control Systems

Cost: £141.80	Cost: £195.00	Cost: £270.12
		
Figure 1: Existing Technology Example One [20].	Figure 2: Existing Technology Example Two [21].	Figure 3: Existing Technology Example Three [22].
Pros: Battery Backup. LCD Display on Keypad. Lower Cost. Key Card and Key Pad.	Pros: Integrated Relay. Small Size. Easy to Mount.	Pros: Lock Included. Robust. Easy to Mount.
Cons: Large Enclosure. Battery-Powered Key Pad.	Cons: High Cost. No Battery Backup.	Cons: High Cost. Large Size. No Battery Backup. Limited Customizability.

Certain advanced security systems integrate wireless communication or cloud-based management, enhancing functionality and remote accessibility [20]. While these features offer significant benefits, this project prioritised a cost-effective yet practical solution through the implementation of a keypad system, providing a balance between security, affordability and

accessibility, particularly in emergency scenarios. As a result of this research, the budget, objective 6, was set at £115 to undercut the majority of existing systems on the market.

Although the project going over budget would not have been ideal, providing the cost remained under £140, the project could still have been deemed successful, as this is the threshold where existing systems meet the required specifications [20]. Analysing existing access control technologies also provided valuable insights into their advantages and limitations, helping further define this project's objectives.

3.3 Battery Considerations

Ensuring the supply of power is critical for an access control system, particularly in security-sensitive environments such as a D.C.S Server Room. UPS solutions mitigate power failures by using a battery to provide extended operational time during outages. Battery capacity was a critical factor in system design, with existing access control solutions offering backup power that can sustain operation for several hours [20]. The environmental impact of the battery was also considered.

Lithium-ion (Li-ion) batteries are among the most commonly used rechargeable batteries in electronic systems due to their high energy density, extended cycle life, and lightweight properties. Nickel-metal Hydride (NiMH) batteries, while more environmentally friendly than Lithium-ion, have lower energy density and a higher self-discharge rate, presented in Table 2. Lead-acid batteries, although cost-effective and reliable for high-power applications, are significantly heavier and have a shorter lifespan. Considering the requirements of this project, Li-ion batteries provided the optimal balance of efficiency, longevity, and compact design [24].

Table 2 - Battery Comparison [23]

Battery Type	Energy Density (Wh/kg)	Life Cycle	Toxicity
Li-Ion	126-190	500-1,000	Low
Ni-Cd	45-80	1000	High
Ni-MH	100	300-500	Low
Li-ion polymer	185	300 – 500	Low
Lead Acid	30-50	200-300	High
Lithium-Sulfur	55	50-100	Non- Toxic

3.4 Ethical and Environmental Considerations

During the design of the system, all materials and components were sourced ethically, prioritising sustainable or recycled components to reduce the environmental impact and energy consumption. Manufacturers were assessed based on their labour practices, environmental policies, and sustainability commitments. Consideration was given to the end-of-life management of components, including responsible battery disposal and recycling.

All aspects of this project have complied with the relevant legal standards and have adhered to site procedures. The system was required to be designed, constructed and tested following industry best practices [12]. Care was required to be taken to ensure the mains supply and battery backup were integrated safely, with appropriate considerations made to prevent electrical hazards such as short circuits, overloading, and accidental shocks, thus ensuring the safety of users [12].

The system will be for the majority housed inside the D.C.S. Server Room, preventing unauthorised access and reducing the risk of hacking and data breaches. No access logs will be kept, so the ethical handling of user information was not a great concern. The system needed to be designed and installed to accommodate a range of users, including those with disabilities, i.e. the keypad will be mounted so individuals with limited mobility, visual impairments, or other challenges can easily access it when needed [21].

As no participants were used within the project's scope, little thought needed to be given to the ethical storage and deletion of data. The only information gathered was regarding the system's performance. The design process needed to be transparent, with decisions documented and justified so that vulnerabilities or defects identified in the system could be addressed immediately.

3.4 Legal Considerations

The design and implementation of the system adhere to several key standards and regulations to ensure safety, reliability, and compliance, such as: BS EN 50133-1:1997 – Alarm Systems: Access Control [25], BS 7671:2018 – IET Wiring Regulations [26], BS EN 62368-1:2020 – Safety of ICT Equipment [27] and BS EN 60839-11-1:2013 – Security Systems [28].

Additionally, compliance with UK GDPR [29], the RoHS & WEEE Directives [30], and BS EN 61000-6-3:2007 – Electromagnetic Compatibility (EMC) [31] was considered. Adhering to these standards ensured that the system was safe, secure, environmentally responsible, and legally compliant.

3.5 Tools and Software

Initially, only Proteus and MikroC were intended to be used; however, later in the design process, MPLAB X IDE was required, due to issues with the MikroC software itself, not being compatible with the programming device itself. Further details can be found in chapter 5.4.

Proteus is a versatile simulation software widely used for designing and testing electronic circuits. It allows integration of microcontrollers with peripheral devices, enabling real-time simulation of embedded systems. As a result, it was used as part of this project to design the circuit itself and simulate the final system using the program developed on MikroC [32],[33].

MikroC is a powerful and user-friendly C compiler developed by MikroElektronika for programming PIC microcontrollers. It offers an intuitive IDE, extensive built-in libraries, and efficient code generation tools. MikroC simplifies embedded system development by enabling rapid code development, debugging, and integration with hardware through features like simulation and device-specific support [34],[35].

MPLAB X IDE is a comprehensive integrated development environment developed by Microchip for programming and debugging PIC microcontrollers. It supports C and assembly languages, offering features such as project management, simulation, and in-circuit debugging. Its user-friendly interface enhances productivity and streamlines embedded system development [36].

The final program was written in C, a high-level, general-purpose programming language widely used in embedded systems due to its efficiency, speed, and control over hardware. It provides low-level memory access, making it ideal for programming microcontrollers, the primary reason it was used for the PIC microcontroller. C's structured approach allows developers to write compact, reliable code suitable for real-time and resource-constrained applications [37].

A wide range of hand tools was used throughout the design and implementation phases of the final system. For testing purposes, a multimeter was used. Initially, a lower-cost multimeter was employed, but it led to inaccuracies and unreliable readings. Consequently, a higher-quality multimeter was sourced to ensure precise measurements and consistent results during the testing phase.

4.0 Component Research

4.1 Component Research Introduction

This chapter provides a comprehensive review of the research that was undertaken before sourcing the components and other materials used within the access control system, excluding miscellaneous components and materials such as resistors, diodes, cable, etc. Coinciding with the component choices is the reasoning behind the type of component and its specification, referencing back to the literature and background research conducted. Further showing the contribution to the design and implementation of the effective access control system.

4.2 Microcontroller

The “Microchip Advanced Part Selector” was used to select the ideal microcontroller. Twelve digital input pins and three digital output pins were required as a minimum. A minimum CPU speed of 20MHz and a program memory size of 4 - 16KB was selected, as it would easily handle the program requirements. To further increase the ease of use, an operating voltage of > 5V was selected so a 7805 Voltage Regulator could be used. Using the selector tool, there were 92 possible options. Having checked, it could be modelled on Proteus, a PIC16F877A was chosen, its specification can be seen in Figure 5 [38].

PIC16F877A		In Production	
Specifications	Dev Tools	Technical Docs	Budgetary Pricing
Family			8-bit MCU
CPU Type			8-bit PIC MCU
Max CPU Speed (MHz)			20 MHz
FPU			
Operation Voltage			(2V-5.5V)
Temp Range			(-40 to +125)
Pin Count			40
Program Memory Size (KB)			14
Error Correction Code Program Flash			
SRAM			368 Bytes
Data EEPROM/HEF (Bytes)			256
Internal DRAM Type			
Internal DRAM Amount (MB)			
Low Power			
ADC Input			8
Max ADC Resolution (Bits)			10
DAC Outputs			
Number of Op Amps			
Hardware Touch Resistor			

Figure 5 - PIC16F877A Specification [39]

4.3 Keypad

The selection of an appropriate keypad was a critical consideration, as the type chosen (Matrix or Telephone) would directly alter the connection method to the microcontroller. The three options were identified through research conducted on market-leading websites, with the initial comparison based on cost, availability, and ease of use. These factors were assessed both from a design and installation perspective, as well as in terms of usability for the end user. The comparison of each option is presented in Table 3.

The second option presented the simplest connection to the microcontroller, as it used a common point configuration rather than a matrix layout. A common point setup requires a single input and multiple outputs, each output corresponding to an individual button. In contrast, a matrix keypad employs a grid of rows and columns, where pressing a button connects a specific row to a specific column. The microcontroller then determines the pressed button by scanning these connections. Option two was chosen due to ease of use, low cost and ease of mounting.

Table 3 - Keypad Comparison

Title: 12 Keys 3x4 Push Buttons Keyboard Module	Title: EOZ IP40 12 Key Keypad (Common Point)	Title: Storm IP65 12 Key Polymer Keypad
Photo:  Figure 8 - Keypad Three [40]	Photo:  Figure 7 - Keypad Two [41]	Photo:  Figure 6 - Keypad One[42]
Cost: £4.66	Cost: £17.42	Cost: £36.56
Pros: Simple. Cheap. Easy to mount.	Pros: Telephone Keypad. Simple. Easy to mount.	Pros: Easy to mount. IP65.
Cons: No IP Rating. Separate enclosure required. Untrusted Source. Matrix Keypad.	Cons: Only IP40. Separate enclosure required. Pins on Rear.	Cons: Separate enclosure required. Pins on Rear. Matrix Keypad.

4.4 Enclosures

Selection of a suitable enclosure was crucial for protection, durability, and component integration. Three options were compared based on size, material, ingress protection, and mounting features, as shown in Table 4.

The Hammond RL Series Grey ABS Enclosure was the largest at $70 \times 150 \times 200$ mm. Its ABS plastic construction provided durability and a lightweight design, with flanges for secure mounting. However, its size made it less suitable for compact applications. The RS PRO Black ABS Enclosure offered a more compact alternative. Its black lid provided a discreet aesthetic, though the lack of a flanged lid limited mounting options. The Takachi TD Series Die-Cast Aluminium Enclosure, measured $80 \times 55 \times 30$ mm, was the smallest and most durable. Its aluminium construction provided superior protection and shielding, but added weight. Option one was selected for its affordability and compact size, minimising the system footprint.

Table 4 - Enclosure Comparison

Title: RS PRO Black ABS General Purpose Enclosure, IP54, Black Lid, 150 x 80 x 50mm	Title: Hammond RL Series Grey ABS General Purpose Enclosure, IP54, Flanged, Grey Lid, 70 x 150 x 200mm	Title: Takachi Electric Industrial TD Series Black Die Cast Aluminium Enclosure, Black Lid, 80 x 55 x 30mm
Photo:  Figure 10 - Enclosure Two [43]	Photo:  Figure 9 - Enclosure One [44]	Photo:  Figure 11 - Enclosure Three [45]
Cost: £8.05	Cost: £36.56	Cost: £17.71
Pros: Cheap. IP54.	Pros: Large Size. IP54.	Pros: Aluminium.
Cons: Small Size.	Cons: High Cost.	Cons: Small Size. IP40. High Cost.

4.5 Power Supply

Selecting the appropriate AC/DC transformer was crucial for ensuring reliable power delivery. Three options were evaluated based on output power, current capacity, and efficiency. An output voltage of 12V was selected because a 7805 could be used to further reduce and regulate the voltage before being introduced into the circuit, and 12V adapters are widely available. Stepping down from 240V to 5V is not as common a practice as 240V to 12V.

The RS PRO 12W Adapter provides an output current at 1A, making it the most compact and power-efficient choice for low-power applications. However, the 12W limit may not be sufficient if the system is expanded upon. The XP Power 24W Adapter and the RS PRO 24W Adapter both delivered 12V DC at 2A, doubling the current capacity of the first option. This allows them to support higher-powered devices or multiple components. While both provide 24W of output, brand reputation and cost differentiate them, with RS Pro looking more reliable and being cheaper, as a result, it was chosen. The comparison of each option is presented in Table 5.

Table 5 - Transformer Comparison

Title: RS PRO 12W Plug-In AC/DC Adapter 12V dc Output, 1A Output	Title: XP Power 24W Plug-In AC/DC Adapter 12V dc Output, 2A Output	Title: RS PRO 24W Plug-In AC/DC Adapter 12V dc Output, 2A Output
Photo: 	Photo: 	Photo: 
Figure 12 - Transformer One [46]	Figure 13 - Transformer Two [47]	Figure 14 - Transformer Three[48]
Cost: £10.00	Cost: £15.26	Cost: £13.60
Pros: Low Price. Long Lead.	Pros: High Output Current.	Pros: High Output Current.
Cons: Low output Current.	Cons: High Cost.	Cons: Short Lead.

4.6 Battery

Selecting the most suitable 12v rechargeable battery depends on factors such as capacity, chemistry and lifespan. The three options were compared based on their capacity, discharge characteristics, and practicality, as shown in Table 6.

The RS PRO 12v T1 Sealed Lead Acid (SLA) Battery offers the highest energy storage at 6.5Ah, known for reliability and affordability but limited by weight and low cycle life, making it suitable for stationary use like backup power. The RS PRO 12v 800mAh NiCd Battery has a much lower capacity but excels in high discharge rates and extreme temperature durability, though it suffers from memory effect and low energy density. The RS PRO 11.1v 2.6Ah Lithium-Ion Battery Pack offers compact size, high energy density, and longer cycle life, but requires careful charging and thermal management. Option three was selected to meet the requirements outlined in Chapter 3.3. Its compact size and sustainability advantages outweighed the higher cost.

Table 6 - Battery Comparison

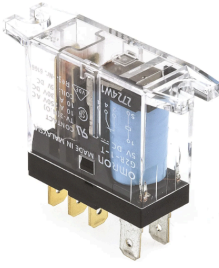
Title: RS PRO 12V T1 Sealed Lead Acid Battery, 6.5Ah	Title: RS PRO RS PRO, 12V, 12V0.8AH, NiCd Rechargeable Battery, 800mAh	Title: RS PRO 11.1V Lithium-Ion Rechargeable Battery Pack, 2.6Ah - Pack of 1
Photo:  Figure 15 - Battery One [49]	Photo:  Figure 16 - Battery Two [50]	Photo:  Figure 17 - Battery Three [51]
Cost: £24.06	Cost: £17.06	Cost: £32.70
Pros: Large Capacity.	Pros: NiCd. Small Size. Termination Leads. Low Cost.	Pros: Lithium-Ion. Small Size. Termination Leads. High Capacity.
Cons: High Cost. Large Size. Lead Acid.	Cons: Low Capacity.	Cons: High Cost.

4.7 Relay

Selecting the appropriate 5v power relay was essential to ensure reliable switching 230v AC with 5v DC. Three options were evaluated based on switching capability, mounting method, and suitability for the application. This comparison can be seen in Table 7.

The Omron PCB Mount Power Relay (DPDT, 5A) could control two circuits, but this wasn't essential for this system. The Omron Panel Mount Power Relay (SPDT, 10A) handles higher power but needs extra space due to its panel mount. The Finder PCB Mount Power Relay (SPDT, 10A) offers the same power capacity in a more compact, PCB-friendly design, making it better suited for space-saving enclosures, hence, it was selected.

Table 7 - Relay Comparison

Title: Omron PCB Mount Power Relay, 5V dc Coil, 5A Switching Current, DPDT	Title: Omron Panel Mount Power Relay, 5V dc Coil, 10A Switching Current, SPDT	Title: Finder PCB Mount Power Relay, 5V dc Coil, 10A Switching Current, SPDT
Photo: 	Photo: 	Photo: 
Figure 18 - Relay One [52]	Figure 19 - Relay Two [53]	Figure 20 - Relay Three [54]
Cost: £5.17	Cost: £6.37	Cost: £3.16
Pros: PCB Mount. Simple. Cheap.	Pros: High Switching Current. Robust.	Pros: Small Size. Low Cost. PCB Mount.
Cons: Only 5A Switching Current. Large in Size.	Cons: Mount Required. Large in Size.	Cons: Less Robust. Harder to Work With.

4.8 LEDs

Selecting the correct open (green) indication LED was required to ensure compatibility with the enclosure, power supply, and environmental conditions. Three options were compared based on mounting hole size, termination type, brightness and current draw, as shown in Table 8.

The Dialight Green Panel Mount Indicator operates at 5V DC, needs a 6.4mm mounting hole, and uses lead wires for easy installation. Its compact size helps minimise enclosure size but may lack sufficient brightness for clear status indication. The Oxley OXL/CLH/80 Series (5V DC, IP67) uses an 8mm hole, offers better durability with IP67 protection, and shares the same wiring. A similar Oxley model (5v AC, IP66/IP67) adds aluminium housing for improved aesthetics. Option one was chosen for its lower cost and smaller footprint, helping reduce overall system size.

Table 8 - Green LED Comparison

Title: Dialight Green Panel Mount Indicator, 5V dc, 6.4mm Mounting Hole Size, Lead Wires Termination	Title: Oxley OXL/CLH/80 Series Green Panel LED, 5V dc, 8mm Mounting Hole Size, Lead Wires Termination, IP67	Title: Oxley OXL/CLH/80 Series Green Panel LED, 5V dc, 8mm Mounting Hole Size, Lead Wires Termination, IP66, IP67
Photo:  Figure 21 - Green LED One [55]	Photo:  Figure 22 - Green LED Two [56]	Photo:  Figure 23 - Green LED Three [57]
Cost: £3.12	Cost: £9.80	Cost: £9.80
Pros: Panel Mount. Preinstalled Leads. Easy Installation. Cheap.	Pros: Panel Mount. Preinstalled Leads. Easy Installation. Bright.	Pros: Panel Mount. Easy Installation. Bright.
Cons: Small Size. Limited Brightness.	Cons: High Cost.	Cons: Termination Leads Required. High Cost.

To maintain a consistent and aesthetically pleasing design, red LEDs visually similar to their green counterparts were selected. As with the green indicator, option one was chosen due to its lower cost and smaller footprint, contributing to a more compact enclosure and overall system design. The comparison of each option is presented in Table 9.

Table 9 - Red LED Comparison

Title: Dialight Red Panel Mount Indicator, 5V dc, 6.4mm Mounting Hole Size, Lead Wires Termination	Title: Dialight Red Panel Mount Indicator, 5V dc, 17.5mm Mounting Hole Size, Lead Wires Termination	Title: Oxley OXL/CLH/80 Series Red Panel LED, 5V dc, 8mm Mounting Hole Size, Lead Wires Termination, IP67
Photo:  Figure 24 - Red LED One [58]	Photo:  Figure 25 - Red LED Two [59]	Photo:  Figure 26 - Red LED Three [60]
Cost: £3.01	Cost: £18.76	Cost: £9.80
Pros: Panel Mount. Preinstalled Leads. Easy Installation. Cheap.	Pros: Panel Mount. Preinstalled Leads. Easy Installation. Bright.	Pros: Panel Mount. Easy Installation. Bright.
Cons: Small Size. Limited Brightness.	Cons: High Cost. Large Size.	Cons: Termination Leads Required. High Cost.

5.0 System Design

5.1 System Design Introduction

The design and development of the access control system consisted of three stages: simulation, program development and physical prototyping. Each stage needed to be completed before the next could be started, hence each was essential in ensuring that the final system functioned reliably and safely after installation.

5.1.1 Simulation and System Modelling in Proteus

The first stage involved designing and simulating the entire circuit using Proteus, a widely used simulation tool for embedded systems. Proteus was chosen due to its ability to emulate microcontrollers alongside peripherals, i.e. keypads, LEDs, etc.

The circuit was built to include all components: a PIC microcontroller, the keypad, LEDs, a relay, etc. The simulation allowed for both testing of the program (input and output logic) and the circuit. On completion of the program, and upload it was to be used to help identify and test issues such as incorrect keypress detection and delays. Before the completion of the program, it was used to identify some miscellaneous components which were needed but not part of the component research.

This stage reduced the risk of hardware damage and helped simplify the component layout for the final prototype.

5.1.2 Program Development in MikroC

Following a successful circuit having been developed, the next stage focused on developing and testing the access control program using the MikroC software. MikroC was selected for its comprehensive support for PIC microcontrollers and its built-in libraries for commonly used peripherals, such as LCDs and keypads. The program was responsible for managing all the core system functions:

- Detecting the keypad inputs.
- Debouncing keypad inputs to prevent false triggering.
- Comparing keypad inputs to the stored pin value.
- Activating the output conditions on successful pin entry.

The program was tested using both the MikroC debugger and within the Proteus environment. Program adjustments were made during testing to achieve accurate keypad input recognition and safe control of the relay module in the event of power loss or system failure. Pin verification was handled using a simple comparison routine with a reset after an incorrect PIN press or a timeout between PIN presses.

5.1.3 Prototyping and Assembly

After the firmware was verified in simulation, the complete system was constructed on two prototyping boards. Special attention was given to the electrical separation between the 12v supply circuit and the 5v control circuit.

The PIC microcontroller was programmed using an external programmer and installed on the board using a Dip Socket. Proper insulation, heat management, and secure mounting were ensured at all times. The final prototype was tested in a controlled environment before being installed on site.

The design was first validated by verifying that the system could reliably detect and verify access codes, operate the relay and provide visual feedback using the LEDs. The next stage of testing involved comparing the simulated and real-world results. Finally, testing of the UPS system was conducted to verify that all initial objectives were met.

All stages of system design were required to identify and address issues such as timing inaccuracies, power supply faults, fabrication issues and response delays.

In summary, this structured design process enabled the design and development of a functional, safe and efficient access control system. The simulation software, program development software and physical testing equipment each played a critical role in transforming the concept into a deployable solution, despite some issues being faced, which are covered later in this report.

5.2 System Design Iterations on Proteus

The system was designed and refined through multiple simulation iterations using Proteus. This approach provided a safe and efficient environment for testing the access control circuit and would later be used to verify the microcontroller's behaviour when the program iterations were uploaded. Each iteration allowed for instant troubleshooting and incremental improvements to the design without risking physical components.

The first iteration solely included push buttons, a microcontroller, LEDs and a relay and revealed several issues, including the need for pull-down resistors on each button. The next iteration built up from the first and included pull-down resistors, ballast resistors for the LEDs and a more accurate to life relay. The next iteration included the addition of a Battery and 12V Supply and a basic UPS system. The system would typically be fed from 240V AC mains power, through a plug transformer giving an output of 12V which would then be reduced to 5V using a 7805 voltage regulator. The final iteration added a clamp after the UPS System to prevent overvoltage (power spike) from damaging the system. Power Spikes and Drops are frequent issues at Eastman due to the number of high-power motors on site.

A normally open (NO) relay contact was used for the access control system to ensure that, in the event of a power failure, the door to the D.C.S. Server Room could still be opened. This design choice prioritises safety, allowing access to resolve any issues during a power outage. If a normally closed (NC) contact had been used instead, the door would remain locked without power, potentially preventing timely access to the server room.

By performing these simulations, the system's core functionality was validated before moving to programming and hardware. This not only reduced development time but also minimised the risk of hardware failure due to critical errors. Using Proteus ensured that only a stable, well-tested circuit was transitioned to the physical prototyping stage.

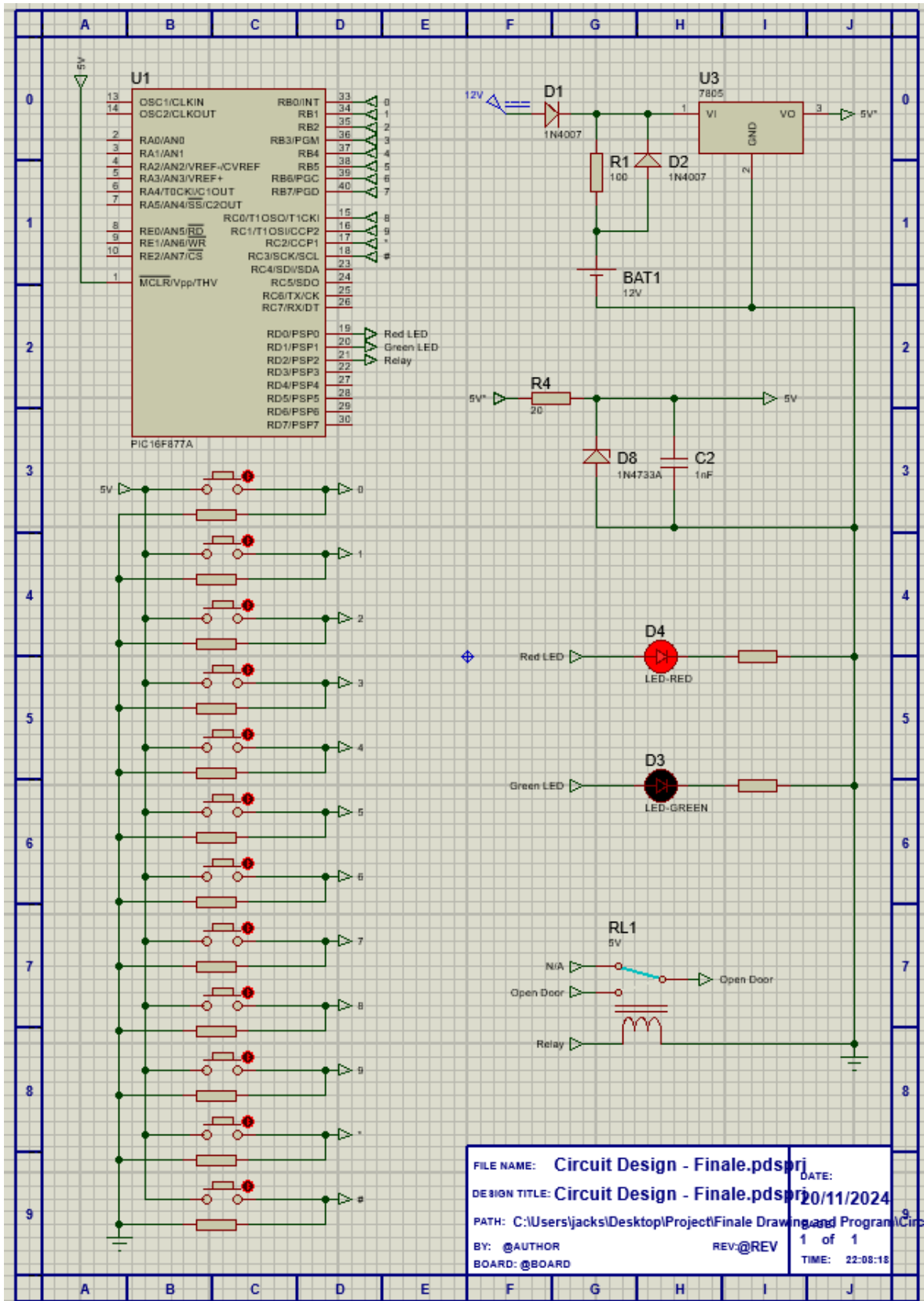


Figure 27 - Proteus Final Design

5.3 System Design Iterations on MikroC

The program development process was carried out using MikroC for PIC. Similarly to the design iteration process with Proteus, program development underwent several iterations focused on refining the system logic, improving reliability, and performance. Each iteration of development involved coding, simulation, debugging and finally validation using Proteus to ensure the program responded correctly to user input and controlled the hardware accurately.

Before any code was developed, a program flowchart was created to streamline the programming process, shown in Figure 28. This flowchart was later revised to incorporate modifications and address issues identified during Draft 6 of the design.

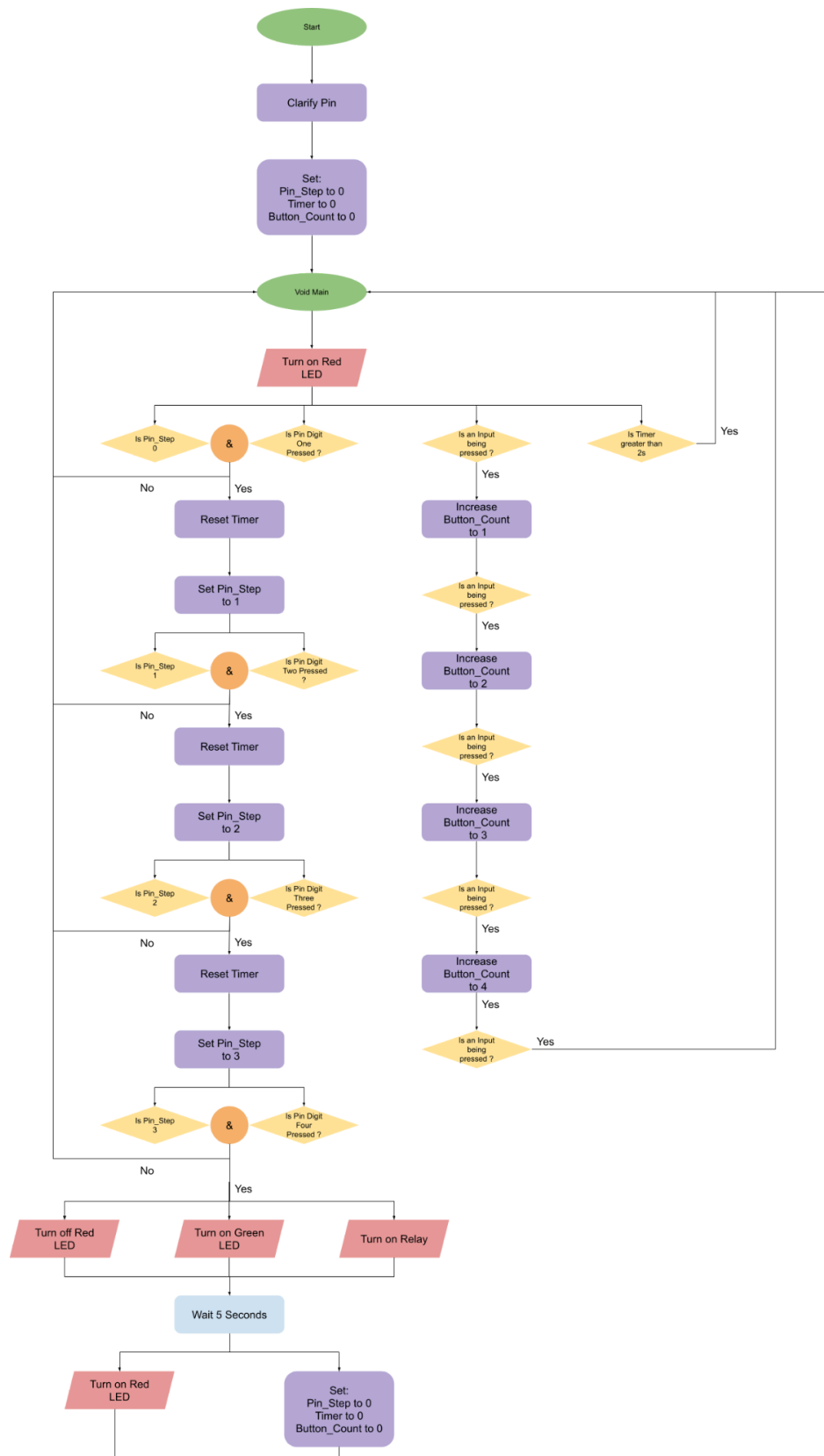


Figure 28 - Program Flow Chart

The Initial code focused on establishing basic keypad input functionality and LED output control, as shown below in Figure 29:

```
// Draft One:

void main() {
    TRISB = 0xFF; // Set Port B as Input
    TRISC = 0xFF; // Set Port C as Input
    TRISD = 0x00; // Set Port D as Output
    PORTD = 0x00; // Initially turn off Port D (LED is off)

    while (1) { // Infinite loop to continually check inputs
        if (PORTB != 0x00 || PORTC != 0x00) { // Check if any input on Port B or Port C is pressed
            PORTD = 0xFF; // Turn on all of Port D (LEDs on)
        } else {
            PORTD = 0x00; // Turn off all of Port D (LEDs off)
        }
    }
}
```

Figure 29 - Program Draft One Snip

During the second iteration, Figure 30, the pin system began development. This included implementing a timer variable to track prolonged intervals between key presses and a variable to indicate the current digit or step of the pin being entered, in an attempt to reset the loop whenever an incorrect digit was input. This was later found to be unreliable as the incorrect pin press wasn't being read.

```
...
while (1) {
    if (step == 0 && (PORTB & 0x01) != 0) {
        time_counter = 0;
        while ((PORTB & 0x01) != 0);
        step = 1;
    }
    if (step == 1) {
        time_counter++;
        if (time_counter >= 100) {
            step = 0;
        }
        if ((PORTB & 0x02) != 0) {
            time_counter = 0;
            while ((PORTB & 0x02) != 0);
            step = 2;
        }
    }
    ...
    if (step == 3) {
        time_counter++;
        if (time_counter >= 100) {
            step = 0;
        }
        if ((PORTB & 0x08) != 0) {
            PORTD = 0x01;
            Delay_ms(1000);
            PORTD = 0x00;
            step = 0;
            while ((PORTB & 0x08) != 0);
        }
    }
    Delay_ms(10);
}
```

Figure 30 - Program Draft Two Snip

The second draft was designed to improve the modification process for the Pin by incorporating HEX addresses for each pin alongside their corresponding identifiers at the top of the program. Additionally, the draft focused on refining the code for improved clarity and making the timer variable more reliable by increasing the allowed time between presses. These changes can be seen in Figure 31.

```
// Draft Three:
// Pin Digit 0 = PORTB & 0x01
// Pin Digit 1 = PORTB & 0x02
// Pin Digit 2 = PORTB & 0x04
// Pin Digit 3 = PORTB & 0x08
// Pin Digit 4 = PORTB & 0x10
// Pin Digit 5 = PORTB & 0x20
// Pin Digit 6 = PORTB & 0x40
// Pin Digit 7 = PORTB & 0x80
// Pin Digit 8 = PORTC & 0x01
// Pin Digit 9 = PORTC & 0x02
// Pin Digit * = PORTC & 0x04
// Pin Digit # = PORTC & 0x08

...

// Pin Digit 4
if (Pin_Step == 3) {
    Timer++;
    if (Timer >= 200) {
        Pin_Step = 0;
    }
    // If Pin Digit 4 has been Pressed
    // Increase Timer by One
    // If Pin Digit 4 not Pressed
    // Reset Pin

    if ((PORTB & 0x08) != 0) {
        while ((PORTB & 0x08) != 0);
        PORTD = 0x00;
        PORTD = 0x06;
        Delay_ms(1000);
        PORTD = 0x00;
        PORTD = 0x01;
        Pin_Step = 0;
    }
    // If Pin Digit 4 is Pressed
    // Pin Digit 4 Released
    // Turn Off Red LED
    // Turn On Green LED and Relay
    // Keep On for 5 Seconds
    // Turn Off Green LED and Relay
    // Turn On Red LED
    // Reset Pin
}

Delay_ms(10); // Delay
}
```

Figure 31 - Program Draft Three Snip

The fourth iteration further streamlined the process of modifying the pin by using #define functions at the beginning of the code. This eliminated the need to manually search through the program for adjusting the PIN, making the program more efficient and improving user friendliness. Additionally, the timer for the green LED and relay was extended from one second to five seconds, further improving the user friendliness of the access control system after installation. Some of the fourth iteration changes can be seen in Figure 32.

```
...  
  
#define PIN1 0x02           // Alter for Pin Digit One  
#define PIN2 0x04           // Alter for Pin Digit Two  
#define PIN3 0x08           // Alter for Pin Digit Three  
#define PIN4 0x10           // Alter for Pin Digit Four  
  
...  
  
// Check if PIN2 (RB1) is pressed after PIN1  
if (Pin_Step == 1) {  
    Timer++;  
    if (Timer >= 200) { // Timeout if no press within 1 second  
        Pin_Step = 0; // Reset step  
    }  
    if ((PORTB & PIN2) != 0) {  
        Timer = 0; // Reset Timer  
        while ((PORTB & PIN2) != 0); // Wait for PIN2 to be released  
        Pin_Step = 2; // Move to the next step  
    }  
}  
  
...
```

Figure 32 - Program Draft Four Snip

Draft five resolved an issue identified in draft four, where pin functionality was limited to inputs from port B. While a straightforward problem, it initially went unnoticed and required significant time to address. Additionally, draft five enhanced the code's structure, improving readability and simplifying future modifications, as shown in Figure 33.

```
// Draft Five:
// Pin Digit 0 = PORTB & 0X01
// Pin Digit 1 = PORTB & 0X02
// Pin Digit 2 = PORTB & 0X04
// Pin Digit 3 = PORTB & 0X08
// Pin Digit 4 = PORTB & 0X10
// Pin Digit 5 = PORTB & 0X20
// Pin Digit 6 = PORTB & 0X40
// Pin Digit 7 = PORTB & 0X80
// Pin Digit 8 = PORTC & 0X01
// Pin Digit 9 = PORTC & 0X02
// Pin Digit * = PORTC & 0X04
// Pin Digit # = PORTC & 0X08

// Define Four Digits for Pin
#define PIN1 (PORTB & 0X01)           // Alter for Pin Digit One
#define PIN2 (PORTB & 0X02)           // Alter for Pin Digit Two
#define PIN3 (PORTC & 0X01)           // Alter for Pin Digit Three
#define PIN4 (PORTC & 0X02)           // Alter for Pin Digit Four

...
```

Figure 33 - Program Draft Five Snip

Iteration six resolved another previously unnoticed issue, where access could be granted if the correct PIN was entered within multiple other key presses, including incorrect key presses. To address this, the Button_Count variable was introduced, limiting the number of key presses to a maximum of three before either a reset or access is triggered, shown in Figure 34.

```
...  
int Pin_Step = 0;           // Variable for Pin Step set to Zero  
unsigned int Timer = 0;     // Timer Variable  
unsigned int Button_Count = 0; // Button Count Variable  
...  
  
while (1) {                 // Pin Program Logic  
    // Reset If Wrong  
    if (PORTB & 0xFF) {     // Check if PORTB is Pressed  
        Button_Count++;    // Increase Button Count  
    }  
  
    if (PORTC & 0xFF) {     // Check if PORTC is Pressed  
        Button_Count++;    // Increase Button Count  
    }  
  
    if (Button_Count > 4) {  // Only Four Buttons Can be Pressed  
        Pin_Step = 0;      // Reset Pin Step  
        Button_Count = 0;  // Reset Button Count  
        Delay_ms(500);     // Delay  
    }  
...  
}
```

Figure 34 - Program Draft Six Snip

Draft seven aimed to introduce a method for altering the PIN using the keypad itself, using the ‘unsigned char’ data type. Extensive research was conducted to overcome challenges, but difficulties persisted. While exploring this approach, concerns were raised regarding security implications, specifically, the risk of any individual possessing the initial PIN, unintentionally altering the PIN, and consequently locking out other users. As a result, draft seven, presented in Figure 35, was deemed unsuitable, and further development was focused on refining draft six.

```
// Draft Seven:
// Default Pin Definitions
#define DEFAULT_PIN1_MASK 0x01
#define DEFAULT_PIN2_MASK 0x02
#define DEFAULT_PIN3_MASK 0x01
#define DEFAULT_PIN4_MASK 0x02

// Mutable Pin Masks
unsigned char PIN1_MASK = DEFAULT_PIN1_MASK;
unsigned char PIN2_MASK = DEFAULT_PIN2_MASK;
unsigned char PIN3_MASK = DEFAULT_PIN3_MASK;
unsigned char PIN4_MASK = DEFAULT_PIN4_MASK;

...

// Redefine Pins Dynamically
if (PORTB & 0xFF) {
    if (PORTB & 0x01) PIN1_MASK = 0x01;
    if (PORTB & 0x02) PIN2_MASK = 0x02;
    if (PORTB & 0x04) PIN3_MASK = 0x04;
    if (PORTB & 0x08) PIN4_MASK = 0x08;
}

// Check PORTB
// Set PIN1 if RB0 is Pressed
// Set PIN2 if RB1 is Pressed
// Set PIN3 if RB2 is Pressed
// Set PIN4 if RB3 is Pressed

if (PORTC & 0xFF) {
    if (PORTC & 0x01) PIN1_MASK = 0x01;
    if (PORTC & 0x02) PIN2_MASK = 0x02;
    if (PORTC & 0x04) PIN3_MASK = 0x04;
    if (PORTC & 0x08) PIN4_MASK = 0x08;
}

// Check PORTC
// Set PIN1 if RC0 is Pressed
// Set PIN2 if RC1 is Pressed
// Set PIN3 if RC2 is Pressed
// Set PIN4 if RC3 is Pressed

...
```

Figure 35 - Program Draft Seven Snip

The final draft used the core structure of draft six, with only minor adjustments. Focusing on improving user accessibility, ensuring that individuals with little programming experience could modify the pin with ease. A portion of the final draft can be seen in Figure 36.

```
//  Finale Draft:

//  To alter Pin, change PIN1,PIN2,PIN3 & PIN4 within the Define Four Digits
//  section, after the #define PINX to the desired value, using the table below.

//  Pin Digit 0 = PORTB & 0X01
//  Pin Digit 1 = PORTB & 0X02
//  Pin Digit 2 = PORTB & 0X04
//  Pin Digit 3 = PORTB & 0X08
//  Pin Digit 4 = PORTB & 0X10
//  Pin Digit 5 = PORTB & 0X20
//  Pin Digit 6 = PORTB & 0X40
//  Pin Digit 7 = PORTB & 0X80
//  Pin Digit 8 = PORTC & 0X01
//  Pin Digit 9 = PORTC & 0X02

// Define Four Digits for Pin
#define PIN1  (PORTB & 0X01)           // Alter for Pin Digit One
#define PIN2  (PORTB & 0X02)           // Alter for Pin Digit Two
#define PIN3  (PORTC & 0X01)           // Alter for Pin Digit Three
#define PIN4  (PORTC & 0X02)           // Alter for Pin Digit Four

...
```

Figure 36 - Program Final Draft Snip

5.4 Design Iterations on MikroC Conclusion

The development of this program followed a rigorous iteration process, using MikroC alongside Proteus for simulation and validation. Each phase of development focused on enhancing system logic, improving reliability and refining performance, ensuring seamless interaction between the user input and the hardware output when installed.

Early iterations or drafts established fundamental functionality, including keypad input handling and LED output control. As development progressed, more sophisticated features were integrated, such as the pin system itself, pin tracking variables and timer functions. The code was also streamlined for simpler pin alteration. These refinements significantly improved usability, efficiency, and system clarity.

Throughout the development cycle, several critical issues emerged, including pin input limitations, security vulnerabilities, and unintended behaviours affecting access control. Each of these challenges was addressed through each iteration, leading to improved accuracy and robustness. While draft seven explored altering the pin via the keypad, security concerns rendered this approach impractical, reinforcing the decision to refine draft six further.

The final draft further improved accessibility, ensuring that users with minimal programming experience could modify the pin effortlessly. With continuous testing and improvements, the program evolved into a reliable and secure system, fully prepared for download into hardware.

6.0 System Design Prototyping

6.1 Introduction

With the program developed and validated through simulation on Proteus, the final stage of the design involved the construction and testing of the complete access control system on two prototyping boards. Transforming the previously simulated design into a functioning, standalone system capable of being installed and used in the real world. All components were integrated and connected according to the validated design. The system was then thoroughly tested for reliability, responsiveness, and safety.

The hardware was distributed across two separate prototyping boards to improve organisation and reduce component congestion. The first board was dedicated to the user interface elements, including the keypad, pull-down resistors, and status indicator LEDs. The second board housed the core control and power systems, comprising the PIC microcontroller, relay module, power regulation circuitry and various supporting components. Prototyping began with the user interface board, as its relatively simple layout provided an opportunity to gain practical experience before progressing to the more complex microcontroller board.

6.2 User Interface Board

The assembly of the user interface board began with a preliminary layout of all components, arranged carefully with a clear, organised structure, to reduce potential signal interference. Once the layout was complete, the components were securely soldered onto the prototyping board. Shown in Figure 37 and Figure 38. Interconnections between components were established using jumper leads and soldered tracks, with careful attention paid to correct pin mapping and stable connections.

During this stage, the first significant hardware design issue was encountered. The connector block intended to link the user interface board with the control board lacked sufficient terminals to accommodate all necessary connections. Specifically, the number of terminals was insufficient for the full keypad matrix, LED outputs, 5v supply line and ground connection. Although two 14-terminal connectors had been initially selected, based on the original Proteus simulation, this design did not account for the additional supplies required for keypad operation.

To resolve this issue within time constraints, a compromise was made by leaving the connections for the '*' and '#' keypad buttons unconnected. These keys were not referenced in the final program, as they were originally intended for implementing a feature to change the PIN directly from the keypad, which was later rejected.

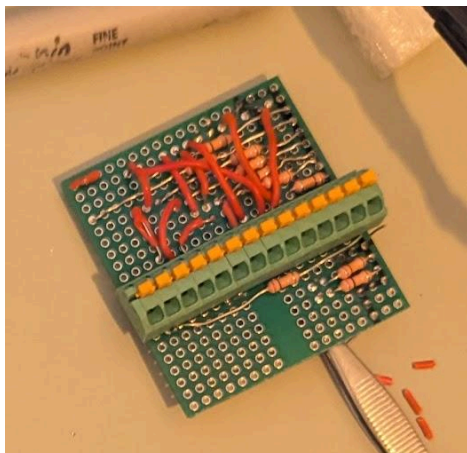


Figure 37 - User Interface Board
Picture One

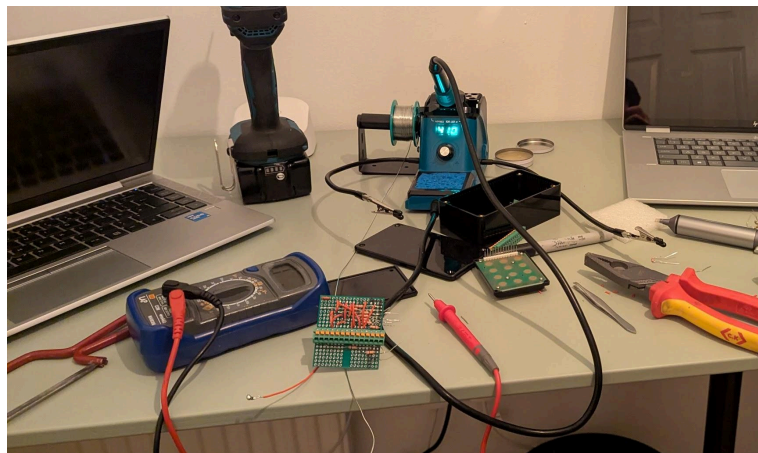


Figure 38 - User Interface Board Picture Two

6.3 Control Board

Similarly to the User Interface Board, assembly began with a preliminary layout of all components, again arranged carefully with a clear, organised structure, to reduce potential signal interference. However, a second hardware issue became evident during this stage; the board was significantly congested. This high component density made soldering particularly challenging and caused the prototyping phase to take considerably longer than initially anticipated. The density of components can be seen in Figure 39 and Figure 40.

The complexity of the layout raised questions about the efficiency of the design process. In hindsight, creating a dedicated circuit diagram specifically for the prototyping board layout might have helped reduce confusion and errors during assembly. The dense arrangement led to mistakes and slowed progress considerably.

Although one possible solution was to purchase a larger prototyping board, doing so would have also required a new enclosure, which would have exceeded the project's budget constraints. Therefore, the decision was made to proceed with the existing board. A slow, methodical soldering approach was adopted to ensure accuracy and reliability, even at the expense of exceeding the originally allocated time frame.

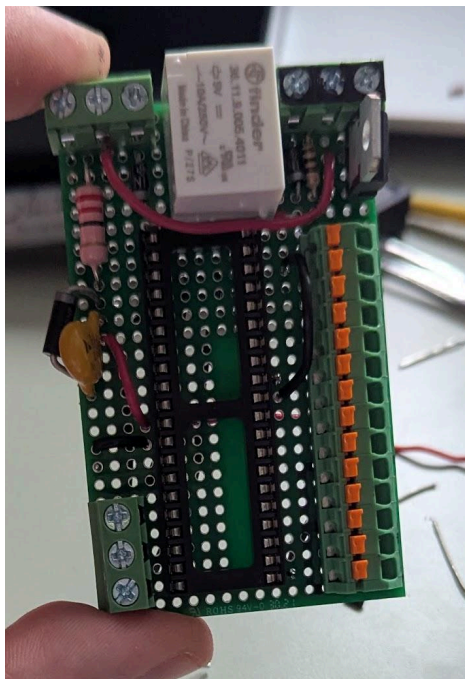


Figure 39 - Control Board Picture One

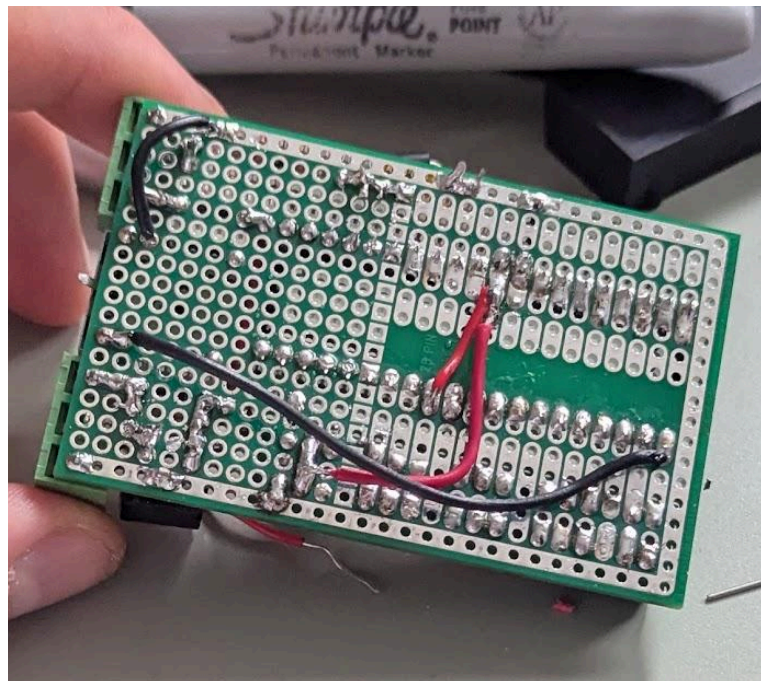


Figure 40 - Control Board Picture Two

6.4 PIC Programming

Before testing and analysis could proceed, the final program needed to be uploaded to the PIC microcontroller using a PICkit 3 programmer. While the initial plan was to use MikroC both for writing and uploading the code, unforeseen issues were encountered during the programming of the PIC. As a result, MPLAB X IDE was adopted as an alternative for flashing the program onto the PIC. This was not originally anticipated in the project scope.

Before programming, the manuals for the PIC16F877A pinout and the PICkit 3 programmer pin configuration were consulted, shown in Figure 41 and Figure 42. Connections were established between the programmer and the microcontroller, including connections to the Memory Clear (MCLR) pin, VDD, VSS, PGD, and PGC lines. Although this process was relatively straightforward, a lack of prior experience with MPLAB X IDE necessitated additional research and external guidance.

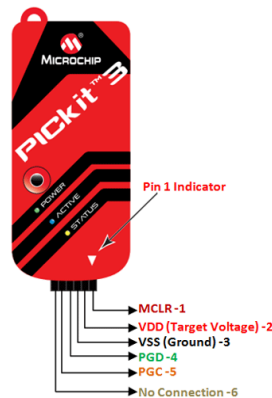


Figure 41 - PICkit3 Pinout [61]

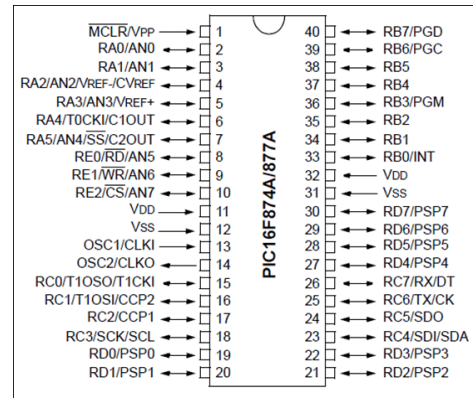
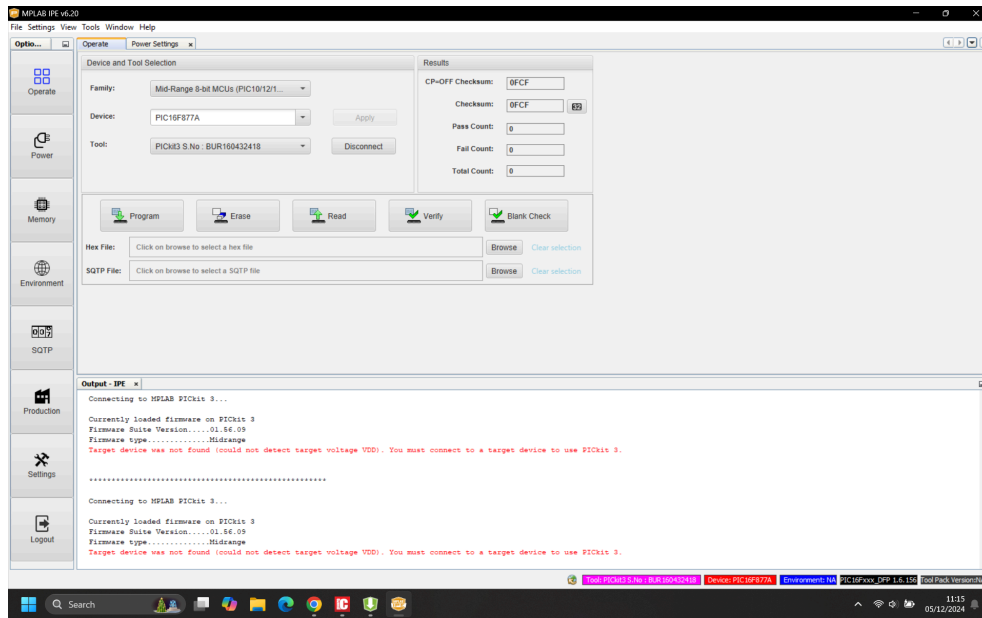


Figure 42 - PIC16F877A Pinout [62]

Within the MPLAB X IDE software, the appropriate device family, Mid-Range 8-Bit MCUs, was selected, along with the specific microcontroller. The PICkit 3 programmer was automatically recognised by the software. To ensure proper compatibility, the Advanced Mode settings were accessed by logging in with the default credentials. This allowed the programmer to supply power directly to the PIC microcontroller. The output voltage was manually set at 4.75V, safely below the maximum operating limit specified for the microcontroller. The Programming of the PIC can be seen in Figure 43 and Figure 44.



Having connected to the microcontroller, a blank check was first performed to follow best practice techniques; then the HEX file, created using MikroC, was uploaded, as shown in Figure 45, Figure 46 and Figure 47.

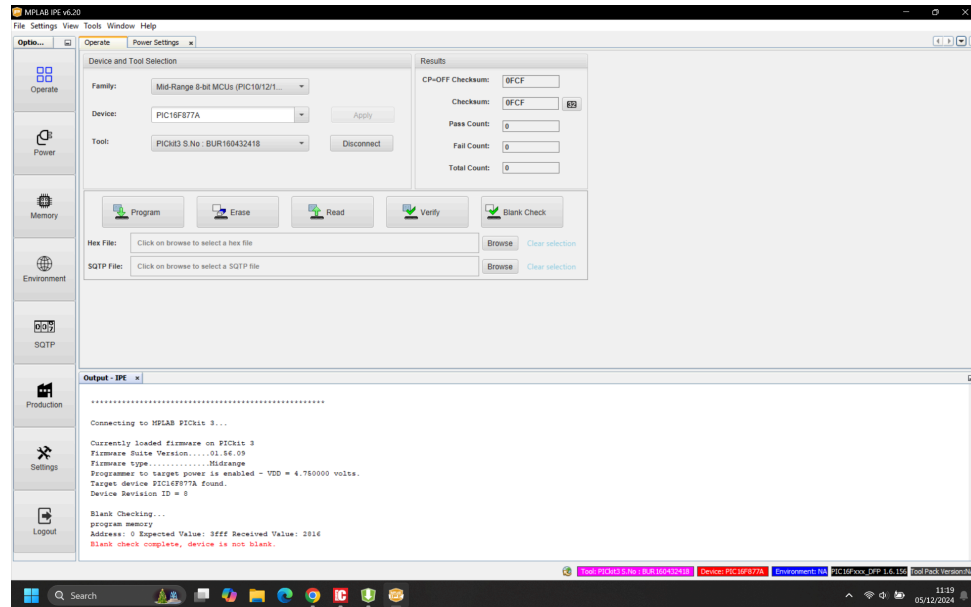


Figure 45 - Programming Hardware Evidence Three

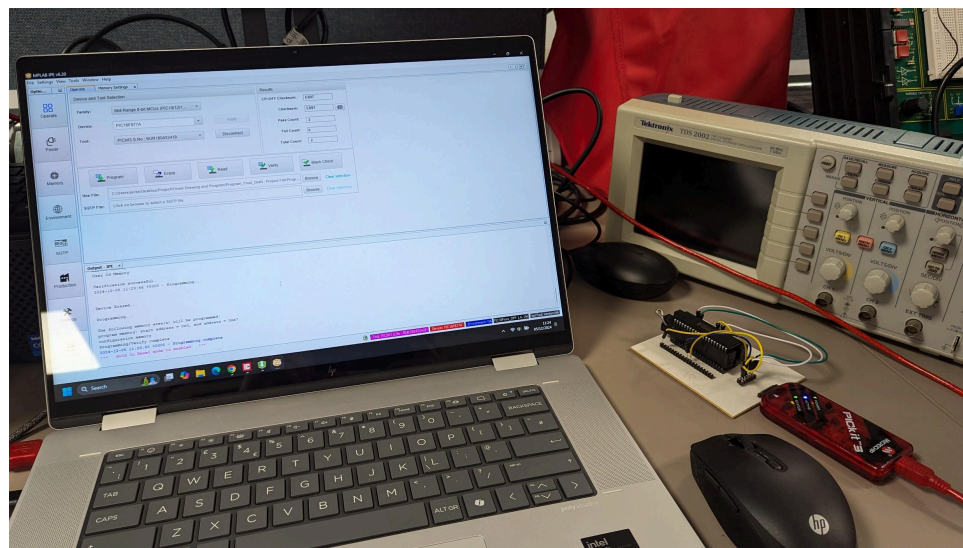


Figure 46 - Programming Hardware Evidence Four

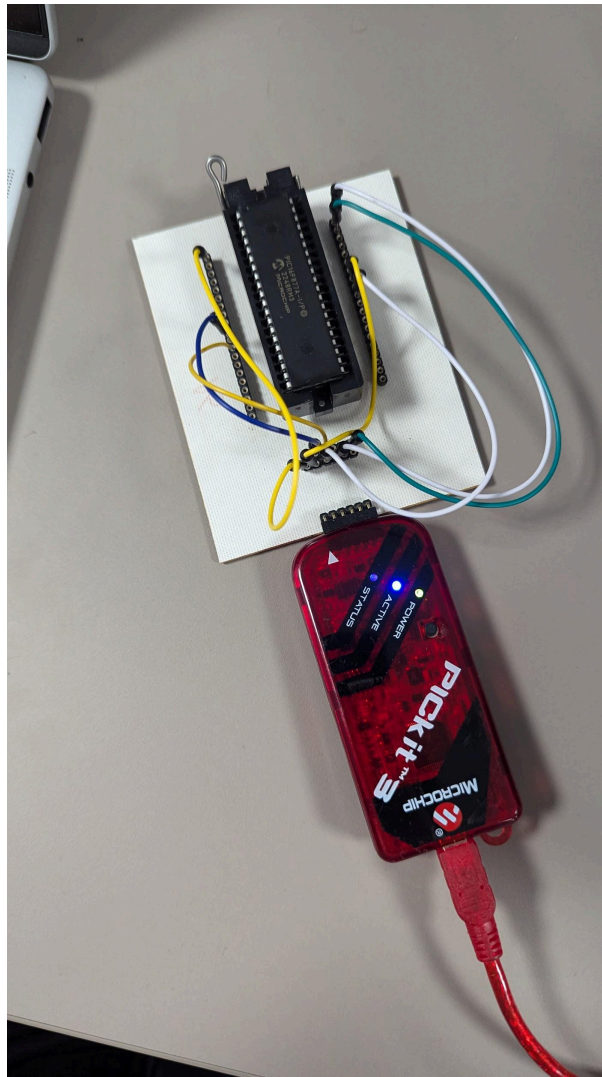


Figure 47 - Programming Hardware Evidence Five

6.5 Enclosure and Assembly

With the PIC successfully programmed and all hardware boards fully assembled, the components were installed into their respective enclosures in preparation for testing, as shown in Figure 49, Figure 50, Figure 51 and Figure 52. The boards fit well within the enclosure, providing sufficient space for heat dissipation while maintaining a compact overall form that avoided a bulky appearance upon installation. The LEDs could now be connected to the User Interface Board. One minor issue encountered during this stage was the physical size of the battery, which was slightly larger than the manufacturer's specified dimensions. Despite this discrepancy, the battery was still able to fit securely within the enclosure without requiring modifications.

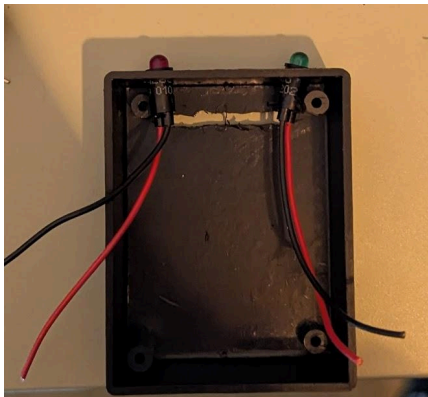


Figure 49 - Enclosure and Assembly Evidence One

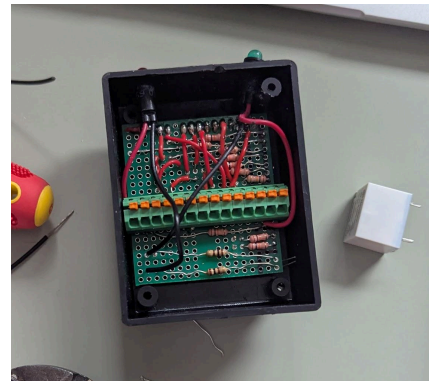


Figure 50 - Enclosure and Assembly Evidence Two

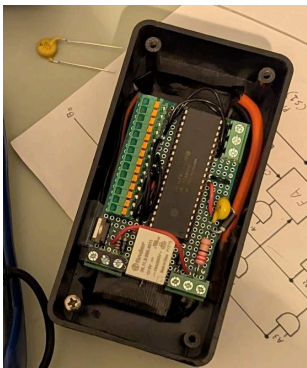


Figure 51 - Enclosure and Assembly Evidence Three

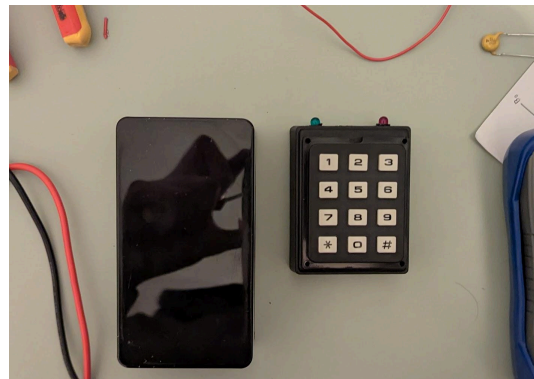


Figure 52 - Enclosure and Assembly Evidence Four

6.6 Prototype Verification

To identify any immediate faults, the User Interface Board and Control Board were connected and the system was powered on for initial validation. During this phase, an issue was observed where the red LED remained permanently off. Both LEDs were subsequently tested, as shown in Figure 53 and Figure 54, and their operating voltages were compared to diagnose the fault. It was quickly determined that the problem stemmed from an unstable connection to the board, likely caused by insufficient flux during the initial soldering process. After addressing the joint and ensuring a stable connection, the fault was resolved. Following this correction, the system was tested through multiple PIN code entries, and the relay's resistance was monitored to simulate the locking mechanism of the door. These tests confirmed that the system was functioning as intended.

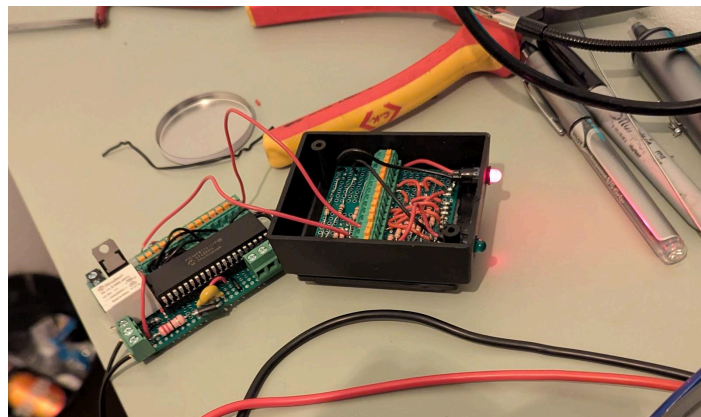


Figure 53 - Prototype Verification Evidence One

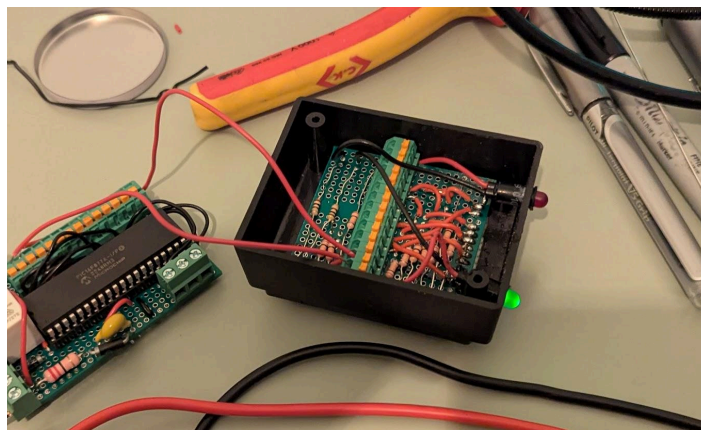


Figure 54 - Prototype Verification Evidence Two

While comparing the voltages across the LEDs, an unexpected issue was identified: the voltage measured was 6.5V, exceeding the expected 5V operating level. Further investigation revealed that the overall supply voltage to the system was 16.52V, significantly higher than the anticipated range of 12V to 14V. These readings are presented in Figure 55 and Figure 56. To prevent potential damage to the microcontroller and other sensitive components, the system was immediately powered down. Although the system had been functioning correctly up to that point, this precautionary step was taken to preserve the hardware. This is further addressed in the testing and analysis section of this report.

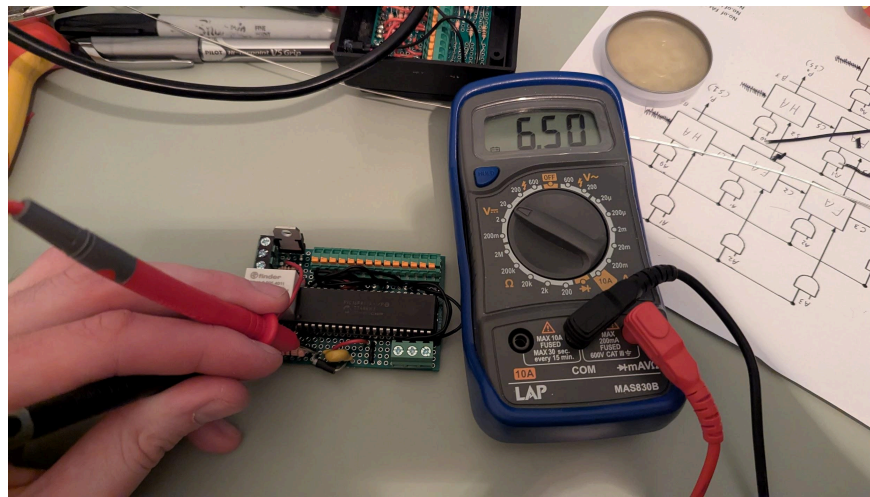


Figure 55 - Prototype Verification Evidence Three

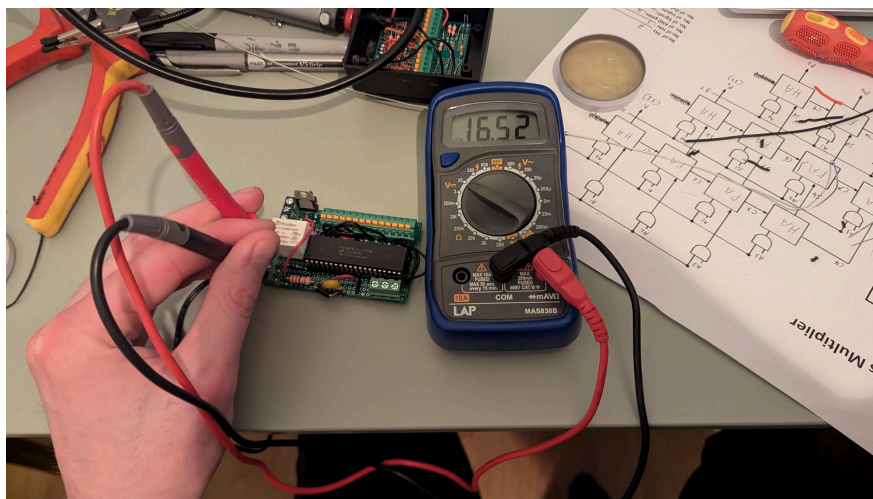


Figure 56 - Prototype Verification Evidence Four

7.0 Final System Summary

The design of the access control system followed a structured, multi-phase development process, including simulation, software development, and physical prototyping. Each stage played a key role in improving the system's reliability and functionality. The waterfall methodology allowed for issues to be seen and fixed quickly and ensured the system met both functional and safety requirements.

The use of Proteus in the initial phase was particularly effective, allowing accurate circuit modelling and safe testing in a simulated environment. Errors, circuit faults, and layout issues were resolved without risking hardware damage, providing a solid foundation for the following stages.

Program development in MikroC was done in iterations, with each draft building on the last to increase functionality and reliability. Core features such as keypad input, debouncing and pin verification were written early, followed by improvements like pin tracking. Integration with Proteus enabled real-time validation, aligning software behaviour with the simulated hardware.

Prototyping was split across two boards to reduce the system's footprint and improve organisation. This also enhanced safety during testing. Challenges such as connector limitations and high component density were addressed through practical compromises and design adjustments. Key lessons were learned about layout efficiency and the value of detailed prototyping diagrams. Other aspects, such as reliable PIC programming via MPLAB X IDE and enclosure space limitations, were solved through research and adaptation.

Overall, the system design process was a valuable learning experience in embedded system development. It demonstrated the importance of simulation, iterative programming, and practical hardware implementation. Despite some challenges, the project achieved its goals, resulting in a reliable, secure access control system. The knowledge gained will inform future microcontroller-based designs.

8.0 Pre-Implementation Testing and Analysis

8.1 Introduction

The testing and analysis phase of this project was conducted in two distinct stages to ensure the system's performance aligned with both the simulated expectations and the project's original goals. The first stage focused on comparing the real-world performance of the hardware to the system simulated using Proteus. This served as a validation of the simulation software's accuracy in predicting actual system behaviour, including input recognition, output responses and voltage levels. The second stage involved evaluating the fully constructed system against the key objectives outlined in Section 1.2, such as reliability, installation time, security and user accessibility. This comprehensive approach ensured that the final implementation not only functioned as intended under simulated conditions but also met all defined requirements in practical operation.

8.2 Practical and Simulated Results Figures

To effectively compare the practical results with those obtained during simulation, voltage and resistance readings were taken at specific points throughout the physical circuit. These measured values were then systematically recorded and organised into a results table for analysis. The measured values can be seen in Figure 57, Figure 58, Figure 59 and Figure 60. Their locations can be seen on the Proteus simulation in Figure 61, Figure 62 and Figure 63.

As referenced in Section 6.6, the initial voltage readings appeared to exceed the microcontroller's specified maximum operating limit, which raised immediate concern regarding the safety and reliability of the power supply. However, there was reason to believe the discrepancy could be attributed to the limited accuracy of the multimeter initially used. To ensure the integrity of the testing process, a more advanced, calibrated multimeter with a higher accuracy specification was sourced and used for all subsequent measurements. This step was taken to eliminate measurement error and ensure that all recorded data accurately reflected the system's real-world performance. The differences between the multimeters can be seen overleaf.

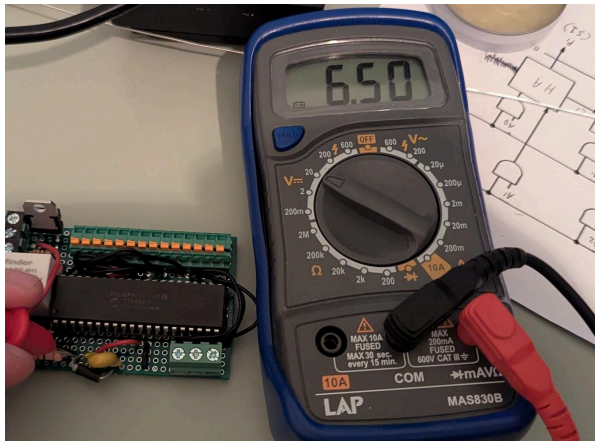


Figure 57 - Pre-Implementation Testing and Analysis Evidence One

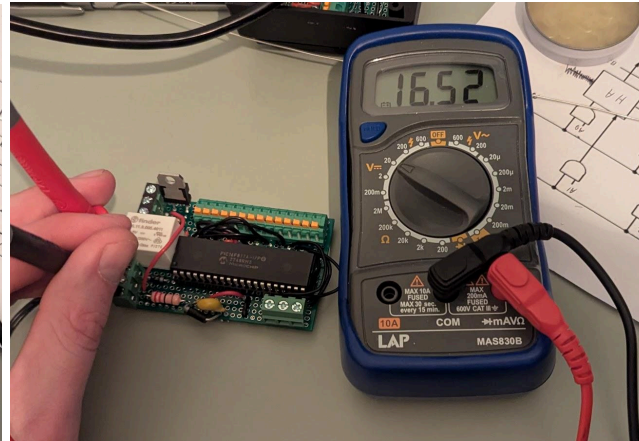


Figure 58 - Pre-Implementation Testing and Analysis Evidence Two

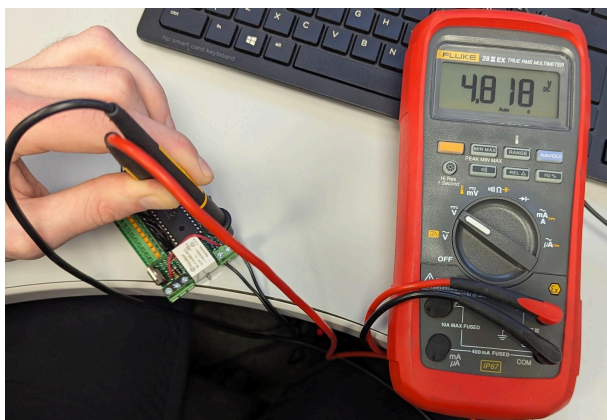


Figure 59 - Pre-Implementation Testing and Analysis Evidence Three

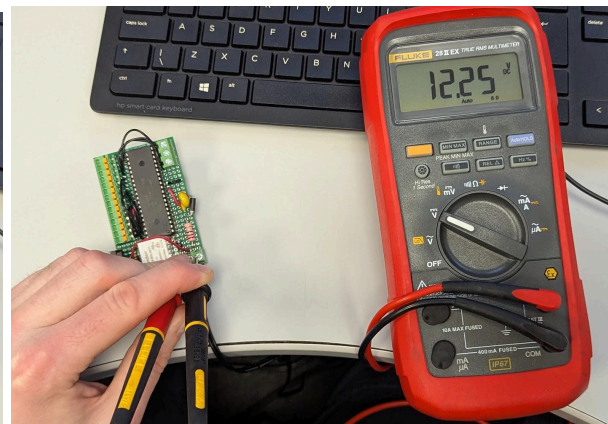


Figure 60 - Pre-Implementation Testing and Analysis Evidence Four

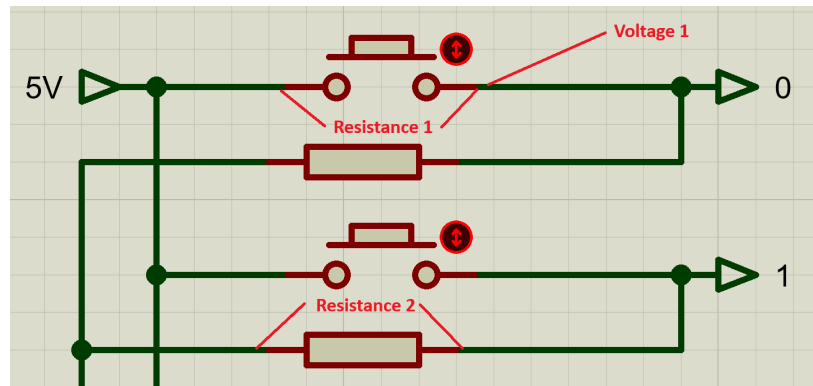


Figure 61 - Pre-Implementation Testing and Analysis of Proteus Evidence One

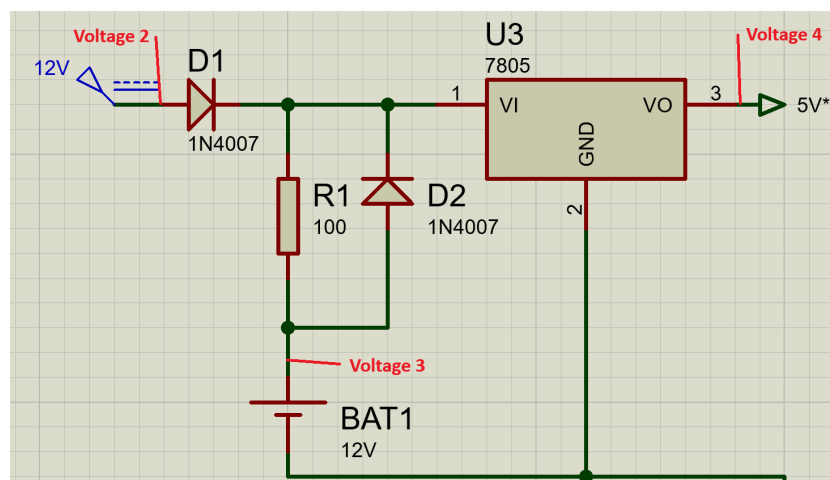


Figure 62 - Pre-Implementation Testing and Analysis of Proteus Evidence Two

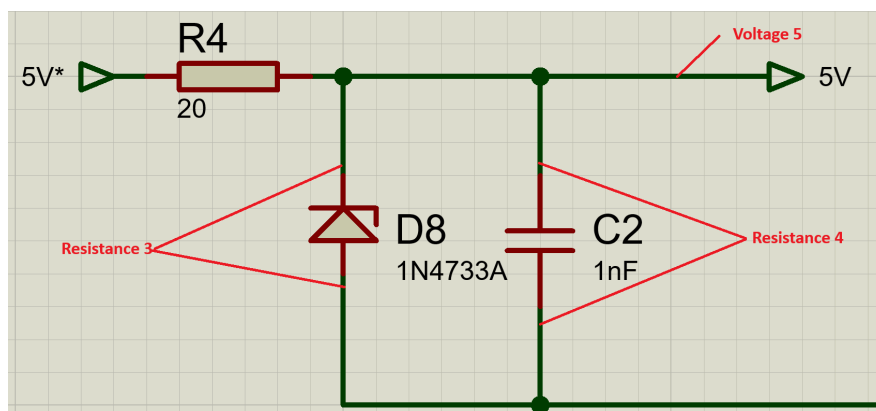


Figure 63 - Pre-Implementation Testing and Analysis of Proteus Evidence Three

8.3 Comparison of Practical and Simulated Results for Voltage

Table 10 - Comparison of Practical and Simulated Results for Voltage

Voltage Point	Title	Proteus Voltage (V)	Real World Voltage (V)
1	Output of Closed Button	4.9933	4.695
2	Mains 12V Supply	12	12.25
3	Battery 12V Supply	12	12.546
4	7805 Unfiltered	5.00521	4.824
5	Output of UPS	5.00271	4.818

Across all measurement points, real-world voltages deviated slightly from the simulated values. These differences are largely attributed to real-world losses due to internal resistance in wiring, minor voltage drops across connectors, and the inherent tolerances of components such as the 7805 regulator. Despite these variations, all voltages remained within acceptable operating ranges for the PIC microcontroller, and the deviations were considered minor enough not to affect overall system functionality. The largest discrepancy was observed in the battery supply voltage (+0.546 V), which was most likely due to a slightly overcharged battery.

8.4 Comparison of Practical and Simulated Results for Resistance

Table 11 - Comparison of Practical and Simulated Results for Resistance

Resistance Point	Title	Proteus Resistance (Ohms)	Real World Resistance (Ohms)
1 (Open)	Open Button	Max	Open Load
1 (Closed)	Closed Button	0.15	0.2
2	10k Resistor	Max	9986
3	Zener Diode	Max	Open Load
4	Capacitor	Max	Open Load

Testing the circuit's resistance values resulted in limited useful data. Although measuring current draw could have provided further insight, it was ultimately ruled out due to the difficulty of fully desoldering components for accurate testing. Additionally, the potential risk of damaging critical components, especially considering the project's limited remaining budget, was deemed unacceptable.

A notable issue emerged during the resistance comparison: a 10k Ω resistor measured at 9986 Ω . While this discrepancy could have resulted from slight probe misalignment during measurement, it is more plausibly explained by the resistor's tolerance rating of $\pm 10\%$, placing the observed value well within acceptable limits.

All other resistance tests behaved as expected. Open circuits were correctly identified as 'Max' or 'Open Load,' and the closed push button returned a resistance value nearly identical to that in the simulation, with a minimal variance of only 0.05 Ω . This confirms the accuracy of the Proteus software in representing simple mechanical switches and passive components under normal conditions.

9.0 Implementation Analysis

9.1 Introduction

The installation took place at Eastman Chemical Company in Newport, an Upper Tier COMAH (Control of Major Accident Hazards) chemical site, as a result, all work and modifications are subject to rigorous permitting and oversight procedures. As part of the site's robust safety culture and management systems, a Modification of Change (MoC) process was required for the installation, despite the relatively small scale of the access control system. Although the MoC system is primarily intended for managing changes to critical process equipment, it was deemed essential to ensure that all relevant personnel, including engineering, operations, and safety departments, were informed and management could sign off on the installation. This ensured traceability and accountability in line with site protocols.

In addition to the MoC, an exposure permit was required to carry out the installation, specifically to ensure that the system was electrically isolated during the work. While the isolation requirement reflects a high standard of safety, it also introduced delays. Considering one of the power supplies in question was a standard 240V plug top, that would be installed as part of the project, and thus posed minimal risk, and the other a simple fused spur, the isolation requirements seemed somewhat excessive. Nonetheless, the permit process, although somewhat tedious in this context, contributed to overall site safety and compliance with strict COMAH standards. The permitting process contributed significantly to the total installation time, addressed later in this report, which could have been reduced if the exposure permit had been written and pre-approved ahead of time.

9.2 Modification of Change Permit

The Management of Change (MoC) process is vital for ensuring that all modifications on a COMAH tier site like Eastman Chemical Company are carried out safely, with transparency and with full accountability. The Management of Change Permit can be seen in Figure 64, Figure 65 and Figure 66. Within the MoC permit, it was required to consult a Subject Matter Expert (SME) before beginning any work, as well as notify the Area Manager and an additional SME with responsibility for electrical and instrumentation systems. A Pre-Start-Up Safety Review (PSSR) was also conducted, shown in Figure 67. The PSSR included specific actions, such as the requirement to add appropriate warning labels to the power supply, indicating that it should not be turned off, to prevent accidental system shutdown. The MoC process also incorporated essential site safety verifications, such as confirming that there was no asbestos present in the partition wall, and outlined the full scope of the proposed work. The MoC approach ensures all relevant personnel are informed and, as a result, all risks are minimised while preserving operational integrity.

EASTMAN Permits 2
New Permit: 384160

Home Menu Theme About UAB256 Config

Save Exit

Type: Permanent Modification

Area: Building 137

Start: 02/04/2025 02:44 PM

End: Wed 26-Feb-2025 10:44

Functional Location: NP-DCS-NTH0-DOPAMS - [NEWPORT SITE PROVOX PR]

Status: Pending Location: DCS Server Room

Work Description: Installation of Keypad Access Control System for DCS Server Room, to replace Key Card System.

Comment: As a result of HAZ ID: HA-20240719-032. Power Supply to be installed. Old Access Control System to be Removed. Partition wall does not contain Asbestos. Please contact J. Spillett for more information.

Screening Hazard & Risk Assessment Approval Attachments HSE Checklist Field Verification / PSSR

Reason For Proposed Change: HAZ ID: HA-20240719-032, Action: AC-INC-20240724-016

Category: Electrical

Risk Assessment & Control Measures:

- 01. This change will increase the potential for a process safety incident or personnel exposure/injury? ☐ No ☐ Yes [Additional Info](#)
- 02. This change will negatively impact a softwired control system interlock or safety critical task? ☐ No ☐ Yes [Additional Info](#)
- 03. This change will impact a SIL rated IPS or Class 1 or 2 Interlock? (Requires plant manager approval) ☐ No ☐ Yes [Additional Info](#)
- 04. This change requires significant or unique training for operators or technical personnel? ☐ No ☐ Yes [Additional Info](#)
- 05. This change deviates from the plant standard? (i.e. engineering specifications or has Halal implications) ☐ No ☐ Yes [Additional Info](#)
- 06. An FED report is required to describe the changes in more detail? ☐ No ☐ Yes [Additional Info](#)
- 07. Does this change impact a Pressure system covered by the Pressure System Safety Regulations? ☐ No ☐ Yes [Additional Info](#)
- 08. This is a permanent change that includes a physical change so a Field Verification/Pre-startup safety review is required. (Not part of an FED) ☒ Yes ☐ No [Additional Info](#)
- 09. This is a permanent change that includes a DCS change to configuration, mimics or control hardware ☐ No ☐ Yes [Additional Info](#)
- 10. Is a TPA required for this change? ☐ No ☐ Yes [Additional Info](#)
- 11. This is a permanent change and requires acknowledgement by operational staff ☐ No ☐ Yes [Additional Info](#)
- 12. Does this change require approval from a subject matter expert (SME)? (Not part of an FED) ☒ Yes ☐ No [Additional Info](#)
- 13. This is an extension of an Asset Integrity (Critical) PM past Due Date or Asset Integrity Recommendation past Due Date. ☐ No ☐ Yes [Additional Info](#)

Figure 64 - Management of Change Permit Snip One

EASTMAN

Permits 2

New Permit: 384160

Home

Menu

Theme

?

U484C96

Config

Save

Exit

Type

Permanent Modification

Area

Building 137

Start

02/04/2025 02:44 PM

Functional Location

NP-DCS-N1H0-DOPAMS - [NEWPORT SITE PROVVOX PE]

End

Wed 26-Feb-2025 10:44

Status

Pending

Location

DCS Server Room

Work Description

Installation of Keypad Access Control System for DCS Server Room, to replace Key Card System.

Comment

As a result of HAZ ID: HA-20240719-032.
Power Supply to be Installed.
Old Access Control System to be Removed.
Partition wall does not contain Asbestos.
Please contact J. Spillett for more information.

Screening

Hazard & Risk Assessment

Approval

Attachments

HSE Checklist

Field Verification / PSSR

Originator

Spillett, Jack @ Wed 19-Feb-2025 10:44

Issued By

Not Issued

Approvals as defined by the Originator.

Role	Requested Approver	Approver Alternate Approval?	Telephone Approval?	Telephone Approver
Area Manager	Watkins, Stephen Richard	No	No	
HSE	None	No	No	
Plant Manager	None	No	No	
SME - Chemical Engineering	None	No	No	
SME - Chemistry	None	No	No	
SME - Control systems	None	No	No	
SME - Electrical	Guppy, Ethan John	No	No	
SME - IACS Cyber Security	None	No	No	
SME - Instrumentation	None	No	No	
SME - Mechanical	None	No	No	

Figure 65 - Management of Change Permit Snip Two

EASTMAN

Permits 2

New Permit: 384160

Home

Menu

Theme

?

U484C96

Config

Save

Exit

Type

Permanent Modification

Area

Building 137

Start

02/04/2025 02:44 PM

Functional Location

NP-DCS-N1H0-DOPAMS - [NEWPORT SITE PROVVOX PE]

End

Wed 26-Feb-2025 10:44

Status

Pending

Location

DCS Server Room

Work Description

Installation of Keypad Access Control System for DCS Server Room, to replace Key Card System.

Comment

As a result of HAZ ID: HA-20240719-032.
Power Supply to be Installed.
Old Access Control System to be Removed.
Partition wall does not contain Asbestos.
Please contact J. Spillett for more information.

Screening

Hazard & Risk Assessment

Approval

Attachments

HSE Checklist

Field Verification / PSSR

Worst Case Pipeline / Equipment

Contents

N/A

Max Temperature (°C)

N/A

Max Pressure (barG)

N/A

People Consulted

SME: E. Guppy

Risk Level Result

WP751

Figure 66 - Management of Change Permit Snip Three

Permanent Mod Permit Checklist for Pre-Startup Safety Review (PrSSR)

Modification number	384154
Date	19/02/2025
PSSR Team Leader	J. Spillett
PSSR Team Members (including at least one operator)	D. Jones, G. Hughes, E. Guppy, D. Newton.

CONFIRM THAT CONSTRUCTION AND EQUIPMENT IS IN ACCORDANCE WITH DESIGN SPECIFICATIONS.		
		Mark each item complete or N/A after verification
Relief Devices	Relief devices (PSVs, rupture disks, rupture disk holders, conservation vents, etc.) and downstream piping inspected, in place, & operational.	N/A
Safety	Safety systems operational (special emphasis on fire protection changes, Deluge Operations)	✓
	All interlocks and emergency stops tested and functional, signed datasheets completed?	N/A
	HazArea Classification correct & equipment conforms to classification. (ATEX Checks Complete)	N/A
	Access to safety equipment not blocked by this change.	✓
	Emergency power systems, including lighting, operational.	✓
Mechanical	Critical Punch list items completed.	N/A
	Mechanical equipment checked for correct operation. (Inc rotation checks)	N/A
	Leak testing of piping & equipment complete. Consider any wider piping that is disturbed.	N/A
	Sample and drain valves closed.	N/A
Electrical & Instrumentation	E&I devices checked from field to operator panel (inputs and outputs verified).	N/A
	Motor rotation checked.	N/A
	All instruments operational	N/A
	Instruments calibrated.	N/A
	E&I devices in normal position/mode, i.e. not in simulate (including instrument manifolds)	N/A
	Power Cables to rotating equipment in plant areas confirmed NOT to be run on the ground.	N/A
Labeling	Lines and equipment labeled.	✓
	Local switches labeled.	✓
Documentation and Permits	P&I drawings verified (lines walked).	N/A
	Critical equipment identified & added to PM Schedule.	N/A
CONFIRM THAT SAFETY, OPERATING, MAINTENANCE AND EMERGENCY PROCEDURES ARE ADEQUATE.		
Other	Heat tracing operable.	N/A
Procedures, Documentation & Training	Safety procedures, emergency plans, written or updated approved, on hand	✓
	Operating Procedures written or updated, approved, on hand.	N/A
	Maintenance procedures updated (if necessary).	N/A
	Preventive Maintenance plans written (if necessary).	N/A
	Confirm that initial training of each employee involved in operating the process is complete	✓
Control Systems and Operator Interfaces	Control system logic complete, documented, and operating. (Witness/ check changes)	✓
	DCS Graphics complete and accurate	N/A
	SIS verification completed	N/A

Action List (Capture any additional actions not already in the mod).

No.	Description	Responsible	Date or required before startup?
1	Action to be closed.	J.S.	ASAP
2	Add label to power supply.	J.S.	ASAP
3			
4			
5			

Please add any post start up actions to iShare.



Form issue date: 22/05/24

Page 1 of 1

Figure 67 - PSSR

9.3 Exposure Permit

An Electrical Exposure Permit was also a critical component in ensuring the safe implementation of the system, presented in Figure 68. This permit clearly defined the scope of the work, detailing all activities to be undertaken and identifying any potential hazards such as exposure to live electricity, lone working, or the risk of unauthorised access to the work area. To mitigate these risks, a range of control measures was specified, including electrical isolation procedures, a lone worker DECT phone and appropriate signage to restrict access during installation. The permit also outlined PPE requirements for the task to ensure all personnel were adequately protected. The comments section was used to record additional important details, such as the removal of the existing key card system and the lifting of raised flooring for routing the new power supply. This comprehensive and cautious approach reflects the high safety standards maintained on site and ensures that all work was completed in a controlled, well-communicated, and risk-aware manner.

Exposure Permit – Id: 384154

Pending

EASTMAN

Valid From Wed 19-Feb-2025 08:35 **Valid Until** Wed 19-Feb-2025 22:30 **Work Area** Building 137 **Location** DCS Server Room

Functional Location NP-DCS-N1H0-DOPAMS (newport site provox process controller) **Sap Work Order**

Work to be done
Installation of Keypad Access Control System for DCS Server Room, to replace Key Card System.

Hazard	Control Measure
Electricity	E&I electrical isolation
Lone working	Lone worker DECT phone
Unauthorised access	Hazard tape area (5m) throughout job

Initial PPE Type	Initial PPE - MPC plus	Relaxed PPE Type	Relaxed PPE - MPC plus
Foot protection	Safety boots (Not shoes)	Foot protection	Safety boots or shoes
Hand/arm protection	Stretch-fit non chemical gloves	Hand/arm protection	Stretch-fit non chemical gloves
Head/Face protection	Goggles		
MPC	Helmet, safety glasses, overalls, safety shoes	MPC	Helmet, safety glasses, overalls and safety shoes

Comments
Work to include:
Installation of Keypad.
Removal of Key Card System.
Lifting of flooring to run in power supply.

Testing to be completed prior to handover.

Goggles to be worn when using drill.

Alarm Point Engineering corridor **Safety Shower** Lab **Emergency Assembly Point** North Foyer

Electrical Isolations

Equipment Isolated	Method Of Isolation
Plug to be installed	Plug disconnected and locked

No Machinery Isolations

No Pipeline Isolations

No Radiation Isolations

Lead Worker Details

Name	Lock
Jack Spillett	JS1

Lock Box Ref. N/A **Total P.O.B Tags**

PLEASE ISSUE THIS PERMIT TO SEE AN ACCEPTOR AND ISSUER SIGN OFF SECTION

Figure 68 - Exposure Permit

9.4 Implementation

Before designing the access control system, a survey was conducted to assess the existing setup and identify potential issues affecting design and installation. The aim was to integrate with the site's electromagnetic door lock. However, due to a lack of documentation, manual testing and investigation were necessary to understand the system, including its failsafe configuration, using a normally open contact to allow access during power loss. This survey ensured a smooth and straightforward installation. The work area can be seen in Figure 69.



Figure 69 - Survey of Work Area

Once finalised, a Management of Change (MoC) permit was prepared following Eastman Chemical Company procedures to inform stakeholders and SMEs of infrastructure changes. On installation day, an Electrical Exposure Permit was obtained, outlining the scope, hazards and PPE. The main delay during installation was obtaining the permit itself, caused by the permit issuer's lack of availability.

A battery drill with an M20 bit was used to create a cable route through the wall. Instrument Cable was prepared to connect the User Interface Board and Control Board. Drilling and cable feeding took longer than expected due to the volume and rigidity of the wires. The use of ribbon cable could simplify installation in the future.

Following cable routing, the enclosures, circuit boards and keypad covers were installed. The Control Board was mounted, and cables for the electromagnetic lock were connected to the relay's Normally Open terminals, matching the previous configuration to ensure access in the event of power loss. The installed system can be seen in Figure 70.



Figure 70 - Final Installation

With wiring complete, the backup battery was fitted. Power routing involved lifting floorboards and temporarily removing capping to run low-voltage cable safely to the Control Board. In line with site policy, the 240v plug was left disconnected until all terminations were complete and the permit was signed off. The Control Enclosure can be seen in Figure 71.

After routing, the flooring and capping were reinstated. A final check confirmed all wiring and fixings were secure. The old system was decommissioned by isolating the fused spur and

removing the keycard scanner. New enclosures were sealed, and the Electrical Exposure Permit was returned.



Figure 71 - Final Installation Back

A Pre-Start-up Safety Review (PSSR) was conducted by site management and SMEs to confirm the system met all safety and operational criteria. One issue was noted: the power supply required labelling to prevent accidental disconnection once the battery discharged. Labels were applied to eliminate ambiguity.

The installation concluded successfully, meeting all safety, functional, and procedural requirements. The process validated the system's design and underscored the importance of integration, planning, and compliance within COMAH-regulated environments.

10.0 Post-Implementation Analysis and Evaluation

After completing the access control system's construction and installation, a comprehensive evaluation was conducted to assess how effectively the implementation met the original design objectives outlined in Section 1.2. The testing process examined both functional performance and practical installation considerations.

10.1 Keypad Functionality and System Operation

The system's primary function, unlocking an electromagnetic lock upon successful PIN entry, was verified successfully on power up. The keypad operated as intended, triggering the internal relay to disengage the locking mechanism. This confirmed the reliable operation of the system's core logic in practice, matching the simulations carried out during the design phase.

10.2 Installation Time

One of the initial aims was for the system to be installable within one hour to minimise disruption. In practice, the physical installation took approximately 46 minutes, excluding the time required to obtain a permit to work. Including the time taken to obtain a permit, the total installation time extended to 1 hour and 26 minutes. The vague wording of the original objective ("installation") led to some ambiguity, which will be addressed in future projects. Time could have been saved by preparing the permit in advance and or by using ribbon cable rather than individual wires.

10.3 PIN Customisation

The system supports PIN alterations through direct access to the microcontroller, shown in Figure 72. By removing the PIC from the Dip Socket and reprogramming it externally, the stored pin can be modified. Although this approach satisfies the objective on a technical level, it is not user-friendly. A future improvement could involve reprogramming using the keypad and a dip switch, which is housed within the Control Enclosure itself, offering an easier solution.

```
// To alter Pin, change PIN1,PIN2,PIN3 & PIN4 within the Define Four Digits
// section, after the #define PINX to the desired value, using the table below.

// Pin Digit 0 = PORTB & 0X01
// Pin Digit 1 = PORTB & 0X02
// Pin Digit 2 = PORTB & 0X04
// Pin Digit 3 = PORTB & 0X08
// Pin Digit 4 = PORTB & 0X10
// Pin Digit 5 = PORTB & 0X20
// Pin Digit 6 = PORTB & 0X40
// Pin Digit 7 = PORTB & 0X80
// Pin Digit 8 = PORTC & 0X01
// Pin Digit 9 = PORTC & 0X02

// Define Four Digits for Pin
#define PIN1 (PORTB & 0X01) // Alter for Pin Digit One
#define PIN2 (PORTB & 0X02) // Alter for Pin Digit Two
#define PIN3 (PORTC & 0X01) // Alter for Pin Digit Three
#define PIN4 (PORTC & 0X02) // Alter for Pin Digit Four
```

Figure 72 - PIN Customisation Evidence

10.4 Power Supply and Battery Backup Duration

The system successfully operates on mains power and automatically switches to battery backup during a power failure. This verified the reliability of the battery backup system. The objectives called for a backup duration of at least 12 hours. While the precise runtime was not recorded due to the extended duration, the system continued to operate far beyond this threshold during testing, exceeding 22 hours. This suggests that the selected battery capacity far exceeded requirements. Hence, a smaller battery could have been used to further reduce cost. However, prioritising reliability by including a larger battery was ultimately a reasonable trade-off.

10.5 Cost Evaluation

Budgeting was another critical constraint, with a maximum allowable cost of £115. The final cost totalled £102.60, keeping the project within budget. The allocation of budget can be seen in Table 12. Based upon the initial research, existing systems (meeting the specifications set out in this project) cost upwards of £120 [20]. This outcome was achieved through careful component selection and the use of affordable materials with little compromise on functionality.

Table 12 - Assumed Costings Compared to Total Costings

Component	Quantity	Estimated Cost	Cost	Deviation
Key Pad	1	£20	£17.42	-£2.58
Microcontroller	1	£5	£6.89	£1.89
Relay	1	-	£3.16	-
LED Green	1	£5	£3.12	-£1.88
LED Red	1	£5	£3.01	-£1.99
240V AC to 12V DC Transformer	1	£15	£13.60	-£1.40
2 Wire Socket	5	-	£2.92	-
12V Battery	1	£15	£16.19	£1.19
10K Ohm Resistors	20	-	£3.40	-
100 Ohm Resistors	10	-	£1.30	-
20 Ohm Resistor	10	-	£2.18	-
Individual Wires	-	-	-	-
14 Wire Socket	2	-	£4.68	-
1N4007 Zener Diode	10	-	£1.90	-
1N4733 Zener Diode	5	-	£2.25	-
7805	10	-	£6.52	-
1nF Capacitor	10	-	£0.08	-
Dip Socket	10	-	£0.541	-
Prototyping Board	2	£10	£8.14	-£1.86
Small Stuffing Gland	-	-	-	-
Enclosure	2	£20	£5.30	-£14.70
Miscellaneous Components	-	£20	-	£8.93
Total		£115	£102.60	-£12.40

Evaluating the final project costs demonstrates a successful adherence to the budgetary constraints, with the final cost totalling £102.60, well within the allocated budget of £115. This is a result of careful component selection and effective sourcing, leading to a cost saving of £12.40 without compromising the system's core functionality. Notably, significant savings were

achieved on the enclosure (saving £14.70), keypad, LEDs, and prototyping boards, while only a few components marginally exceeded their estimated costs, including the microcontroller and 12V battery. Furthermore, when compared to commercially available systems offering similar functionality, typically priced at over £120, the project presents a notably more cost-effective solution. Although several components lacked initial cost estimates, their inclusion did not adversely affect the overall budget. The combination of economical material choices and practical design decisions resulted in the project being under budget.

10. 6 Timeframe and Project Deadline

The overall project progressed well, though several deviations from the initial schedule were encountered, all of which due to unforeseen circumstances. One of the earliest delays occurred during the component procurement stage. Components were ordered approximately two weeks later than planned, as it was essential to complete the Proteus circuit simulation first. A decision to avoid unnecessary repeat orders. By finalising the circuit design prior to placing any orders, it was possible to confirm the required component list with greater accuracy, reducing the risk of compatibility issues.

The design phase, including both the circuit layout and program development, largely proceeded according to plan. However, the programming aspect took slightly longer than anticipated, primarily due to a lack of prior experience with MikroC. This required additional time for learning and troubleshooting, which extended this part of the schedule marginally.

The physical construction and installation phases commenced approximately two weeks behind schedule due to personal scheduling conflicts, including starting a new role and purchasing a house. Despite this delay, the board construction and preparation stages went smoothly. However, the final implementation of the access control system was completed later than planned, largely due to challenges during prototyping, as detailed earlier in this report.

In contrast, the project documentation stage adhered closely to the original timeline. All sections were completed on schedule, except for the conclusion and final draft. These final elements extended slightly into the allocated contingency period but did not impact overall project delivery. These timings are better presented overleaf, in Figure 73.

10.7 GANTT Chart

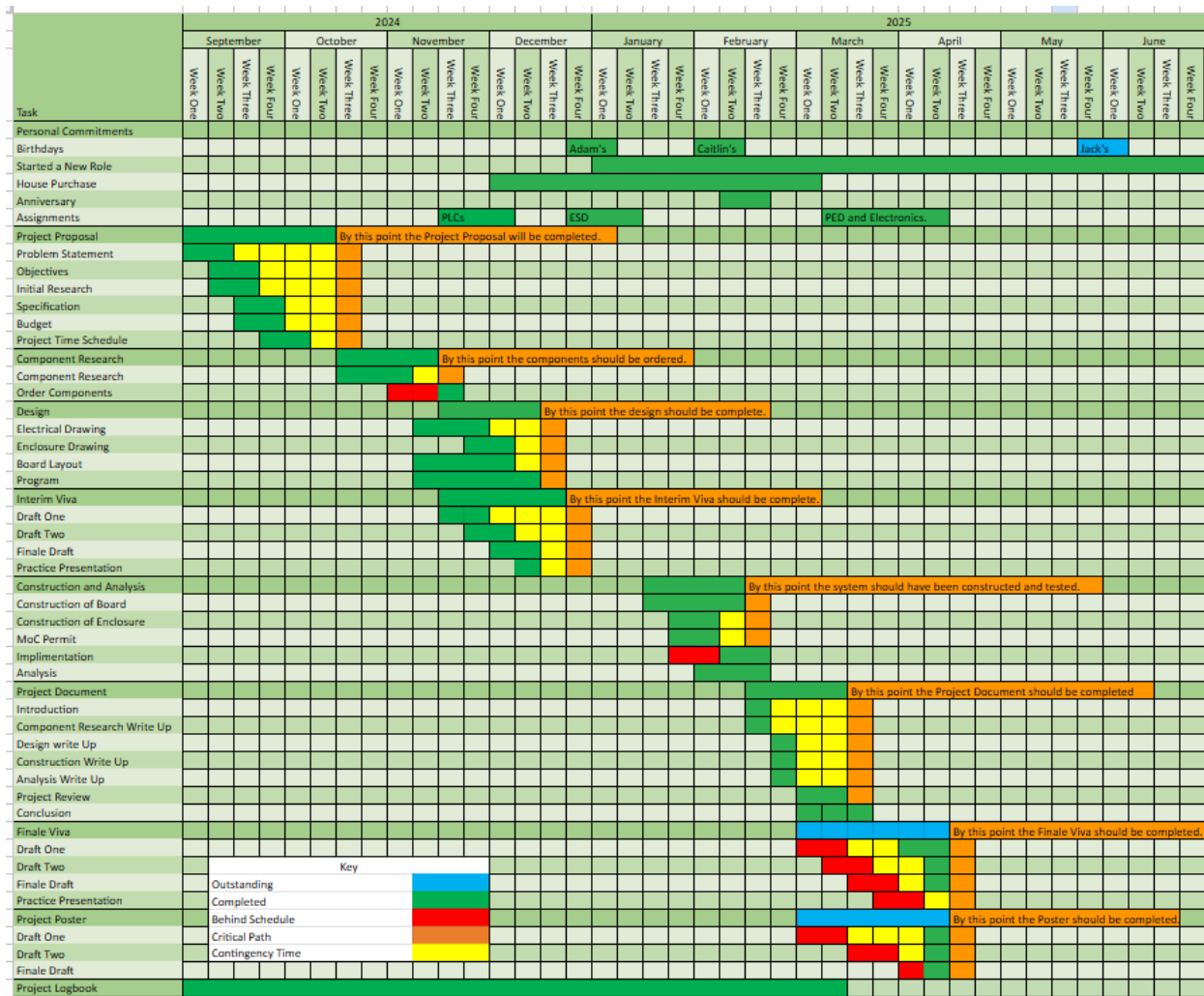


Figure 73 - GANTT Chart

In summary, while some delays were experienced, the project was completed successfully. All core objectives were achieved, and the timeline remained broadly in line with expectations, thanks to proactive planning and the inclusion of buffer periods for unforeseen challenges.

11.0 Conclusion

This project set out to design, construct and implement a secure and reliable access control system for the D.C.S. Server Room at Eastman Chemical Company. Through careful planning, research and iterative development, the project has successfully achieved all primary aims and objectives. The final system offers an effective solution for access control, integrating a keypad, microcontroller, LED indicators and an output relay.

The system functioned as intended, with the keypad reliably accepting user input and triggering the locking mechanism following successful PIN entry. Testing verified that this functionality mirrored results from the initial simulation in Proteus, demonstrating a strong correlation between simulated and practical outcomes. The simulation process played a critical role in preempting potential issues and streamlined the prototyping and installation phases.

The system was also designed to account for loss of power, incorporating a mains power supply with battery backup functionality. During testing, the system exceeded the 12-hour minimum battery runtime, achieving over 22 hours of continuous operation, thus surpassing expectations and reinforcing the reliability of the design. Additionally, while the method of PIN customisation currently involves manual reprogramming of the PIC microcontroller, it satisfies the technical requirement and can be refined in future iterations for improved user accessibility.

From a cost perspective, the project remained within its £115 budget, with a final expenditure of £102.60. This was achieved through the strategic selection of components and materials, without compromising performance or system reliability. Compared to similar commercially available systems, the final system offered equal functionality at a reduced cost.

Although some minor delays were encountered, particularly relating to component procurement, personal scheduling conflicts, and the challenges of prototyping on limited board space, the final system and project as a whole were not compromised. All site procedural requirements, including the Management of Change (MoC) and Electrical Exposure Permits, were completed during installation, ensuring compliance with Eastman's strict safety protocols.

In summary, the project has successfully delivered a robust, functional, and cost-effective access control system. The system performs reliably under test and practical conditions and provides a platform for future improvements. The overall result is a practical, scalable solution that not only addresses the initial security concerns but also adds long-term value to site infrastructure.

12.0 Recommendations

Throughout the design, implementation and evaluation stages of this project, several improvements have been identified. These were either highlighted through testing, installation challenges, or general reflections during the development process. While the system fulfilled its original objectives, the following improvements could enhance performance, usability and maintainability in future iterations:

The main improvement if this project were to be undertaken again would be that the current method for updating the system's PIN requires manual reprogramming of the PIC microcontroller, using external tools. Although this meets the objective on a technical level, it is not user friendly or flexible for end users. A key recommendation for improvement involves incorporating PIN reconfiguration using the keypad in combination with a dip switch or secured programming mode. This would only allow authorised users to update the access code without needing to remove or reprogram the microcontroller externally.

While the installation was completed within the time frame, part of the delay was attributed to the use of individual wires, which proved cumbersome and difficult to route through the enclosure. Future implementations would benefit from using ribbon cables or pre-terminated wiring looms, simplifying installation. Additionally, the installation process could be further streamlined by preparing the required exposure permit in advance.

The battery backup system was intentionally oversized to ensure reliability, exceeding the 12-hour minimum runtime by nearly double. While this achieved the required objectives, future designs should consider using a battery with a smaller capacity to reduce cost and space.

The layout of the control board became crowded during prototyping, particularly when separating 12V power and 5V power. A more spacious board could simplify the construction of the board, while also improving airflow and heat dissipation. This could also facilitate future expansion.

The largest concern throughout the project was found during prototype testing and verification, where it was observed that one multimeter showed a slightly higher voltage than the

true value. This issue was later resolved through the use of an alternative multimeter. The variation was likely attributable to differences in calibration, internal resistance and the overall build quality between the budget and professional instruments. To ensure consistency in future projects, it is recommended that all measurements be taken using a calibrated multimeter wherever possible.

13.0 Reflection

Completing this project has been deeply valuable both professionally and personally. It has provided an opportunity to apply the theoretical knowledge learned through the course of my education in a practical, real-world context with little direction or guidance for what the scope should entail.

From a technical perspective, I have gained significant experience in circuit design, simulation and programming. Prior to this project, my familiarity with software such as Proteus and MikroC was limited. Through repeated trial, error and testing, I have developed a deeper understanding of microcontrollers and their programming. I have also learned how to troubleshoot effectively, particularly when dealing with inconsistent readings from different instruments.

However, the lessons extended far beyond technical skills. This project forced me to confront the reality of real-world constraints, including scheduling conflicts, delayed component orders, and installation challenges. Managing this project alongside major life events, starting a new job and purchasing and renovating a house, taught me the value of time management and maintaining composure under pressure. These "soft" skills were just as critical to the project's success as my engineering knowledge.

One of the key takeaways was the importance of contingency planning. While I had anticipated some delays, the real value of including buffer time became evident as the project progressed. I also realised my lack of familiarity with programming and simulation tools as well as soldering equipment; further experience could have saved considerable time and frustration. If I were to undertake a similar project again, I would aim to provide a greater amount of time for prototyping. I would have also finalised the circuit simulation earlier to enable faster procurement.

This experience has not only increased my confidence in completing technical projects independently, but has also changed the way I approach problem solving. I now place greater emphasis on risk assessment and the need for documentation. Moreover, my understanding of how to communicate effectively with stakeholders, follow industrial safety protocols, and work

within budget has improved. This project has enhanced my ability to think like a professional engineer, rather than just a student.

In summary, this project has helped bridge the gap between my academic study and my engineering career at Eastman Chemical Company. It has helped push me from a technician to an engineering project manager. Additionally, the skills I have developed, both technical and personal, will benefit me in future professional roles.

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Appendices

Appendix One: Final Program

Finale Draft:

```
// To alter Pin, change PIN1,PIN2,PIN3 & PIN4 within the Define Four Digits
// section, after the #define PINX to the desired value, using the table below.
// Pin Digit 0 = PORTB & 0X01
// Pin Digit 1 = PORTB & 0X02
// Pin Digit 2 = PORTB & 0X04
// Pin Digit 3 = PORTB & 0X08
// Pin Digit 4 = PORTB & 0X10
// Pin Digit 5 = PORTB & 0X20
// Pin Digit 6 = PORTB & 0X40
// Pin Digit 7 = PORTB & 0X80
// Pin Digit 8 = PORTC & 0X01
// Pin Digit 9 = PORTC & 0X02

// Define Four Digits for Pin
#define PIN1 (PORTB & 0X01) // Alter for Pin Digit One
#define PIN2 (PORTB & 0X02) // Alter for Pin Digit Two
#define PIN3 (PORTC & 0X01) // Alter for Pin Digit Three
#define PIN4 (PORTC & 0X02) // Alter for Pin Digit Four

int Pin_Step = 0; // Variable for Pin Step set to Zero
unsigned int Timer = 0; // Timer Variable
unsigned int Button_Count = 0; // Button Count Variable

void main() { // Main Program Below
    TRISB = 0XFF; // Set Port B as Input
    TRISC = 0XFF; // Set Port C as Input
    TRISD = 0X00; // Set Port D as Output
    PORTD = 0X01; // Set Port D Pin Zero On

    while (1) { // Pin Program Logic
        // Reset If Wrong
        if (PORTB & 0xFF) { // Check if PORTB is Pressed
            Button_Count++; // Increase Button Count
        }

        if (PORTC & 0xFF) { // Check if PORTC is Pressed
            Button_Count++; // Increase Button Count
        }

        if (Button_Count > 4) { // Only Four Buttons Can be Pressed
            Pin_Step = 0; // Reset Pin Step
            Button_Count = 0; // Reset Button Count
            Delay_ms(500); // Delay
        }

        // Pin Digit One
        if (Pin_Step == 0 && PIN1) { // If Pin Digit 1 is Pressed
```

```

    Timer = 0;
    while (PIN1);
    Pin_Step = 1;
}

// Pin Digit Two
if (Pin_Step == 1) {
    Timer++;

    if (Timer >= 200) {
        Pin_Step = 0;
    }
    if (PIN2) {
        Timer = 0;
        while (PIN2);
        Pin_Step = 2;
    }
}

// Pin Digit Three
if (Pin_Step == 2) {
    Timer++;

    if (Timer >= 200) {
        Pin_Step = 0;
    }
    if (PIN3) {
        Timer = 0;
        while (PIN3);
        Pin_Step = 3;
    }
}

// Pin Digit Four
if (Pin_Step == 3) {
    Timer++;

    if (Timer >= 200) {
        Pin_Step = 0;
    }
    if (PIN4) {
        while (PIN4);
        PORTD = 0x00;
        PORTD = 0x06;
        Delay_ms(5000);
        PORTD = 0x00;
        PORTD = 0x01;
        Pin_Step = 0;
        Button_Count = 0;
    }
}
Delay_ms(10);
}
}

// Reset Timer
// Pin Digit 1 Released
// Set Pin Step to One

// If Pin Digit 1 has been Pressed
// Increase Timer by One

// If Pin Digit 2 not Pressed
// Reset Pin Step

// If Pin Digit 2 is Pressed
// Reset Timer
// Pin Digit 2 Released
// Set Pin Step to Two

// If Pin Digit 2 has been Pressed
// Increase Timer by One

// If Pin Digit 3 not Pressed
// Reset Pin Step

// If Pin Digit 3 is Pressed
// Reset Timer
// Pin Digit 3 Released
// Set Pin Step to Three

// If Pin Digit 3 has been Pressed
// Increase Timer by One

// If Pin Digit 4 not Pressed
// Reset Pin Step

// If Pin Digit 4 is Pressed
// Pin Digit 4 Released
// Turn Off Red LED
// Turn On Green LED and Relay
// Keep Green LED and Relay On for 5 Seconds
// Turn Off Green LED and Relay
// Turn Red LED On
// Reset Pin Step
// Reset Button Count

// Delay for Debouncing

```

