Project Report – PLC Controlled Factory System

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L6 – Applied Programmable Logic Controllers

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Module Code – ACDA6000

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3. Abstract

This report covers the design and programming of a PLC controlled box sorting process. The process was simulated in Factory IO, which is a factory simulation software, and programmed using Siemens TIA S7-PLCSIM V16 which is a PLC programming software. Siemens TIA STEP 7 V16 used ladder logic for programming PLCs, and this was used to program the process for simulation. The simulated process and the ladder logic is shown and explained in this report.

The process required the following functions:

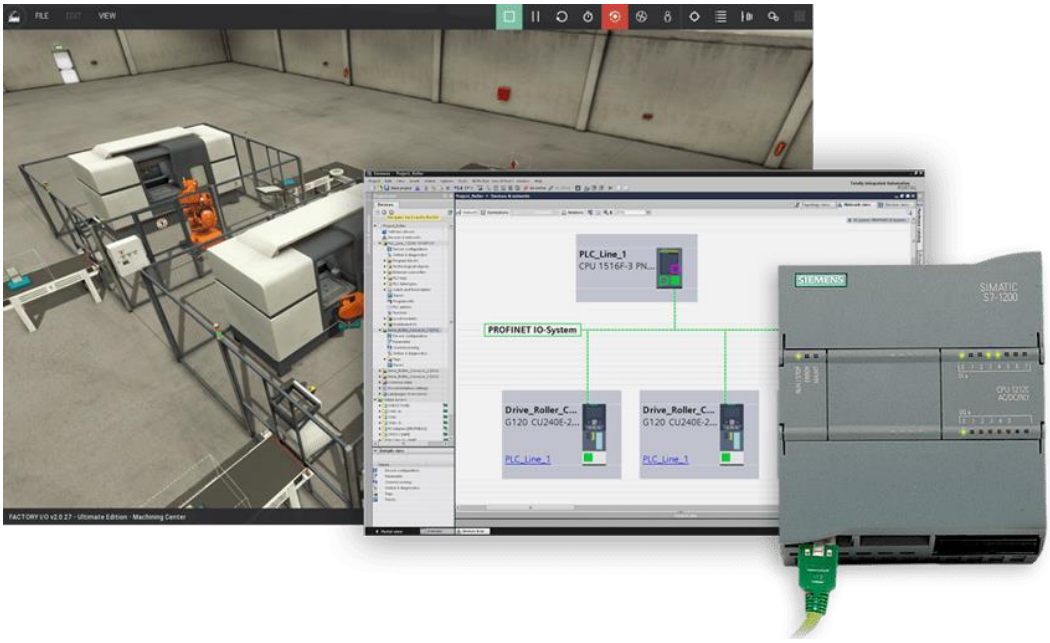
1. Must sort boxes by size and weight.
2. Process controls on a panel and a HMI.
3. HMI for controlling the process, viewing alarms, and setting the counters.
4. Emergency stop buttons.
5. Box counters and a reset count function.
6. Stack lights in the process and the HMI
7. Warning and alarm indicators for fault identification.
8. Conveyors for directing the boxes through the process.

The process in Factory IO included all of these functions, and they performed as required. The Siemens TIA V16 PLC ladder logic program controlled the process correctly, and the HMI as well as the control panel allowed operators to control the process and view alarms. The boxes were sorted by size and weight, and separated into different removers to simulate successful packing.

4. Introduction

The purpose of this task was to produce a PLC controlled factory, being simulated in Factory IO, [1] [2] and programmed via Siemens TIA V16 PLC logic software as shown in figure 2. [3] The factory must sort 4 different variations of packaging depending on size and weight as shown in figure 1. The system also required a HMI (human-machine interface) which allowed a user to operate the system and monitor warning and alarm indicators, as well as reset them as required. There was a requirement for counters to count lost boxes, with these alarming once settable counts were exceeded. This report describes the Factory IO process design, and the PLC ladder logic programming design, as well as the simulation results.

Figure 1 - All Boxes Being Sorted (Large, Medium, Small, Pallet)

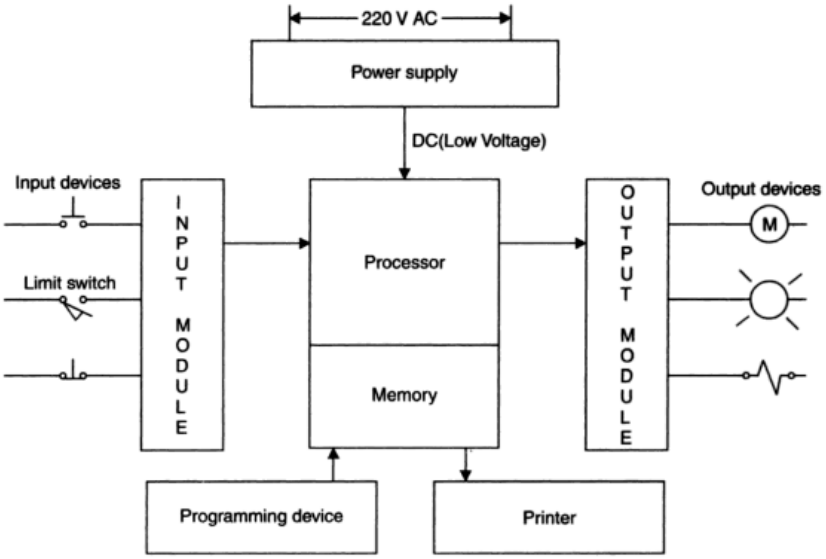


[4] Figure 2 - Siemens Programming Software Connected to a Simulated Process on Factory IO

5. Research

5.1. What are PLCs?

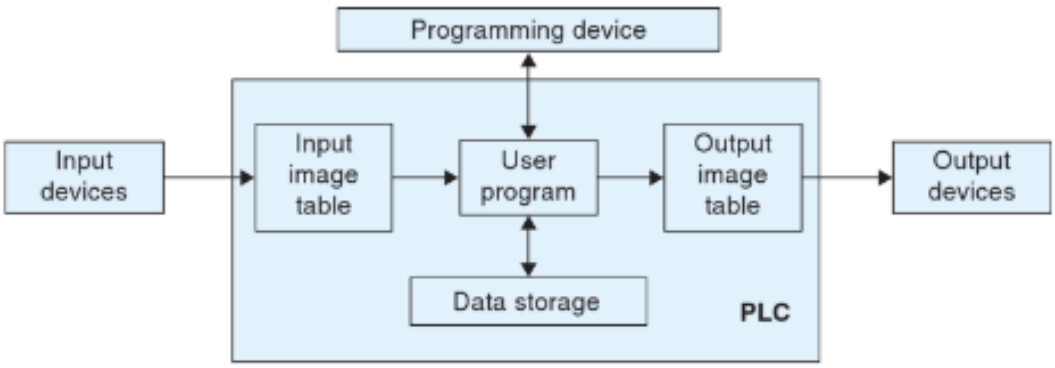
PLCs are microcontroller based industrial control devices which are designed to receive a number of electrical inputs and switch a number of outputs, depending on the programmed logic stored in the PLC. [5] Figure 3 illustrates how the inputs enter the PLC, how the user program makes decisions based upon the program's logic, then provides the required outputs for process control. PLCs are composed of five components, including the CPU, memory, power supply, I/O interfacing, and the communications module. [6]



[7] Figure 3 - Components of a Programmable Logic Controller

PLCs replace the old logic circuitry that was required to control automated systems, before the introduction of PLCs. A great advantage of PLCs, is that the program can be quickly modified at any time to change how a process is controlled, or to accommodate additional equipment being added to a process.

Figure 5 shows a Siemens PLC CPU. This is the Siemens SIMATIC S7-1200, which is modular and can be expanded with numerous communications and I/O modules as shown in figure 6. [8] These modules are simply attached to the CPU The program is stored in this CPU, and a programming pc can be connected to this module to make changes to the program.



[5] Figure 4 - Architecture of a PLC

[9] Figure 5 - SIMATIC S7-1200 PLC

[10] Figure 6 - SIMATIC S7-1200 Signal modules Connected to the CPU

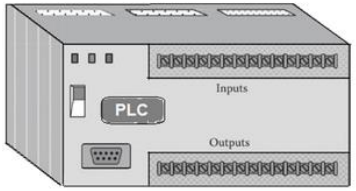
Figure 7 shows a Siemens LOGO! 8 unitary PLC, which has a fixed I/O quantity (8 x inputs & 4 x outputs), fixed communications interfaces, fixed memory, and cannot be expanded. [11]

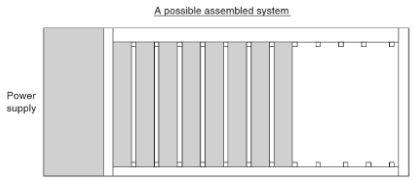
[12] Figure 7 - Siemens LOGO! 8 Logic Module Unitary PLC

5.2. Different Types of PLCs

Table 1 shows a comparison of different types of PLCs that are currently available.

Types of PLCs	Images & Illustrations of Examples	Description and Applications	Pros	Cons
Unitary/Compact PLCs	 *[13] Figure 8 - Siemens LOGO! 8 PLC* *[14] Figure 9 - Allen Bradley Micro820 PLC* *[15] Figure 10 - Allen Bradley MicroLogix 1000*	These are ideal for more basic applications with a small amount of input and outputs required. No additional modules are required with unitary PLCs as the CPU, power supply, as well as the inputs and outputs are all utilized in the one device. [13] This makes them easy to use and install for small hobbyists. They are still useful in industrial applications as they are robust, low cost, and can be quickly installed in a machine that doesn't require more than approximately 8 inputs and 4 outputs [11], or up to 12 or 24 inputs, and 8 or 16 outputs. [17]	ost due to their low exity. n size and weight which these suitable for ations with less space in a l panel. ommunications, inputs and nd the power supply are all ated in the one device which installation easier and less onsuming.	1. Unitary PLCs are not expandable due to the communications, CPU, as well as the inputs and outputs all being built in to the one device. This makes these devices not suitable to machines and processes which will require expansion in future. To expand on a unitary PLC, it must be replaced with a larger unit. 2. The communication types are severely limited due to the PLC only offering communication for programming and interfacing with the factory installed ports. The Siemens LOGO! 8 PLC only has an ethernet port for

	 Compact PLC *[16] Figure 11 – Illustration of a Compact / Unitary PLC*			communication for example. [13] 3. Limited memory size due to there being no options for expandability. 4. Once a part of the PLC fails, the whole unit must be replaced.
Rack Mounted PLC	 *[18] Figure 12 – SIEMENS S7-400 PLC Racks* *[19] Figure 13 - SYSMAC CS1 Rack PLC* *[20] Figure 14 - Mitsubishi Q Series PLC CPU*	Rack mounted PLCs are designed so each part of the PLC is connected to a rack in a control panel, which allows individual parts to be added or removed when required. The rack features a data communications bus, which is hard wired internally in the rack to allow each module to communicate. [21] This is highly suited to large process control applications in industrial settings due to the expandability this offers. These are designed to be mounted inside large control panels with space for future expansion, which is usually a requirement of constantly improving and evolving factory processes. Extension racks are another function of rack PLCs that allow further	1. The racks allow for limitless expandability, which makes these highly effective in constantly evolving and growing factory processes. Processes where additional equipment is regularly introduced, meaning more PLC control requirements. 2. Expandable memory via adding more cards to the rack also makes	1. The initial cost of these devices is usually considerable due to their high complexity and size. A single Siemens input module for a rack PLC costs more than an entire Siemens LOGO!8 unitary PLC. Being £525.60 for the rack PLC, and £156.00 for the unitary. [11] [22] 2. These require a large amount of space to install inside a panel due to the large size of

	 *[17] Figure 15 – Illustration of a Possible Arrangement of a Rack System*	remotely connected 'remote I/O' [21] to provide another expansion rack to allow input and output modules. These remote PLCs being connected via ethernet or TCP/IP. Special modules designed to interface with motors, encoders, different control equipment can be added to a rack to allow excellent adaptability to different processes. Unitary PLCs do not have this option due to their I/Os being fixed in the original single-piece design.	these effective for us in growing factory processes. 3. Different communications units can be added to the rack to cater to different types of connections, such as ethernet, profibus, profinet, modbus, and many others. 4. If a part of the PLC fails such as the power supply unit, this single unit can be replaced without changing any of the other parts. This makes repairability more cost effective and easier in large control applications.	the rack and chassis.

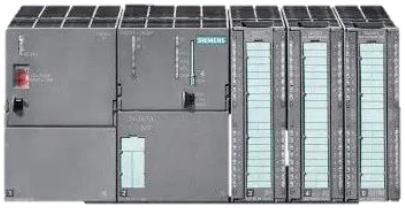
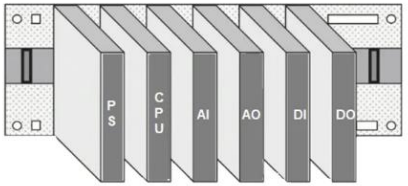
Modular PLC	 *[8] Figure 16 - Simatic S7-1200 Module*  *[23] Figure 17 - Modular PLC Siemens S7-300* *[24] Figure 18 - AS Series - Compact Modular Midrange PLC*  **Modular PLC** *[16] Figure 19 – Illustration of a Modular PLC*	Modular PLC are highly similar to rack mount PLCs, as they are mounted to a rack in rows of modules, with each module having a specific function in the rack. The different modules that add up to form a modular PLC system include the power supply, CPU, communications module(s), input module(s), and output module(s). Modular PLCs have the potential for remote expansion units, which allow for even more modules to be connected to the PLC, but located elsewhere to save space.	1. Highly expandable due to the potential for adding many additional input and output modules, as well as various custom communications and control modules. 2. If a part fails, that single module can be easily replaced by unplugging it from the other modules, and reconnecting another. The rest of the PLC can be left as each module is separate and replaceable, saving costs when compared to a unitary PLC which will require full replacement of the PLC in the event of a failed part.	1. Large up-front cost due to the large scale and complexity of a modular PLC. 2. Requires a larger amount of space inside a control panel when compared with a compact/unitary PLC, due to the large number of modules being connected directly next to each other.

Table 1 - Comparison of the Different Types of PLCs Currently Available

6. Factory Process for Package Sorting in Factory IO

6.1. Full Process

Factory IO is a factory design and simulation software which can be connected to PLC programming software to allow the user to plan, design, and program their own custom factory process. Factory IO has a library of typical factory parts such as conveyors, sensors, pushers, scales, and many others for producing a custom process. [2] Factory IO utilizes drivers to communicate with simulated PLC software, and Siemens TIA Portal V16 was used to produce a logic program for the Factory IO process to interface with.

A factory process was designed in Factory IO, with the purpose of identifying and sorting four different package variations. These packages being sorted by dimensions and weight. There is an 'emitter' at the start of the process which produces all four variations of boxes. The boxes are transferred around the process via 12 conveyors, until the boxes reach the 4 different removers which delete the boxes once they have reached the end of the process after being sorted.

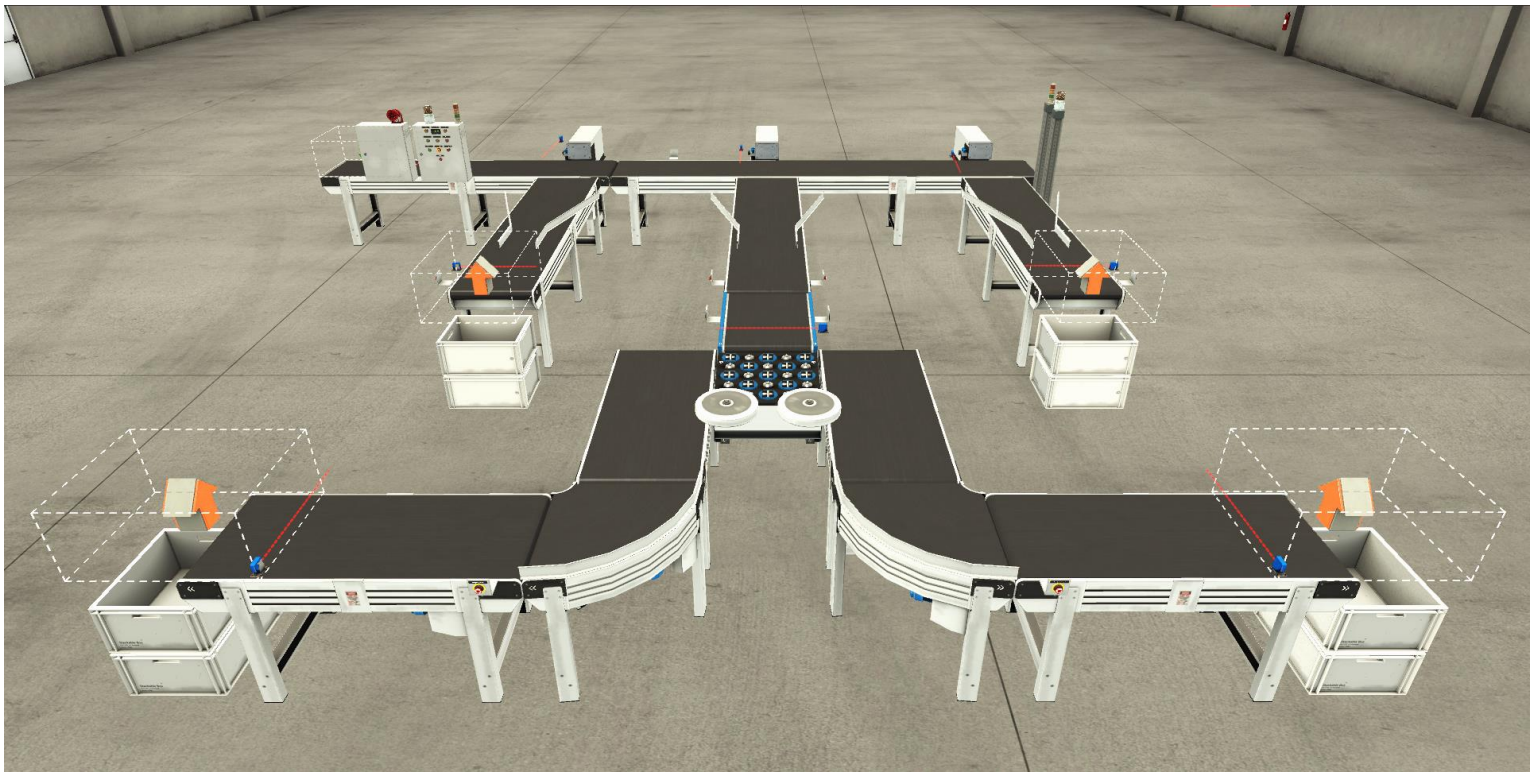


Figure 20 - View of Full Package Sorting Process - Factory IO

6.2. Control Panel

A control panel was designed and implemented into the process to allow an operator to manually interface with the process. The panel has control for starting and stopping the process. There is a green light to show that the process is running healthily, as well as a red light to show that the process has stopped. An emergency stop button has been implemented into the panel to allow an operator to quickly stop the process in an emergency. The process can then only be started again once the reset button on the panel has been pressed. There are indicator lights to display whether a warning or an alarm is present in the process. Mounted to the top of the panel are a warning light to light up when an alarm is active, and a stack light to show the green run and red stop lights, as well as an amber light for when there is a warning or alarm active.

Figure 21 - View of the Control Panel - Factory IO

6.3. Pushers

Three pushers have been implemented to separate the different boxes based on their heights as they traverse along the first two conveyors. Each pusher has its own laser diffuse sensor for detecting the boxes. The sensors are placed at heights from the conveyors which decrease for each pusher as you look across the process. First pusher separates the large boxes, second pusher separates the medium and small boxes, and the third pushes the smallest pallet boxes. The large and pallet boxes are now separated and sorted, however the medium and small boxes are the same height. These must be sorted by measuring their weights. This process is shown in figure 22.

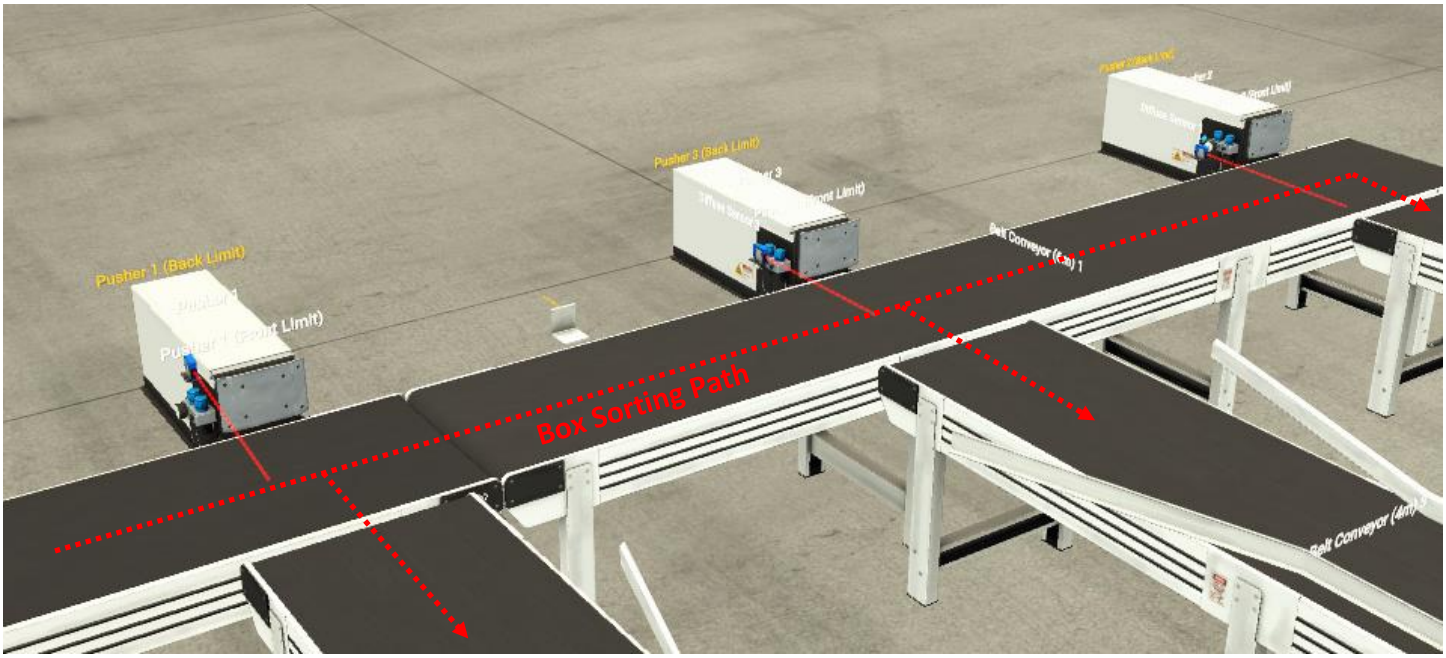


Figure 22 - Three Pushers - Factory IO

6.4. Conveyor Scale

To separate the medium and small boxes once they have traversed across the conveyor from the pusher, their weights must be measured. The weights are measured using a conveyor scale. The medium box weighs 5kg, whereas the small box weighs 4kg. The scales can then signal to the simulated PLC program, which box is currently being processed. This is shown in figure 23.

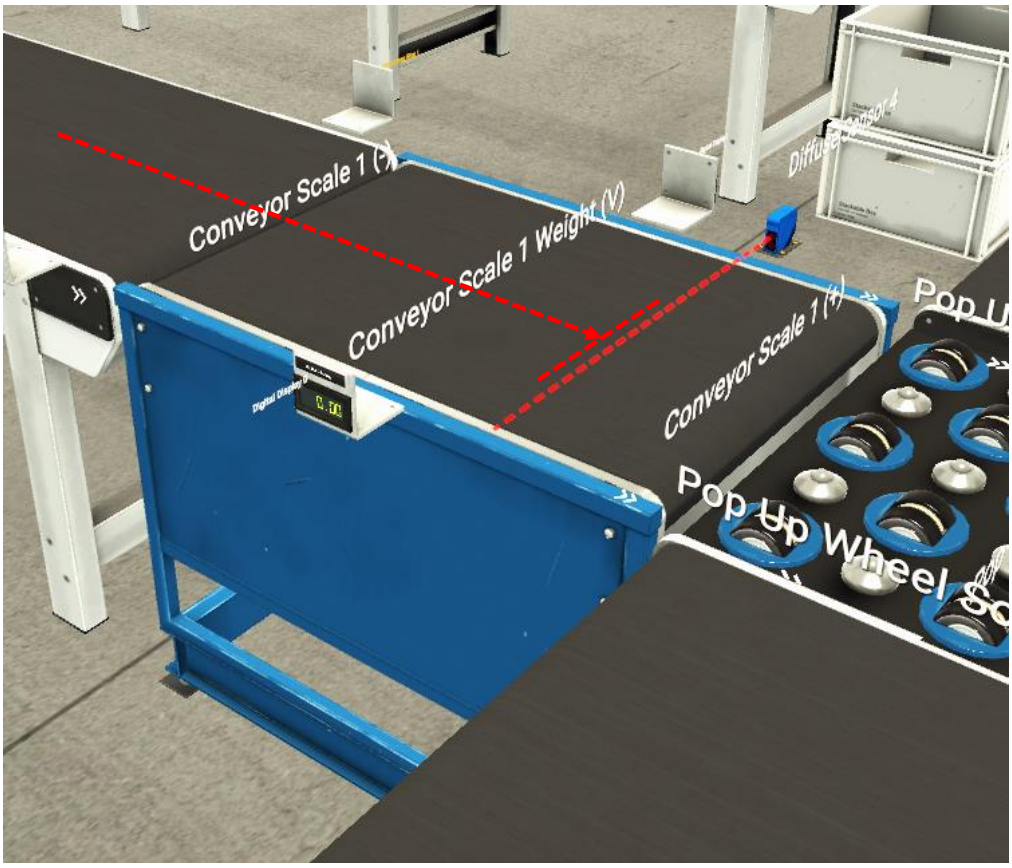


Figure 23 - Conveyor Scale - Factory IO

6.5. Pop Up Wheel Sorter

Once the weight has been determined via the conveyor scale, the pop up wheel sorter sends the box either to the right or left conveyor to sort the medium and small boxes by weight. Medium 5kg boxes go left (looking at figure 24), and small 4kg boxes go right.

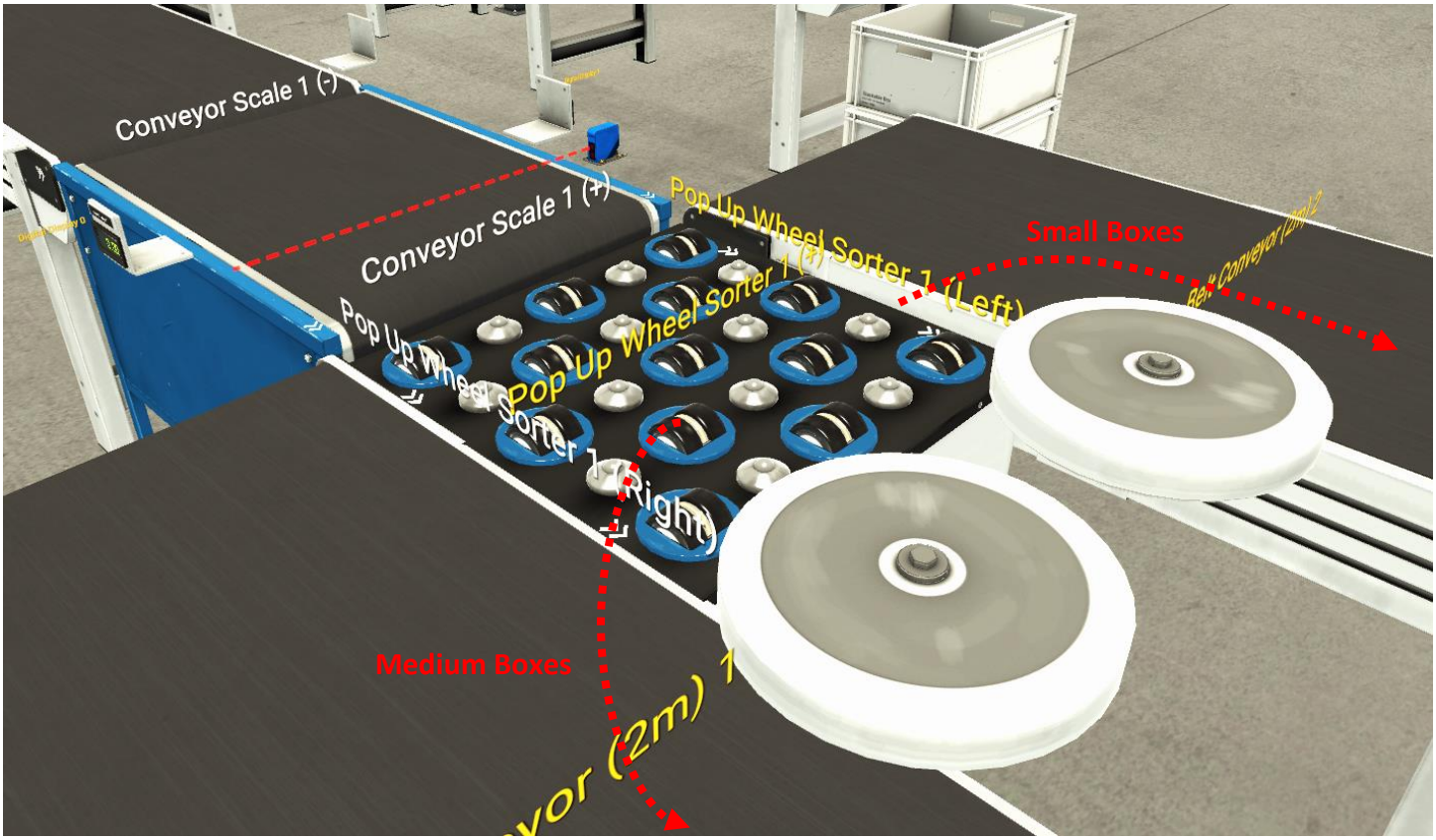


Figure 24 - Pop Up Wheel Sorter - Factory IO

6.6. Emergency Stops

There are 8 x emergency stops positioned around the process. This is to allow operators to quickly stop the process in the event of an emergency from anywhere around the process. This allows the process to comply with The Supply of Machinery (Safety) Regulations 2008, as this states that there must be at least one emergency stop device fitted, and they must be accessible at all times. [25] Figure 25 shows the locations of all of the emergency stops.

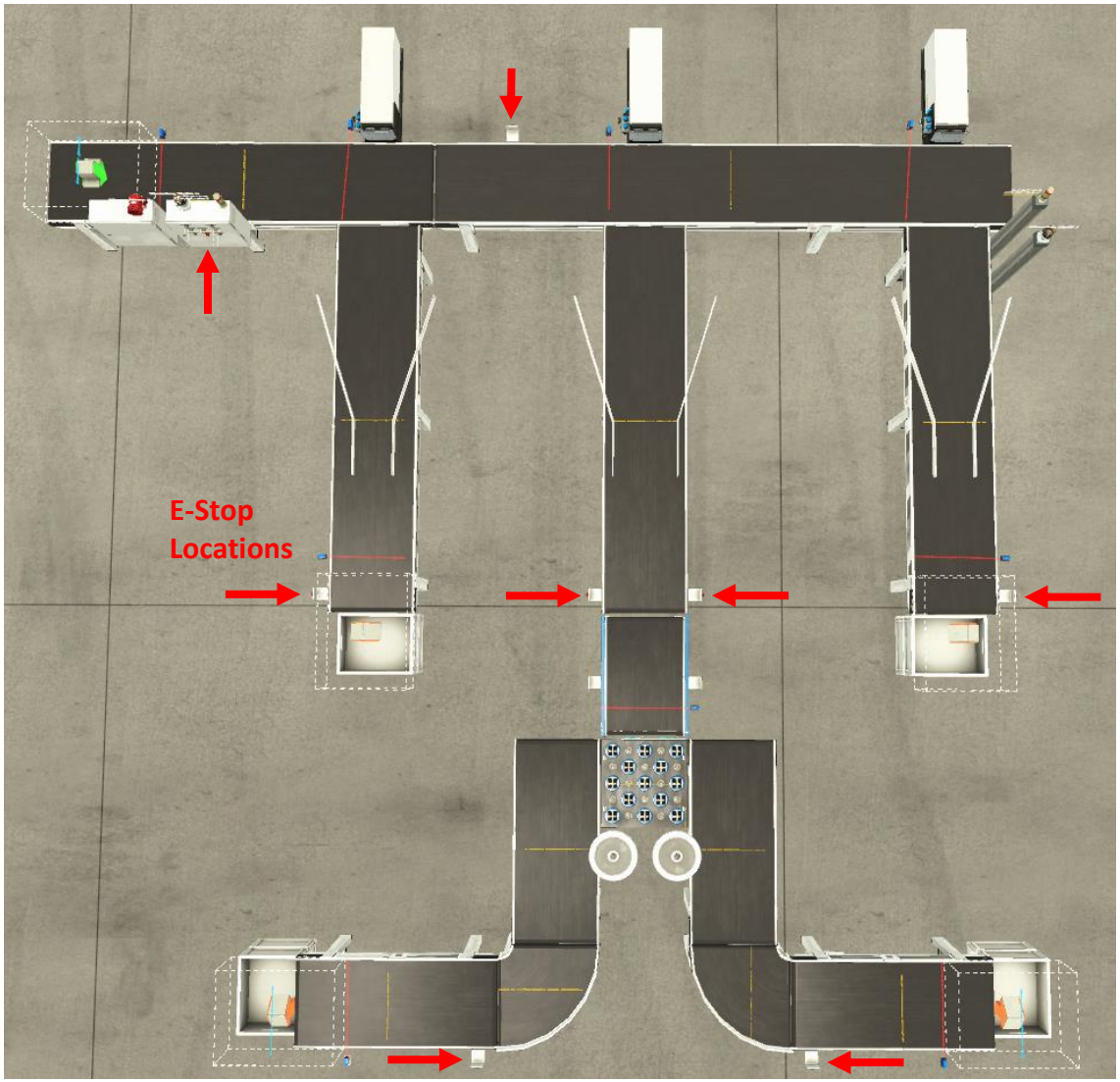


Figure 25 - Emergency Stops - Factory IO

6.7. PLC Inputs & Outputs

In Factory IO, the simulated PLCs inputs and outputs must be named so that the PLC programming software can be linked via PLC tags in the Siemens TIA programming software. This simulated how a real PLC's input and output modules would be connected to various contactors, relays, and motor drives to control the process. The inputs are on the left side, and the outputs are on the right. Each input and output has the connected part of the process named next to it. Figure 26 shows the PLC I/O connections

Figure 26 - Factory IO PLC Inputs & Outpu

7. Ladder Logic Program – Siemens TIA Portal V16

The program for the simulated PLC was produced in Siemens TIA V16. This was produced in ladder logic form, with each various process function being separated in networks or rungs.

7.1. Breakdown of the Process's PLC Ladder Logic Programming

Network 1

This shows what type of PLC is being simulated, being a Siemens S7 1200.

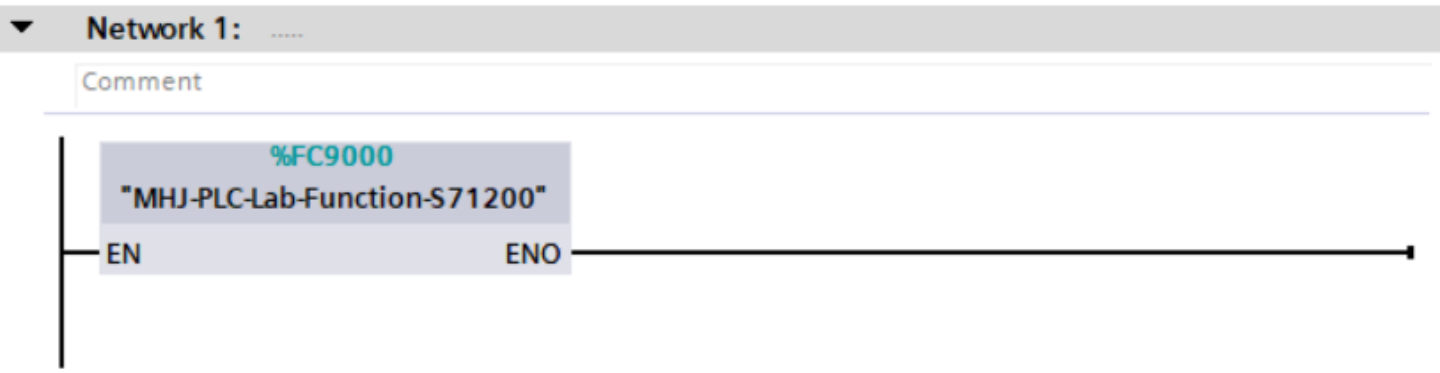


Figure 27 - Ladder Logic Network 1

Network 2

Start operations are located here with the NO start and stop inputs, and an 'operate' tag to retain the on request. Next are the NC alarm and e-stop flags to switch the 'operate' output off.

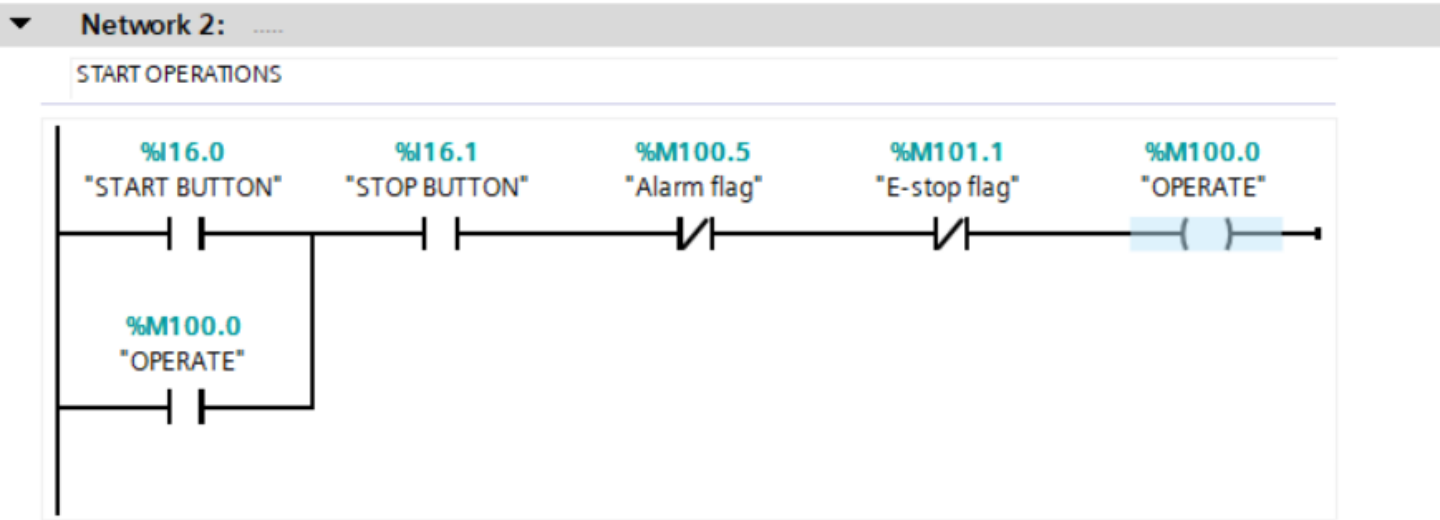


Figure 28 - Ladder Logic Network 2

Network 3

This rung includes the reset button for resetting the e-stop flag, and a flag .

Figure 29 - Ladder Logic Network 3

Network 4

This rung contains all of the e-stops in the process and HMI, as well as the reset button flag. The e-stops will set the output, and the reset button will reset the output to turn it off. This ensures the process cannot start up until the reset has been pressed to remove the warning.

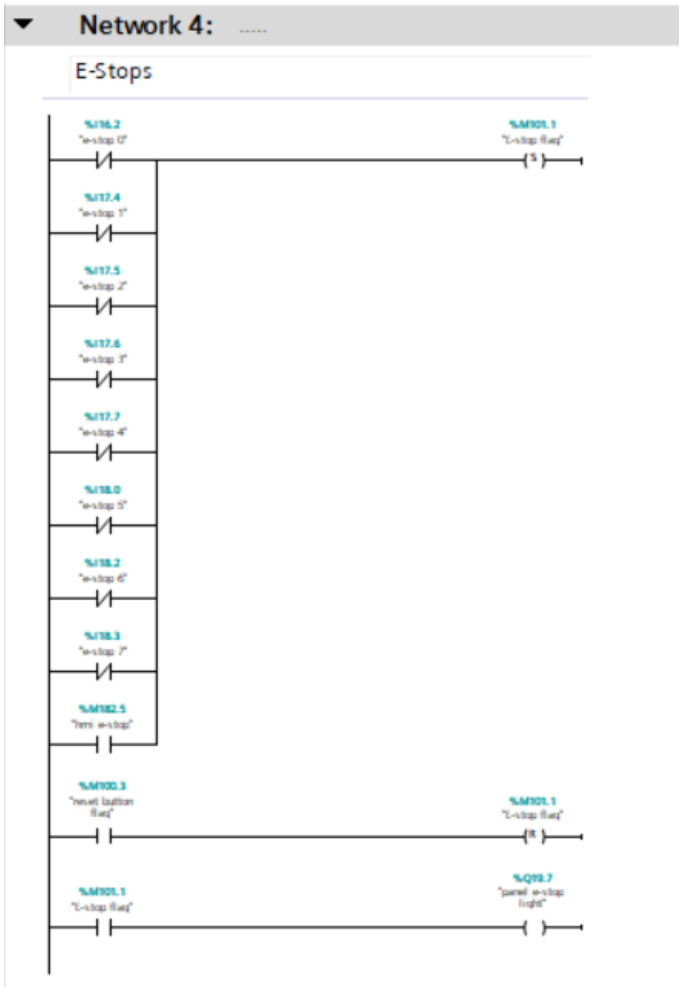


Figure 30 - Ladder Logic Network

Network 5

Network 5 uses a pulse timer to reset the scale conveyor reading either when the reset error count button is pressed on the HMI, or when the process is stopped.

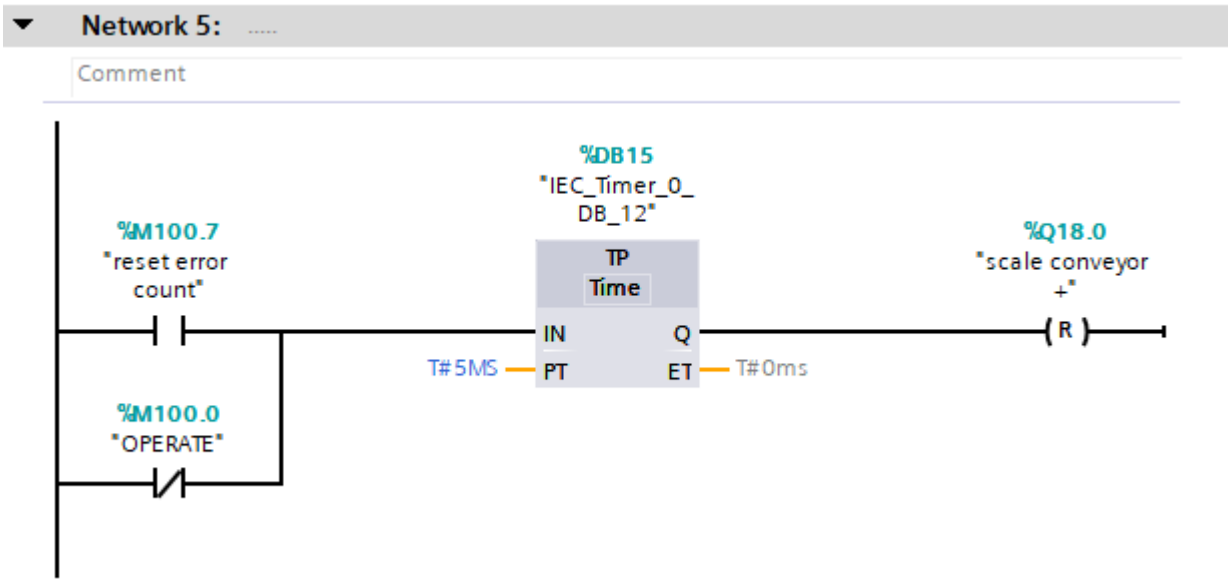


Figure 31 - Ladder Logic Network 5

Network 6

Network 6 includes TON timers to delay the startup of all conveyors to prevent pulling too much current on start up. A TP provides briefly activates the siren on start up to notify people that the process is starting.

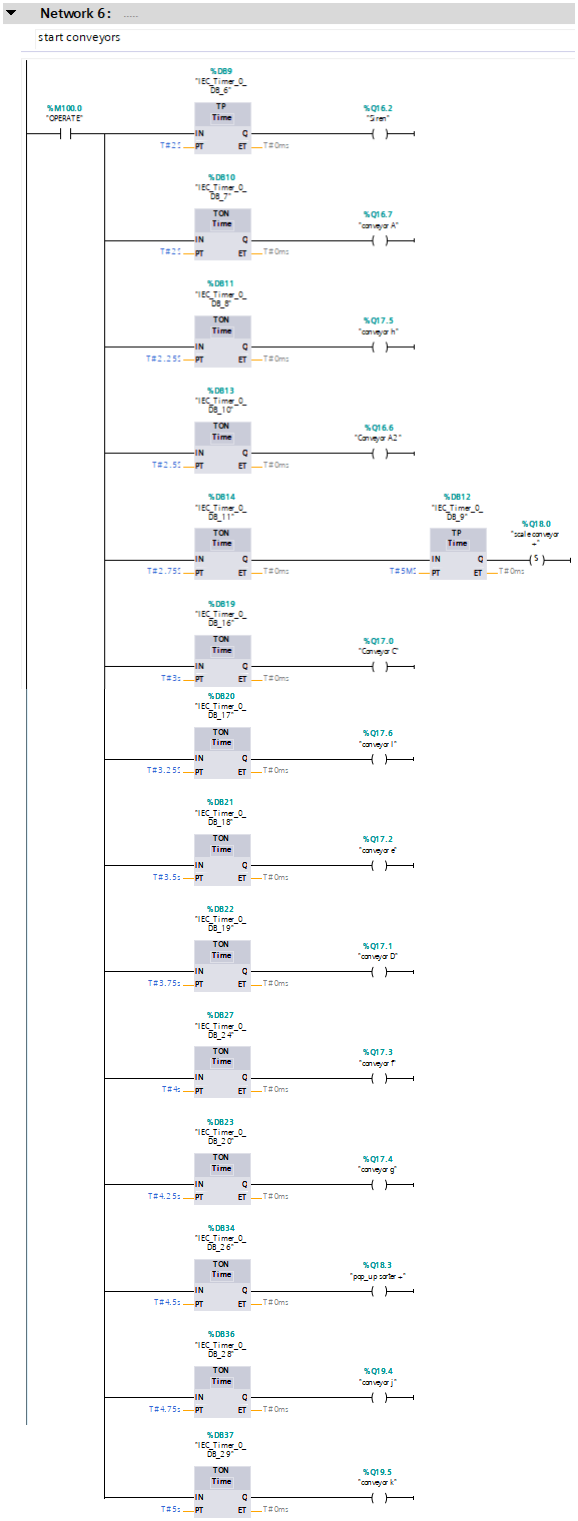


Figure 32 - Ladder Logic Network 6

Network 7

This rung controls the green run light and red stopped light, depending on the operate tag from network 2.

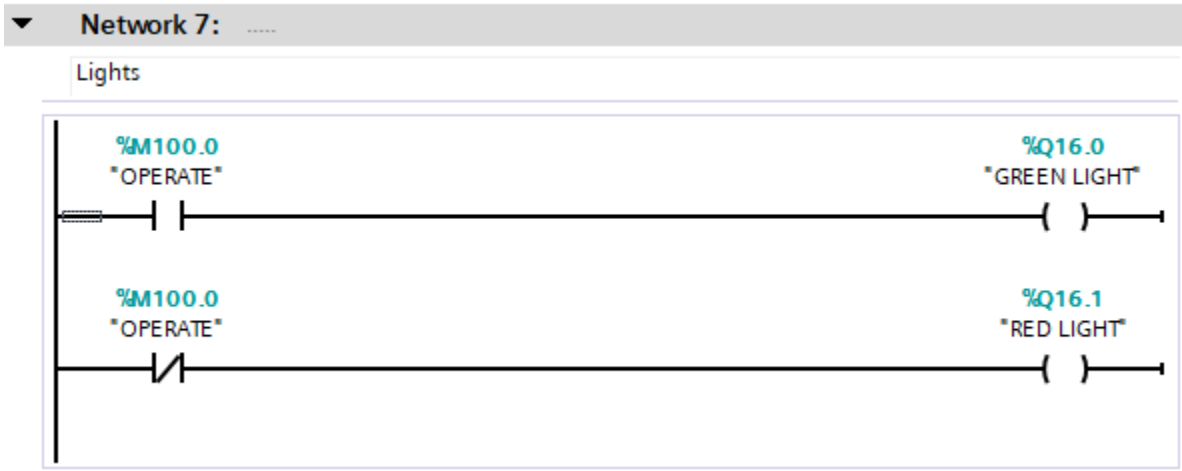


Figure 33 - Ladder Logic Network 7

Networks 8, 9, & 10

These networks contain timing operations for each pusher. The box will pass the diffuse sensor, then the TON and TP will provide a delayed output to the pusher to centrally connect with the box in order to move it. The TOF will then switch the signal off, ready for the next box. NC flags are for the E-stops to prevent the pushers from operating.

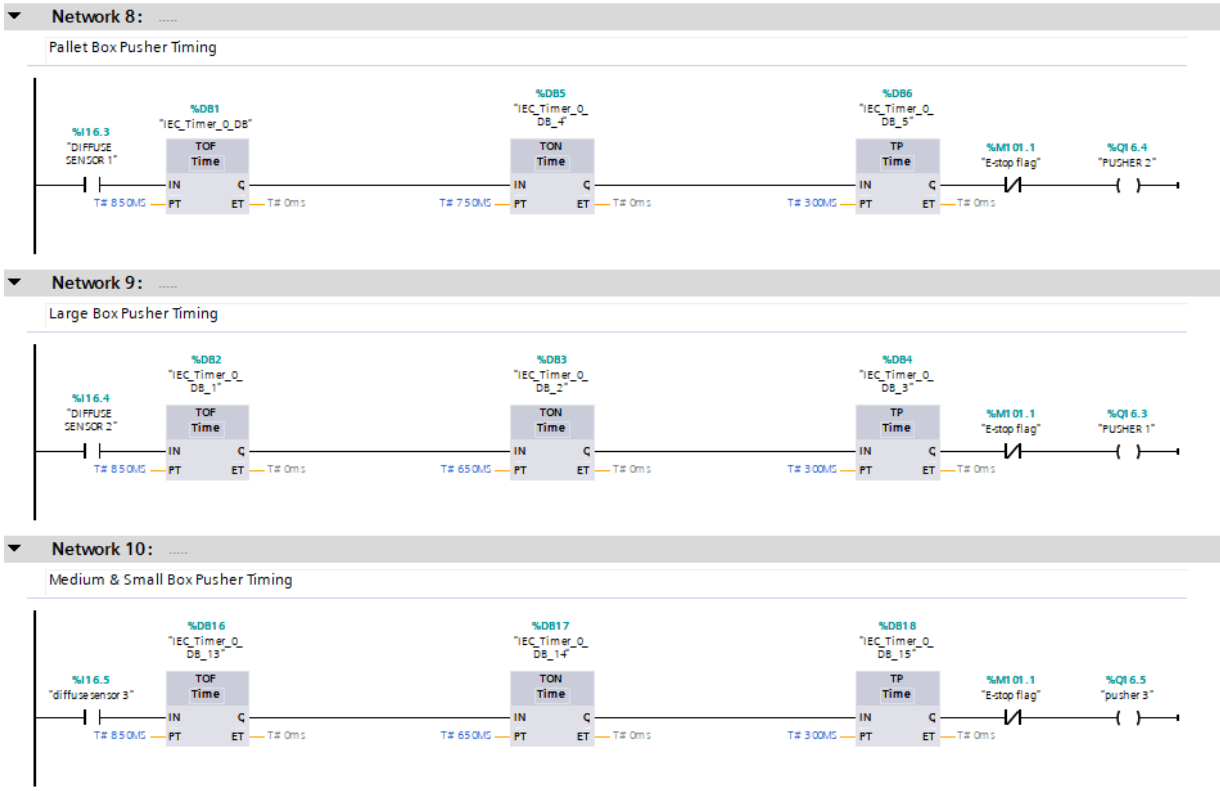


Figure 34 - Ladder Logic Networks 8, 9, & 10

Network 11

This rung includes counters for the production output of each type of box as well as for total production output. The inputs are from diffuse sensors located at the ends of the final conveyors, which are contacted once each box is sorted. There is an input from an HMI button for resetting the production counts, which links to the 'R' inputs on all counters to reset them.

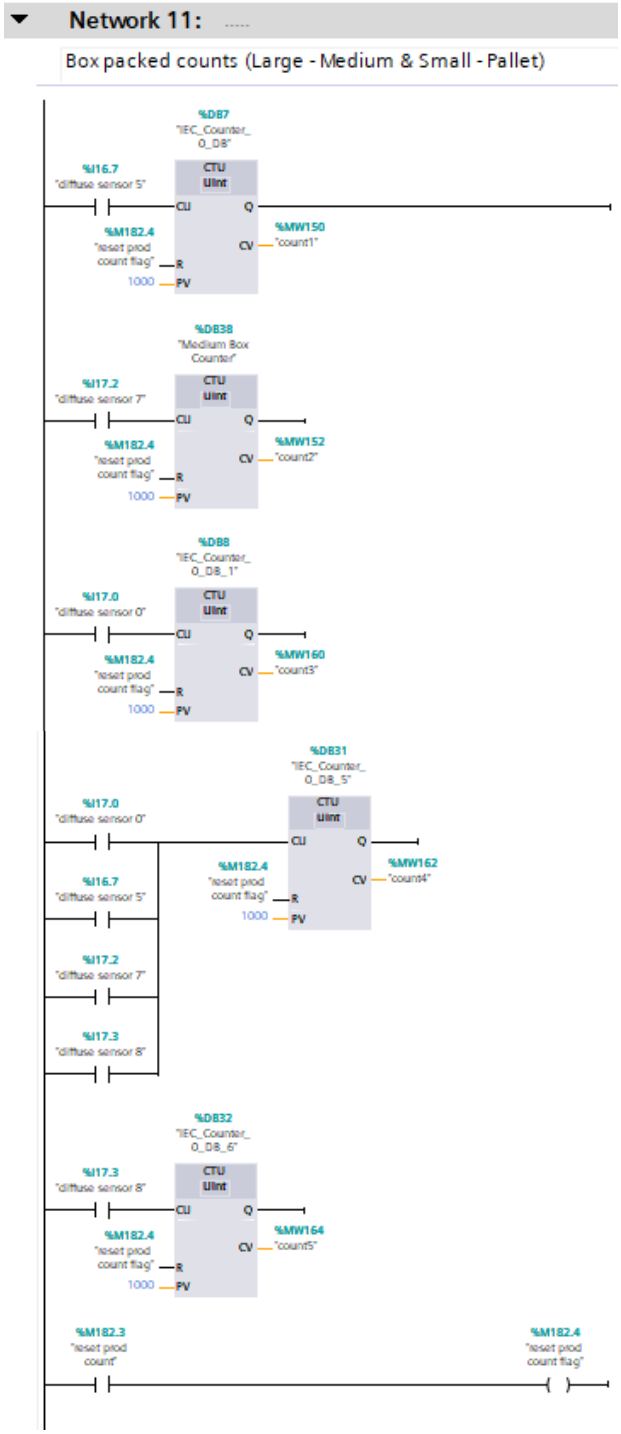


Figure 35 - Ladder Logic Network 11

Network 12

This rung includes a CTUD counter for counting total boxes in process which counts up with the input from the diffuse sensor mounted near the box emitter. The counter then counts down with each diffuse sensor, mounted at the ends of each final sorted conveyor. This is resetted via a signal from the HMI's 'reset error count' button.

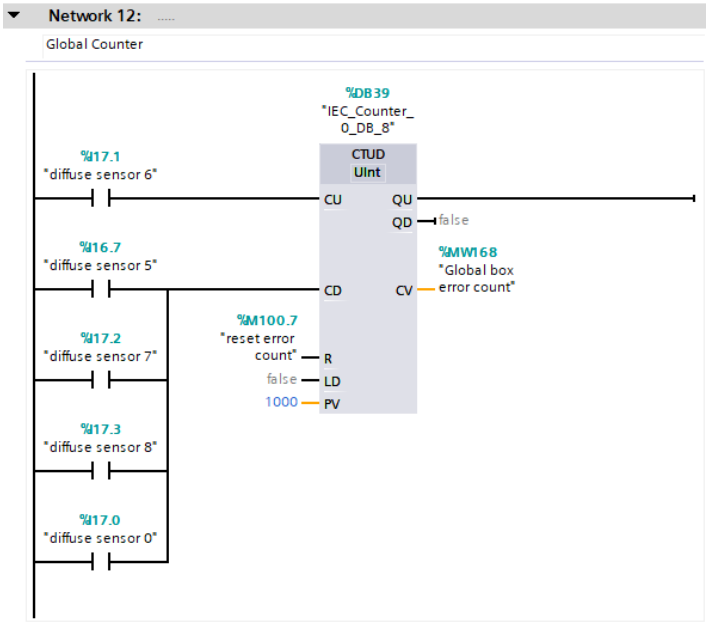


Figure 36 - Ladder logic Network 12

Network 13

This rung generates the flags for warnings, master alarm, and the alarm flag. A <> comparator set to 'byte' has been used to receive inputs from all warning and alarm signals.

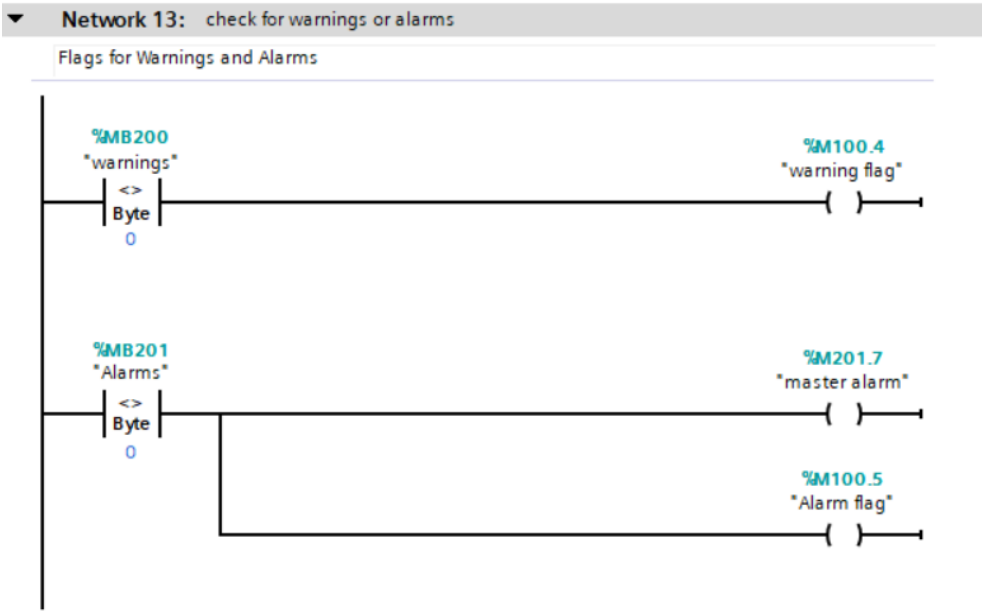


Figure 37 - Ladder Logic Network 13

16		warning 0	Default tag table	Bool	%M200.0
17		warning 1	Default tag table	Bool	%M200.1
18		Warning 2	Default tag table	Bool	%M200.2
19		warning 3	Default tag table	Bool	%M200.3
20		warning 4	Default tag table	Bool	%M200.4
21		warning 5	Default tag table	Bool	%M200.5
22		warning 6	Default tag table	Bool	%M200.6
23		warning 7	Default tag table	Bool	%M200.7
24		warnings	Default tag table	Byte	%MB200

Figure 38 - Warning PLC Tags & Warning Byte Tag

Network 14

This rung utilizes a TON timer switched by the scales box sensor to pause the conveyor once a box is on the conveyor, helping to take an accurate weight reading. The TP timer then sets the conveyor output on to switch the conveyor back on. The R (reset) scale output stops the conveyor, and the S (set) starts the conveyor back up. The 'ready' output tells the conveyor to provide a weight output for the PLC to read.

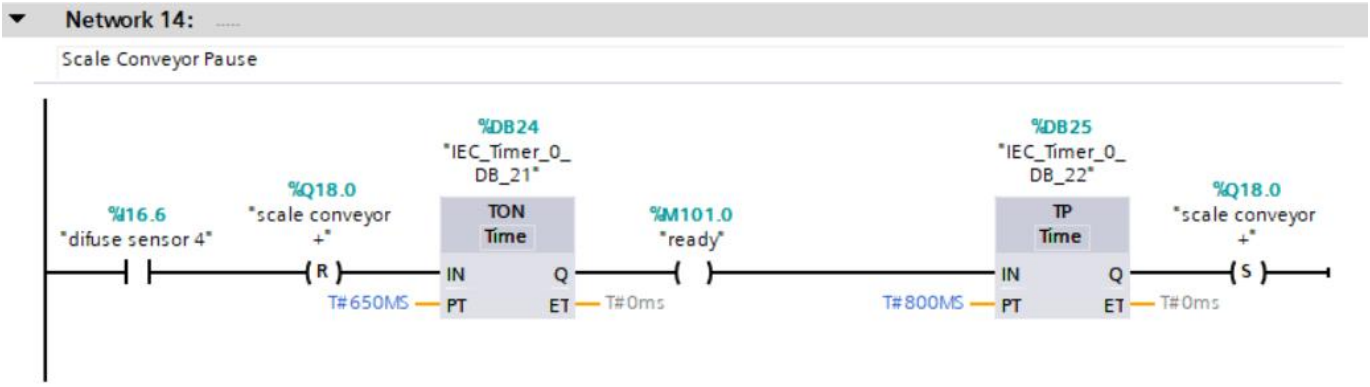


Figure 39 - Ladder Logic Network 14

Network 15

This network takes the 'ready' signal from network 14, and moves the conveyor scale's weight to the three displays on the conveyor, panel, and the HMI.

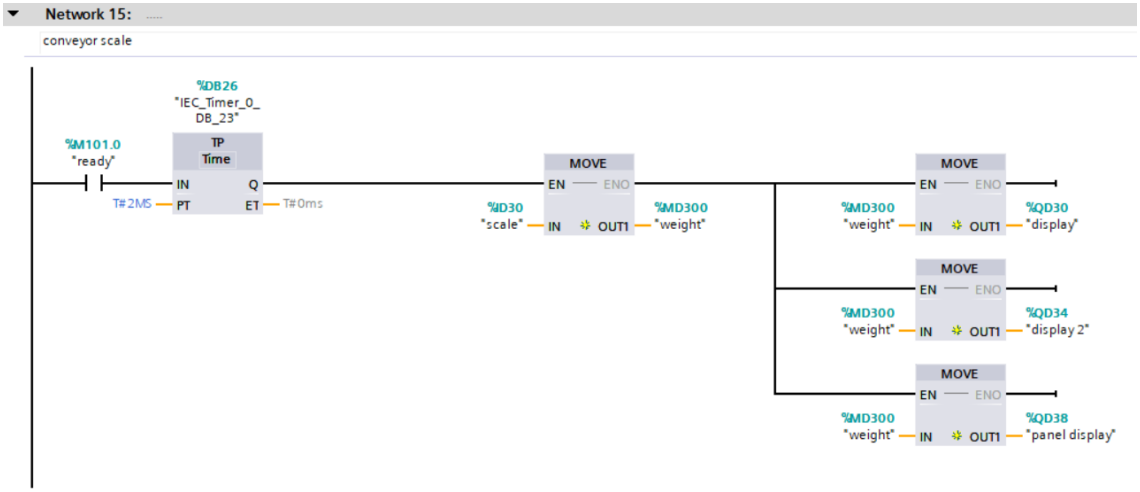


Figure 40 - Ladder Logic Network 15

Network 16

Network 16 controls whether the box is directed right or left, depending on the weight being 5kg or 4kg. Comparator inputs direct the weight signal to the pop up outputs for either left or right, with resets to prevent the opposite direction.

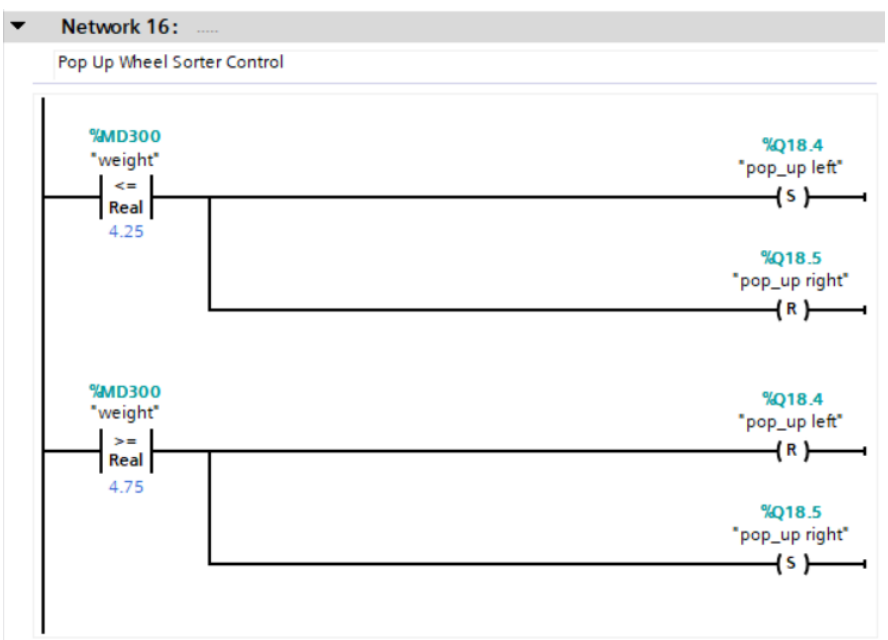


Figure 41 - Ladder Logic Network 16

Network 17

This is for including a count for boxes lost from the process, so that the process can stop automatically once a threshold has been met. Comparators for detecting when the box count increases above the amount set on the HMI, for either a warning or an alarm output.

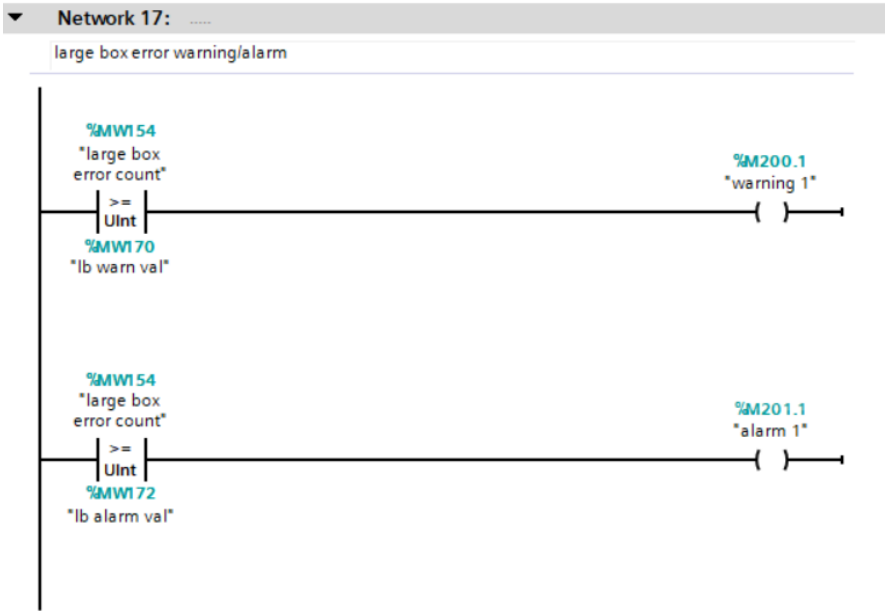


Figure 42 - Ladder Logic Network 17

Network 18

Identical to network 17, but for medium boxes.

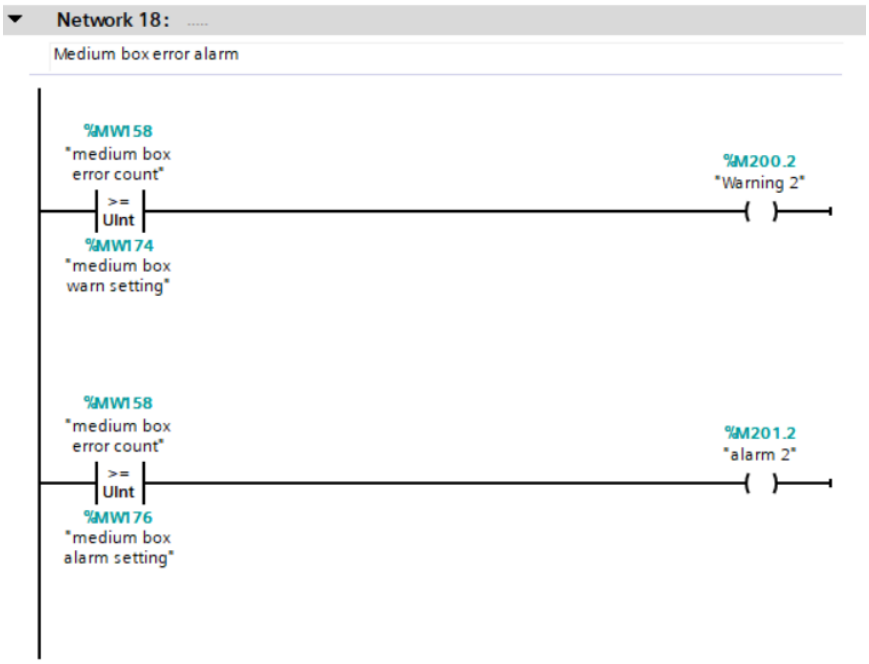


Figure 43 - Ladder Logic Network 18

Network 19

Identical to networks 17 and 18, but for the pallet boxes.

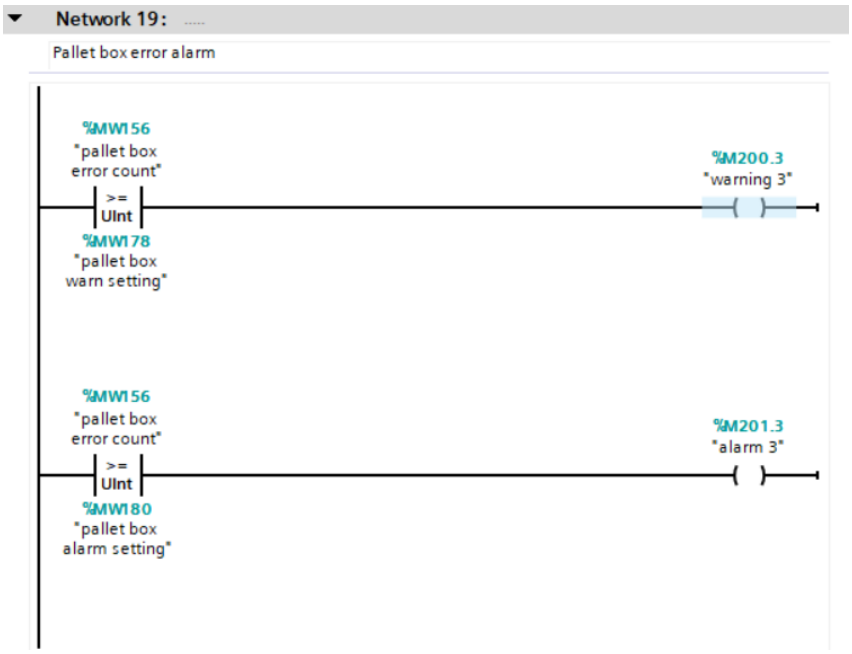


Figure 44 - Ladder Logic Network 19

Network 20

Identical to networks 17, 18, and 19, but for boxes lost within the whole process.

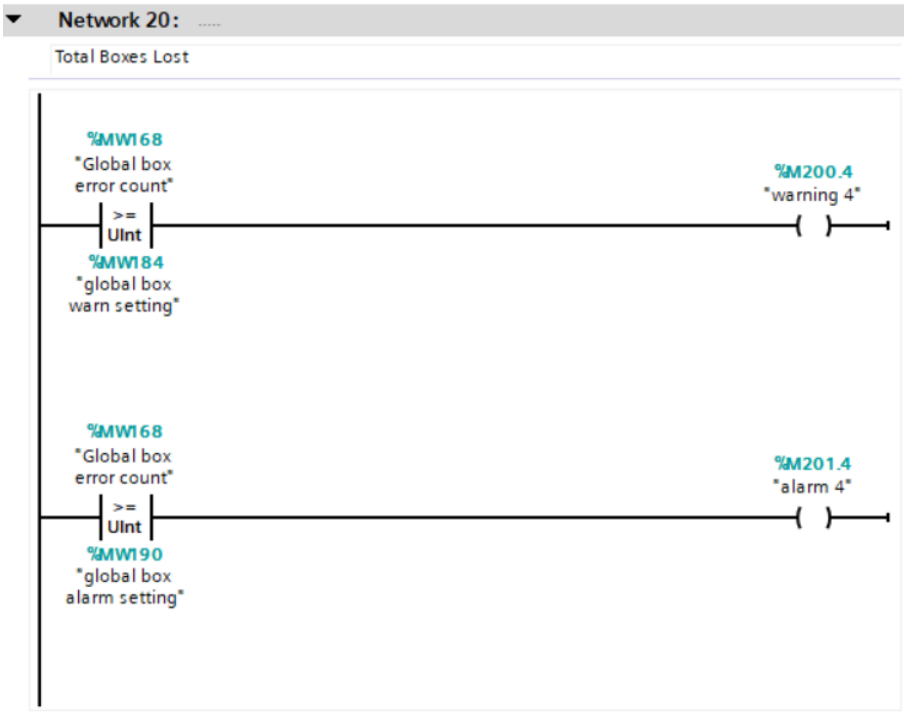


Figure 45 - Ladder Logic Network 20

Network 21

This counts the pallet boxes in progress from the pusher sensor to the remover sensor, and signals to the comparator to monitor the count.

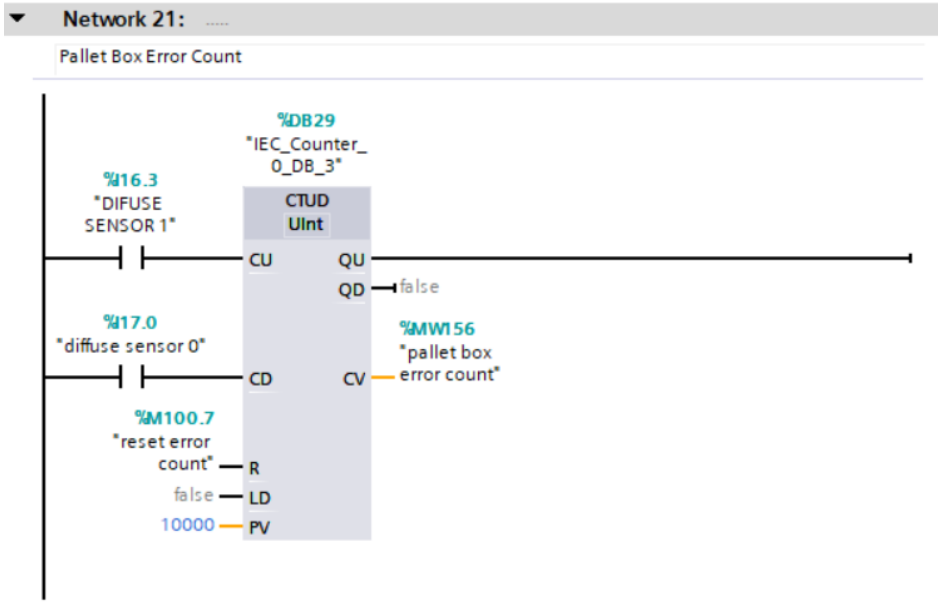


Figure 46 - Ladder Logic Network 21

Network 22

Identical to network 21 but for large boxes.

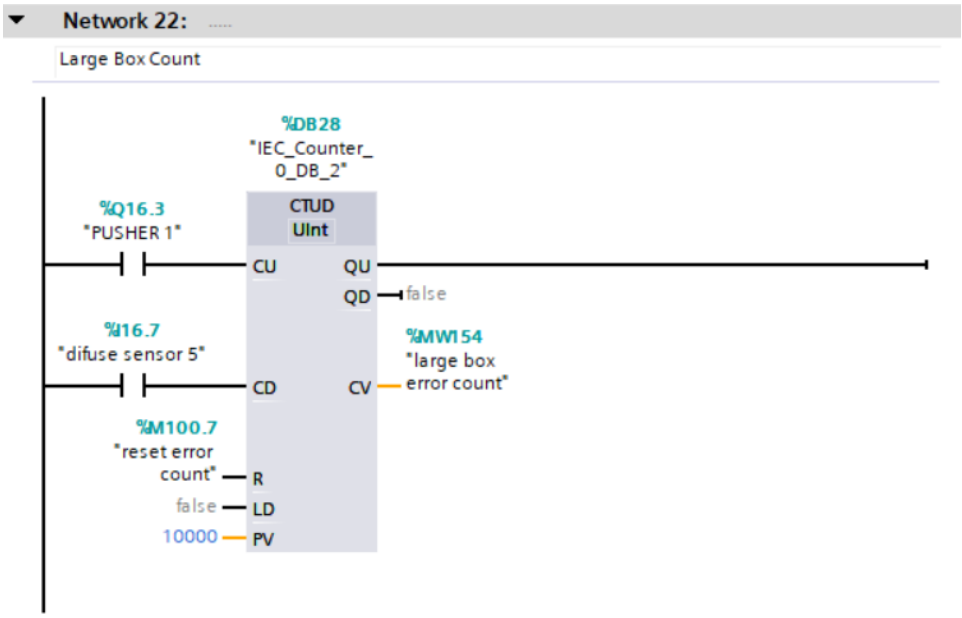


Figure 47 - Ladder Logic Network 22

Network 23

Identical to networks 21 and 22 but for counting the medium and small boxes, so two diffuse sensor inputs.

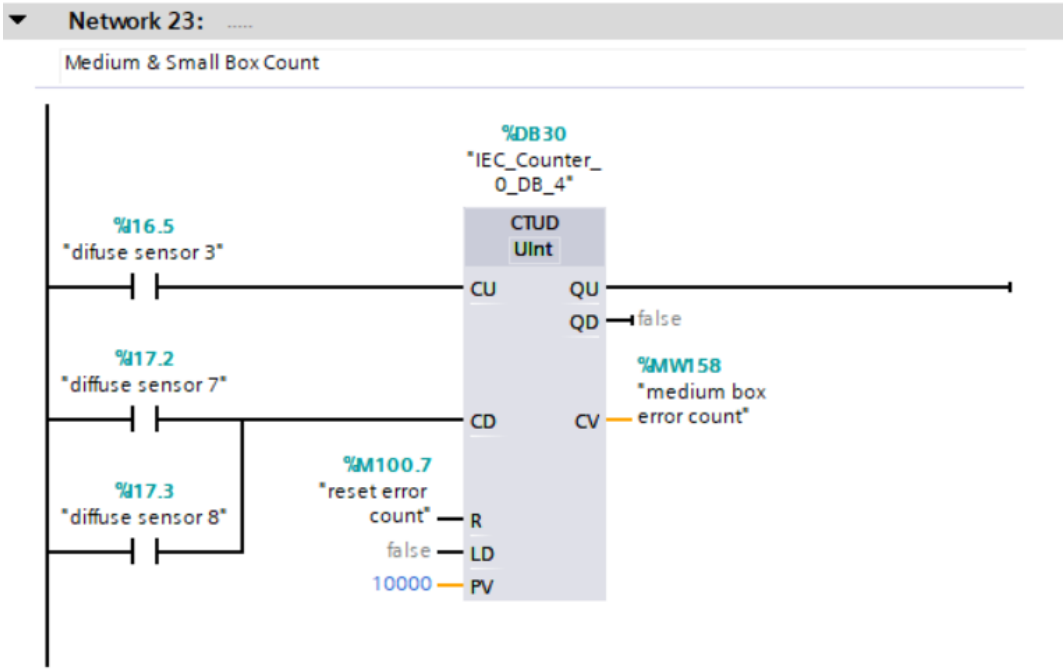


Figure 48 - Ladder Logic Network 23

Network 24

This shows the outputs for the red and green stack lights. The signal from the first conveyor is used with either a NO or NC input.

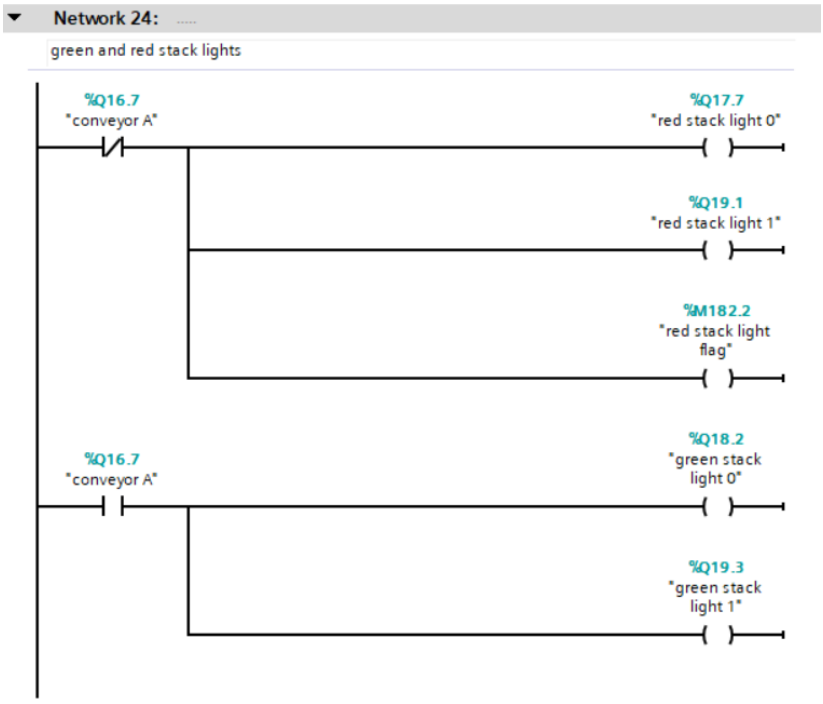


Figure 49 - Ladder Logic Network 24

Network 25

This rung controls the amber stack lights. This light will operate with either the siren flag, or the flashing amber stack light flag from network 27.

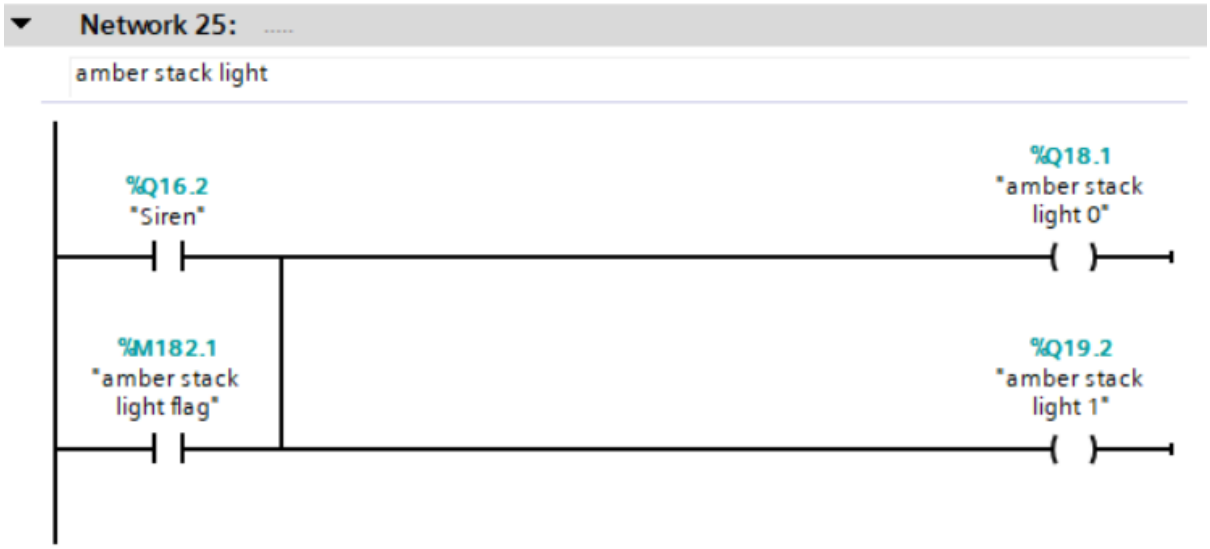


Figure 50 - Ladder logic Network 25

Network 26

This rung controls the panel warning lights and external red warning lights. The alarm flag and e-stop flag switch the panel alarm light, external warning lights, and the siren. The warning flag switches the panel warning light.

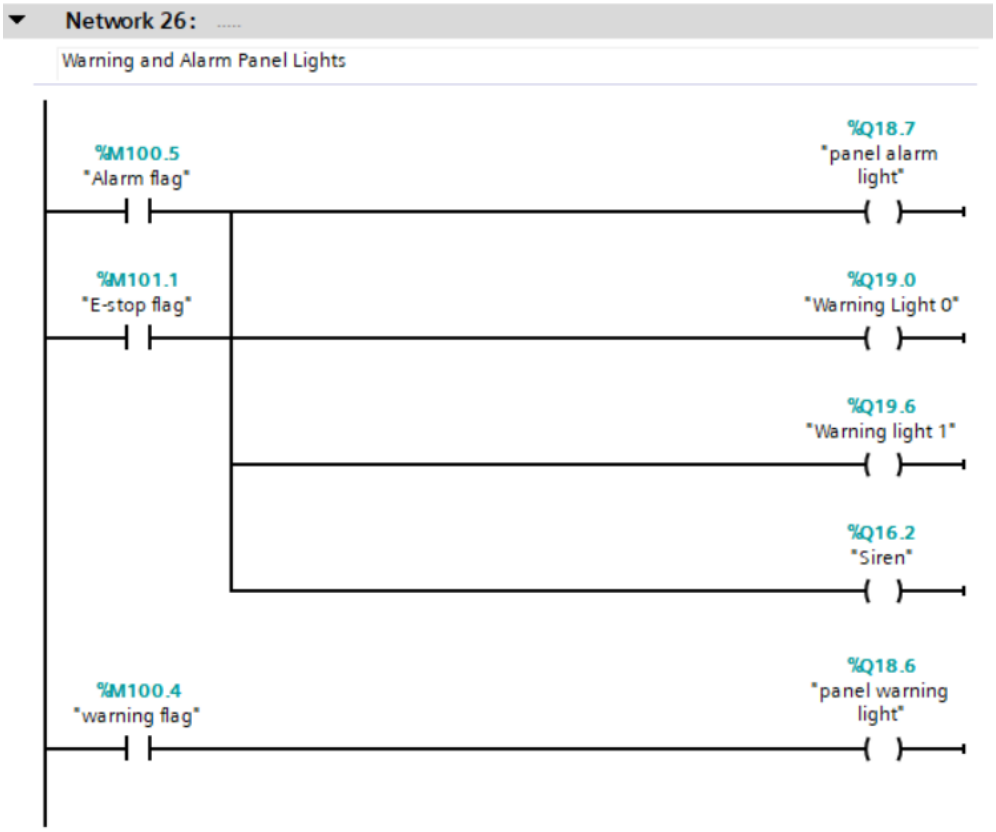


Figure 51 - Ladder Logic Network 26

Network 27

This network introduces a blinking output to the amber stack lights when an alarm or warning flag is active. Two TON timers with inversely linked NO and NC inputs connected to the IN connections, allow them to alternate every 0.5 seconds, to switch the bottom NO contact and amber light flag on and off.

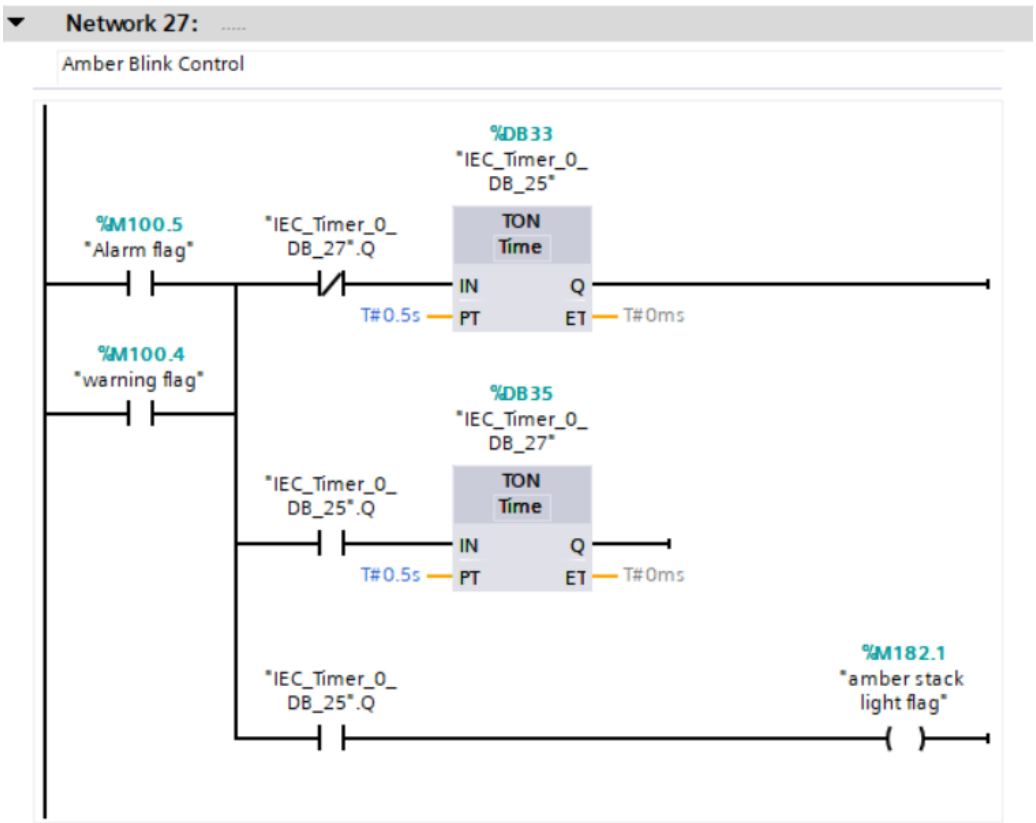


Figure 52 - Ladder Logic Network 27

8. HMI Panel Design

For operators to control the process, view current warning and alarms, as well as allow maintenance to inspect and reset the counters, a HMI is required. There are three screens, including a main root screen, alarms screen, and an engineering screen. The HMI was located on the panel just left to the main control panel.

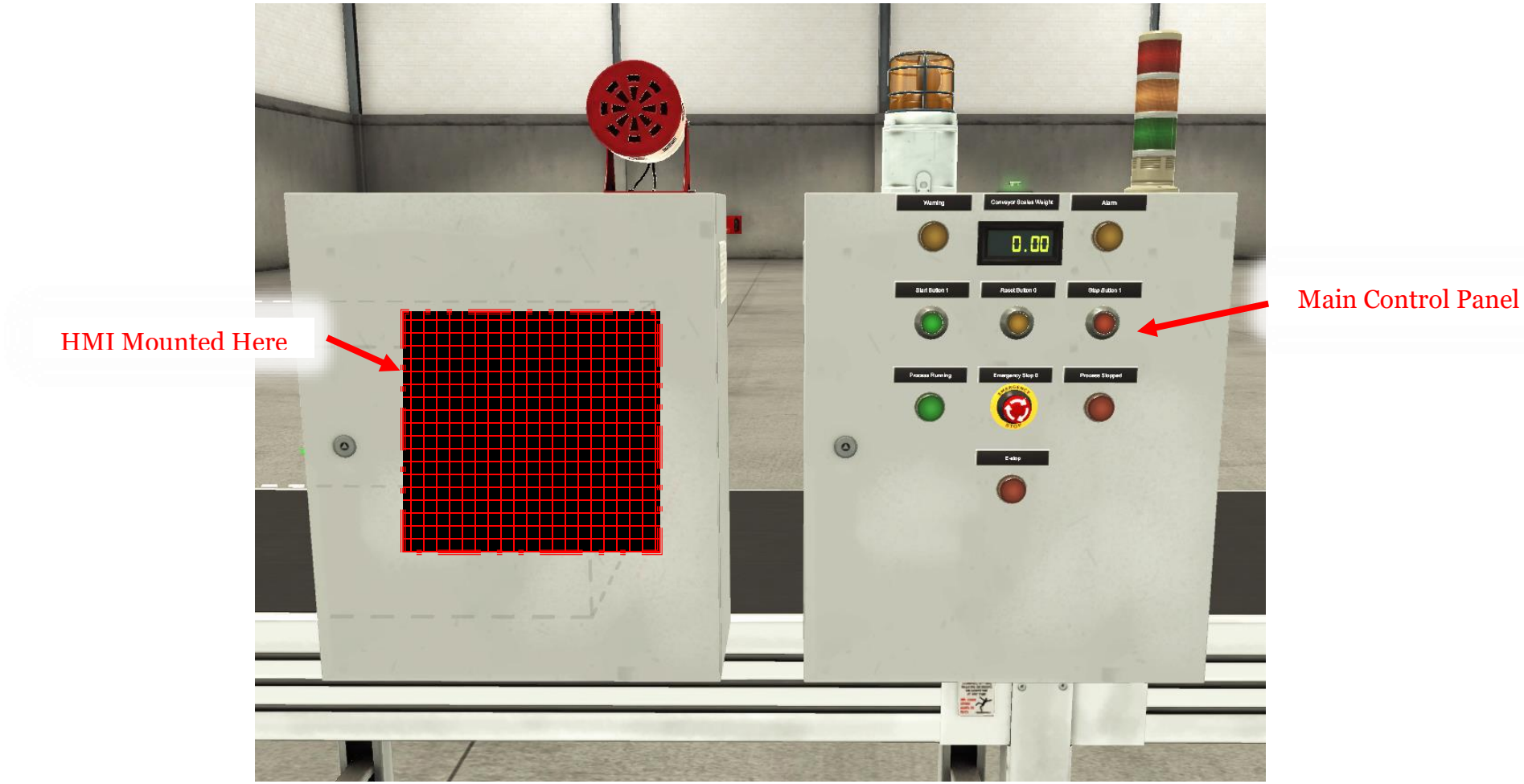


Figure 53 - HMI Location in the Process

8.1. Root Screen

The root screen shown in figure 54 is the main page for the operator to have access to for controlling the process.

- The productions counts are on the left with the live weight of the medium or small box shown. At the center is a button to reset the production counts. These are taken from the counters shown in network 11.
- Above is an indicator for when an e-stop has been pressed.
- A replica of the stack lights on the right. Uses the conveyor output for green and red, and the alarm flag for amber, with the blink timers.
- At the center are the start, stop and reset buttons.
- The reset button is used to reset the e-stop flag. The process will not start if an e-stop flag is active and the reset has not been pressed. Below is an emergency stop button.
- Bottom right are indicator lights for when an alarm or warning flag is active.
- Two screen select buttons to navigate the HMI screens.

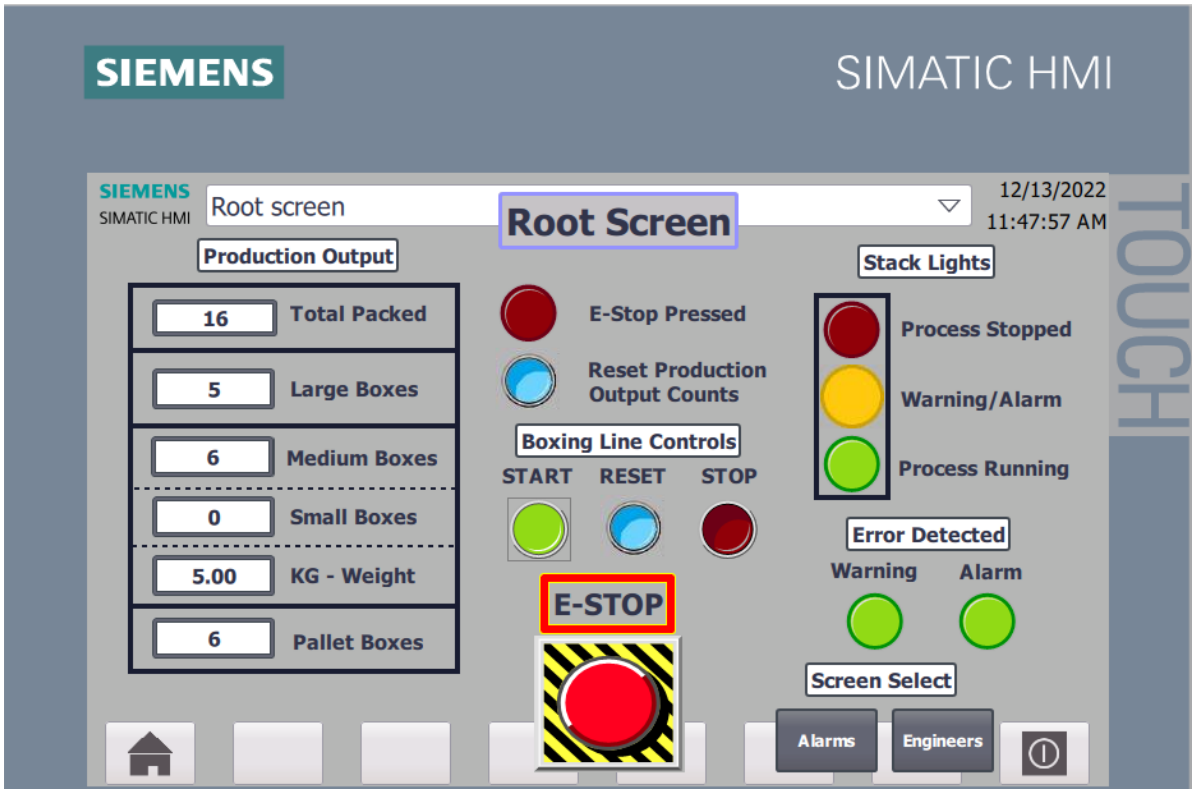


Figure 54 - HMI Root Screen

8.2. Alarm Screen

The alarms screen shown in figure 55 allows an operator to check what part of the process is flagging a warning or alarm signal.

- The box error warnings and alarms are set on the engineer screen, and are activated by the counters in networks 21, 22, and 23.
- E-stop at the bottom.
- Buttons at the bottom for navigation between screens.

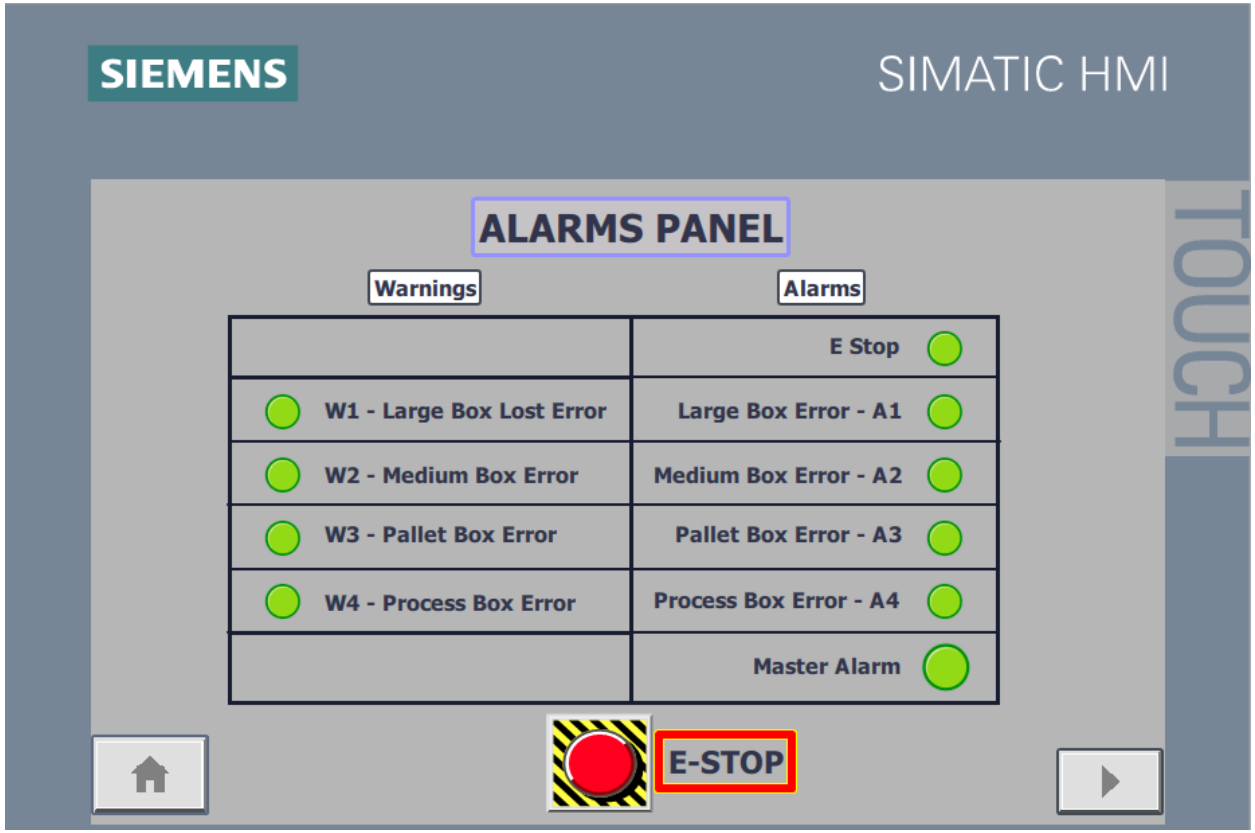


Figure 55 - HMI Alarm Screen

8.3. Engineer Screen

The engineer screen shown in figure 56 allows maintenance or team leaders to set the counts for when the PLC will provide a warning or alarm flag, in the event that boxes are lost from the process. These adjustable counts are on the left.

- The amount of boxes currently in progress are shown on the right.
- Medium includes medium and small boxes as they both travel along the same conveyor before being sorted.
- At the top right are indicator lights for when the pushers are either forward or back, which aids maintenance with fault finding. Master reset resets all warnings and alarms.
- Emergency stop button is at the bottom.
- The master reset will reset all warnings and alarms, as long as the cause has been removed.
- The reset count button will drop all four counts to 0.
- At each bottom corner there are navigation buttons to return to root or alarm screens.

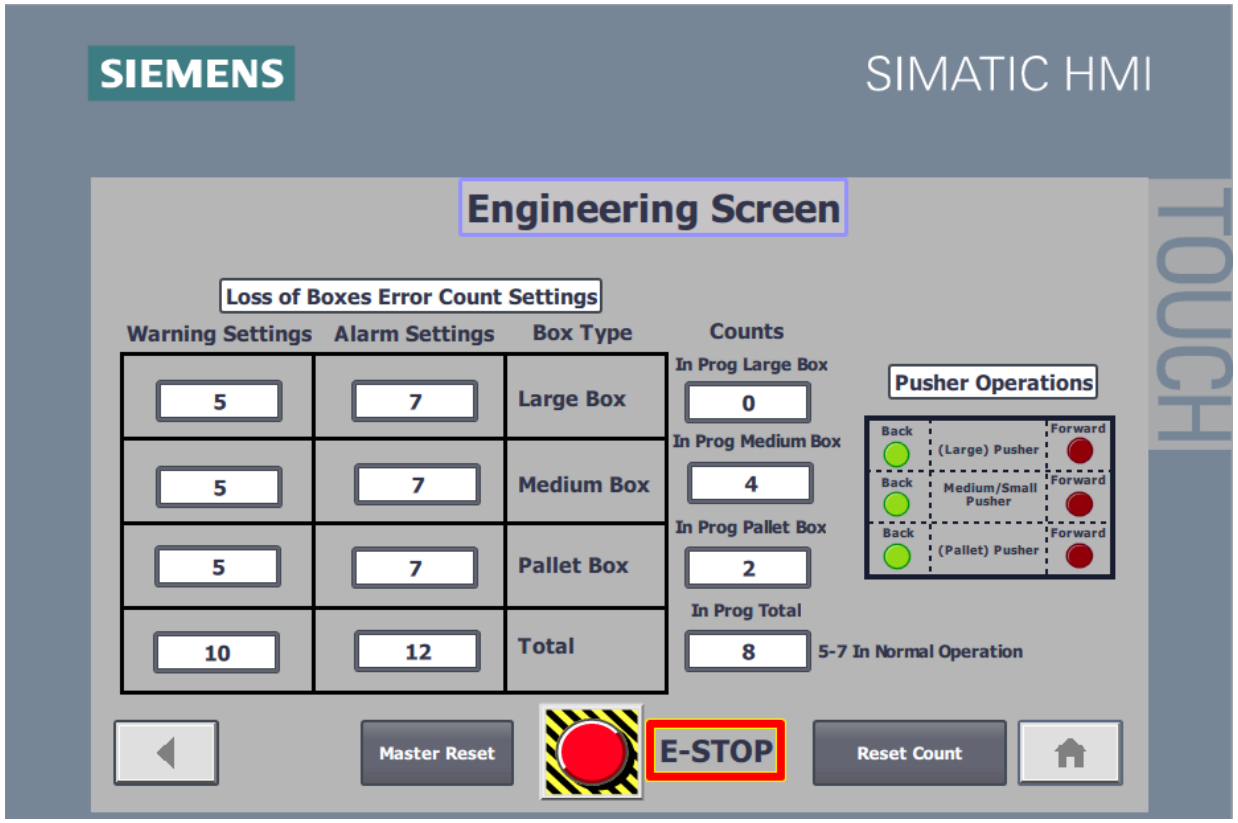


Figure 56 - HMI Engineering Screen

9. Alarm & Warning Strategy

The process is protected by a number of warnings and alarms for each type of box, which are programmed into the PLC. The warnings will cause the amber stack light and panel warning light to light up to warn operators of an issue. The alarms will stop the process, then cause the siren to sound, light up the red stack lights, light up the alarm light on the control panel, as well as light up the larger warning lights.

Pressing an e-stop will cause an alarm to operate and the process will stop. The process will then only restart once the reset button is pressed on the root screen.

The engineering screen features the maximum box error settings functions. These allow an engineer to set the maximum permittable values of lost boxes for warnings and alarms. Once the warning setting is exceeded, the warning light will operate to notify the operator, but the process will continue. Once the alarm setting is exceeded, the process will stop and the alarm signal will be shown. An engineer must be called to access the engineer screen, and press the 'master reset' button, which is shown in figure 56. The current count is shown in the 'in prog' box in figure 57.

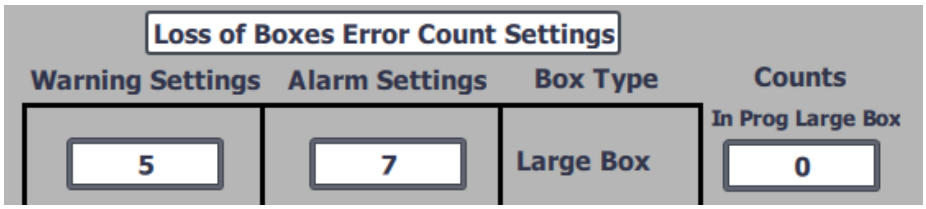


Figure 57 - Close-up View of Warning/Alarm Settings

All boxes are added as they enter the process, and subtracted once they exit as required. If a box is lost, the number will not subtract and will increase towards the numbers set. Therefore, the maximum permittable box settings will result in a warning or alarm is adjustable via the boxes on the left of figure 57. Figure 58 illustrates the box counting process.

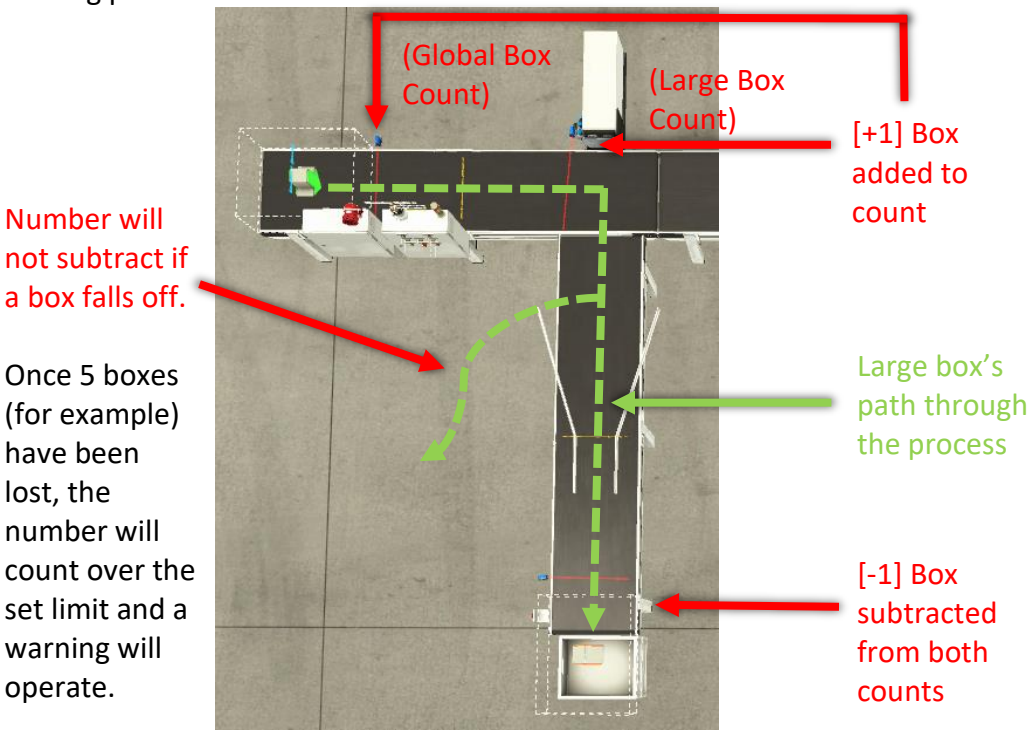


Figure 58 - Illustration of Lost Box Monitoring System

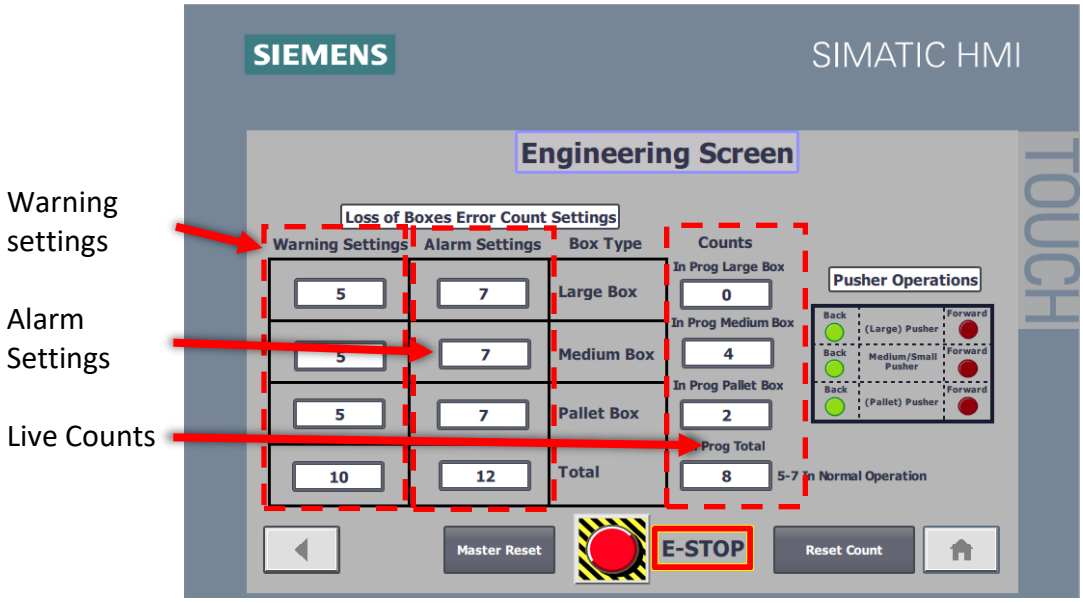


Figure 59 – Illustration of Different Settings on the HMI Engineering Screen

Figure 59 shows where the different settings are located with the live counts next to them.

10. Process Operational Flow Chart

The flow chart shown in figure 60 illustrates the box sorting process from emitting of the random box, to removal of the sorted box.

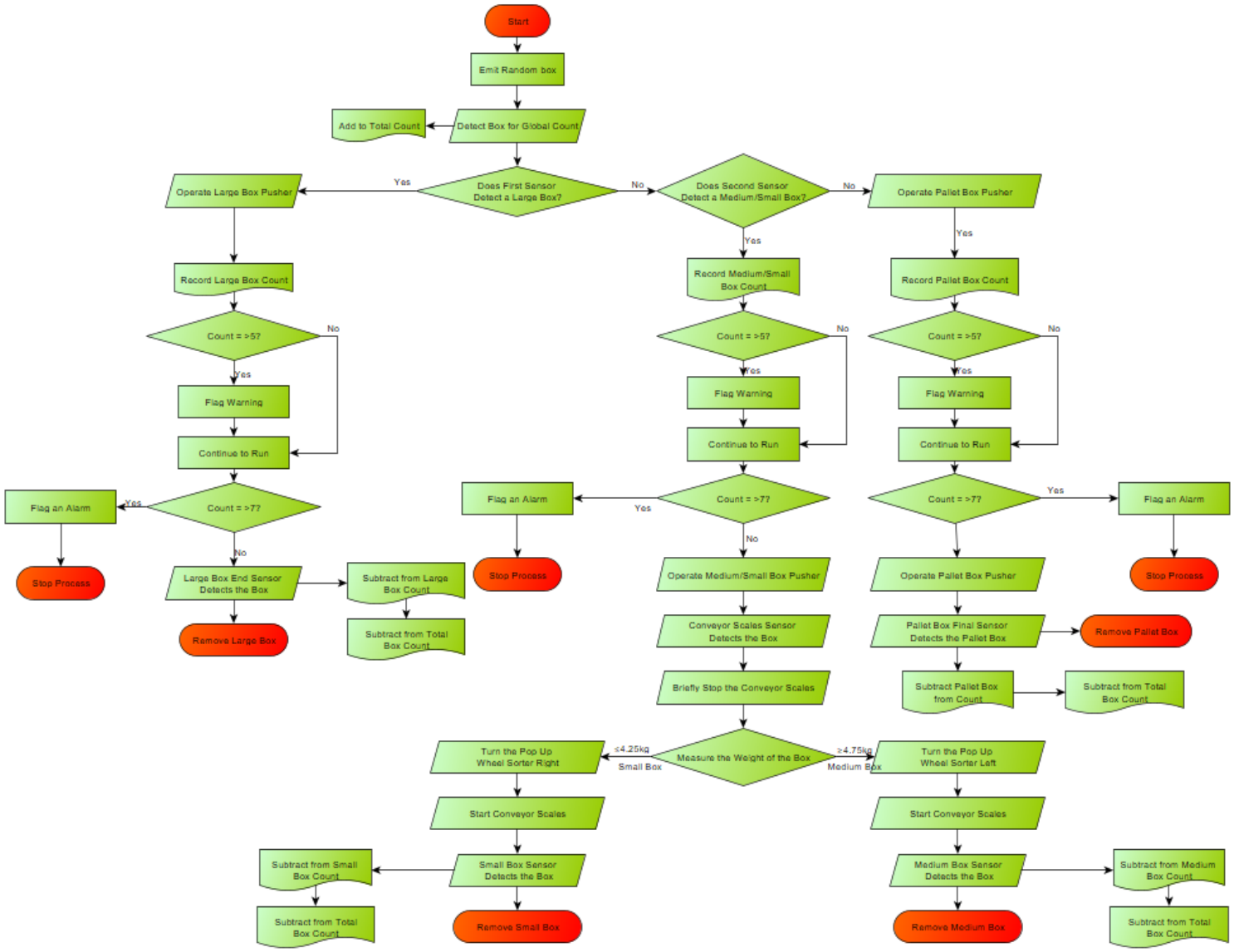


Figure 60 - Process Operational Flow Chart

11. Conclusion

To conclude, the factory process that was produced in Factory IO, effectively sorted all four variations of boxes that were emitted into the process for them to be removed individually. Figure 61 shows the completed process.

The following aspects of the process functioned successfully:

1. Pushers and sensors detected the box dimensions to send them to separate conveyors. This split the boxes into three groups, large, medium/small, and pallet boxes.
2. Medium and small boxes were separated by measuring their weight and splitting them via a pop up wheel sorter.
3. Any boxes lost from the process were detected by the warning and alarm counter system, with the count being set by an operator/engineer.
4. E-stops were easily accessible and halted the process.
5. Process could be controlled via the panel buttons, or the HMI.
6. Stack lights in the process and the HMI displayed the current status of the process.
7. Conveyors drove the boxes around the process in a neat manner.

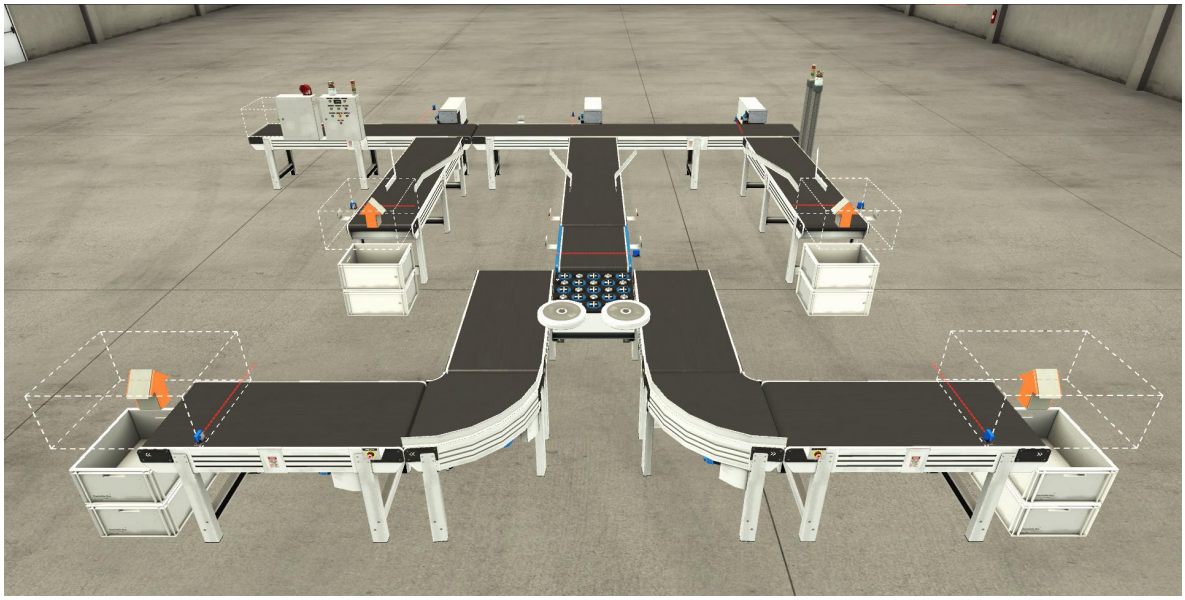


Figure 61 - Completed Box Sorting Process - Factory IO

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