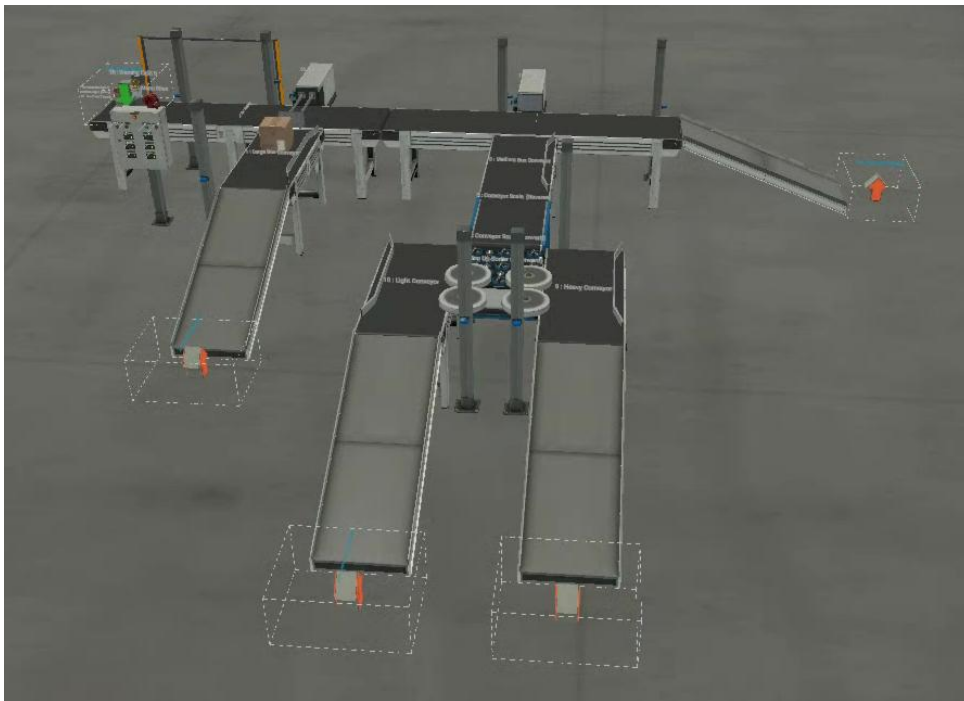




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Control Technology

PLC Control Systems-ACMA6001

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3 Introduction

Programmable logic controllers (PLCs) play a key role in modern industrial automation. Used across industries such as automotive, food processing and logistics. Providing reliable, flexible and safe control of processing in manufacturing. Automated material handling systems (AMHS) are an essential part of industry 4.0, helping to improve throughput, quality consistency all while reducing operator intervention. Achieved by the integration of sensors, actuators, safety devices and human machine interfaces (HMIs). PLC based system deliver accurate reliable and user-friendly operation.

The aim of the project is to design, implement and analyse a PLC- controlled automated box sorting system using Factory I/O software which allows you to create simulated factory environments with automation technologies including sensors, actuators and HMIs (Mora-Salinas & Hernández, 2022).

The second software package used is Codesys, where the program can be designed for the PLC (Gusarova & Shilkina, 2019).

The system designed sorts four package types according to size and weight while integrating industry standard safety features such as emergency stops, start/stop buttons, warning sirens and stack lights. The report documents the design, implementation, testing and evaluation of the control program developed.

4 Actuation and control

4.1 Hydraulic and pneumatic systems.

The advantages and limitations of pneumatic and hydraulic systems stem from the contrasting properties of low-density, compressible gases and high-density, incompressible liquids. Pneumatic systems generally deliver smoother and softer motion, whereas hydraulic systems, though more rigid, can generate shock loads in piping that may lead to noise and wear. However, liquid-based hydraulic systems are capable of operating at much higher pressures and temperatures than pneumatic systems, enabling them to produce significantly greater forces (Parr, 2011).



Figure 1-Pneumatic pusher (Bricspac-Customised conveying automation, 2025)

In hydraulic systems, pressurised fluid generates motion and force. They are commonly used in heavy-duty equipment, for example presses and lifting systems. Benefits are a high level of control with disadvantages being a high level of maintenance with regular fluid changes required and leak checks (The workshop press company, 2025).

Pneumatic actuators are widely used as key force generating devices in industrial application. Their static and dynamic behaviour play a crucial role in system performance. They offer advantages such as cleanliness, low cost, high power to weight ratio, ease of maintenance. The loss air compression over time being one of the biggest disadvantages (Hazem I, et al., 2009).

4.2 Electrical actuation.



Figure 2-Electrically controlled pusher sorter (Falcon autotech, 2025)

Electrical actuation, which includes motors, solenoids, and servo systems, has become the dominant choice in automated material handling. PLCs integrate directly with these devices, enabling programmable flexibility and precise control (Bolton, 2006)

Advantages:

- High accuracy and repeatability.
- Easy integration with PLCs and HMIs.
- Minimal maintenance requirements.
- Scalable and reconfigurable, ideal for Industry 4.0 systems.

Limitations:

- Generally, less capable of producing very high forces compared to hydraulics.
- Sensitive to electrical disturbances in certain environments.

While hydraulics and pneumatics remain essential in specific sectors, electrical actuation aligns most closely with the needs of automated material handling systems. Electric drives provide precise control, energy efficiency, and seamless integration with PLC logic and HMI visualisation. This makes them particularly suited to environments such as the Factory I/O simulation, where conveyor belts, sorters, and pushers are all modelled as electrically driven devices.

5 System design and control requirements.

5.1 Control requirements

The human machine interface (HMI) serves as the operator's main point of interaction with the system, providing both control and feedback during operation. From the root screen, the operator can start, stop, reset, or trigger an emergency stop.

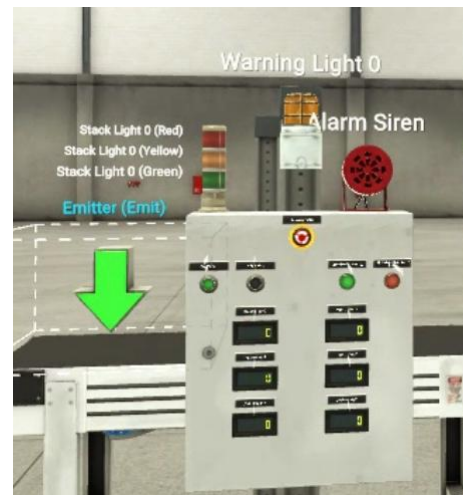
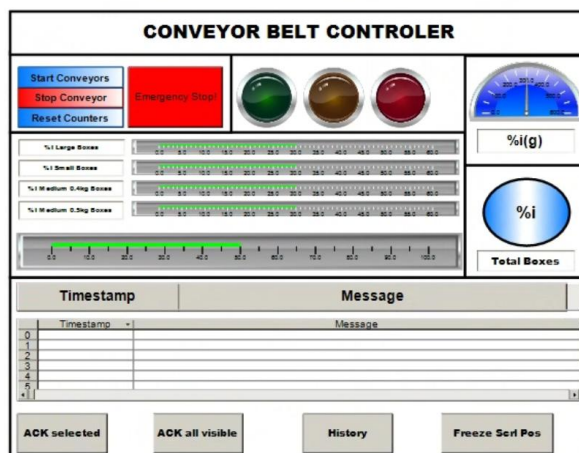


Figure 3-HMI controller in Codesys (left), HMI controller Factory IO (Right)

When the Start button is pressed, the HMI initiates the warning siren and sequential conveyor startup begins with a 500ms delay of each conveyor to prevent excessive current draw. Then packages are released, and the sorting process begins. During the start-up the amber stack light will illuminate, and siren will sound for two seconds.



Figure 4-Codesys ladder logic for start-up and stack light sequence

Real-time counters are displayed on screen, showing the number of packages in each of the four bins as well as the total throughput. The Stop button pauses the process safely, halting conveyors and actuators without cutting power abruptly, allowing the system to be restarted smoothly. If the

Emergency Stop is activated, the HMI immediately halts all actuators, displays a warning message, and switches on the red stack light alarm beacon flashes, ensuring operators are clearly alerted to the fault condition. This occurrence is then stored on the HMI, here the history of any occurrence is stored. Finally, the Reset button clears all counters to zero, preparing the system for a new operational cycle. This structure ensures that the HMI provides intuitive control, real-time feedback, and critical safety functionality in support of automated sorting operations. The operational flow of the process is shown in figure 5.

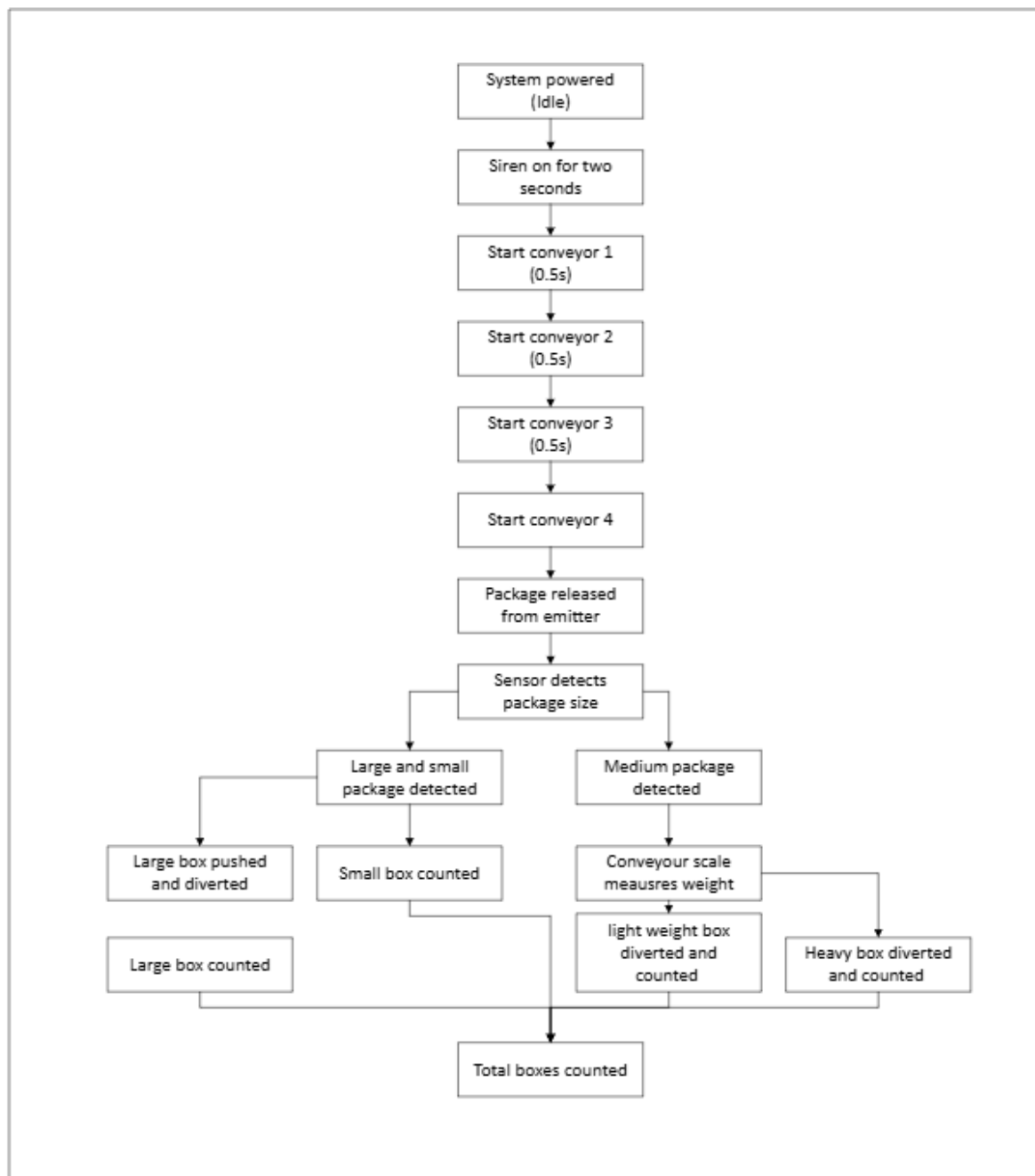


Figure 5- Conveyor belt operational flow chart (Purnell-Whitehead, 2025)

5.2 Inputs, Outputs and System Constraints.

Inputs (sensors and operator controls):

- Start button (HMI and physical input).
- Stop button (HMI and physical input).
- Emergency stop (normally closed).
- Reset button (HMI).
- Diffuse sensors for package size detection (small/large).
- Conveyor scale for package weight detection (light/heavy).

Outputs (actuators and indicators):

- Warning siren and beacon
- Stack lights (green = running, amber = standby, red = emergency).
- Conveyor motors.
- Pneumatic pushers.
- Pop-up sorter (for diverting packages).
- Counters displayed on HMI (4 for each variant of package, 1 for total throughput).
- Package count progress bar.
- Conveyor package weighing scale with display.

Constraints:

- Startup sequencing must avoid simultaneous conveyor activation.
- Packages must not be misclassified; sensor logic must ensure one pusher activates per package.
- Safety systems override all other logic.
- Operator controls must be intuitive and prevent accidental activation.

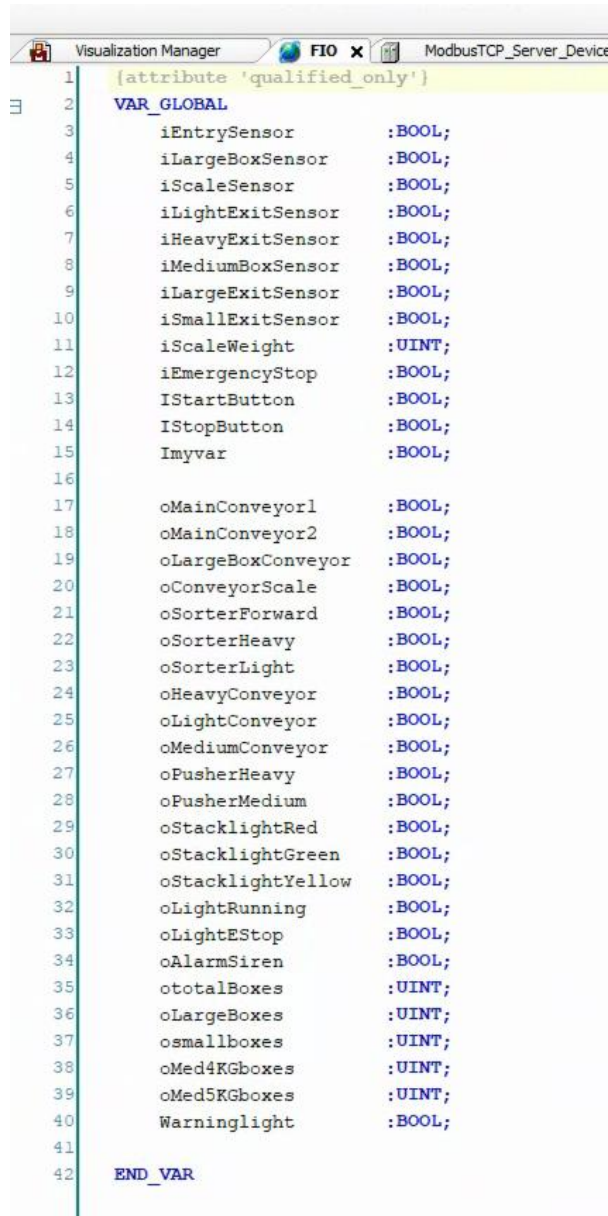


Figure 6-Factory IO- Sensor and actuators (Purnell-Whitehead, 2025)

The list of sensors and actuators that have been applied to the Factory IO modelling system are shown in figure 6.

The components above were assigned to the list of global variables set in Codesys. Figure 7. Boolean (BOOL) variables which are a data type with two possible values, True/false and Unsigned Integers (UInt) which are whole numbers.

The PLC program was carefully annotated. All variables have been defined to help fully describe the function. Each have been named and begin with an I or O to indicate if the component is an input or output. Clearly defining variables and tags is important for other users to be able to understand the programme created and can help problem solving, maintaining and modifying if required.



```

1  {attribute 'qualified_only'}
2  VAR_GLOBAL
3      iEntrySensor          :BOOL;
4      iLargeBoxSensor       :BOOL;
5      iScaleSensor          :BOOL;
6      iLightExitSensor      :BOOL;
7      iHeavyExitSensor      :BOOL;
8      iMediumBoxSensor      :BOOL;
9      iLargeExitSensor      :BOOL;
10     iSmallExitSensor       :BOOL;
11     iScaleWeight           :UINT;
12     iEmergencyStop         :BOOL;
13     IStartButton           :BOOL;
14     IStopButton            :BOOL;
15     Imyvar                 :BOOL;
16
17     oMainConveyor1         :BOOL;
18     oMainConveyor2         :BOOL;
19     oLargeBoxConveyor      :BOOL;
20     oConveyorScale         :BOOL;
21     oSorterForward         :BOOL;
22     oSorterHeavy           :BOOL;
23     oSorterLight           :BOOL;
24     oHeavyConveyor         :BOOL;
25     oLightConveyor         :BOOL;
26     oMediumConveyor        :BOOL;
27     oPusherHeavy           :BOOL;
28     oPusherMedium          :BOOL;
29     oStacklightRed         :BOOL;
30     oStacklightGreen       :BOOL;
31     oStacklightYellow      :BOOL;
32     oLightRunning          :BOOL;
33     oLightEStop            :BOOL;
34     oAlarmSiren            :BOOL;
35     ototalBoxes            :UINT;
36     oLargeBoxes            :UINT;
37     osmallboxes            :UINT;
38     oMed4KGboxes           :UINT;
39     oMed5KGboxes           :UINT;
40     Warninglight           :BOOL;
41
42  END_VAR

```

Figure 7- Codesys-FIO global variables

6 PLC Program Documentation

The PLC program was developed in a structured manner to meet the control requirements of the automated box sorting system. The functional section was programmed using ladder logic. A PLC operates through inputs and output relays whose logic is programmed by the user, typically using ladder logic. The graphical programming language represents relay operations in a diagram similarly to Boolean logic gates, making knowledge of digital logic a useful prerequisite. In ladder logic programs are built by placing inputs, outputs and control elements into a visual sequence rather than typing code (DeGuglielmo, et al., 2020).

6.1 Startup logic

The startup logic was implemented using timers. The siren immediately sounds when the start button is pressed, each conveyor then receives a delayed run signal in sequence to limit current draw see figure 8.

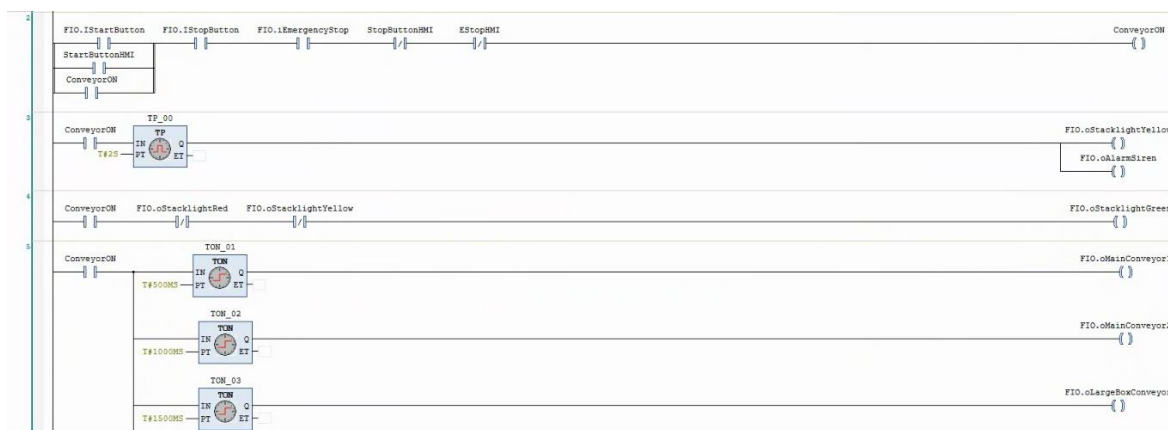


Figure 8-Codesys-Start up ladder logic (Purnell-Whitehead, 2025)

6.2 Safety interlocks

All outputs are interlocked with the Emergency stop function FIO.iEmergencyStop. When triggered, the Emergency stop overrides all normal operating logic and shuts down all actuators down. Doing this also switches on the red stack light and warning beacon to warn of the emergency state. The HMI also writes an Emergency stop instance to the display. See figure 9.

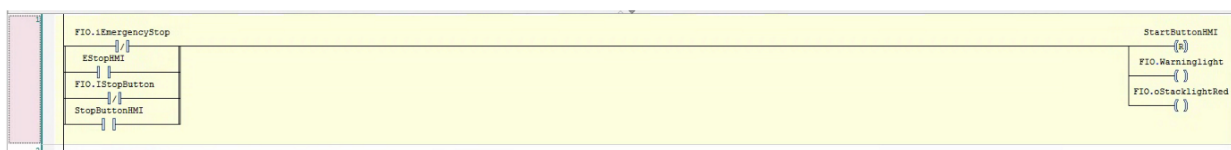


Figure 9-Codesys- Emergency stop system (Purnell-Whitehead, 2025)

6.3 Sorting logic

The sorting logic needed to sort boxes of different sizes and weights. Split into four box categories, Large, small, medium heavy and medium light.

Each box would trigger the diffuse sensor which are set at the desired height to differentiate the boxes as they pass. Once the sensor beam is broken, this would trigger pusher to guide the package onto the correct conveyor. See Figure 10.



Figure 10-Codesys sorting logic (Purnell-Whitehead, 2025)

After the being pushed on to the correct conveyor according to size. The box progresses and stops to be weighed. The logic applied here is if equal to 440g or less it is determined that the box is light and is guide to the lightweight path. Boxes measured 460g or over are moved onto the heavy box conveyor.



Figure 11-Codesys sorting logic (Purnell-Whitehead, 2025)

6.4 Counter logic

After being sorted into each category. Each box passes through a diffuse sensor triggering a count and displays on the HMI, see figure 12. An additional counter for total boxes has been added. See figure 11 for sorting logic.

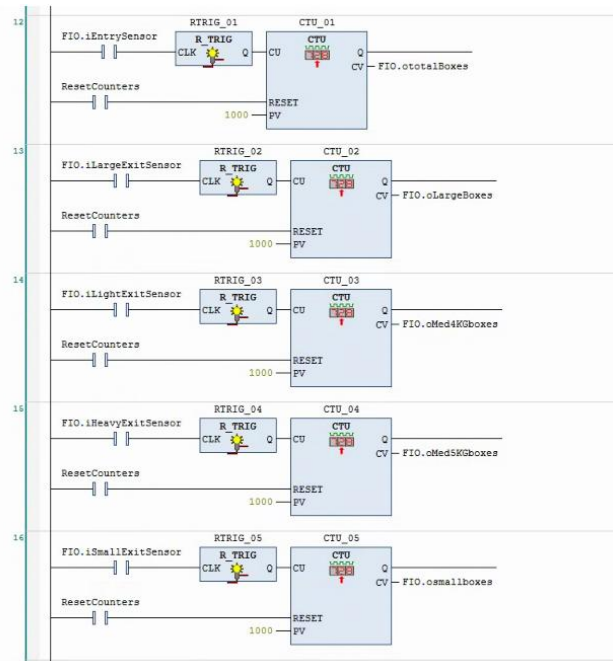


Figure 12-Codesys-Counter logic (Purnell-Whitehead, 2025)

The counts are displayed as numerically and as a progress bar. A visual aid to track production targets, see figure 3.

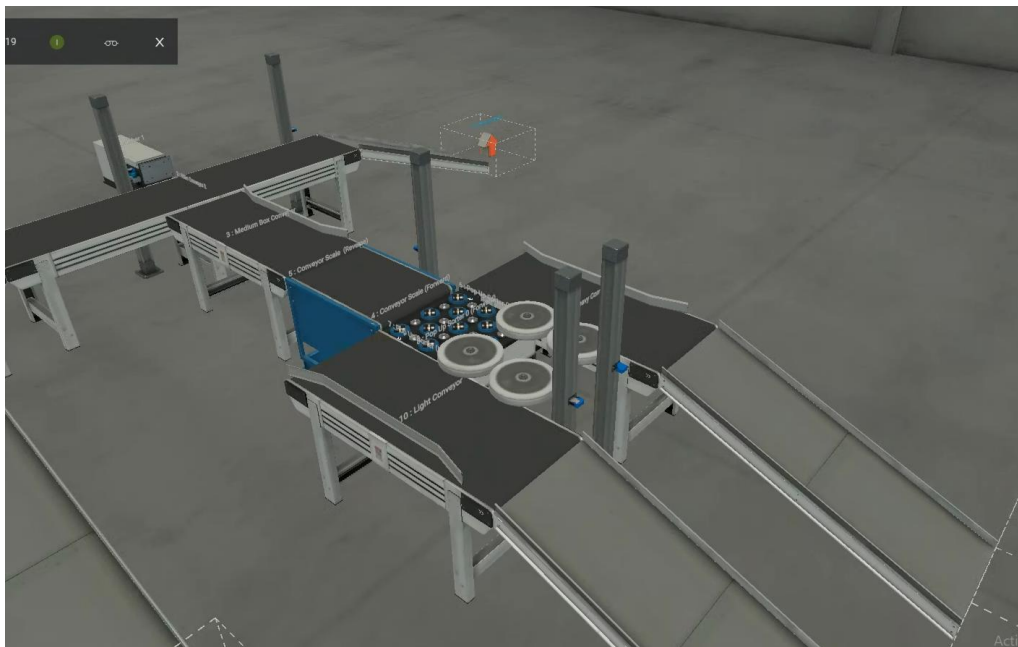


Figure 13-Factory IO- conveyor scale (Purnell-Whitehead, 2025)

6.5 HMI integration

The HMI was programmed to display:

- Start, Stop, Reset and Emergency Stop controls.
- Real time counter, Total box counter and progress bar display
- Traffic light style stack light indicators of system status.
- Andon board displaying emergency stop instances
- A display of real time conveyor weighing scale.

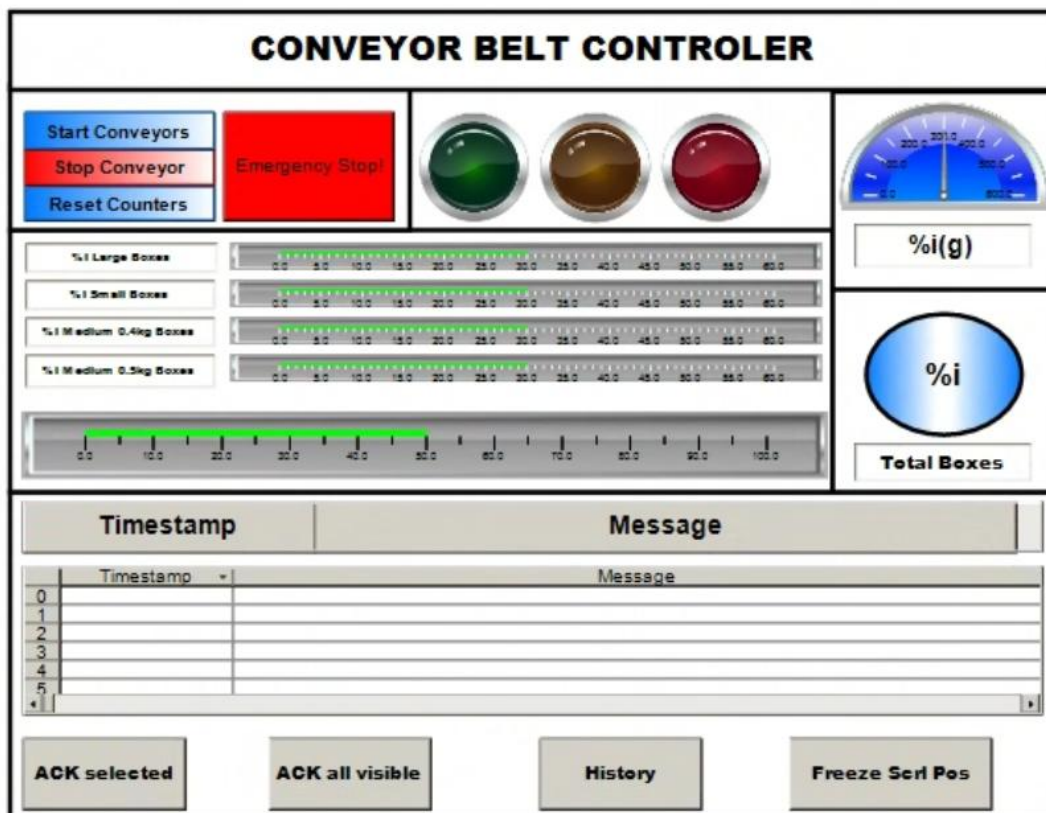


Figure 14-Codesys- HMI display (Purnell-Whitehead, 2025)

HMI a widely used throughout production at the Aston Martin production facility in St Athan.

Example used is shown in figure 15. After seeing real the real-world application, one improvement to the logic of the box sorting conveyor is the introduction of a Takt time.



Figure 15-HMI at Aston Martin Lagondas production facility (Purnell-Whitehead, 2025)

7 Observation and Verification.

The PLC programme was tested within the Factory I/O environment to verify that the defined requirements were met. With the focus on four key areas. The start-up sequence, sorting, safety interlocks and HMI integration.

7.1 Start-up sequence

During the testing, the start-up sequence was confirmed to operate as intended. With the start button press a 2 second delay with the siren sound and yellow stack light illuminated before the conveyor start-up. A further 500ms section delay before each conveyor start-up to prevent current draw.

7.2 Sorting

The sorting logic was validated by monitoring the system while various boxes were processed. Each package being correctly sorted onto the correct conveyor according to the detected size and weight. The pushers would activate briefly and returned to the resting position ensuring only the intended package is diverted. No actuator overlaps or misclassification was observed indicating the correct logic and reliable function.

7.3 Safety system

The safety system was also tested extensively. Pressing the stop button halted all conveyors and actuators, allowing operations to resume when re-started.

Pressing the emergency stop button would immediately de-energise all outputs, with the red stack light and beacon illuminating and a warning message displayed on the HMI. The system could not be restarted until the Emergency Stop was reset, demonstrating compliance with industrial such as ISO 13849-1:2023

It was observed when the emergency stop button is pressed. The simulation environment adds another package. This is not due to the PLC programming as the programming is not responsible for the loading of the package to the simulation. During testing this caused package loading out of sync causing a package jam at the first diverting pusher.

7.4 HMI interface.

The HMI interface provides a clear and responsive operator interaction. Counters incremented in real time as packages were sorted, With the four diffuse sensors counting each box completing processes and an overall total count of boxes. Each counter also displaying a progress bar.

The weighing conveyor has a scale and digital display for each package displaying ahead of re-direction.

It was confirmed the reset button clears all counters to zero and progress bars displayed allowing new operational cycles to be counted.

Stack lights, siren and beacon all synchronised with system states (Green for running, amber for idle and red for emergency) ensuring both local and remote indicators of status is available.

Overall, verification confirmed that the PLC programme achieved the intended functionality. The system responded predictably to inputs, handled normal and fault conditions correctly, and provided accurate operator feedback. These observations suggest that the programme not only met the control requirements but also operated with robustness and reliability under simulated conditions.

8 Analysis and evaluation

The developed PLC control programme demonstrated robust and modular design, ensuring reliable operation of the automated sorting system. Each segment of the control logic startup, emergency handling, classification, and counter management was compartmentalized, improving maintainability and fault isolation. As emphasized by (Petruszella, 2011), modular ladder logic structures are essential for scalable industrial control systems.

One of the system's major strengths was its reliable emergency stop functionality, which immediately halted all actuators and provided visual and HMI-based alerts. This aligns with best practices in safety-critical environments, where operator protection and machinery safety are paramount (Romero, et al., 2018). Similarly, the sequenced conveyor startup initiated by a 2-second siren and staggered by 0.5 second intervals.

The package classification logic, driven by size and weight sensors, accurately sorted items via pneumatic pushers and a pop-up sorter. Fluid power actuation, particularly pneumatics, proved effective for high-speed sorting, consistent with the performance characteristics outlined by (Esposito, 2014). However, fixed classification thresholds limited flexibility, changing product parameters would require programme modification, which is inefficient in dynamic manufacturing settings. One recommendation is integrating operator adjustable thresholds via HMI for improved adaptability. One example that could benefit from adjustable thresholds in the logic in the box sorting system is the weighing process. The logic set is at risk. The logic accounts for packages weighing 440g or less and 460g and above. The logic programmed does not account for this range of weight, figure 16.

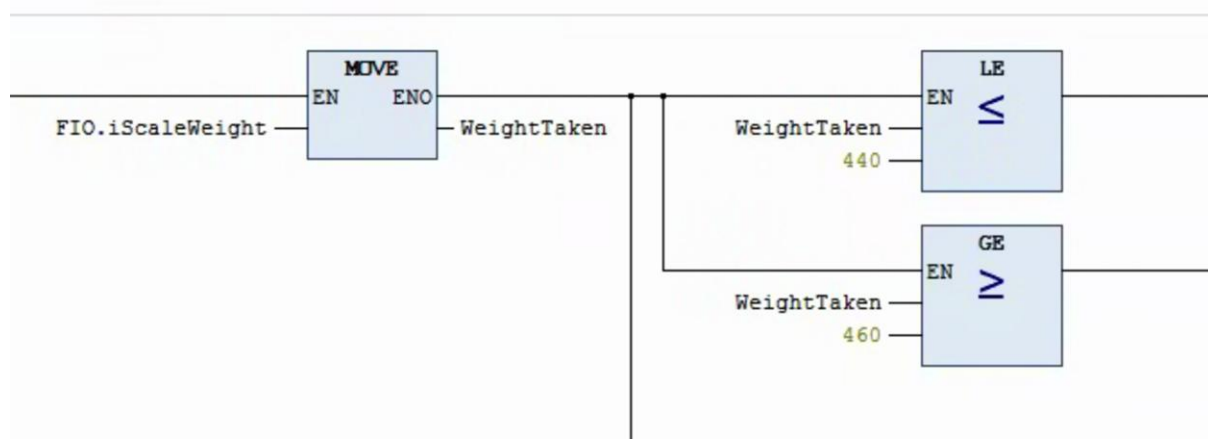


Figure 16-Codesys weight taken logic (Purnell-Whitehead, 2025)

Despite strong foundational logic, the system lacked diagnostic feedback and fault detection. For instance, no alerts were triggered for sensor disconnection or missed packages, limiting real-time fault awareness. (Hristov, 2025) suggest implementing feedback loops for increased system resilience. Furthermore, the use of fixed timers, instead of sensor-based feedback for startup validation, could result in synchronisation issues if a conveyor fails to start.

The HMI design was intuitive and responsive, but could be enhanced by adding error codes, system health indicators, and operator accessible configuration tools.

The control logic effectively met the operational requirements of the simulated system. It combined real-time performance and safety logic. However, enhancing flexibility, error detection, and adaptive controls would elevate the system to meet Industry 4.0 standards of intelligence and resilience.

9 Suggested improvements

9.1 Integrate sensor-based feedback for conveyor readiness

Current logic uses fixed delays between conveyor start-ups. A more robust report would be to use a sensor feedback or motor status monitoring to confirm readiness before proceeding on to the next conveyor. This would prevent synchronisation issues should a motor fail (Fedorko, 2019).

9.2 Predictive maintenance

Predictive Maintenance, enabled by Industry 4.0 technologies like IoT and cloud systems, helps reduce breakdowns, cut costs, and improve reliability giving manufacturers a competitive edge. It is especially valuable in industries with costly, sensitive, or high-risk equipment such as aviation, oil and gas, and mining. Future focus should be on organizational adoption, workforce impact, and improving diagnostic and prognostic tools (Sahli, et al., 2021) .

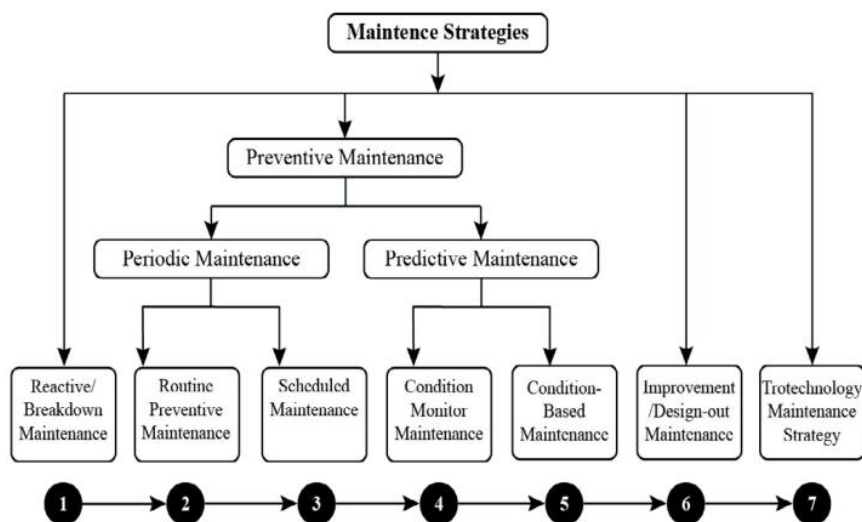


Figure 17-Maintenance strategies showing ascending order of technology (Sahli, et al., 2021)

9.3 Modern technology

9.3.1 ASRS (Automated Storage and Retrieval Systems)

ASRS can handle the full picking process by delivering products in sequence to Goods-to-Person stations. Though it requires higher throughput capacity and capital investment, it helps reduce double handling (Box Logic, 2025)



Figure 18-ASRS (Box Logic, 2025)

9.3.2 Robotic picking

Robotic picking systems use vision and intelligent programming to perform repetitive tasks accurately, reducing manpower, errors, and costs while boosting productivity and customer satisfaction across various industries (Bricspac-Customised conveying automation, 2025).



Figure 19-Robotic picker (Bricspac-Customised conveying automation, 2025)

10 Conclusion

The development and simulation of the PLC-controlled automated box sorting system successfully demonstrated the application of industrial automation principles using Factory I/O and Codesys. Through careful design and modular programming, the system fulfilled all operational requirements including accurate sorting by weight and size, real-time HMI feedback, and critical safety functionality. Verification and testing confirmed the system's reliability under normal and emergency conditions, with intuitive operator interfaces and responsive control logic. The project highlights the effectiveness of electrical actuation in automated material handling, supported by programmable logic for dynamic control.

Despite its strengths, the system presents opportunities for enhancement, particularly in fault detection, adaptive classification logic, and integration of feedback-based sequencing. Introducing predictive maintenance strategies and Industry 4.0 innovations like robotic picking and ASRS would further elevate the system's intelligence, resilience, and operational efficiency. Overall, this project serves as a robust foundation for understanding real-world industrial automation and offers practical insights into the design of scalable, safe, and efficient control systems for modern manufacturing environments.

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