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L5 – Applied Programmable Logic Controllers (ACDA6000)

Factory Control

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Electrical and Electronic Engineering

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Introduction

This report outlines the design, implementation, and control of a factory system capable of sorting packages by size and weight. The factory, developed using Factory I/O, incorporates essential features such as conveyor belts, pushers, sensors, and an HMI for efficient operation and interaction. It includes an alarm strategy, a detailed ladder logic program, and a professional report on the completed tasks.

Background Research

Programmable Logic Controllers (PLCs) in Industry PLCs are widely used in industrial automation to control processes and machinery. Below is a review of several popular PLC brands:

PLC Brand	Pros	Cons
Siemens (S7-1200)	High reliability, integrated HMI support, and robust programming tools.	Expensive, steep learning curve for beginners.
Allen-Bradley	Widely used in North America, excellent support, and versatile hardware. [2]	Expensive licensing, limited community support outside the U.S.
Mitsubishi	Compact design, cost-effective, and easy integration with robotics.[3]	Less popular globally, limited advanced features.
Schneider Electric	Energy-efficient, modular design, and user-friendly programming. [4]	May lack scalability for larger projects.
Omron	Affordable, compact, and suitable for small-scale automation. [5]	Limited advanced features compared to Siemens or Allen-Bradley.

Regions of Use:

- Siemens (S7-1200)

Popular globally, especially in Europe, Asia, and regions focusing on Industry 4.0 due to its advanced connectivity and communication protocols.

- Allen-Bradley

Predominantly used in North America due to Rockwell Automation's strong presence there.

- Mitsubishi

Highly popular in Asia, especially in Japan and Southeast Asia, due to Mitsubishi's regional dominance.

- **Schneider Electric**

Common in Europe and regions focused on energy-efficient solutions.

- **Omron**

Widely used in Asia, particularly Japan, due to Omron's local expertise and market penetration.

Most Common Applications

- **Siemens (S7-1200)**

- Packaging lines in manufacturing.
- Building automation systems (e.g., HVAC controls).
- Water treatment plants.
- IoT-enabled factories for data acquisition and monitoring.

- **Allen-Bradley**

- Automotive manufacturing lines.
- Food and beverage production facilities.
- Oil and gas industries (e.g., pipeline controls).

- **Mitsubishi**

- Small-scale production lines.
- Basic machine automation (e.g., CNC machines).
- Simple packaging systems.

- **Schneider Electric**

- Smart building controls (lighting, HVAC).
- Energy monitoring and optimization systems.
- Simple conveyor and motor control systems.

- **Omron**

- Assembly lines for electronics manufacturing.
- Simple robotic applications (pick-and-place systems).
- Home automation for energy efficiency.

Why Choose Siemens S7-1200 Over Other PLCs?

Reliable Performance: Ideal for small to medium automation tasks, offering industrial-grade reliability for manufacturing, utilities, and building automation.

Scalability: Handles a range of applications and integrates seamlessly with other Siemens products like the S7-1500 for future expansion.

Integrated Engineering: Simplifies programming and diagnostics through TIA Portal, enabling unified control of PLCs, HMIs, drives, and networks.

Advanced Features: Includes Profinet communication, built-in PID control, high-speed counters, and modular I/O expandability.

Cost-Effective: Balances affordability with essential features, making it suitable for budget-conscious projects.

Safety and Security: Supports fail-safe applications and advanced cybersecurity measures to protect against unauthorized access.

Industry 4.0 Ready: Offers IoT integration, cloud connectivity, and real-time data monitoring via modern protocols like OPC UA.

Global Support: Backed by extensive documentation and worldwide Siemens support.

Proven Reputation: Siemens is a trusted leader in industrial automation, known for quality and reliability. [1]

When the S7-1200 May Not Be Ideal:

High-End Applications: Use the S7-1500 for complex motion control or high processing power needs.

Budget Constraints: Opt for simpler options like Mitsubishi FX or Allen-Bradley MicroLogix for basic tasks.

Regional Preferences: In regions like North America, Allen-Bradley may provide better local support and parts availability.

Factory Design

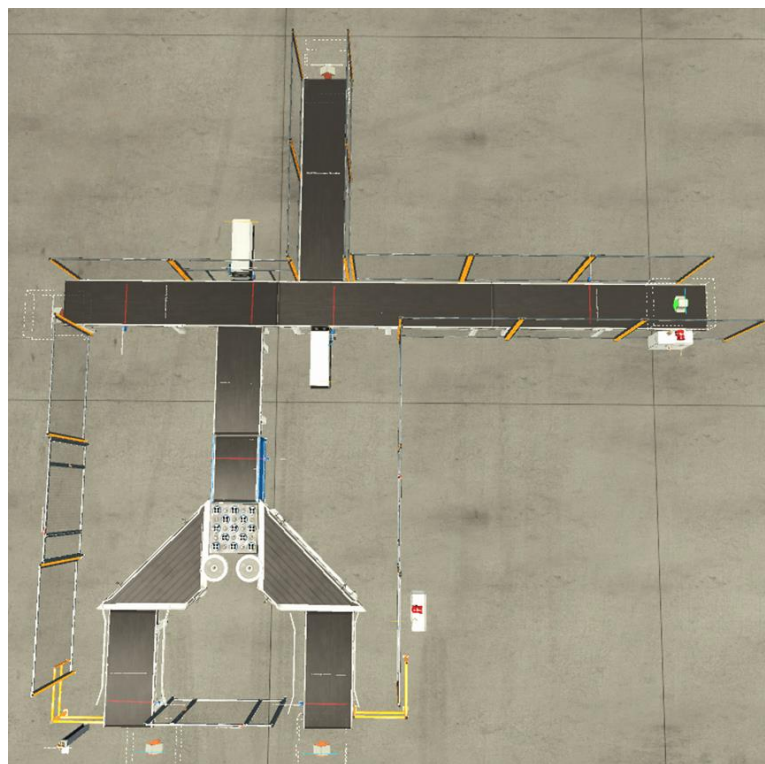


Figure 1 - Factory IO Top View

Figure 1 above gives a view of the Factory IO layout. There are many components required to ensure the factory operates to meet the specification. Here's an overview of the equipment used on the factory floor:

Equipment	Number Used	Use
Belt Conveyor (2m)	3	Transport the boxes
Belt Conveyor (4m)	4	Transport the boxes
Conveyor Scale	1	Weigh and move the boxes
Pop Up Wheel Sorter	1	Direct the boxes to different conveyors
Pushers	2	Push the boxes onto different conveyors
Alarm Siren	2	Alarm the operators
Stack Lights	2	Visual representation of operating, warning and alarm
Warning Light	1	Warn the operators
Control Panels	2	House the PLC, HMI, buttons etc.
Diffuse Sensors	6	PLC input to recognise boxes
Emergency Stops	2	Shut off process in emergency
Safety Doors	3	Shut off process for maintenance

Sorting Process

Once the boxes are loaded onto the conveyor, they will pass a series of diffuse sensors. The diffuse sensors are set at various heights to decide which conveyor they go down:

- High diffuse sensor – Large box conveyor
- Medium diffuse sensor – Medium box conveyor
- Low diffuse sensor – Small box conveyor

To begin the process the 'Start' button can be pressed either on the control panel, or on the HMI (as long as no alarms are present):

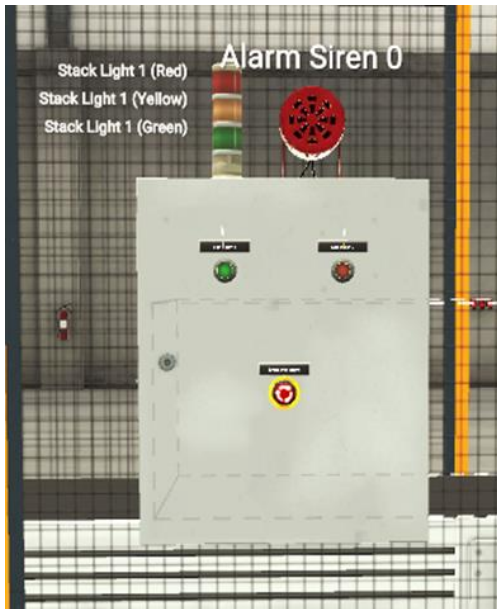


Figure 2 - Control Panel

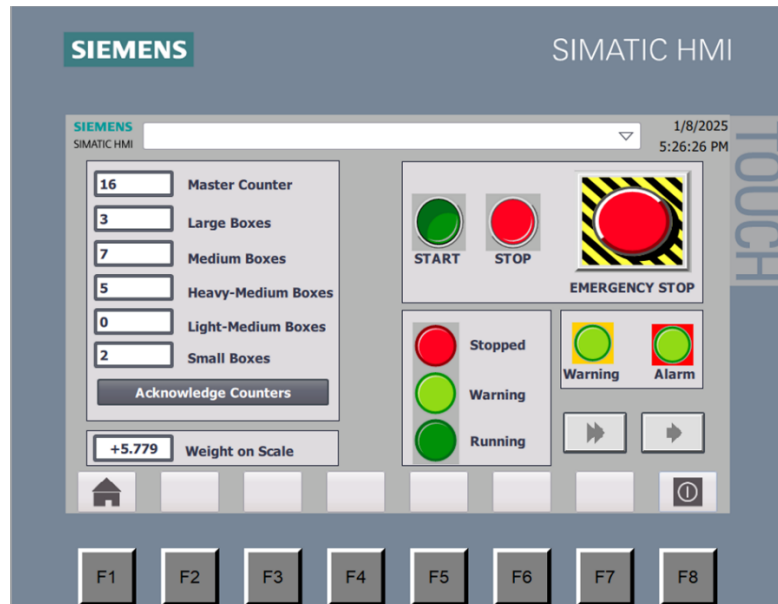


Figure 3 - HMI Screen

When the operation begins, the alarm siren will sound momentarily, and a green stack light will be visible along with a warning light to ensure anyone in the vicinity are aware of the operation.



Figure 4 - Warning Light

If the large or medium diffuse sensors are activated, these will activate the large or medium pushers, which shifts the boxes onto the corresponding perpendicular conveyor. The pushers in turn activate a counter with every push they complete. Figure 5 below shows their layout:

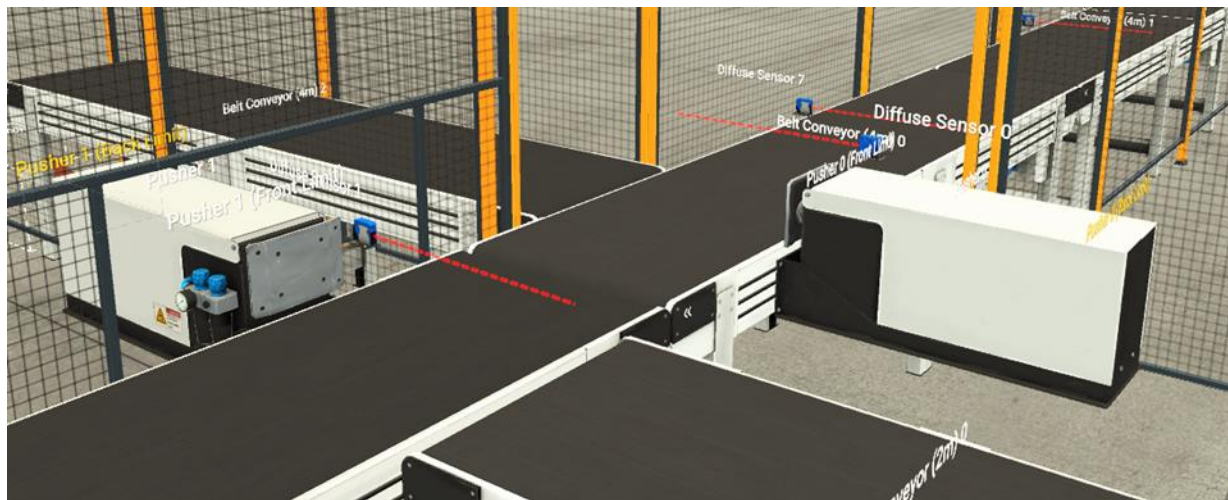


Figure 5 - Large/Medium Pushers and Diffusers

If the large or medium diffuse sensors are **not** activated, the boxes will continue straight down the conveyor, and pass the small box diffuser. In this case, the diffuser is used to count the small boxes.

Following down from the medium box pusher there is a weigh scale and a pop-up sorter. The weight threshold is determined from the HMI, where a user can input as required. Any boxes weighing below the threshold will go down the left-hand conveyor, whilst any boxes over the threshold will go down the right-hand side.

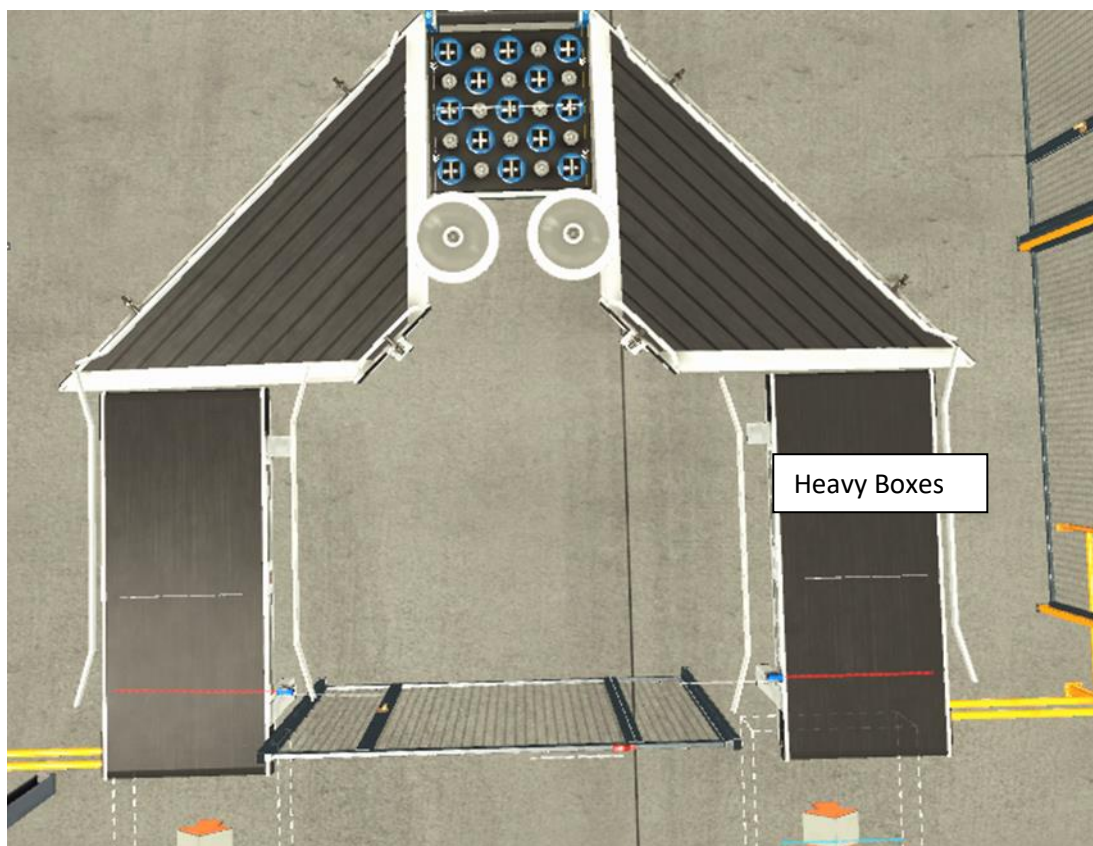


Figure 6 - Medium Box Sorter



During the weighing phase of the medium box sorter, the weight is displayed upon the LCD display on the electrical panel outside of the guarding

Safety Process

Safety is paramount when using a conveyor system like this. Conveyor systems are integral to various industries in the UK, but they also pose significant safety risks if not properly managed. Notable incidents include:

Food Manufacturing Sector:

Stateside Foods: Two workers suffered severe hand injuries due to inadequately guarded conveyor belts, leading to an £800,000 fine for the company.

Pork Farms: Similarly, this company was fined £800,000 after workers lost fingers in conveyor belt accidents at its Nottingham bakeries. [6]

Recycling Industry:

The Health and Safety Executive (HSE) reports that machinery safety is the most common cause of fatal accidents at recycling plants, with conveyor systems being a significant contributor. [7]

Recent Incident:

In August 2023, a company was fined £400,000 after a worker's hand was drawn into a gap between two conveyor belts while attempting to clean a sensor, resulting in major injuries. [8]

These incidents underscore the critical importance of implementing and maintaining stringent safety measures for conveyor systems in the UK to protect workers from potential hazards.

Within the factory there are multiple emergency stop push buttons:



Figure 7 - Panel E-Stop



Figure 8 - Field E-Stop



Figure 9 - HMI E-Stop

The emergency stops displayed in Figure 7 & 8 are hard wired emergency stops which are commonly found in the field. The emergency stop shown in Figure 9 is on the HMI, this uses a memory in the PLC rather than being hardwired. All three emergency stops are used in conjunction with one another, if one is operated the alarm is raised and the plant is shut down until it is cleared.

Communication between Factory IO and Siemens TIA

Start Button 1	%I16.0	%Q16.0	Belt Conveyor (4m) 0
Stop Button 0	%I16.1	%Q16.1	Belt Conveyor (4m) 1
Emergency Stop 0	%I16.2	%Q16.2	Belt Conveyor (4m) 2
Emergency Stop 1	%I16.3	%Q16.3	Belt Conveyor (4m) 3
	%I16.4	%Q16.4	Belt Conveyor (2m) 0
	%I16.5	%Q16.5	Belt Conveyor (2m) 1
	%I16.6	%Q16.6	Belt Conveyor (2m) 2
	%I16.7	%Q16.7	Alarm Siren 1
Diffuse Sensor 0	%I17.0	%Q17.0	Alarm Siren 0
Diffuse Sensor 1	%I17.1	%Q17.1	Pusher 0
Diffuse Sensor 2	%I17.2	%Q17.2	Pusher 1
Diffuse Sensor 3	%I17.3	%Q17.3	Stack Light 1 (Red)
Diffuse Sensor 4	%I17.4	%Q17.4	Conveyor Scale 0 (+)
Diffuse Sensor 5	%I17.5	%Q17.5	Pop Up Wheel Sorter 0 (+)
Diffuse Sensor 6	%I17.6	%Q17.6	Pop Up Wheel Sorter 0 (Left)
	%I17.7	%Q17.7	Pop Up Wheel Sorter 0 (Right)
	%I18.0	%Q18.0	Straight Spur Conveyor 0 (-)
Pusher 0 (Back Limit)	%I18.1	%Q18.1	Straight Spur Conveyor 1 (+)
Pusher 1 (Back Limit)	%I18.2	%Q18.2	Warning Light 0
Pusher 0 (Front Limit)	%I18.3	%Q18.3	Stack Light 0 (Green)
Pusher 1 (Front Limit)	%I18.4	%Q18.4	Stack Light 0 (Yellow)
Safety Door 0	%I18.5	%Q18.5	Stack Light 0 (Red)
Safety Door 1	%I18.6	%Q18.6	Stack Light 1 (Green)
Safety Door 2	%I18.7	%Q18.7	Stack Light 1 (Yellow)
Conveyor Scale 0 Weight (V)	%ID30 (REAL)	(REAL) %QD30	Digital Display 0
	%ID34	%QD34	
	%ID38	%QD38	
	%ID42	%QD42	
	%ID46	%QD46	
	%ID50	%QD50	
	%ID54	%QD54	
	%ID58	%QD58	

Figure 10 - Factory IO Drivers

To ensure seamless communication between Factory IO and TIA Portal, it's imperative that the correct PLC was chosen on the drivers page to match TIA, including the same amount of inputs and outputs. When the TIA portal is simulating, this talks to Factory IO over modbus.

Also on the Factory IO drivers page, it's essential to map the inputs, outputs and signals identical to the address in TIA portal.

Operational Flowchart

Figure 10 below gives a brief idea into how the conveyor system needs to run, emphasizing the fact that if any alarms are present, the system will not operate.

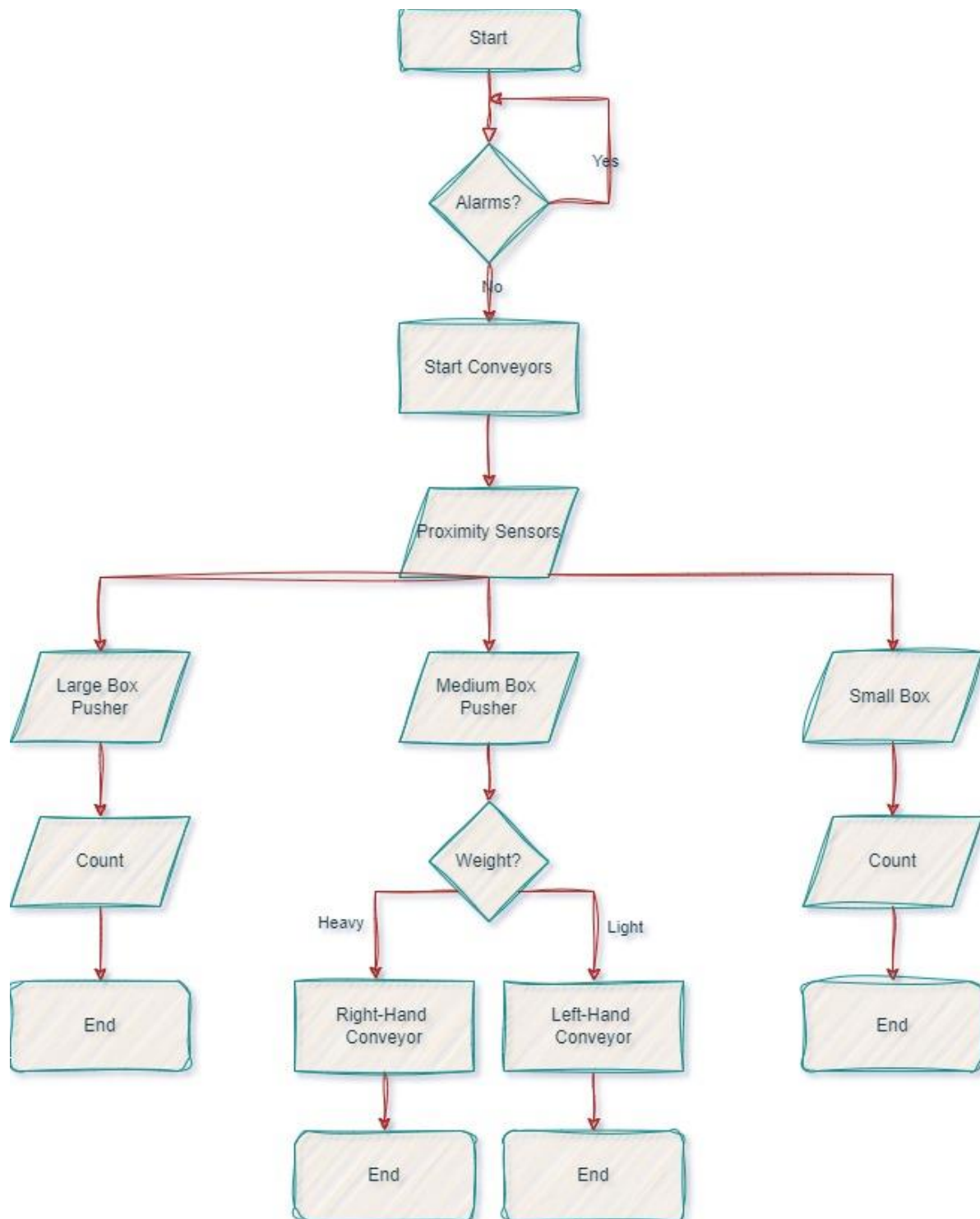


Figure 11 - Flowchart

Ladder Logic Program

Project 1 Latest / PLC_1 [CPU 1214C DC/DC/DC] / Program blocks

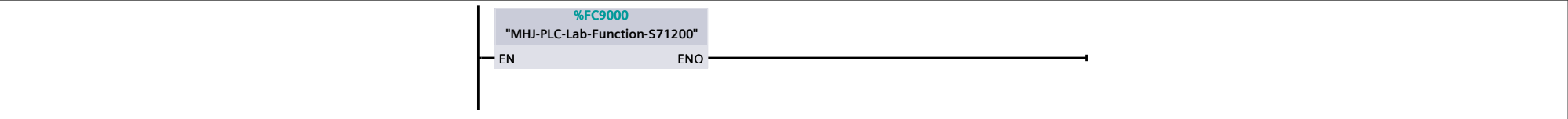
Main [OB1]

Main Properties							
General							
Name	Main	Number	1	Type	OB	Language	LAD
Numbering	Automatic						
Information							
Title	"Main Program Sweep (Cycle)"	Author		Comment		Family	
Version	0.1	User-defined ID					

Main			
Name	Data type	Default value	Comment
▼ Input			
Initial_Call	Bool		Initial call of this OB
Remanence	Bool		=True, if remanent data are available
Temp			
Constant			

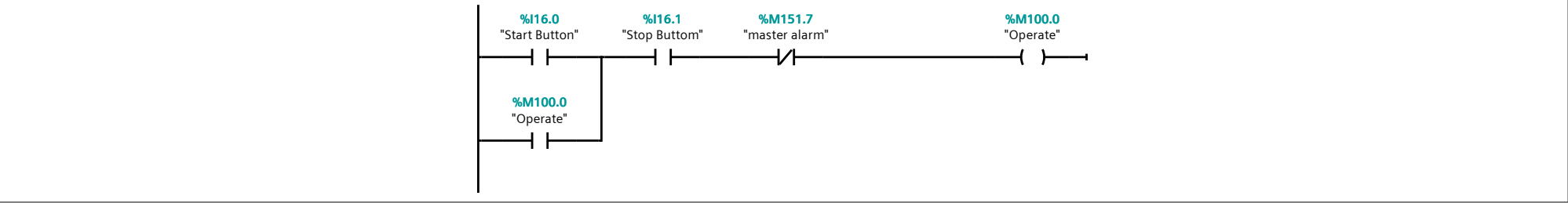
Network 1: MHJ-PLC Lab Function

This is the primary function for the PLC logic execution.



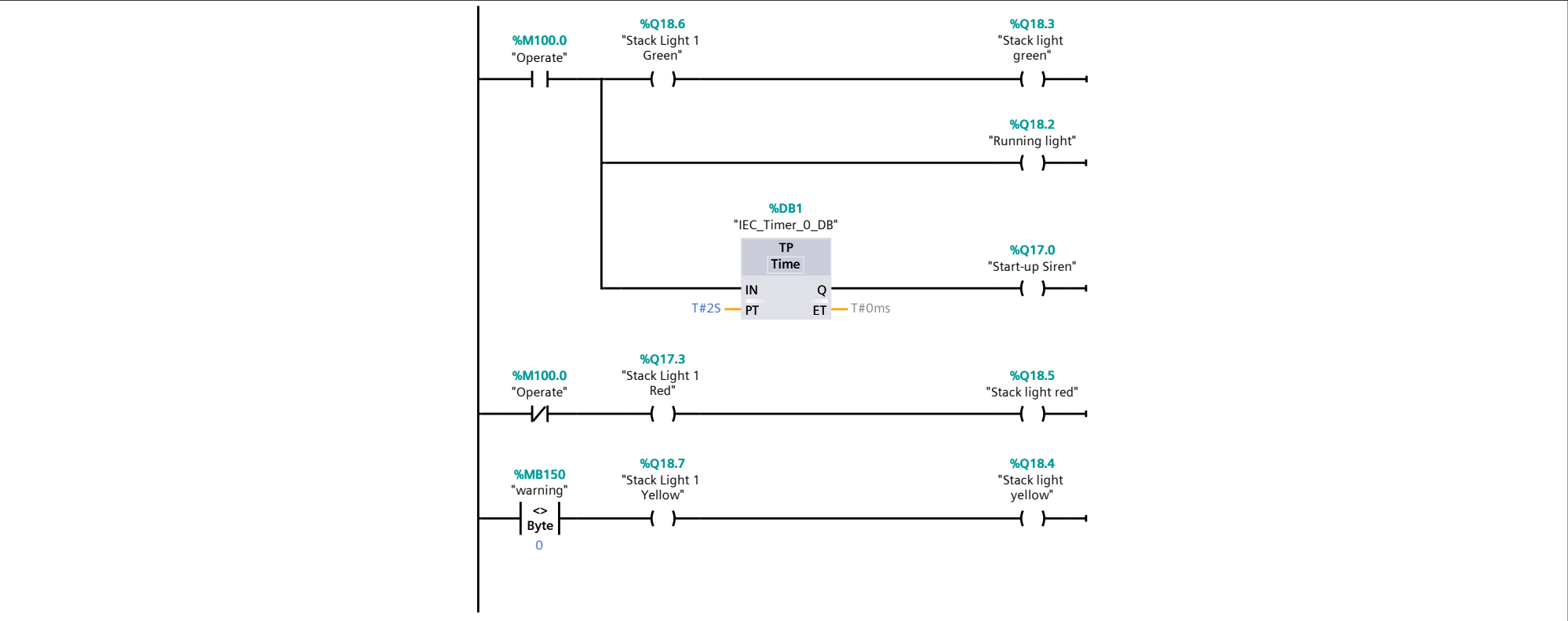
Network 2: Stop/Start Circuit

- When the Start button is pressed, this is momentary, but will latch the Operate, maintaining system operation until it's explicitly stopped.
- When the Stop button is pressed this will actually open the circuit and stop operation as the contact is NC on Factory IO.
- If the Master Alarm is set, thsi will stop the Operate state being activated.
- Operate bit represents the operational status of the system. When no alarms are present, and the Stop button is NOT pressed, this ill be set to True when the Start button is pressed. It will be reset to False when the Stop button is pressed of a alarm is detected.



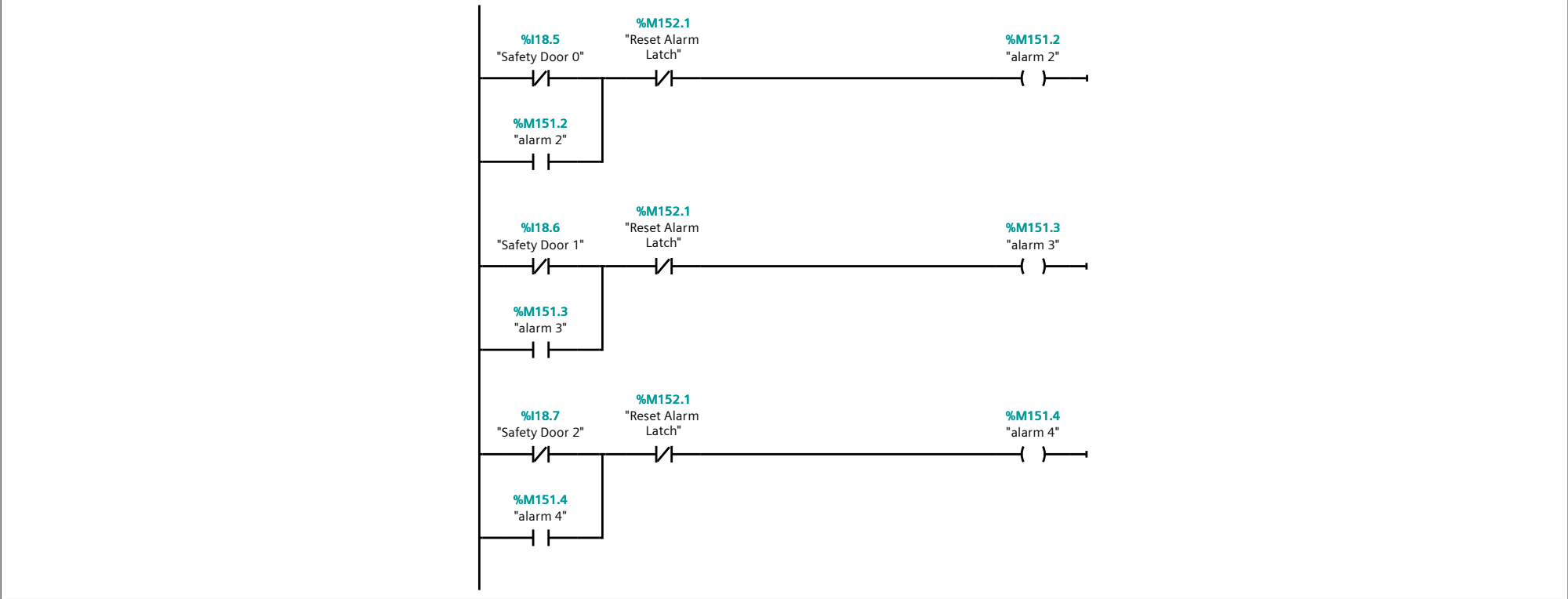
Network 3: Warning & Stack Lights / Sirens

- When the system is operating, the green stack light and running light comes on to show normal operation along side a Start-up siren which lasts for 2 seconds.
- When the system is not operating, a red stack light will be visible.
- If any of the warnings are detected, they are stored in MB150 and the yellow stack light is activated to alert the operator of a warning condition.



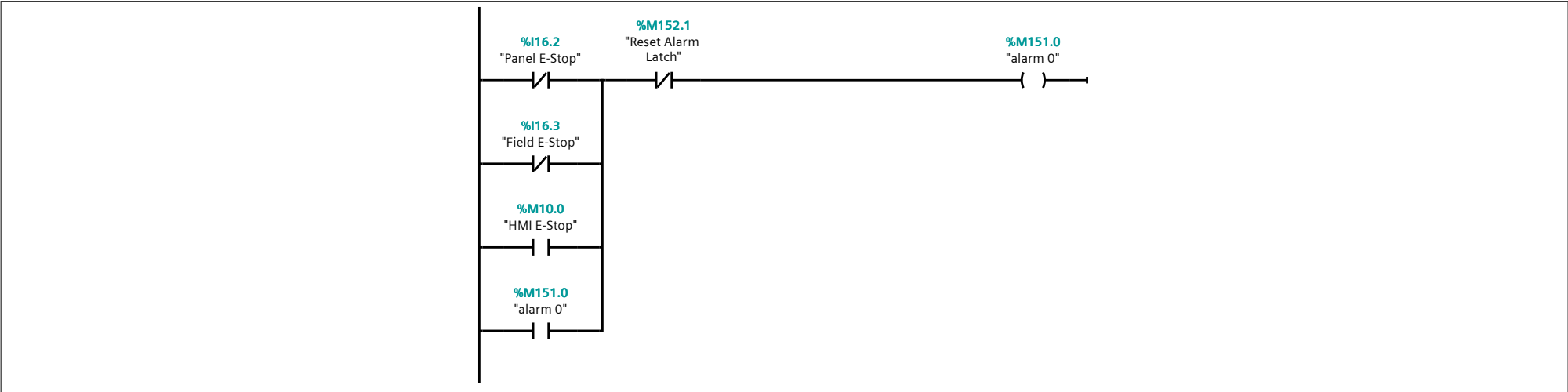
Network 4: Safety Door Alarms

- If any Safety Door input is triggered in the field, the corresponding alarm flag is activated. Alarm2 will display Safety Door 0 Open, Alarm 3 will display Safety Door 1 Open and Alarm 4 will display Safety Door 2 Open.
- The alarms are latched with the safety doors. If a safety door was shut after the alarm was set, the alarm light would clear, so a latch is used to ensure the alarm which set is shown.



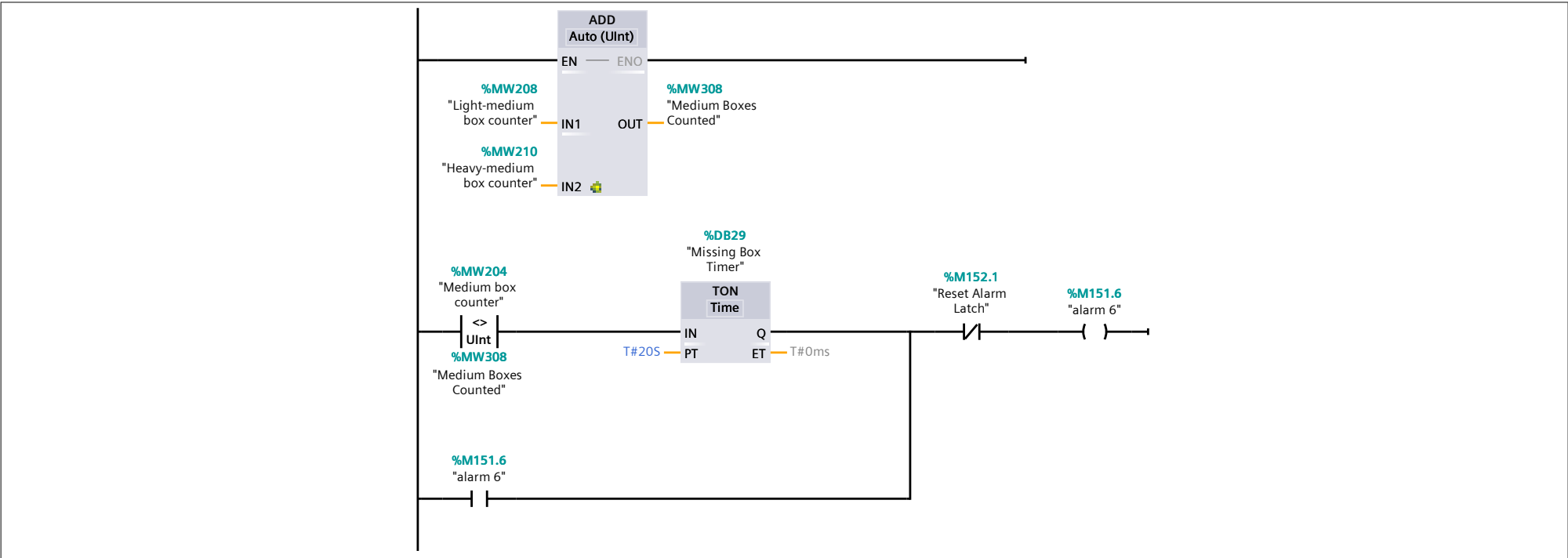
Network 5: Emergency Stops

- When the Panel E-Stop, Field E-Stop or HMI E-Stop is pressed, Alarm 0 is activated which displays 'Emergency Stop Operated' on the Error screen.
- The alarm is latched to ensure the alarm can be seen prior to it being removed.



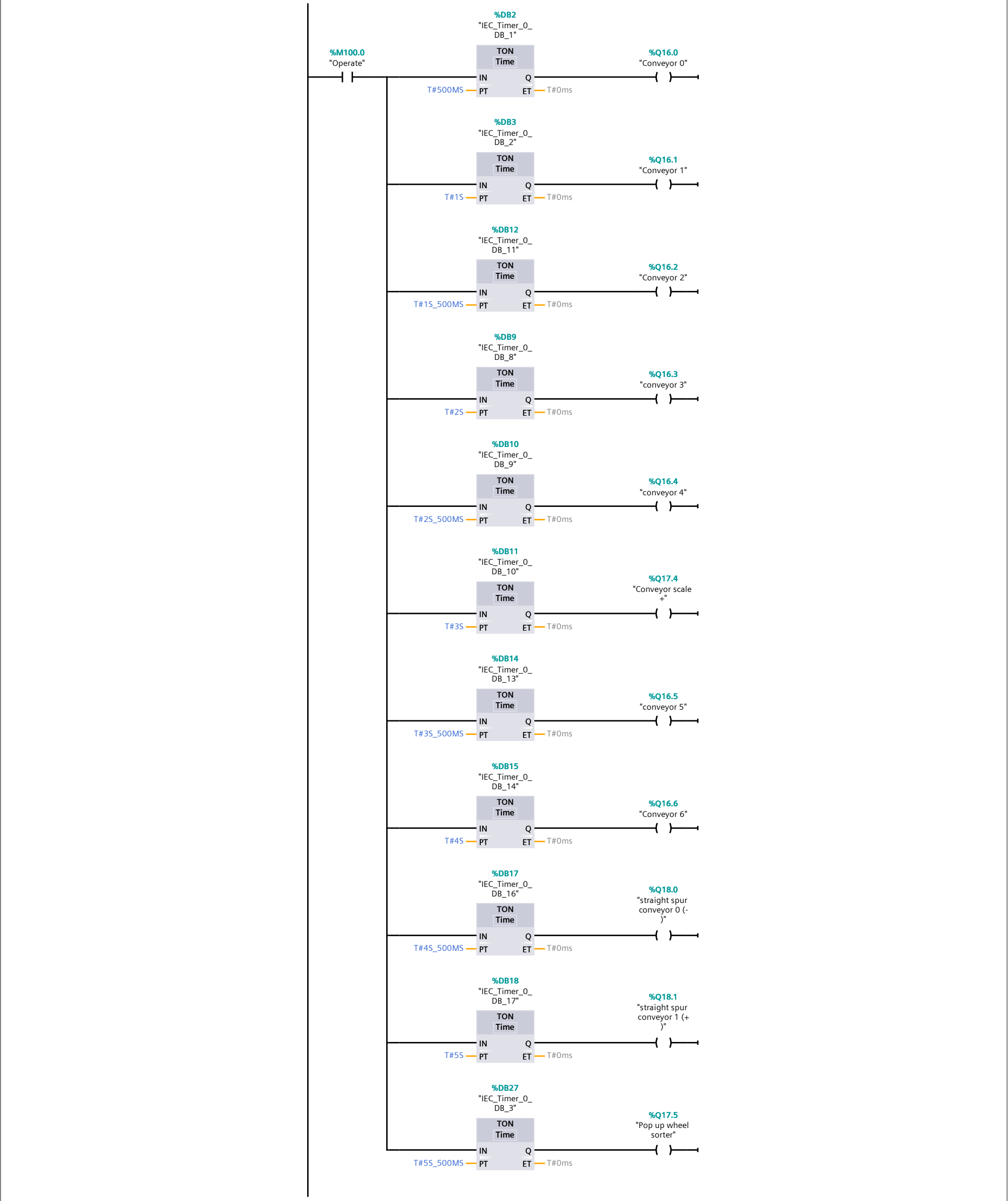
Network 6: Medium Box Loss

- Boxes can be lost at the medium box area due to space and lack of rails so a box loss alarm has been created.
- Memories from the Light-Medium and Heavy-Medium counters are added together using the ADD Math function to give a Medium Boxes Counted memory.
- Using a compareter, Medium Box Counter and Medium Boxes Counted must be equal, or after 20 seconds as a TON timer will bring on Alarm 6 - Lost Box Alarm on the rror Screen.
- The alarm is latched to ensure the alarm can be seen prior to it being removed.



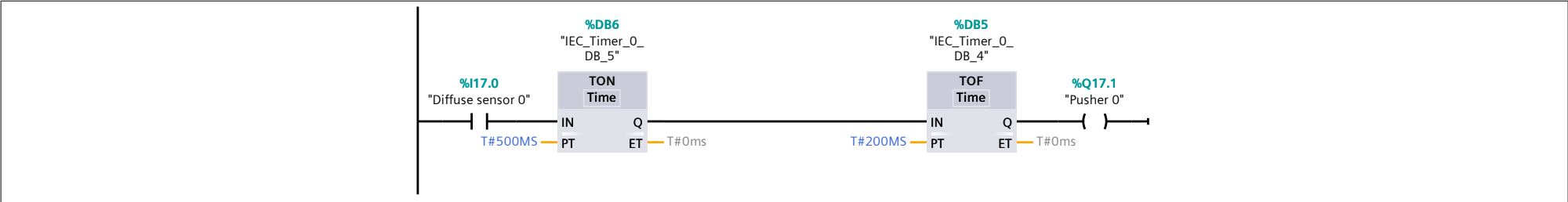
Network 7: Conveyor & Sorter Control

- When the system operates, each conveyor is started using respective TON timers for a smooth start-up, and to stop high in-rush currents.



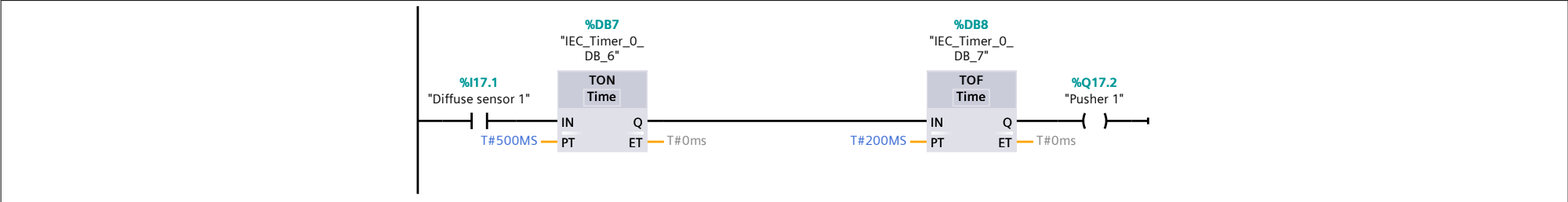
Network 8: Large Box Pusher

- When the diffuse sensor detects a large box (due to the height it's set at in the field), the Large Box Pusher is activated after 500ms to allow for the box to be positioned correctly on the conveyor.
- The TOF timer is used to return the pusher back to it's original position after 200ms. The timers together ensure the pusher moves the boxes at the correct time and position.



Network 9: Medium Box Pusher

- When the diffuse sensor sees the medium box (positioned slightly lower than the Large Box Pusher), the Medium Box Pusher is activated after 500ms to allow for the box to be positioned correctly on the conveyor.
- The TOF timer is used to return the pusher back to it's original position after 200ms. The timers together ensure the pusher moves the boxes at the correct time and position.



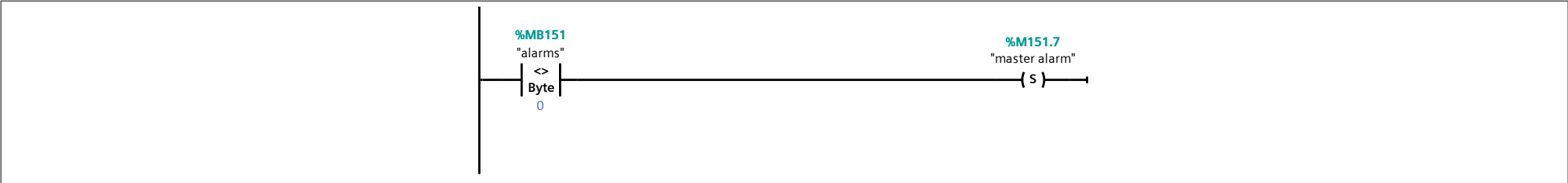
Network 10: Setting the Alarms

- When the alarms byte changes due to one of the alarms, it sets the master alarm output.

This behavior ensures that whenever any critical alarm condition is active, the master alarm is triggered, effectively halting the system to ensure safety and prompt operator intervention.

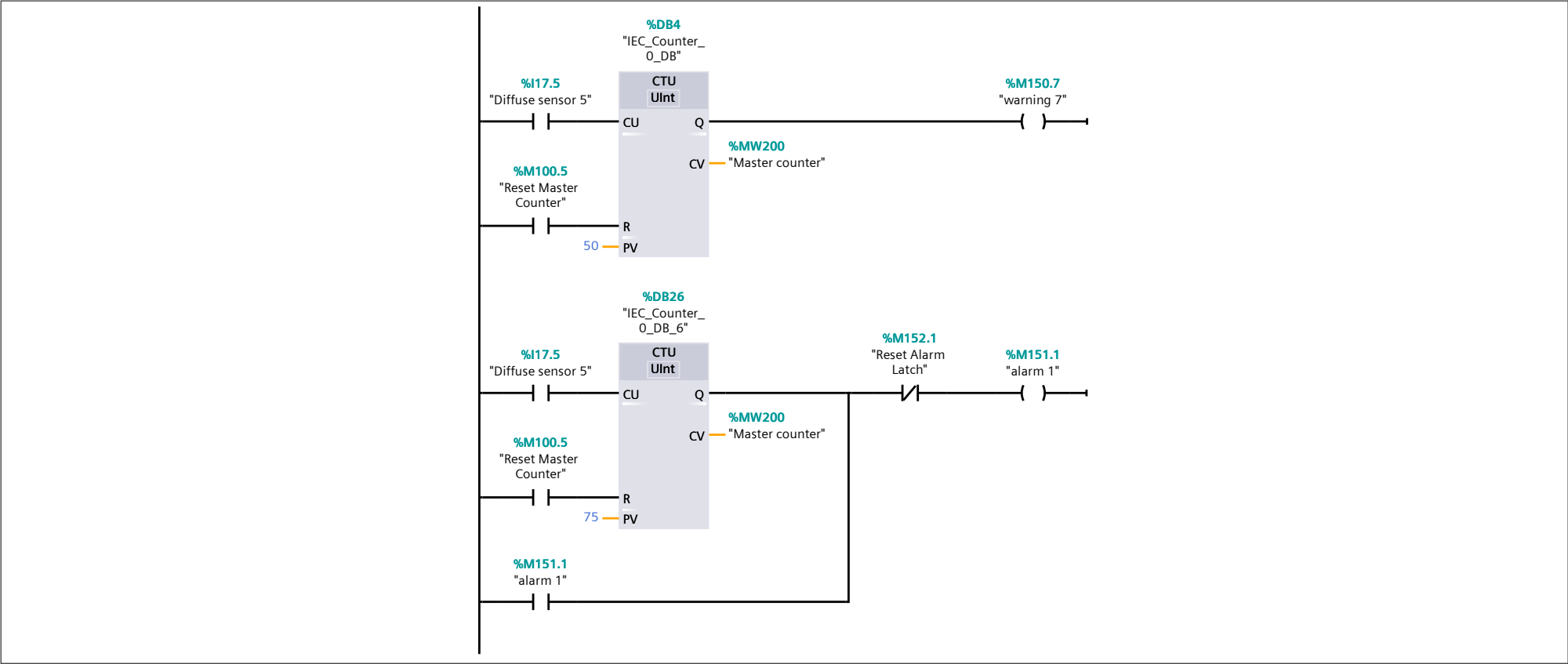
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If all alarm bits within the alarms byte are cleared, the master alarm can be reset using the Master Alarm Clear button on the HMI, allowing the system to resume normal operation.



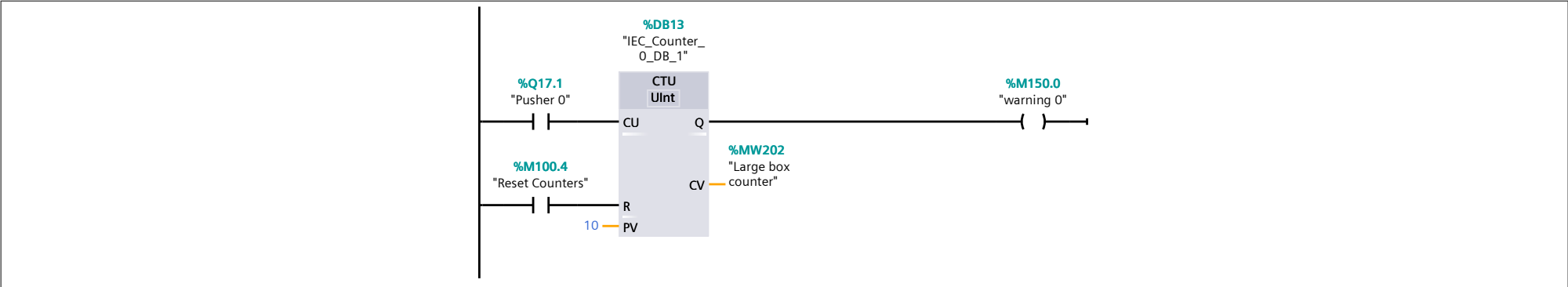
Network 11: Master Counter

- Diffuse sensor 5 counts every box that is sends down the first conveyor. This gives us the total amount of boxes being output. This is saved in the memory location Master Counter.
- Every 50 boxes completes a cycle, which would then bring up a order complete warning (warning 7).
- After the count of 75 boxes, if the counters haven't been reset, a order overload alarm will turn on and bring on the Order Overload Alarm 1 which will stop operation.
- The counters can be reset using the reset buttons on the Engineer Screen, this will remove the warnings/alarms as you need.
- The alarm is latched to ensure the alarm can be seen prior to it being removed.



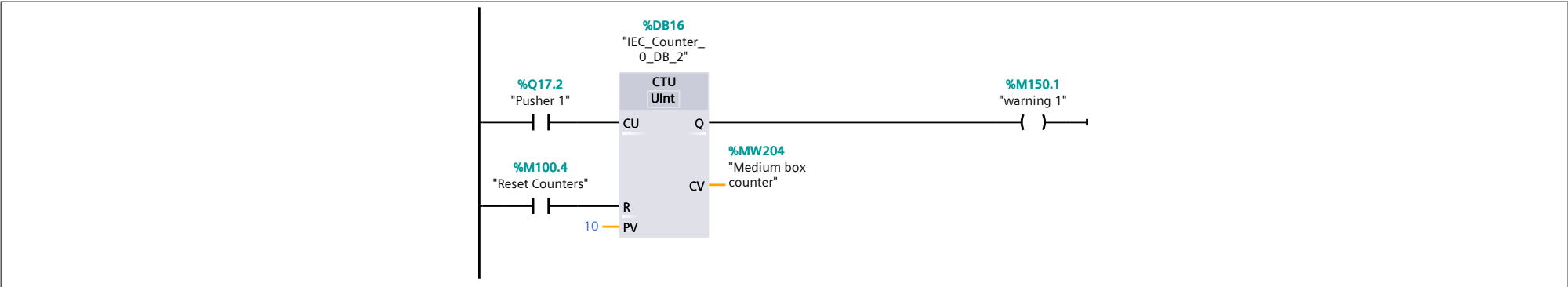
Network 12: Large Box Counter

- When Pusher 0 is operated, the counter increases and is saved in the memory location Large Box Counter which is displayed on the HMI.
- After the count of 10 boxes, the counter will outut Q to bring on a warning on the error screen for 'Large Boxes Warning'.



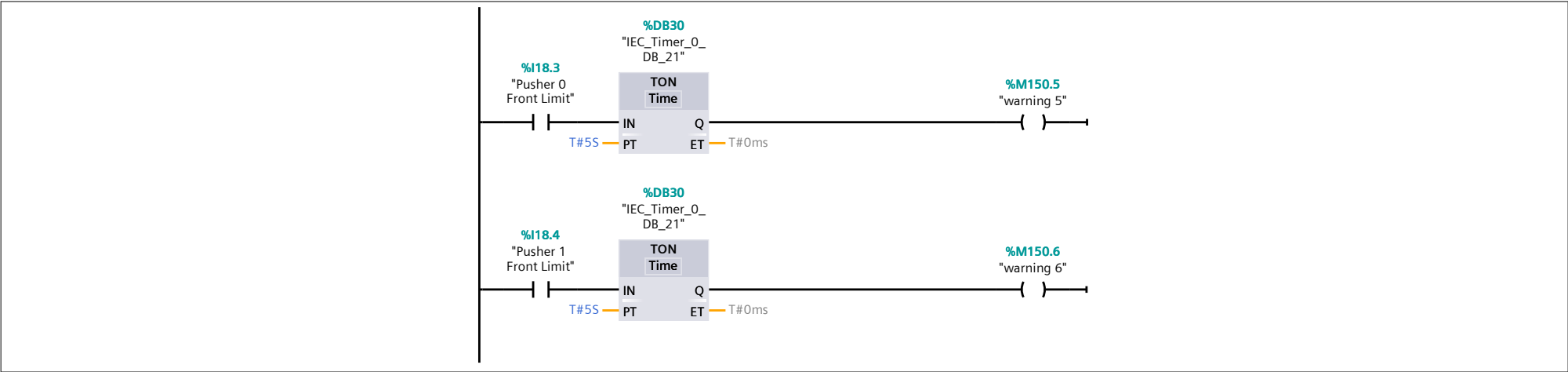
Network 13: Medium Box Counter

- When Pusher 1 is operated, the counter increases and is saved in the memory location Medium Box Counter which is displayed on the HMI.
- After the count of 10 boxes, the counter will output Q to bring on a warning on the error screen for 'Medium Boxes Warning'.



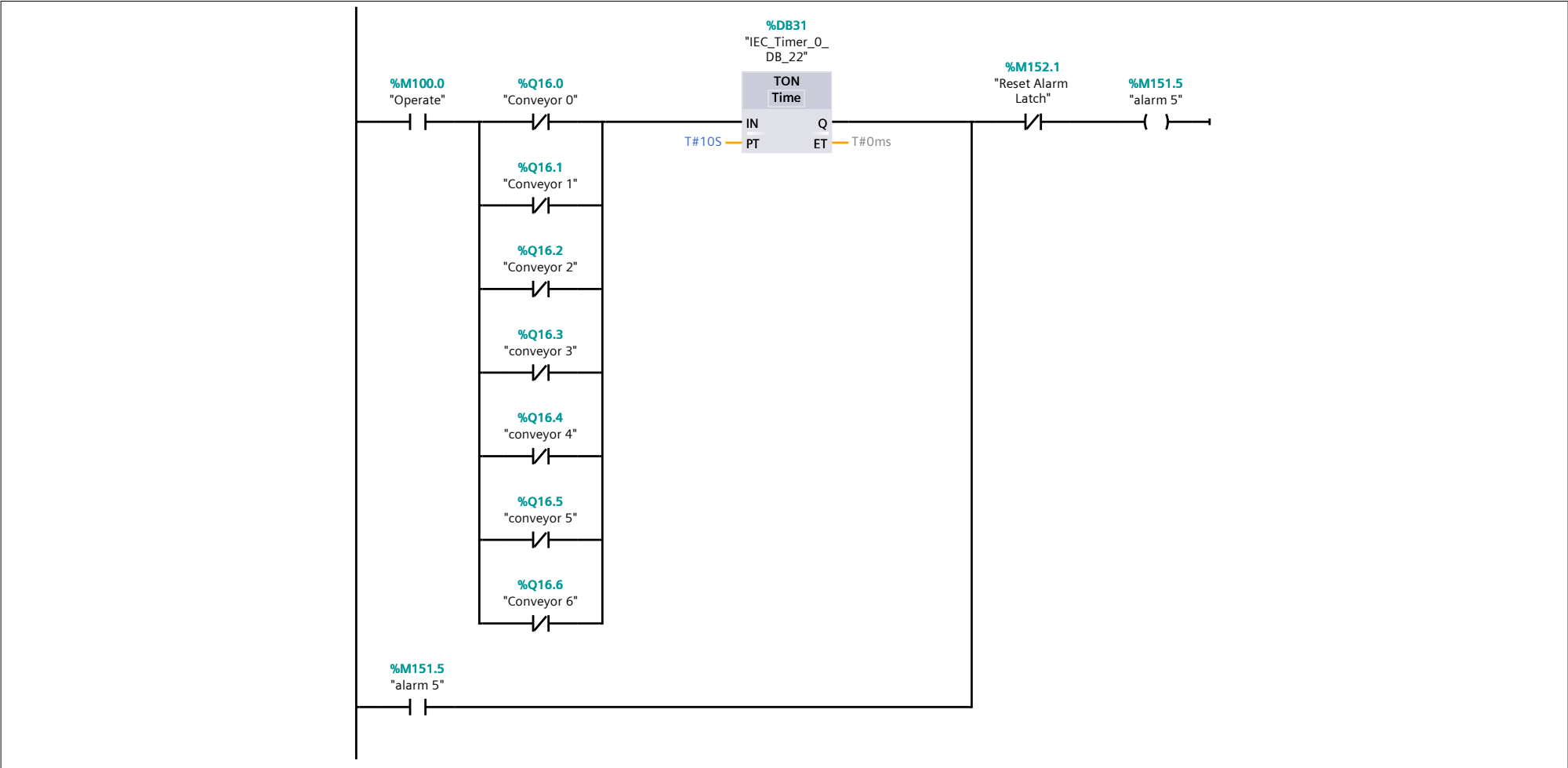
Network 14: Pusher Stuck Limits

- When Pusher 0 or Pusher 1 is stuck out, the TON timer will bring on Warning 5 or Warning 6 after 5 seconds to alert the operator that the pushers are stuck.



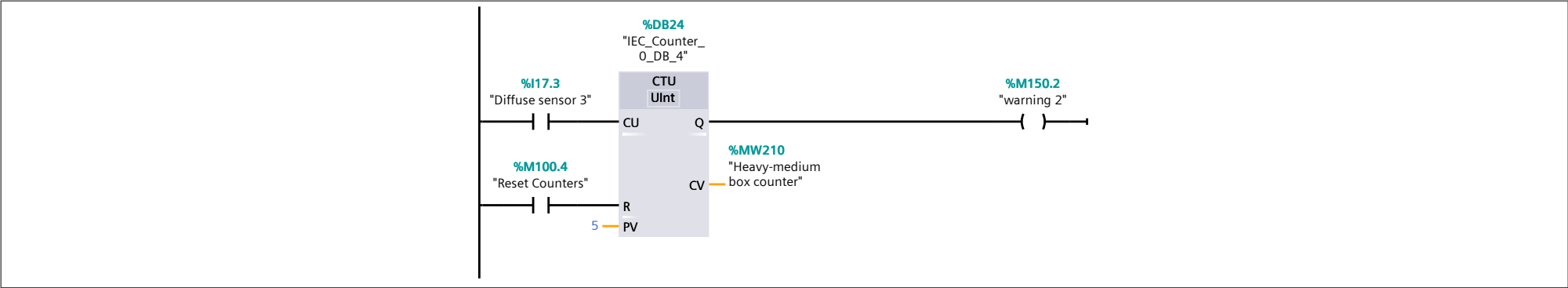
Network 15: Conveyor Failure

- When the system is Operating, the conveyors run. which changes the state to normally open. If any of the conveyors don't run, their state will stay closed which will complete the circuit.
- The delay timer is used prior to the Alarm 5 - Conveyor Fault Alarm because the conveyors start up sequentially, totalling around 5 seconds. This prevents any false alarms coming on.
- The alarm is latched to ensure the alarm can be seen prior to it being removed.



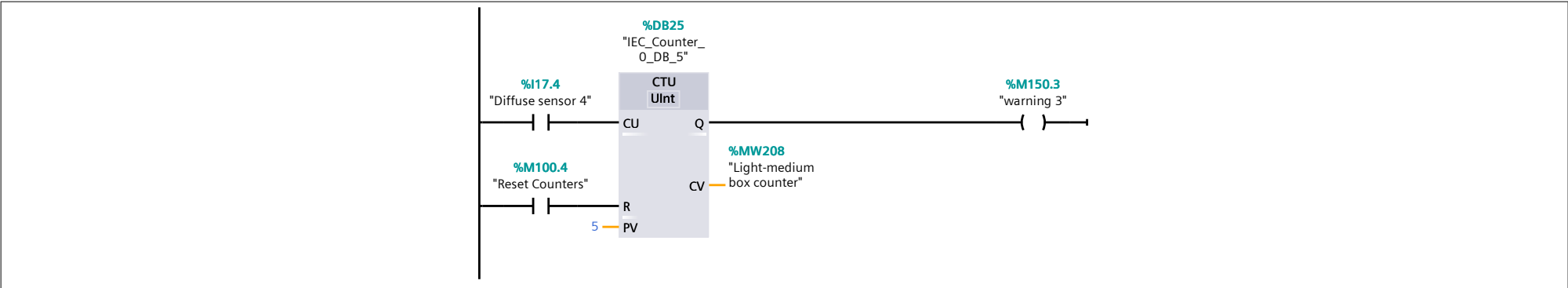
Network 16: Heavy-Medium Box Counter

- Diffuse Sensor 3 is placed at the end of the right-hand conveyor after the Pop-up Sorter to count the boxes as they pass.
- Each box that passes the diffuser is saved in memory Heavy-medium box counter.
- When the count reaches 5, Warning 2 - Heavy-Medium Box Warning is shown on the Error Screen.
- The counter can be reset using the Reset Counters button on the Engineer Screen.



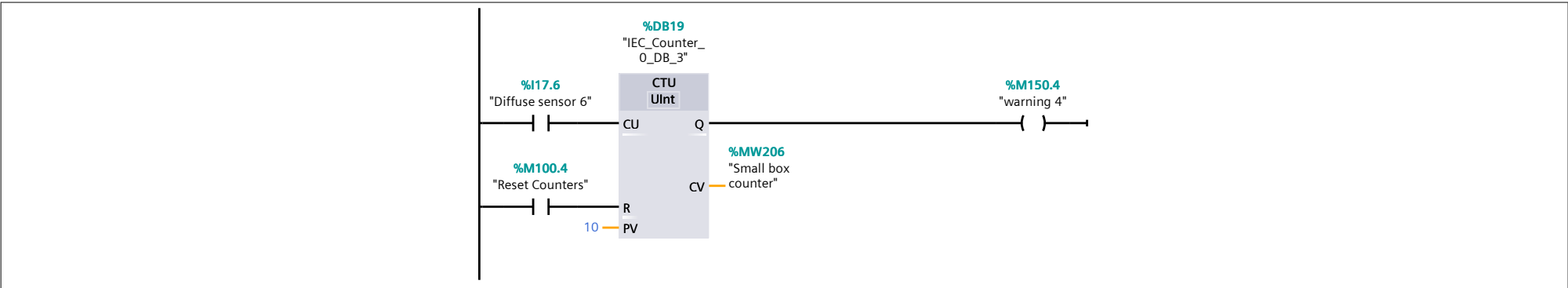
Network 17: Light-Medium Box Counter

- Diffuse Sensor 4 is placed at the end of the left-hand conveyor after the Pop-up Sorter to count the boxes as they pass.
- Each box that passes the diffuser is saved in memory Light-medium box counter.
- When the count reaches 5, Warning 3 - Light-Medium Box Warning is shown on the Error Screen.
- The counter can be reset using the Reset Counters button on the Engineer Screen.



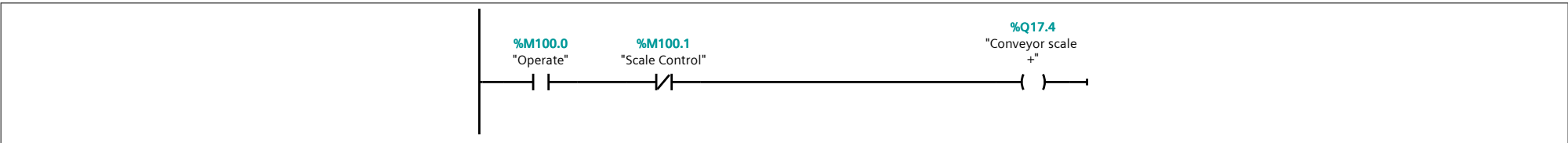
Network 18: Small Box Counter

- Diffuse Sensor 6 is placed at the end conveyor to count the small boxes as they pass.
- Each box that passes the diffuser is saved in memory Small box counter.
- When the count reaches 10, Warning 4 - Small Box Warning is shown on the Error Screen.
- The counter can be reset using the Reset Counters button on the Engineer Screen.



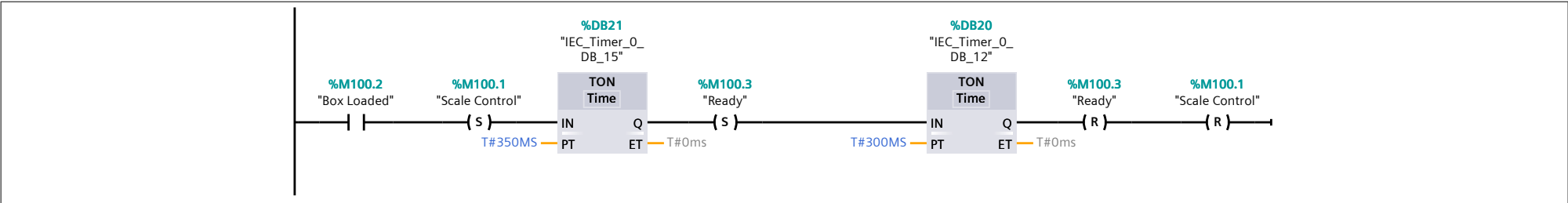
Network 19: Scale Control

- When the system is Operating, the Scale Control bit is activated, which enables the Conveyor Scale to process boxes requiring weight measurement.



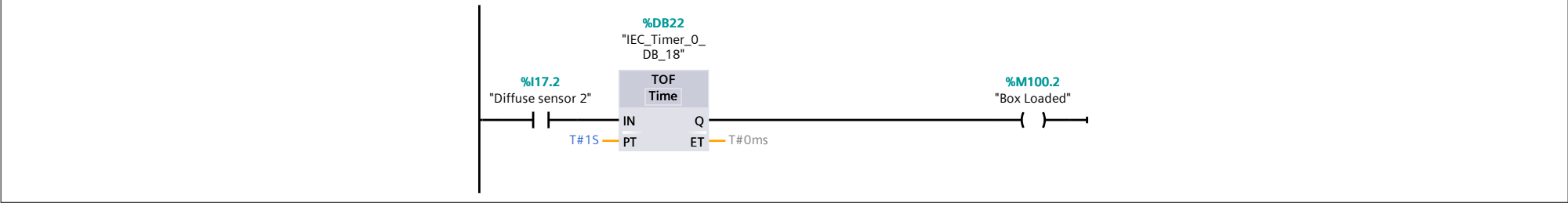
Network 20: Box Loading and Ready State

- When a box is loaded, the Box Loaded bit is set, and the Scale Control bit is activated.
- Two timers are used to delay the transition to the "Ready" state by 350ms and 300ms, respectively.
- Once the timers expire, the system signals that the box is ready for the next process by setting the "Ready" bit.



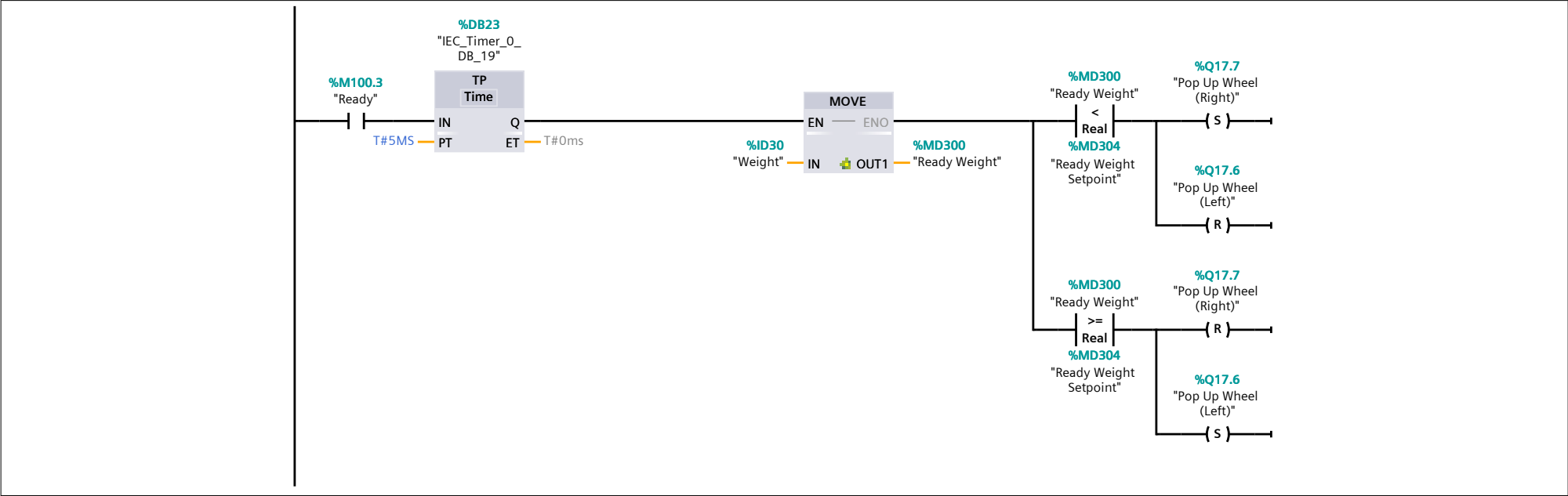
Network 21: Box Loaded Detection

- The diffuse sensor detects when a box is loaded onto the scale.
- A timer ensures the "Box Loaded" bit is only activated if the detection lasts for at least 1 second.



Network 22: Weight Comparison

- The weight of a box, stored in Ready Weight, is compared to a predefined setpoint from the HMI.
- If the weight is less than the setpoint, the Pop-Up Wheel (Left) is activated to divert the box to the left.
- If the weight meets or exceeds the setpoint, the Pop-Up Wheel (Right) is activated to divert the box to the right.
- A timer ensures smooth operation of the pop-up mechanism with a 5ms delay.



Network 23: LCD Display

- The Ready Weight (%MD300) is moved to the LCD Display (%QD30) to show the real-time weight of the current box.



HMI Design

An HMI or Human Machine Interface is a user screen to enable a human to interact with a machine or process. HMIs are typically found in industrial settings to allow operators to monitor and control processes.

Root Screen

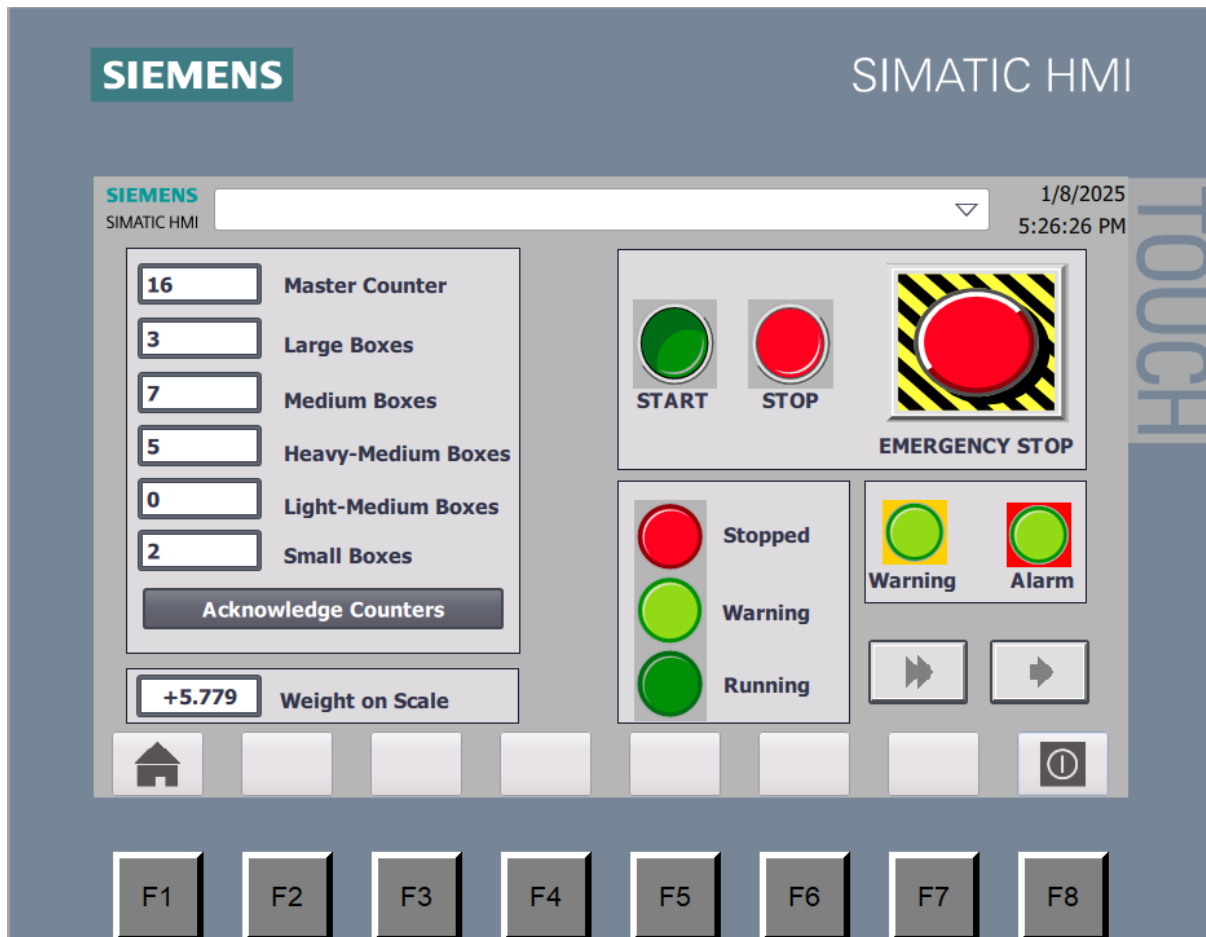


Figure 12 - Root Screen

Figure 12 above shows the Root Screen, which is the main screen on the HMI. There are multiple sections designated by the background colours. The left hand side is dedicated towards counting and weighing boxes. The Acknowledge Counters button will clear all the counters except for the Master Counter. The Weight on Scale displays the real time weight of the boxes as they pass over the conveyor scale.

In the middle, the Stopped, Warning and Running lights are just a visual representation of the stack lights which are found on top of the panels.

On the top right-hand side, the Start, Stop and Emergency Stop buttons can be found. This enables the operator to start and stop the process at any time, and in case of an emergency, the emergency stop can be hit to stop the process starting again.

At the right-hand side, the alarm and warning lights can be found, this will be a visual prompt for the operator to visit the Error Screen if these are illuminated.

Error Screen

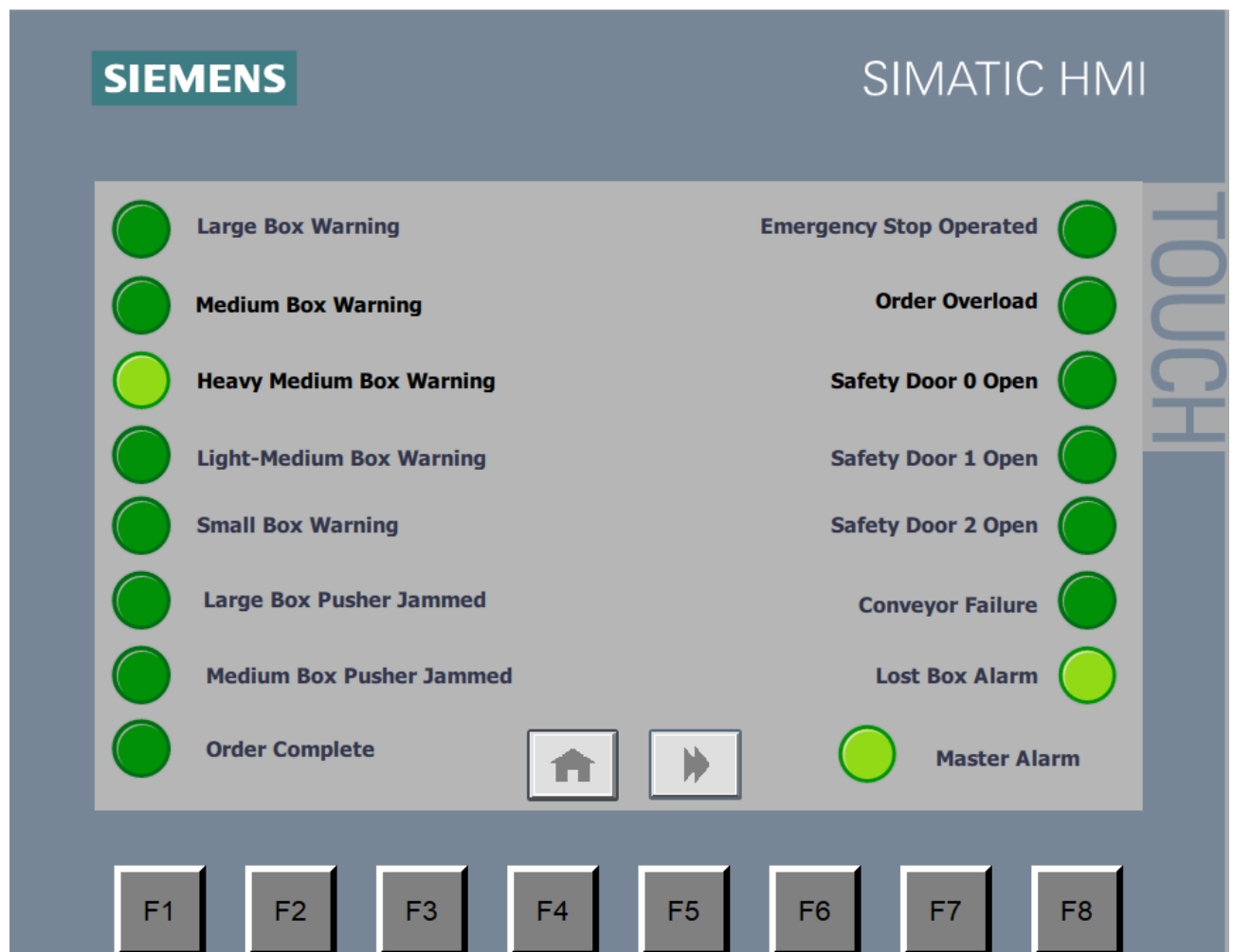


Figure 13 - Error Screen

Figure 13 above shows the error Screen on the HMI. If a warning or an alarm is triggered during the operation of the plant, the corresponding pilot light will be illuminated here. All the warnings are situated on the left-hand side, whilst the alarms are situated on the right-hand side. The warnings are coordinated as follows:

PLC Tag	Error Screen Name
Warning 0	Large Box Warning
Warning 1	Medium Box Warning
Warning 2	Heavy Medium Box Warning
Warning 3	Light Medium Box Warning
Warning 4	Small Box Warning
Warning 5	Large Box Pusher Jammed
Warning 6	Medium Box Pusher Jammed
Warning 7	Order Complete

The box warnings are to alert the operator that the amount of boxes processed have reached the desired target (warning 0-4).

Warning 5 & 6 relate to the pushers, if the front limit of the pusher is held over a certain amount of time, the warning lights will illuminate to alert the operator that the pushers are jammed out. Potentially a box may get stuck etc.

Warning 7 alerts the operator to show that the desired output of boxes for that cycle has been reached.

The alarms are coordinated as follows:

PLC Tag	Error Screen Name
Alarm 0	Emergency Stop Operated
Alarm 1	Order Overload
Alarm 2	Safety Door 0 Open
Alarm 3	Safety Door 1 Open
Alarm 4	Safety Door 2 Open
Alarm 5	Conveyor Failure
Alarm 6	Lost Box Alarm
Master Alarm	Master Alarm

Alarm 0, 2, 3 & 4 are very similar. When an emergency stop is operated or safety door is opened, this will change their contact and raise the alarms and shut the plant down. This can only be reset when the doors are shut again, the emergency stops are retracted and the Master Alarm Clear button is pressed on the Engineer Screen.

Alarm 1 is activated when the boxes output reaches 150%. This ensures the operator takes the necessary actions to clear the boxes and reset all alarms in preparation for the next batch.

Alarm 5 is raised if a conveyor fails to start. When the system operates, the output to the conveyors close. If for some reason the conveyor doesn't start, the conveyor contact will stay closed in the ladder logic. This will complete the alarm circuit and shut the plant down.

Alarm 6 is raised using a comparison of the medium boxes pushed and the medium boxes counted. If the totals don't equal within 20 seconds the alarm is raised to alert the operator that a box has been lost on the medium box conveyor section.

The Master Alarm is illuminated if any alarm is activated. This can only be cleared if the fault is cleared and the Master Alarm Reset button is pressed.

Engineers Screen

Figure 14 below shows the engineer screen. This is accessed if any alarms have been raised, to reset counters & master counter, or to adjust the set point of the scale.

The engineer will be able to adjust the setpoints by pressing the LCD display and typing in the desired set point. The outcome of changing the set point will separate boxes onto the heavy-medium and light-medium conveyors as required.

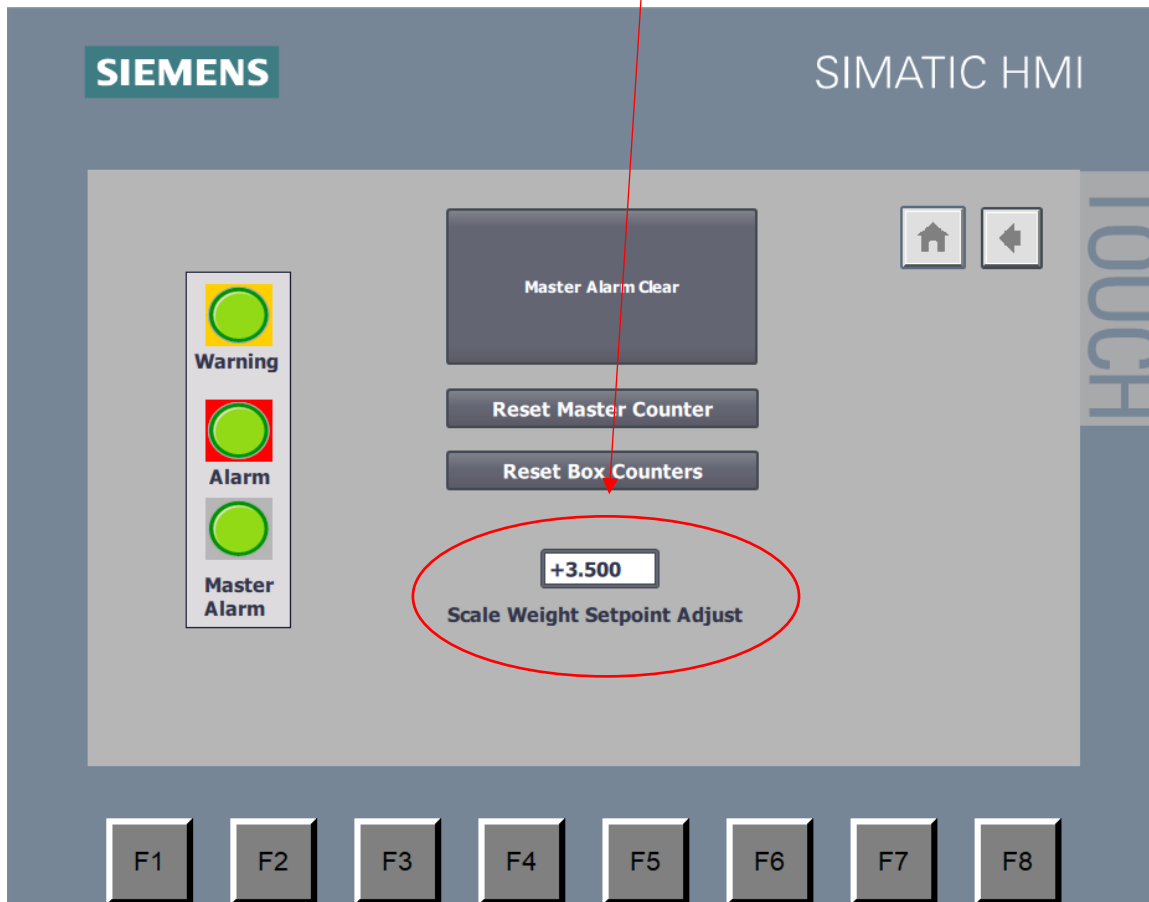


Figure 14- Engineers Screen

Conclusion

The factory system successfully sorts four different types of packages based on size and weight using Factory I/O. It includes essential components such as conveyor belts, pushers, a conveyor scale, sensors, emergency stops, buttons, sirens, warning lights, and stack lights, all controlled by a PLC ladder logic program. The system minimises current draw by starting conveyors sequentially and includes a manual reset for alarms after issues are resolved. The HMI provides essential operator controls and allows for counter settings.

Future Additions:

To enhance the system, the following additions are recommended:

- Automated Diagnostics for proactive fault detection.
- Remote Monitoring for off-site oversight and adjustments.
- Energy Efficiency improvements such as variable-speed drives.
- Safety Enhancements like proximity sensors to prevent jams.

- Data Logging for performance tracking and analysis.

These improvements would optimise efficiency, safety, and scalability, preparing the system for future upgrades.

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