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PLC CONTROL SYSTEMS

Control Technology – ACMA6001

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Table of Contents

List of Figures	
List of Tables	
Glossary of Terms	
1. Introduction	1
2. Literature Review: Fluid Power in Actuation and Control	2
3. Control Requirements for the Modelled System.....	4
3.1 Desired Behaviour of the System	4
3.2 Inputs and Outputs (I/O List).....	4
3.3 Machine Layout in Factory I/O	6
3.4 Operational Flow Chart.....	10
4. PLC Program Documentation	12
4.1 PLC Configuration	12
4.2 Program Structure and Architecture.....	14
4.3 HMI Screen and Alarm System.....	18
5. Verification and Observations	20
6. Analysis: Strengths, Weaknesses and Potential Improvements.....	22
7. Conclusion	24
8. References.....	25
9. Appendix	27

List of Figures

Figure 1: Ratings of hydraulic, pneumatic, and electric actuation systems (Pustavrh et al., 2023).	3
Figure 2: Factory I/O material flow.	6
Figure 3: Large package diffuse sensor location.	7
Figure 4: Medium package sorting area.	7
Figure 5: Pusher trap point.	8
Figure 6: Machine guarding.	8
Figure 7: Control panel.	9
Figure 8: Operational flowchart.	11
Figure 9: Field input/output variables.	13
Figure 10: POU emergency stop logic and start sequence.	14
Figure 11: POU conveyor start-up sequence.	15
Figure 12: POU large box sorting logic.	16
Figure 13: POU medium box sorting logic.	16
Figure 14: POU medium box weighing and sorting logic.	17
Figure 15: POU box entry counter logic.	18
Figure 16: HMI layout with emergency stop warning message.	19
Figure 17: HMI layout with conveyor error message.	19
Figure 18: Robot package handler (Kokare, 2023).	23

List of Tables

Table 1: Machine-level field inputs and outputs.	5
Table 2: PLC program test results.	21
Table 3: Improvement Action Plan for the Material Handling System.	23

Glossary of Terms

Abbreviation	Definition
CV	Current Value
FBD	Functional Block Diagram
FIO	Fieldbus Input/Output
HMI	Human Machine Interface
I/O	Input / Output
IEC	International Electrotechnical Commission
IP	Internet Protocol
ISO	International Organization for Standardization
LD	Ladder Diagram
PLC	Programmable Logic Controller
POU	Program Organisation Unit
PT	Preset Time value
PV	Preset Value
SR	Set/reset
ST	Structured Text
TCP	Transmission Control Protocol
TON	Timer-on-delay
UINT	Unsigned Integer

1. Introduction

Automation is a fundamental component in contemporary manufacturing. While earlier systems relied on relays or fluidic controls, Programmable Logic Controllers (PLCs) have become essential for achieving the efficiency, safety, reliability, and scalability demanded by modern industry. These advancements have greatly enhanced package handling systems in logistics, manufacturing, and distribution, enabling them to keep pace with the rising demand created by the expansion of e-commerce.

This project aimed to design and implement a PLC-controlled material handling system in Factory I/O to sort packages based on size and weight. Safety requirements, including emergency stops, sequential conveyor start-up, and guarding, were incorporated into the design. An operator HMI (human-machine interface) was also developed to provide system controls, counters, and warnings. The program's performance was validated against an operational flowchart, with additional testing conducted to assess the effectiveness of error-handling logic.

Factory I/O, a 3D factory simulation software package, was used to model the material handling system, while CODESYS, an integrated development environment for controller programming, was employed to control the simulation. This virtual simulation approach provided several advantages over physical implementation, including enhanced safety, avoidance of equipment damage, and faster testing cycles.

2. Literature Review: Fluid Power in Actuation and Control

Fluid power systems, particularly pneumatic and hydraulic actuation, remain widely used in industrial automation due to their ability to provide rapid, reliable, and forceful motion. In material handling applications like the system simulated in this project - which involves sorting lightweight cardboard packages - pneumatics are typically favoured for actuating pushers, gates, and sorters because of their fast cycle rates, simple construction, and relatively low cost (Esposito, 2014). Pneumatic cylinders are ideal for repetitive tasks with short stroke requirements and moderate forces, such as diverting packages based on weight and size. While hydraulics offer superior force and precision, their application in lightweight systems is often excessive, introducing unnecessary complexity, fluid leakage risks, and higher maintenance demands (Esposito, 2014; Casoli and Rundo, 2023). For this reason, pneumatics were the more appropriate fluid power choice in the control system developed for this project.

However, when compared to electric actuation, fluid power systems show both strengths and limitations. Pustavrh et al. (2023) conducted a direct comparison of pneumatic, hydraulic, and electric actuators under identical conditions (Figure 1), finding that electric actuators achieved the smoothest motion profiles and lowest power consumption, making them particularly well-suited to applications requiring precision and energy efficiency. In contrast, pneumatic actuators, while fast and simple, exhibited greater variability in motion characteristics and higher energy use. That said, their robustness, cost-effectiveness, and ease of integration still make them a practical choice for high-speed package handling systems where motion smoothness is less critical. To improve performance, fluid power systems are increasingly being integrated with smart control technologies. Electropneumatic valves, digital pressure regulators, and embedded sensors now allow PLCs to monitor and control actuation with greater precision, reducing cycle time variability and supporting energy-saving strategies (Dindorf, Takosoglu and Wos, 2022). The use of PLC-controlled pneumatic actuators in the system developed for this project offers a suitable compromise between performance and cost, enabling repeatable sorting with minimal mechanical complexity, while offering room for future optimisation.

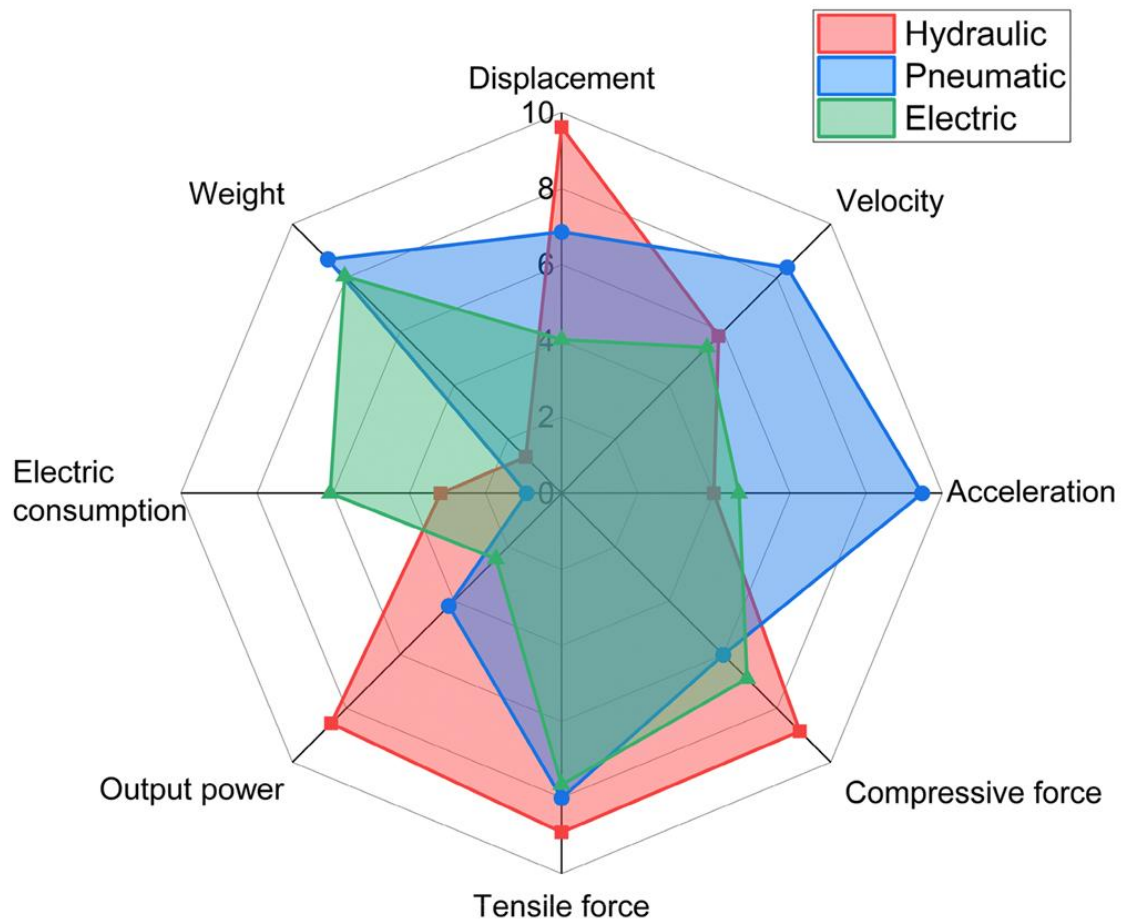


Figure 1: Ratings of hydraulic, pneumatic, and electric actuation systems (Pustavrh et al., 2023).

3. Control Requirements for the Modelled System

3.1 Desired Behaviour of the System

The material handling system was developed to identify and sort four distinct types of cardboard packages by evaluating their size and weight, assigning each to the appropriate outlet; the four categories of packages are small, medium-light, medium-heavy, and large. The system can be operated via physical controls or an HMI screen. In the event of an emergency, the operator must be able to halt all machine operations immediately by activating one of two emergency stop buttons.

During system start-up, each conveyor was required to start in sequence - following a 2-second warning siren - with a 0.5-second delay between each conveyor activation. This sequencing was implemented to prevent excessive current draw, which could arise when multiple induction motors started simultaneously. To monitor product throughput, counters were implemented for both the incoming and sorted packages. Areas that posed a risk of harm to operators required appropriate guarding to prevent injury.

3.2 Inputs and Outputs (I/O List)

In PLC systems, the input/output (I/O) configuration enables interaction between the controller and the physical process. Inputs allow the PLC to monitor real-world conditions - such as sensor states or switch positions - while outputs are used to actuate devices like motors or solenoids. The I/O system acts as the interface that bridges the internal control logic with external equipment, enabling the PLC to execute logical decisions based on real-time conditions. Without a well-defined and structured I/O setup, the controller would be unable to observe or influence the system it is designed to control. Therefore, proper identification, categorisation, and configuration of I/O points are essential for ensuring reliable operation, maintainability, and scalability of automated systems (Bolton, 2015).

A list of the machine-level field I/O is presented in Table 1. The digital inputs and outputs are Boolean data types, representing either a TRUE or FALSE state (1 or 0). The holding registers store integer values, i.e., whole numbers.

Table 1: Machine-level field inputs and outputs.

PLC Address	Signal Type	Device/Function	Description
0	Digital Input	Sensor (Entry)	Detects package at system entry
0.1	Digital Input	Sensor (Large Box)	Detects large boxes
0.2	Digital Input	Sensor (Scale)	Detects package presence on scale
0.3	Digital Input	Sensor (Light Box Exit)	Detects light box at exit
0.4	Digital Input	Sensor (Heavy Box Exit)	Detects heavy box at exit
0.5	Digital Input	Sensor (Medium Box)	Detects medium boxes
0.6	Digital Input	Sensor (Medium Box Exit)	Detects medium box at exit
0.7	Digital Input	Sensor (Small Box Exit)	Detects small box at exit
1	Digital Input	Reset Button	Resets system counters
1.1	Digital Input	Stop Button	Stops system operation
1.2	Digital Input	Start Button	Starts system operation
1.3	Digital Input	Emergency Stop	Halts all system operations
4	Analog Input	Scale Weight	Analog signal representing box weight
0	Digital Output	Main Conveyor 1	Drives the main conveyor (section 1)
0.1	Digital Output	Main Conveyor 2	Drives the main conveyor (section 2)
0.2	Digital Output	Large Box Conveyor	Drives conveyor for large box
0.3	Digital Output	Conveyor Scale (Forward)	Drives scale conveyor
0.4	Digital Output	Pop Up Sorter (Forward)	Activates forward pop-up sorter
0.5	Digital Output	Pop Up Sorter (Heavy)	Activates heavy box sorter orientation
0.6	Digital Output	Pop Up Sorter (Light)	Activates light box sorter orientation
0.7	Digital Output	Heavy Conveyor	Drives heavy box conveyor
1	Digital Output	Light Conveyor	Drives light box conveyor
1.1	Digital Output	Medium Box Conveyor	Drives medium box conveyor
1.2	Digital Output	Pusher 0	Pushes large boxes into specific lane
1.3	Digital Output	Pusher 1	Pushes medium boxes into specific lane
1.4	Digital Output	Reset Button (Light)	Indicator for reset button
1.5	Digital Output	Stop Button (Light)	Indicator for stop button
1.6	Digital Output	Start Button (Light)	Indicator for start button
1.7	Digital Output	Alarm Siren	Activates warning siren before start
2	Digital Output	Stack Light (Red)	Indicates emergency stop or fault
2.1	Digital Output	Stack Light (Yellow)	Indicates warning or standby state
2.2	Digital Output	Stack Light (Green)	Indicates system running normally
4	Holding Register	Small Box Counter	Tracks small box throughput
4.1	Holding Register	Medium Box Counter	Tracks medium box throughput
4.2	Holding Register	Large Light Box Counter	Tracks large light box throughput
4.3	Holding Register	Large Heavy Box Counter	Tracks large heavy box throughput
4.4	Holding Register	Total Box Counter	Tracks total packages processed
4.5	Holding Register	Weight Display	Displays real-time weight

3.3 Machine Layout in Factory I/O

The material handling system was modelled within the Factory I/O simulation environment (Figure 2). An automated package emitter introduces a package into the system every 11 seconds. The packages are transported along a sequence of interconnected conveyor systems, where they are analysed and subsequently directed to one of four designated outlets.

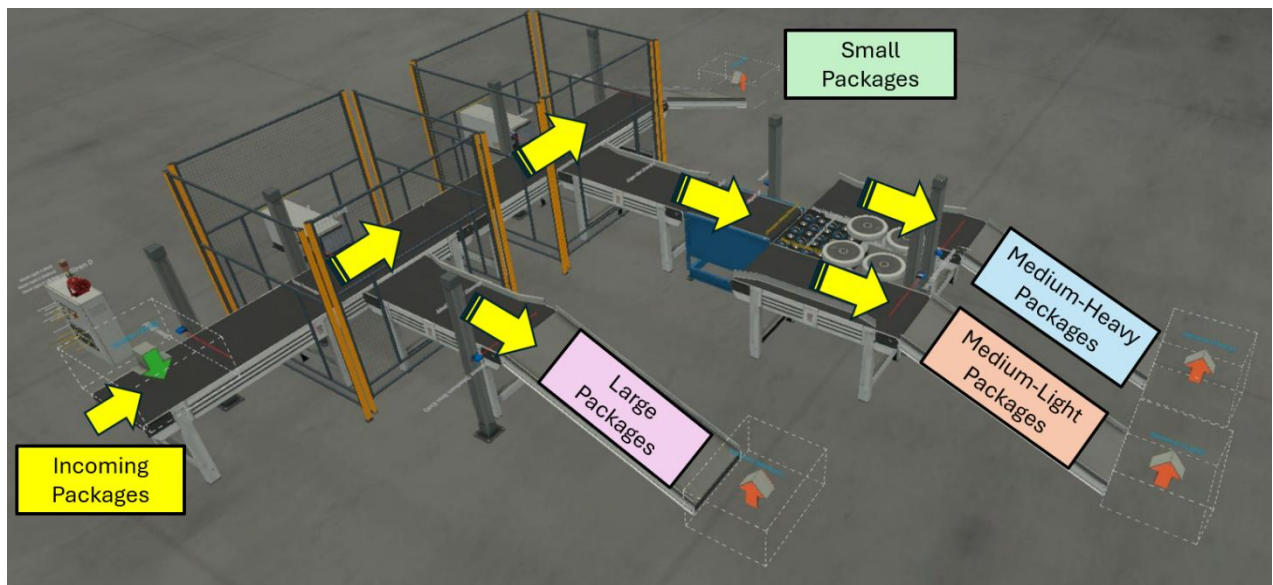


Figure 2: Factory I/O material flow.

Diffuse sensors are positioned at the box entry point and each output line; these signals are used to update the corresponding package counters. Additional diffuse sensors are employed for size detection. As shown in Figure 3, the first of these is mounted at a height such that only large packages break the light beam, triggering a pusher to divert the package to the designated outlet. The same principle is applied further down the conveyor to detect medium packages. Packages that do not activate either of the height-based diffuse sensors are transferred directly to the small package outlet.



Figure 3: Large package diffuse sensor location.

Medium-sized packages undergo additional processing to determine their weight, with heavy packages defined as those weighing more than 450 g (see Figure 4). A diffuse sensor detects when a package is centred on the conveyor's weighing scale, at which point its weight is recorded. The sorting conveyor then orients its rollers in one of two directions, depending on whether the package weight is above or below 450 g.

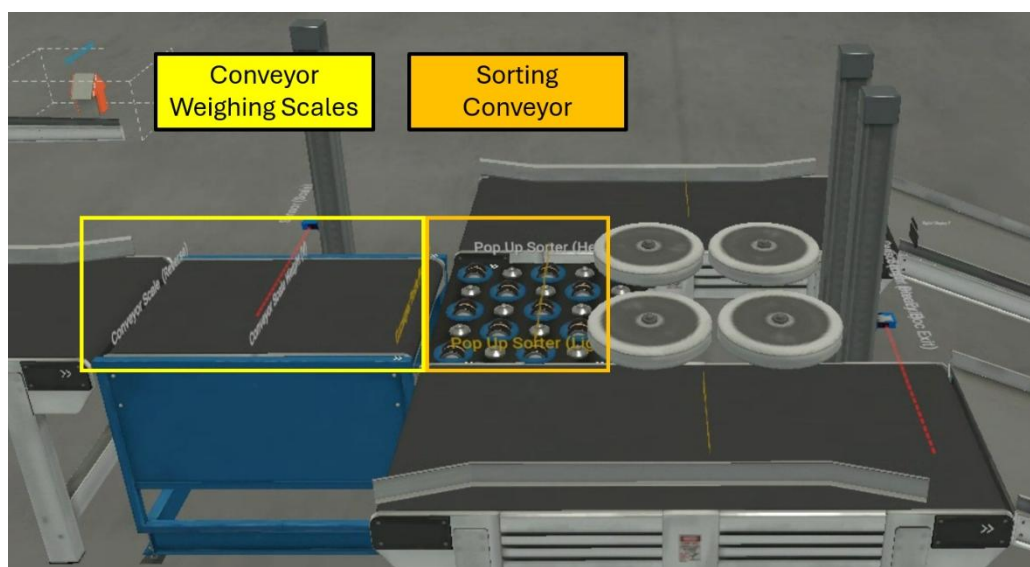


Figure 4: Medium package sorting area.

Numerous ISO (International Organization for Standardization) standards specify machine safety principles. Two particularly relevant to this system are ISO 13854:2017, *Minimum gaps to avoid crushing of parts of the human body*, and ISO 13857:2019, *Safety distances to prevent hazard zones being reached by upper and lower limbs* (International Organization for Standardization, 2017, 2019). Due to the risk of hand and arm entrapment between the pusher mechanisms displayed in Figure 5, guarding was installed around them at a sufficient distance to prevent operators from reaching the mechanisms, as shown in Figure 6. The low operating speed of the conveyor systems presented a minimal risk of injury; as a result, no additional guarding was deemed necessary.

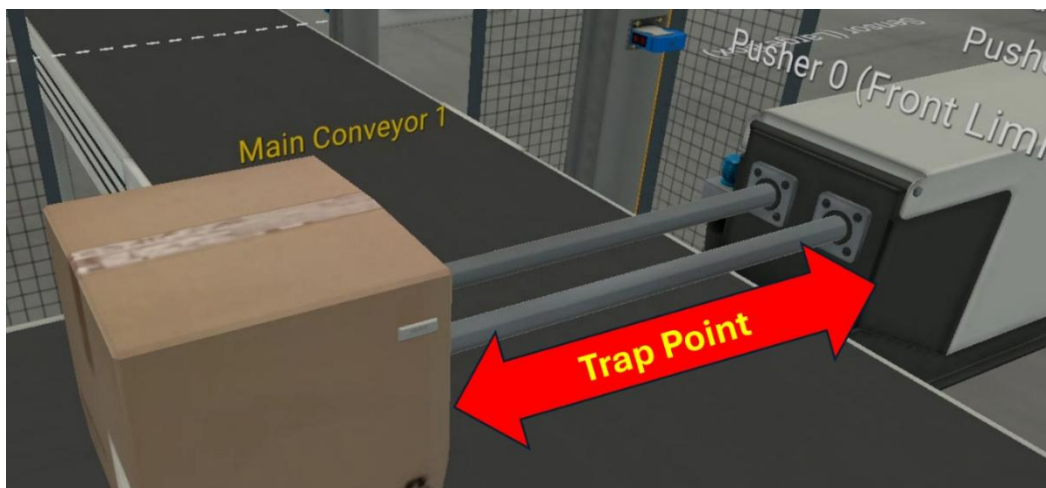


Figure 5: Pusher trap point.



Figure 6: Machine guarding.

The control panel illustrated in Figure 7 contains all the relevant machine controls, counters, a warning siren, and Andon lights, allowing operators to monitor production status and respond quickly to any faults or stoppages.



Figure 7: Control panel.

3.4 Operational Flow Chart

Before developing the PLC program, an operational flowchart was created to visually represent the control system's logic. This flowchart, shown in Figure 8, serves both as a guide for program development and as a reference during program validation. It outlines a step-by-step logic for initiating and controlling operations, starting with safety checks and the sequential startup of conveyors. Package movement is managed through timed stages, with sensors triggering sorters or pushers and updating counters for each package type. Weight checks determine routing for heavy or light boxes, while detection errors - such as packages becoming jammed - trigger amber stack light warnings and HMI messages, consistent with fault detection and alarm strategies employed in other PLC-controlled manufacturing systems (Singh and Verma, 2018; Hala H. Hadi and Maher Y. Sallom, 2019). Operators can stop operations at any point or reset counters, ensuring both safety and process accuracy.

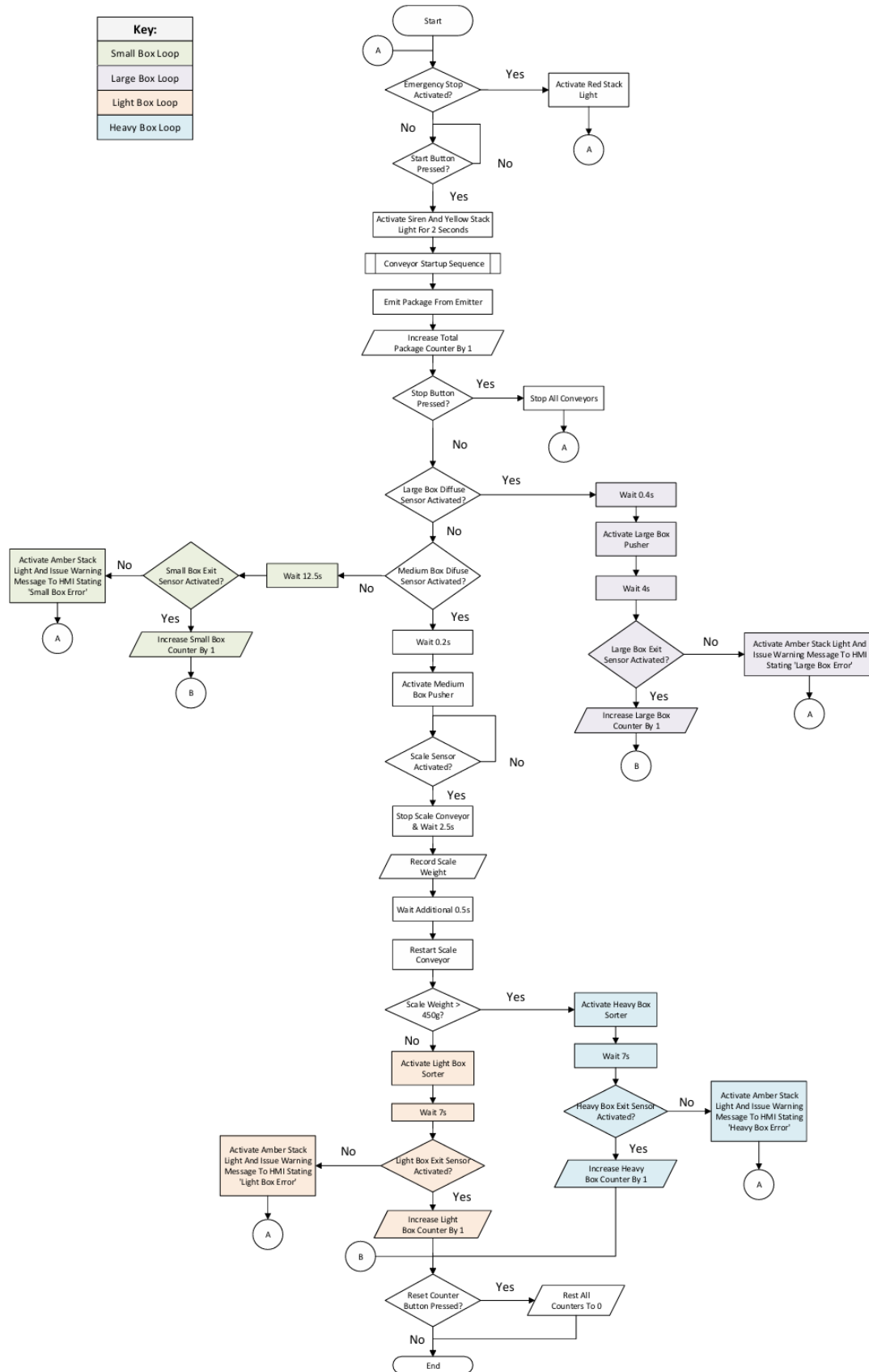


Figure 8: Operational flowchart.

4. PLC Program Documentation

Before the introduction of the Programmable Logic Controller (PLC) in the 1960s, control systems such as the one in this project would have relied on hardwired relays and timer circuits to implement the necessary logic defined in the operational flowchart (Control Guru, 2018). The advent of PLCs offered a more flexible, reliable, and easily reconfigurable solution, enabling modern tools such as CODESYS to be used for programming and simulation across multiple hardware platforms. In this project, the client's factory PLC operated as the Modbus master, while the Factory I/O environment functioned as the slave, exchanging real-time I/O data with the control program. CODESYS supports all IEC 61131-3 languages, including Ladder Diagram (LD), Structured Text (ST), and Function Block Diagram (FBD). For this application, Ladder Logic was selected for its intuitive graphical structure that is modelled on traditional relay schematics (Bolton, 2015; CODESYS, 2025).

4.1 PLC Configuration

The initial PLC programming task involved configuring the FIO (Fieldbus Input/Output) list; this maps variables within the CODESYS program to the physical inputs and outputs of the Factory I/O Modbus TCP/IP client module. It is essential that the variable order exactly matches that of the client I/O module, as illustrated in Figure 9.

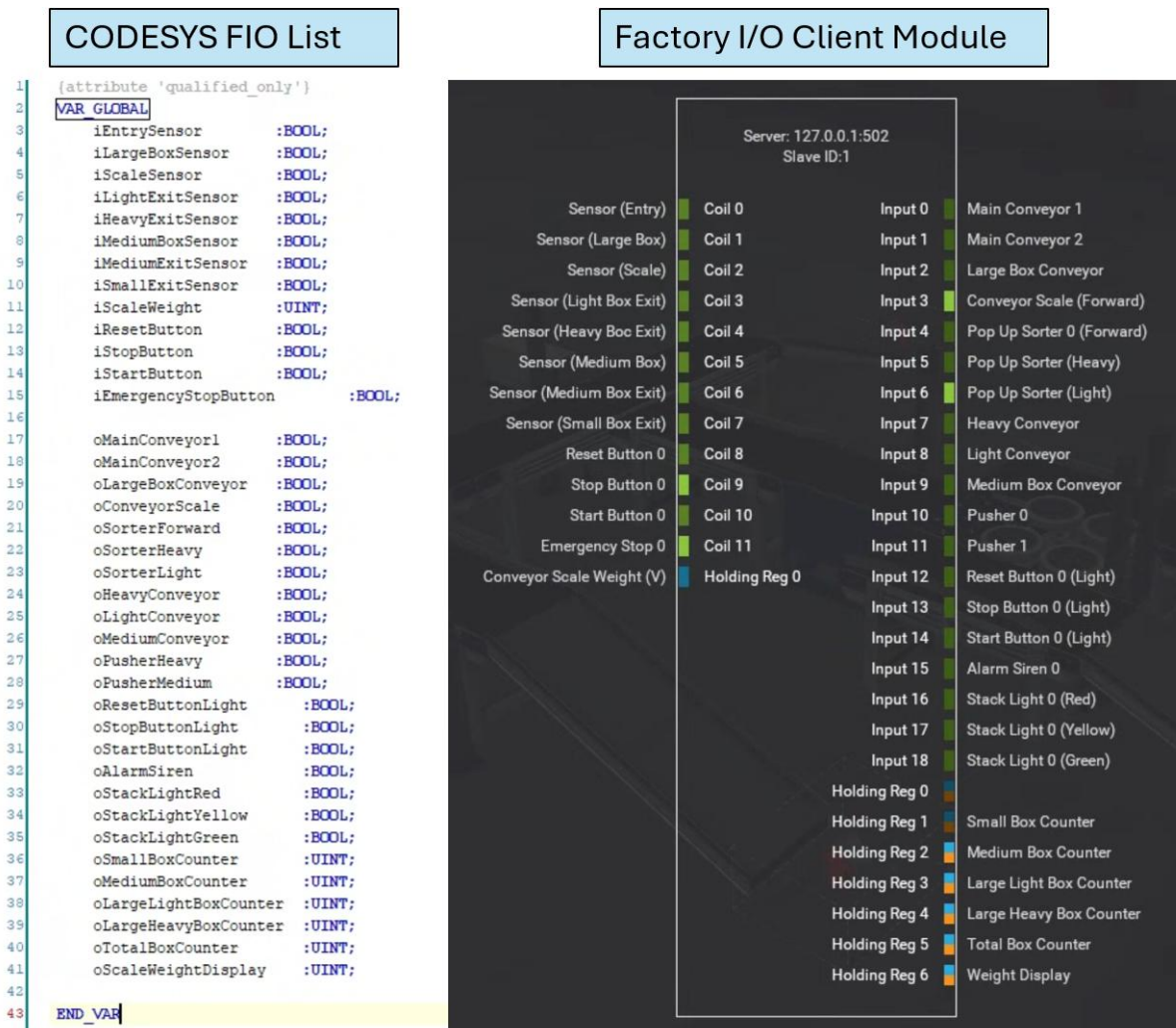


Figure 9: Field input/output variables.

In this project, all control logic was implemented within a single Program Organisation Unit (POU), which serves as the main execution block in the CODESYS application (Appendix 1). The POU contains a series of declared variables that represent the system's internal states, operator commands, and fault conditions. Boolean variables such as `ConveyorON`, `ScaleON`, and `WeightReady` are used to store on/off states for machine functions, while `StartButtonHMI`, `StopButtonHMI`, and `ESopHMI` capture control inputs from the HMI. Additional Boolean variables, such as `MediumBoxError`, are reserved for fault detection in specific parts of the system. The variable `WeightTaken` is an unsigned integer (UINT) that stores the weight value obtained from the conveyor scale during the weighing process. By grouping all these

variables within the POU, the program maintains a clear and centralised structure for managing the system's logic and data (CODESYS, 2025).

4.2 Program Structure and Architecture

Ladder Logic is executed sequentially from left to right across each rung and from the top rung to the bottom rung of the program, resembling how text is read in Western languages. At the top of the program structure is the emergency stop logic, as shown in the organisational flowchart. In Figure 10, rung 1 requires multiple input conditions to be satisfied - specifically, the start button must be engaged while both the stop buttons and emergency stop buttons remain disengaged - before the `ConveyorON` output variable can be latched. This action triggers the `TP_0` pulse timer function block for two seconds, during which the yellow stack light and warning siren are activated. The green stack light is illuminated during normal operation, whereas the red stack light is illuminated when an emergency stop is engaged.

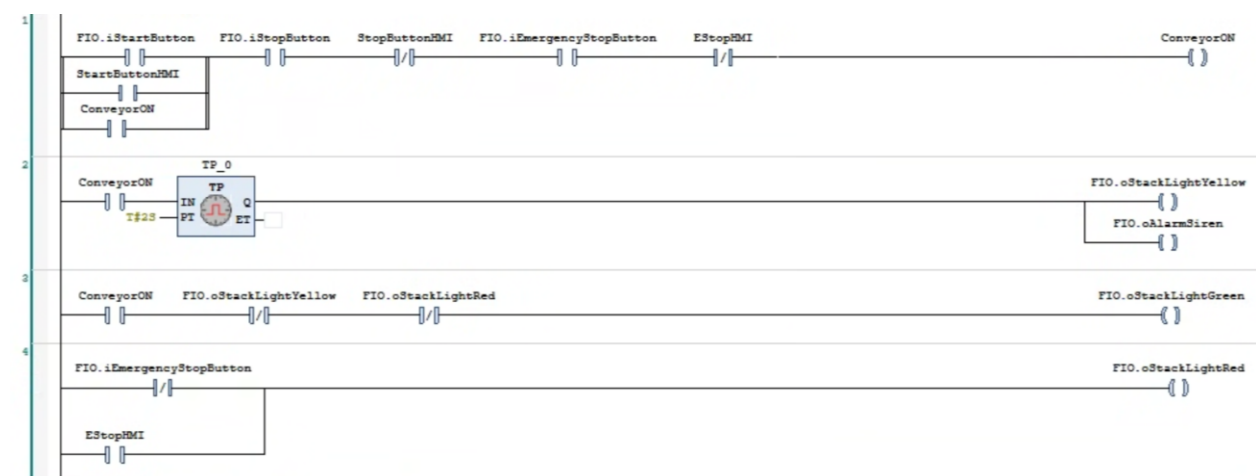


Figure 10: POU emergency stop logic and start sequence.

The conveyor start-up sequence, illustrated in Figure 11, incorporates multiple timer-on-delay (TON) function blocks. When these timers receive the input signal `ConveyorON`, their outputs are delayed by the preset time value (PT). This logic ensures that the first conveyor starts only after a 2-second delay, with each

subsequent conveyor initiating at 0.5-second intervals to prevent excessive current draw during start-up.

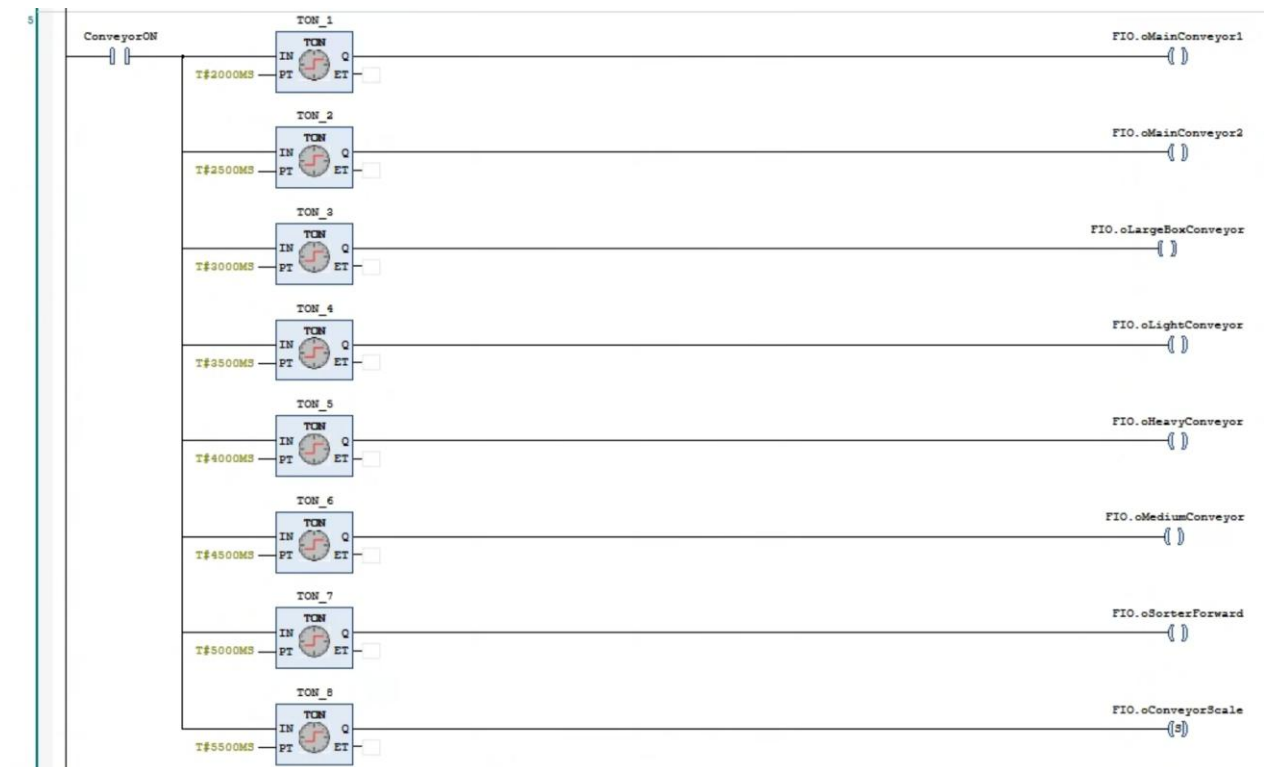


Figure 11: POU conveyor start-up sequence.

The following section implements the large box sorting logic (Figure 12). When `ConveyorON` is `TRUE` and `iLargeBoxSensor` detects a package, pulse timer `TP_01` initiates an output signal for 4 seconds; however, this signal is delayed by 0.4 seconds by `TON_09`, to allow the box to centre in front of the pusher before being energised. An additional branch from the `TON_09` output feeds into a set/reset (SR) function block, which maintains its output until reset by one of three inputs: `iMediumExitSensor`, `StartButtonHMI`, or `iStartButton`. `SR_01`'s output is connected to `TON_12`, a 4-second on-delay timer that, when complete, activates `oStackLightYellow` and `MediumBoxError`, and resets `ConveyorON`. This combination of logic issues a warning on the HMI and stops the conveyor system if the large box fails to trigger the `iMediumExitSensor` within the allotted time. The same ladder logic is used for highlighting errors with small boxes.

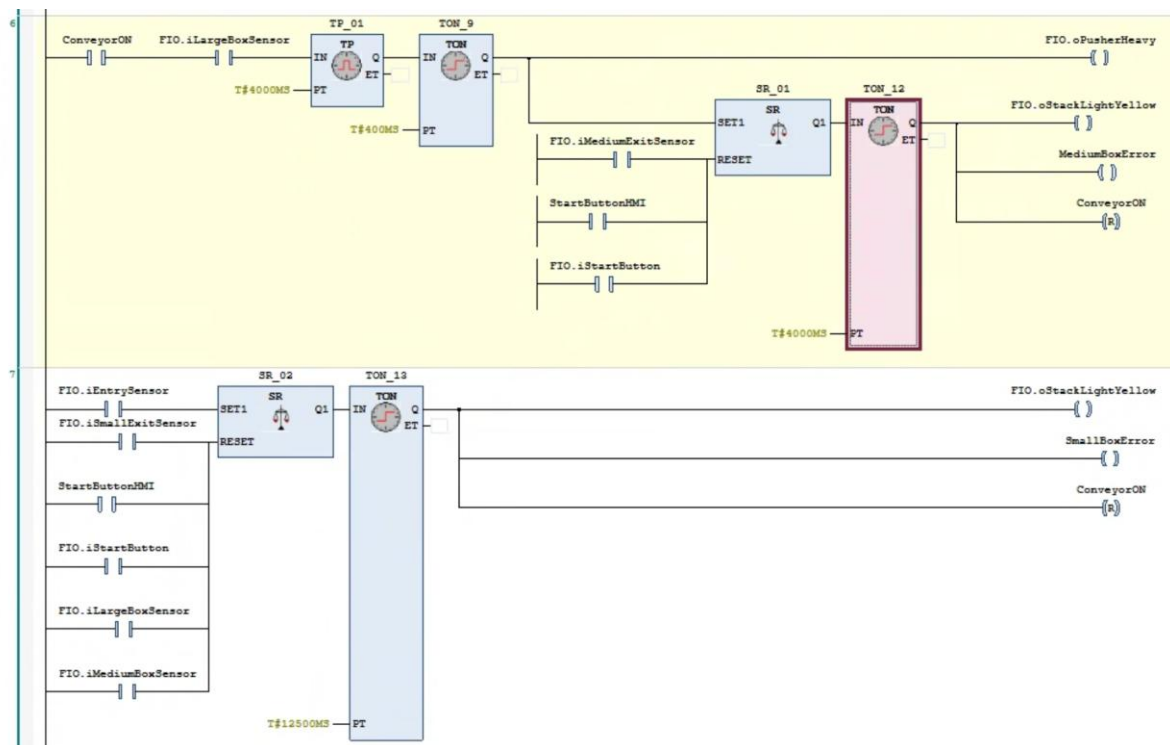


Figure 12: POU large box sorting logic.

Rung 9, shown in Figure 13, contains the medium-sized box detection logic. The following rung includes pulse timer TP_02, which deactivates oConveyorScale for 3 seconds once the box triggers iScaleSensor. In parallel, TON_11 sets the variable WeightRecorded to TRUE after a 2.5-second delay, ensuring the box is stable before the weight measurement is taken.

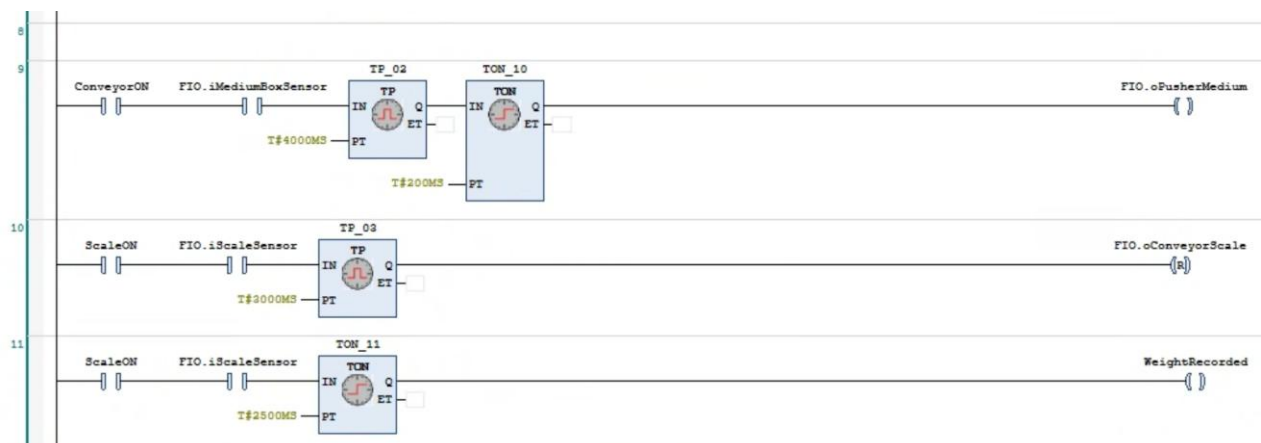


Figure 13: POU medium box sorting logic.

Once the variable `WeightRecorded` is `TRUE`, `TP_04` outputs a 50 ms pulse to the `MOVE` function block, which transfers the weight value from `iScaleWeight` into the variable `WeightTaken` (Figure 14). In parallel, `WeightRecorded` is reset to `FALSE`, preparing the system for the next weighing cycle. Two comparator blocks (`LE` and `GE`) evaluate whether `WeightTaken` is less than 440 g or greater than 460 g. Based on this evaluation, either `oSorterLight` or `oSorterHeavy` is activated, directing the package to the appropriate outlet. Conveyor error-handling logic is also incorporated in this step.

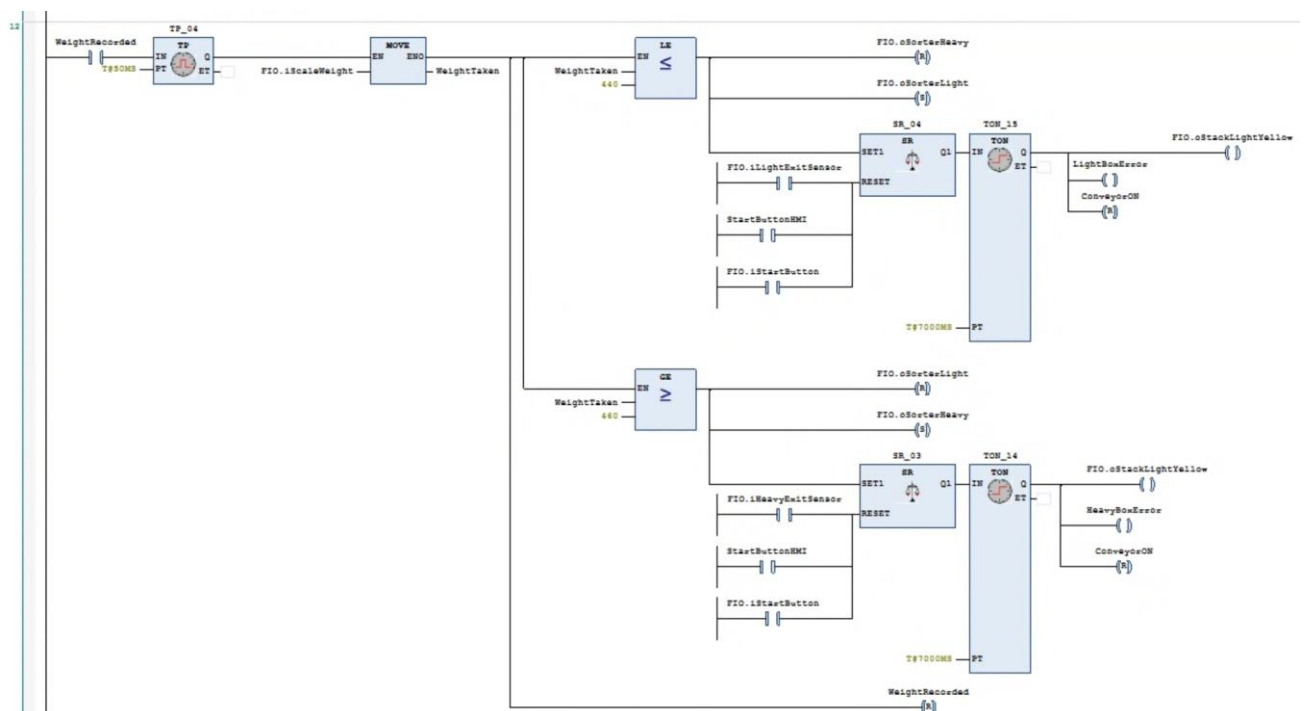


Figure 14: POU medium box weighing and sorting logic.

The final section of the POU implements the counter logic. As shown in Figure 15, the function block `RTRIG_01` generates a single pulse each time `iEntrySensor` is activated. This pulse is passed to `CTU_01`, an up-counter function block that increments its count until reaching the preset value (PV). The counter's current value (CV) is sent to `oTotalBoxCounter`, where it is displayed on both the physical control panel and the HMI. The counter is reset when either `iResetButton` or `ResetCounterHMI` is activated. The same logic is used for the box exit counters.

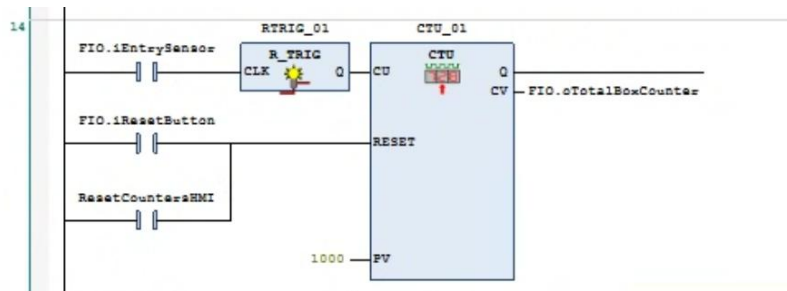


Figure 15: POU box entry counter logic.

4.3 HMI Screen and Alarm System

The HMI layouts in Figures 16 and 17 were designed per ISA-101.01 principles for high-performance HMIs (International Society of Automation, 2015). The interface is divided into functional areas: 'Primary Controls' (start, stop, and emergency stop) are positioned on the left for immediate operator access; 'Part Counters' occupy the centre to provide real-time throughput data; and 'Alarms' are placed on the right, displaying active banners and a timestamped historical log. A priority-based colour scheme - green for start, amber for stop, and red for emergency - ensures rapid recognition of critical controls. Warnings, such as an emergency stop being activated, use high-contrast red banners to indicate urgent attention, while system errors, such as a box being lost on the conveyor, are shown in amber to signal operational faults without implying immediate danger. The lower section displays 'Package Weight' in grams for process monitoring.

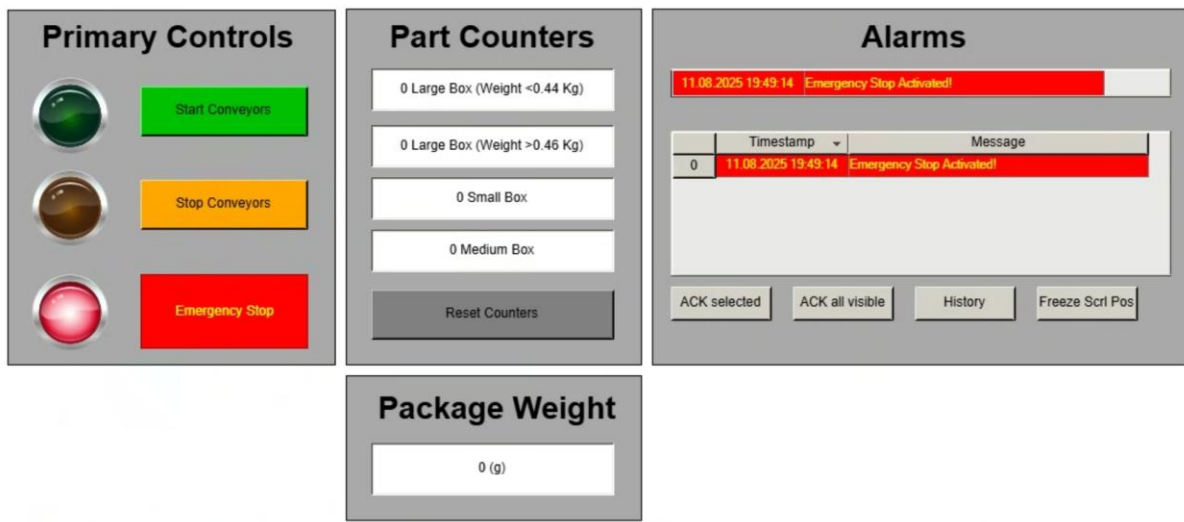


Figure 16: HMI layout with emergency stop warning message.

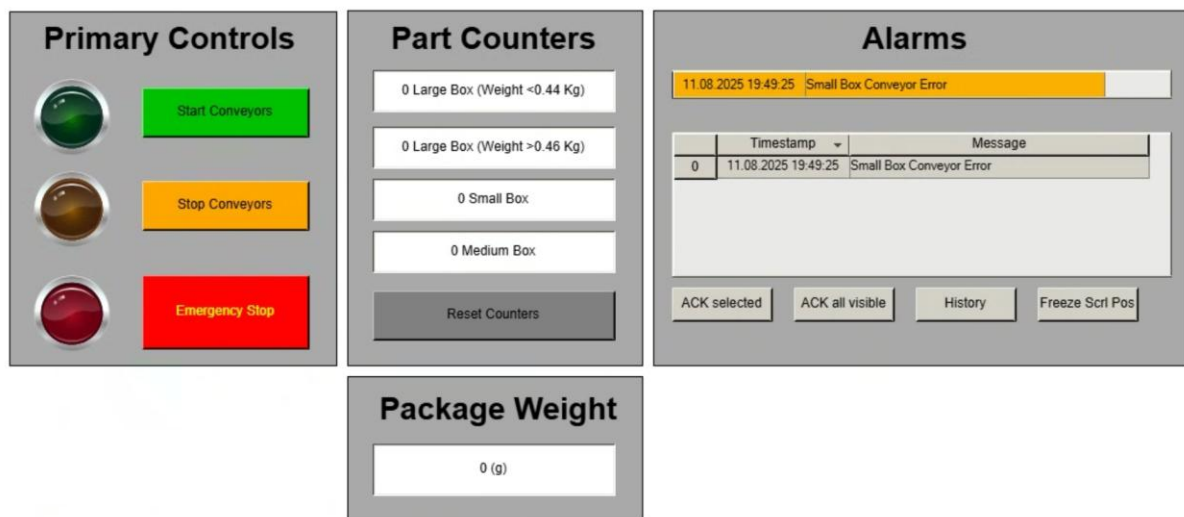


Figure 17: HMI layout with conveyor error message.

5. Verification and Observations

Testing of the PLC program was carried out entirely within a virtual environment using Factory I/O, a method that is safe, fast, and eliminates the risk of equipment damage during commissioning. The simulation allowed seamless real-time communication between Factory I/O and the CODESYS PLC, ensuring all mapped inputs and outputs were correctly aligned. Following recommended verification practices, testing began with isolated modules such as conveyor sequencing, large-box sorting, and weighing logic, applying a unit-testing approach to detect errors early (Fernández *et al.*, 2013). Once each module met its requirements, complete integration testing was performed.

The operational flowchart served as a functional benchmark, with system behaviour compared against each defined sequence to confirm compliance (Borja Fernández Adiego *et al.*, 2013). Factory I/O was configured to simulate multiple packages of varying sizes and weights, enabling assessment under realistic load scenarios. Error-handling logic was tested by manually holding packages stationary, confirming that the HMI displayed the appropriate warnings, and the conveyors stopped as intended.

A complete list of the test results is provided in Table 2, which demonstrates that the implemented control logic met all specified control requirements. However, simulations are inherently limited by the accuracy of their input data, and validation on physical hardware may reveal unexpected behaviours not captured in the virtual environment (Dzinic and Yao, 2013).

Table 2: PLC program test results.

Test #	Test Description	Outcome	Test Pass
1	Engage HMI start button.	Warning siren and yellow stack light was activated for 2 seconds. Conveyors then started with 0.5 s intervals and green stack light remained activated.	Y
2	Engage physical start button.	Warning siren and yellow stack light was activated for 2 seconds. Conveyors then started with 0.5 s intervals and green stack light remained activated.	Y
3	Engage HMI e-stop button.	All equipment stopped. Red stack light activated. Warning message shown on HMI screen.	Y
4	Engage physical e-stop button.	All equipment stopped. Red stack light activated. Warning message shown on HMI screen.	Y
5	Engage HMI stop button.	All equipment stopped. No lights were activated.	Y
6	Engage physical stop button.	All equipment stopped. No lights were activated.	Y
7	Insert small package.	Diverted to small package outlet and part counter incremented by 1.	Y
8	Insert small package.	Diverted to small package outlet and part counter incremented by 1.	Y
9	Insert large package.	Diverted to large package outlet and part counter incremented by 1.	Y
10	Insert small package.	Diverted to small package outlet and part counter incremented by 1.	Y
11	Insert medium-light package.	Diverted to medium-light package outlet and part counter incremented by 1.	Y
12	Insert medium-heavy package.	Diverted to medium-heavy package outlet and part counter incremented by 1.	Y
13	Insert small package.	Diverted to small package outlet and part counter incremented by 1.	Y
14	Insert large package.	Diverted to large package outlet and part counter incremented by 1.	Y
15	Insert medium-light package.	Diverted to medium-light package outlet and part counter incremented by 1.	Y
16	Insert large package.	Diverted to large package outlet and part counter incremented by 1.	Y
17	Engage reset counters button on HMI.	All physical and HMI counters reset to 0.	Y
18	Engage reset counters button on physical control panel.	All physical and HMI counters reset to 0.	Y
19	Hold large box for 4 seconds after large diffuse sensor has been enabled.	All equipment stopped. Yellow stack light activated. Error message shown on HMI screen stating 'large box conveyor error'.	Y
20	Hold small box for 12.5 seconds after box entry diffuse sensor has been enabled.	All equipment stopped. Yellow stack light activated. Error message shown on HMI screen stating 'small box conveyor error'.	Y
21	Hold medium-light box for 7 seconds after weighing has completed.	All equipment stopped. Yellow stack light activated. Error message shown on HMI screen stating 'medium-light conveyor error'.	Y
22	Hold medium-heavy box for 7 seconds after weighing has completed.	All equipment stopped. Yellow stack light activated. Error message shown on HMI screen stating 'medium-heavy conveyor error'.	Y

6. Analysis: Strengths, Weaknesses and Potential Improvements

The developed PLC-controlled material handling system demonstrates several notable strengths. Its modular design enables straightforward scalability, while the use of robust, simple components ensures reliable operation. The intuitive layout facilitates ease of use, and good physical access enables straightforward maintenance. Most importantly, the system satisfies all defined control requirements, a benchmark also emphasised in similar PLC-based conveyor sorting studies (R Gowrishankar *et al.*, 2025).

Despite these strengths, the system also has limitations. Continuous conveyor operation leads to unnecessary energy consumption, raising sustainability concerns, which are increasingly central in modern automation (Reformasi Baene, Aryza and Dani, 2025). The large footprint, partly imposed by Factory I/O constraints, reduces its suitability for real-world deployment where space efficiency is critical. Furthermore, throughput is limited by both the pushers and the weighing mechanism, similar to challenges identified in other pneumatic-based conveyor systems (Setiawan *et al.*, 2024). Finally, the system is limited in the types of packages it can process and requires a compressed air supply, which reduces its flexibility and efficiency.

To address these issues, several improvements are suggested. For example, conveyors could be enabled only when required, reducing energy use (Vacca, 2018). At the same time, advanced technologies such as vision systems or robotic pick-and-place units (Figure 18 (Kokare, 2023) could increase throughput and flexibility, albeit at a higher cost (Dzinic and Yao, 2013). Enhancements to the HMI, such as cycle-time displays and maintenance dashboards, would also improve usability and fault-finding. The relationship between weaknesses and proposed improvements is summarised in Table 3.



Figure 18: Robot package handler (Kokare, 2023).

Table 3: Improvement Action Plan for the Material Handling System.

Weakness	Proposed Improvement	Expected Impact
Continuous conveyor operation wastes energy	Implement logic to enable conveyors only when required	Reduces energy consumption, supporting sustainability goals; aligns with recommendations for energy-efficient fluid power and automation (Vacca, 2018).
Large machine footprint (Factory I/O constraint)	Redesign layout or integrate vision-based pick-and-place system	Minimises space requirements and improves industrial viability; vision-based solutions have been shown to increase flexibility in constrained environments (Dzinic and Yao, 2013).
Limited throughput (pushers and scales)	Upgrade actuation methods or introduce robotic sorting	Increases capacity and scalability; research shows robotic sorters outperform pneumatic pushers in high-throughput contexts (Setiawan et al., 2024).
Restricted range of package sizes and orientations	Replace diffuse sensors with vision system	Enables handling of diverse package dimensions and orientations, consistent with industry trends in flexible automation (R Gowrishankar et al., 2025).
Dependency on compressed air supply	Explore electric actuators instead of pneumatic pushers	Lowers energy usage and reduces infrastructure requirements; electric actuation is increasingly preferred for sustainability and controllability (Reformasi Baene, Aryza and Dani, 2025).
Limited diagnostic and monitoring functions	Add cycle-time display and maintenance dashboard on HMI	Enhances usability, simplifies fault detection; automated diagnostic feedback is widely recommended in PLC verification studies (Dzinic and Yao, 2013).

7. Conclusion

This project aimed to develop and evaluate a PLC-controlled material handling system in a virtual environment, capable of sorting boxes based on their size and weight. Pneumatics were identified as a suitable actuation method, though the reliance on a compressed air supply introduced additional complexity and cost. The work highlighted the importance of clear I/O naming conventions for programming and fault-finding, as well as the need for safety measures such as guarding in automated systems. Similarly, the creation of an accurate and easy-to-interpret operational flowchart proved essential for program development and validation. Configuring timing elements, including pulse timers and on-delay functions, was also shown to be vital in achieving robust and reliable system performance.

The system successfully met all defined control requirements using a modular and intuitive design that was straightforward to operate and maintain. Nevertheless, energy inefficiency and the significant physical footprint raised sustainability concerns, highlighting limitations for real-world application. Testing in a virtual environment demonstrated the value of simulation for safe and rapid development, though physical hardware trials remain essential to uncover unexpected behaviours not represented virtually.

Overall, the simulated material handling system demonstrated an effective solution to the defined problem. Future improvements, such as incorporating vision systems or robotic handling units, could achieve higher efficiency and a reduced footprint. However, these enhancements would need to be carefully weighed against cost through a structured cost–benefit analysis.

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9. Appendix

Appendix 1 – Material Handling Program Organisation Unit (POU)

