

Factory Control Assignment

**Control Technology
(ACMA6001)**

David Adams 1908506

Table of Contents

Table of Contents.....	2
Table of Figures	5
1 Introduction	6
2 Literature Review	7
2.1 Siemens SIMATIC S7-1500	7
2.2 Allen-Bradley ControlLogix 1756-L71	7
2.3 Mitsubishi Electric MELSEC Q Series	8
2.4 Omron Sysmac NX7	9
2.5 Schneider Electric Modicon M340	9
2.6 Siemens SIMATIC S7-1200	10
2.7 Beckhoff CX5140	11
2.8 Pros/Cons Table	12
2.9 Score Matrix.....	14
2.10 Technical Specifications.....	15
3 Operational Flow Chart	17
4 Ladder Logic Program.....	21
4.1 Network 1: Connection to Factory IO	21
4.2 Network 2: Sequence Start Conditions.....	21
4.3 Network 3: Sequence Start Warning	21
4.4 Network 4: Conveyor start time delay sequence	21
4.5 Network 5: Conveyors.....	21
4.6 Network 6: Pushers.....	21
4.7 Network 7: Light Stacks	21
4.8 Network 8: Weigher 1 Part present	22
4.9 Network 9: Convert Weigher 1 Value	22
4.10 Network 10: Determine Weigher 1 Weight	22
4.11 Network 11: Weigher 2 Part Present.....	22

4.12	Network 12: Convert Weigher 2 Value	22
4.13	Network 13: Determine Weigher 2 Weight	22
4.14	Network 14: In count	22
4.15	Network 15: WIP Count	23
4.16	Network 16: Out Count	23
4.17	Network 17: Warnings.....	23
4.18	Network 18: Alarms.....	23
4.19	Network 19: Check Counters	23
4.20	Network 20: Defaults.....	23
4.21	Network 21: LCD Displays	24
5	Alarm/Warning Strategy	24
5.1	Error Checking.....	24
5.2	Warnings	25
	Warnings 1, 2, 3 and 4 - Package did not complete traverse for each size / Lost package counter for each package size.	25
	Warnings 5, 6, 7 and 0 - Counter warning number exceeded for each counter.	25
5.3	Alarms	27
	Alarm Master - Emergency Stop activated.	27
	Alarms 0,1,2,3 and 4 - Max lost package alarm number exceeded for each sorter.....	28
	Alarm 5 - Counter alarm number exceeded for each counter/sorter.	28
	Alarm 6 – Weigher 2 overweight	28
6	Conclusion	31
6.1	Major challenges.....	31
6.2	Troubleshooting	32
6.3	Improvements	35
6.4	Summary	36
7	Bibliography	37
8	Appendices	39

8.1	Appendix 1: Ladder Logic Program – Project 7.pdf	39
-----	--	----

Table of Figures

Figure 1 - Siemens S7-1500 [11]	7
Figure 2 - Allen-Bradley ControlLogix 1756-L71 [13]	7
Figure 3 - Mitsubishi Electric MELSEC Q Series [14]	8
Figure 4 - Omron Sysmac NX7 [15]	9
Figure 5 - Schneider Electric Modicon M340 [16]	9
Figure 6 - Siemens Simatic S7-1200 [12]	10
Figure 7 - Beckhoff CX5140 [17]	11
Figure 8 - Operational Flow Chart pt.1	17
Figure 9 - Operational Flow Chart pt.2	18
Figure 10 - Operational Flow Chart pt.3	19
Figure 11 - Operational Flow Chart (complete).....	20
Figure 12 - Error Checking Ladder Logic.....	24
Figure 13 - Warnings 1.....	26
Figure 14 - Warnings 2.....	27
Figure 15 - Alarms 1.....	29
Figure 16 - Alarms 2.....	30
Figure 17 - Alarms 3.....	30
Figure 18 - Alarms 4.....	31
Figure 19 - WIP and OUT counters displayed on HMI.....	32
Figure 20 - Trace of diffuse sensors during cycle	32
Figure 21 - Previous OUT count logic	33
Figure 22 - Improved OUT count logic 1.....	34
Figure 23 - Improved count logic 2	35

1 Introduction

Industrial control technology plays a crucial role in modern manufacturing processes, enabling the automation and optimization of various operations. Programmable Logic Controllers (PLCs) have emerged as key components in industrial automation, offering flexible and reliable control solutions for complex systems. This report aims to provide a comprehensive analysis of different PLC models and their suitability for autonomously controlling a system that sorts four different packages based on size and weight.

The sorting of packages based on size and weight is a common task in manufacturing and logistics industries, where efficiency and accuracy are paramount. By implementing an autonomous sorting system, manufacturers can streamline their operations, reduce labour costs, and enhance productivity. PLCs offer the necessary functionality and flexibility to manage such intricate tasks, making them an ideal choice for controlling the sorting process.

In this report, I will explore and evaluate several PLC models commonly used in industry, focusing on their capabilities, features, and suitability for autonomous sorting applications. The selected PLCs will be assessed based on their performance, scalability, ease of programming, integration options, and cost-effectiveness. By understanding the strengths and weaknesses of each PLC, I aim to provide insights into possible options when looking to autonomously control an industrial system for sorting packages based on size and weight.

Throughout the report, I will rely on a combination of academic research, industry publications, and technical documentation to support the analysis and findings. By the end of this report, readers will have a comprehensive understanding of different PLC models and their potential applications in industrial automation.

To summarise, the integration of PLC technology in industrial automation has revolutionized the way manufacturing processes are controlled and optimized. By examining the capabilities of various PLC models, this report aims to provide valuable insights into the selection and implementation of a suitable controller for autonomously sorting packages. With the right PLC in place, manufacturers can achieve enhanced efficiency, accuracy, and productivity in their sorting operations, contributing to overall process optimization. Additionally, the integration of PLC technology has also led to improved safety measures in industrial automation. PLCs can detect potential hazards and take immediate corrective actions, ensuring the well-being of workers and preventing accidents. Moreover, PLCs offer real-time data monitoring and analysis, allowing manufacturers to identify bottlenecks, optimize production schedules, and make informed decisions for continuous improvement. The advancements in PLC technology have truly transformed the manufacturing industry, providing a solid foundation for efficient and streamlined operations.

2 Literature Review

2.1 Siemens SIMATIC S7-1500



This is a high-performance PLC with advanced features. It offers a wide range of modules and communication options, making it suitable for complex automation systems. The integrated safety functionality and scalability are notable advantages of this PLC. However, the high initial cost can be considered a drawback.

Figure 1 - Siemens S7-1500 [11]

- Performance: The SIMATIC S7-1500 offers advanced features and high processing power, enabling efficient and reliable control in complex systems.
- Scalability: It provides scalability options with various modules and expansion capabilities, allowing flexibility for future system expansions.
- Ease of Programming: Siemens TIA Portal software provides a user-friendly programming environment with powerful tools and libraries.
- Integration Options: The SIMATIC S7-1500 offers extensive communication options, allowing seamless integration with other devices and systems.
- Cost-Effectiveness: The initial cost of the SIMATIC S7-1500 can be higher compared to some other PLC models, but its performance and features justify the investment for large-scale applications.

2.2 Allen-Bradley ControlLogix 1756-L71



Figure 2 - Allen-Bradley ControlLogix 1756-L71 [13]

This is a popular PLC from Rockwell Automation. It provides excellent scalability, flexibility, and high-speed processing capabilities. The compatibility with various programming languages and extensive range of modules are key strengths of

ControlLogix 5580 controllers. On the downside, the cost of the hardware and software licenses can be relatively high.

- **Performance:** ControlLogix 1756-L71 offer high-performance capabilities and are well-suited for demanding control applications.
- **Scalability:** These PLCs are highly scalable, allowing for easy expansion and integration of additional modules and devices.
- **Ease of Programming:** The Rockwell Automation software suite provides a range of programming options, including ladder logic and structured text, catering to diverse programming preferences.
- **Integration Options:** ControlLogix 1756-L71 PLCs support various communication protocols, enabling seamless integration with different devices and systems.
- **Cost-Effectiveness:** The cost of Allen-Bradley ControlLogix 5580 hardware and software licenses can be higher compared to some other PLC brands, making it more suitable for larger-scale applications.

2.3 Mitsubishi Electric MELSEC Q Series



Figure 3 - Mitsubishi Electric MELSEC Q Series [14]

The Q Series PLCs by Mitsubishi Electric are known for their reliability and robustness. They offer excellent motion control capabilities and support various communication protocols. The modular design and high-speed processing contribute to its performance. However, the programming software can be less user-friendly compared to other PLCs.

- **Performance:** MELSEC Q PLCs are known for their reliability, robustness, and excellent motion control capabilities, ensuring precise control in industrial environments.
- **Scalability:** These PLCs offer scalability options, allowing for easy expansion and integration of additional modules and devices.
- **Ease of Programming:** Mitsubishi Electric provides programming software with a comprehensive set of tools, though it may have a steeper learning curve for beginners.
- **Integration Options:** The MELSEC Q series provides various communication options for seamless integration with different devices and systems.

- **Cost-Effectiveness:** Mitsubishi Electric MELSEC Q PLCs offer a good balance between performance and cost, making them a cost-effective choice for many applications.

2.4 Omron Sysmac NX7



Figure 4 - Omron Sysmac NX7 [15]

These PLCs are designed for high-speed and high-precision applications. They offer advanced motion control, integrated safety functions, and seamless connectivity with other devices. The programming environment and the ability to handle complex logic are notable advantages of this PLC. However, the initial cost and limited availability of third-party software can be considered as

drawbacks.

- **Performance:** The Sysmac NX7 PLCs offer advanced motion control and safety functions, delivering high-performance control capabilities.
- **Scalability:** These PLCs provide scalability options, allowing for easy expansion and integration of additional modules and devices.
- **Ease of Programming:** Omron provides user-friendly programming software with intuitive interfaces and powerful programming capabilities.
- **Integration Options:** The Sysmac NX7 Series supports various communication protocols, enabling seamless integration with different devices and systems.
- **Cost-Effectiveness:** Omron Sysmac NX7 Series PLCs may have a higher initial cost, but their advanced features and performance justify the investment for complex applications.

2.5 Schneider Electric Modicon M340



Figure 5 - Schneider Electric Modicon M340

[16]

The Schneider Electric Modicon M340 is a versatile midrange PLC suitable for various applications. It offers a wide range of communication options, extensive module selection, and integrated web services for remote monitoring and control. The compact

design and cost-effectiveness are key benefits of this PLC. However, the programming software seems to be less intuitive for beginners.

- **Performance:** The Modicon M340 PLCs offer versatility and extensive communication options, ensuring efficient control and monitoring of industrial processes.
- **Scalability:** These PLCs provide scalability options, allowing for easy expansion and integration of additional modules and devices.
- **Ease of Programming:** Schneider Electric offers user-friendly programming software with a range of programming languages, though it may have a slightly steeper learning curve for beginners.
- **Integration Options:** The Modicon M340 supports a wide range of communication protocols and offers integrated web services for remote monitoring and control.
- **Cost-Effectiveness:** The Modicon M340 PLCs are known for their cost-effectiveness, providing a balance between performance and affordability.

2.6 Siemens SIMATIC S7-1200



Figure 6 - Siemens Simatic S7-1200 [12]

Siemens SIMATIC S7-1200 is a compact and cost-effective PLC suitable for small to medium-scale applications. It offers integrated communication, analogue and digital I/O, and easy programming with the TIA Portal software. The modular design and expandability are notable advantages of this PLC. However, it has limited processing power compared to

higher-end PLCs and may not be suitable for large and complex systems.

- **Performance:** The SIMATIC S7-1200 PLCs offer compact and cost-effective control solutions, suitable for small to medium-sized applications.
- **Scalability:** These PLCs have limited scalability options, making them more suitable for standalone or smaller-scale applications.
- **Ease of Programming:** Siemens provides user-friendly hardware configuration and programming software, simplifying the programming process for beginners.
- **Integration Options:** The SIMATIC S7-1200 supports various communication options, enabling integration with different devices and systems.

- **Cost-Effectiveness:** The SIMATIC S7-1200 PLCs are known for their cost-effectiveness, offering a good balance between performance and affordability for smaller applications.

2.7 Beckhoff CX5140



Figure 7 - Beckhoff CX5140 [17]

Beckhoff CX5140 series is a control system that combines computer-based PLC, motion control, and HMI functionalities. It offers real-time control and programming using the IEC 61131-3 standard. The openness, scalability, and flexibility of CX5140 make it suitable for a wide range of applications. The integration of automation and IT systems is a key strength of Beckhoff PLCs. However, the reliance on PC hardware can introduce potential vulnerabilities and requires regular

maintenance.

- **Performance:** CX5140, being a PC-based control system, offers high-performance capabilities with real-time control and integration of automation and IT systems.
- **Scalability:** CX5140 provides a scalable architecture, allowing for distributed systems and easy expansion as per application requirements.
- **Ease of Programming:** Beckhoff supports various programming languages, but programming CX5140 may have a steeper learning curve for beginners.
- **Integration Options:** CX5140 offers extensive integration options with industrial protocols and interfaces, enabling seamless connectivity with different devices and systems.
- **Cost-Effectiveness:** CX5140's cost-effectiveness can vary dramatically as it relies on PC hardware, which may require regular maintenance and has additional costs associated with PC-based control.

2.8 Pros/Cons Table

PLC	Pro's	Con's
Siemens SIMATIC S7-1500	Advanced features and scalability	High initial cost
	Integrated safety functionality	Complexity of programming
	Extensive module and communication options	Steep learning curve for beginners
	Wide industry acceptance and support	Limited availability of third-party software
Allen-Bradley ControlLogix 1756-L71	Scalability and flexibility	Cost of hardware and software licenses
	Compatibility with various programming languages	Steady migration towards Studio 5000 software
	Extensive range of modules and I/O options	Longer development cycles due to firmware updates
	Strong vendor support and community	Steep learning curve for beginners
Mitsubishi Electric MELSEC Q	Reliability and robustness	Less user-friendly programming software
	Excellent motion control capabilities	Limited availability of training resources
	Wide range of communication protocols	Higher initial cost
	Strong support for process automation	Relatively smaller user community
Omron Sysmac NX7	Advanced motion control and safety functions	Higher initial cost
	Seamless connectivity with other devices	Limited availability of third-party software
	Integrated vision and robotics capabilities	Complex programming syntax for certain functions
	Excellent real-time performance	Limited software compatibility with older models

Schneider Electric Modicon M340	Versatility and extensive communication options	Less intuitive programming software for beginners
	Integrated web services for remote monitoring	Relatively slower processor speeds
	Compact design and cost-effectiveness	Limited availability of advanced features
	Wide range of supported protocols and networks	Potential compatibility issues with third-party I/O
Siemens SIMATIC S7-1200	Compact and cost-effective	Limited processing power for complex systems
	Integrated communication and easy programming	Limited scalability for largescale applications
	User-friendly hardware configuration	Limited support for advanced motion control
	Solid reliability and wide market presence	Restricted number of I/O modules
Beckhoff CX5140	PC-based control with real-time capabilities	Reliance on PC hardware and potential vulnerabilities
	Integration of automation and IT systems	Regular maintenance required
	Wide range of supported programming languages	Steep learning curve for beginners
	Scalable architecture for distributed systems	Higher upfront cost for PC hardware and licenses

2.9 Score Matrix

I have scored the selected PLCs using the manufacturers information and literature, and the reading materials referenced determine a score from 1 to 5 for each category. It is worth noting that my personal experience with these PLCs is limited to Siemens, Allen Bradley and Beckhoff models only, and I believe this is also reflected in my scoring.

PLC Model	Performance	Scalability	Ease of Programming	Integration Options	Cost-Effectiveness	Total
Siemens SIMATIC S7-1500	5	5	4	5	3	22
Allen-Bradley ControlLogix 1756-L71	5	5	3	5	3	21
Mitsubishi Electric MELSEC Q	4	5	3	4	4	20
Omron Sysmac NJ/NX Series	5	4	3	5	3	20
Schneider Electric Modicon M340	3	3	4	4	4	18
Siemens SIMATIC S7-1200	3	4	5	4	5	21
Beckhoff CX5140	4	5	3	5	4	21

2.10 Technical Specifications

<i>PLC Model</i>	<i>Max Digital Inputs</i>	<i>Max Digital Outputs</i>	<i>Max Analog Inputs</i>	<i>Max Analog Outputs</i>	<i>Communication Protocols</i>	<i>Programming Languages</i>	<i>Operating Temperature</i>	<i>Power Supply Voltage</i>
Siemens SIMATIC S7-1500 [1]	65,536	65,536	4,096	4,096	PROFINET, PROFIBUS, Modbus TCP, OPC UA, TCP/IP, ISO-on-TCP/IP, UDP/IP, HTTP, SNMP, FTP, SMTP, MQTT	STEP 7, TIA Portal - ladder diagram (LAD), function block diagram (FBD), structured control language (SCL), and statement list (ST). IEC 61131-3 standard.	-25°C to +60°C (-13°F to +140°F)	24V DC
Allen-Bradley ControlLogix 1756-L71 [2]	128,000	128,000	4,000	4,000	EtherNet/IP, ControlNet, DeviceNet, Modbus TCP, PROFIBUS DP, PROFINET, Data Highway Plus, Remote I/O, DH-485, ASCII, Ethernet/IP	Studio 5000, RSLogix 5000 - ladder diagram (LD), function block diagram (FBD), structured text (ST), sequential function chart (SFC), and instruction list (IL). IEC 61131-3 standard.	0°C to +60°C (32°F to 140°F)	24V DC
Mitsubishi Electric MELSEC	4,096	4,096	4,096	4,096	CC-Link IE Field Basic, CC-Link IE Control, CC-Link, Ethernet/IP,	GX Works2, GX Works3 - ladder diagram (LD), structured text (ST),	0°C to +55°C	24V DC, 100-

Q [3]					<i>Modbus TCP/IP, PROFIBUS-DP, PROFINET</i>	<i>and function block diagram (FBD). IEC 61131-3 standard.</i>	<i>(32°F to 131°F)</i>	<i>240V AC</i>
Omron Sysmac NX7 [4]	8,192	8,192	4,080	4,080	<i>EtherCAT, EtherNet/IP, Modbus TCP, PROFIBUS, PROFINET, DeviceNet, SERIAL, OPC UA, FINS/TCP, FINS/UDP</i>	<i>Sysmac Studio, ladder diagram (LD), structured text (ST), function block diagram (FBD), and sequential function chart (SFC). IEC 61131-3 standard</i>	<i>0°C to +55°C (32°F to 131°F)</i>	<i>24V DC, 100-240V AC</i>
Schneider Electric Modicon M340 [5]	2,048	2,048	64	64	<i>Modbus, Modbus TCP/IP, CANopen, PROFIBUS DP, Ethernet/IP, EtherNet/IP, EtherCAT, Modbus Plus, AS-Interface</i>	<i>Unity Pro - ladder diagram (LD), function block diagram (FBD), structured text (ST), and sequential function chart (SFC). IEC 61131-3 standard.</i>	<i>-25°C to +70°C (-13°F to +158°F)</i>	<i>24V DC, 100-240V AC</i>
Siemens SIMATIC S7-1200 [6]	2,048	2,048	128	128	<i>PROFINET, PROFIBUS, Modbus TCP, OPC UA, TCP/IP, ISO-on-TCP/IP, UDP/IP, HTTP, SNMP, FTP, SMTP, MQTT</i>	<i>STEP 7, TIA Portal - ladder diagram (LAD), function block diagram (FBD), structured control language (SCL), and statement list (ST). IEC 61131-3 standard.</i>	<i>-20°C to +60°C (-4°F to +140°F)</i>	<i>24V DC</i>
Beckhoff CX5140 [7]	65,536	65,536	256	256	<i>EtherCAT, OPC UA, ADS, Modbus TCP, CANopen</i>	<i>TwinCAT 3 - ladder diagram (LD), function block diagram (FBD), structured text (ST), and instruction list (IL). IEC 61131-3 standard.</i>	<i>0°C to +50°C (32°F to 122°F)</i>	<i>24V DC</i>

3 Operational Flow Chart

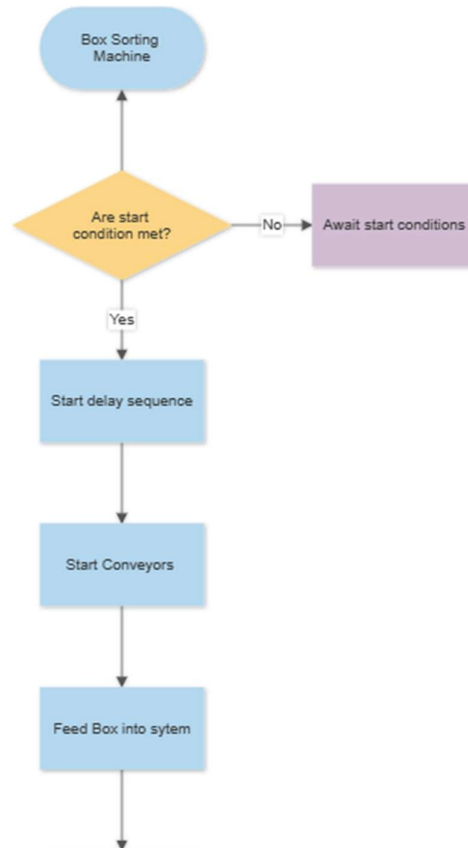


Figure 8 - Operational Flow Chart pt.1

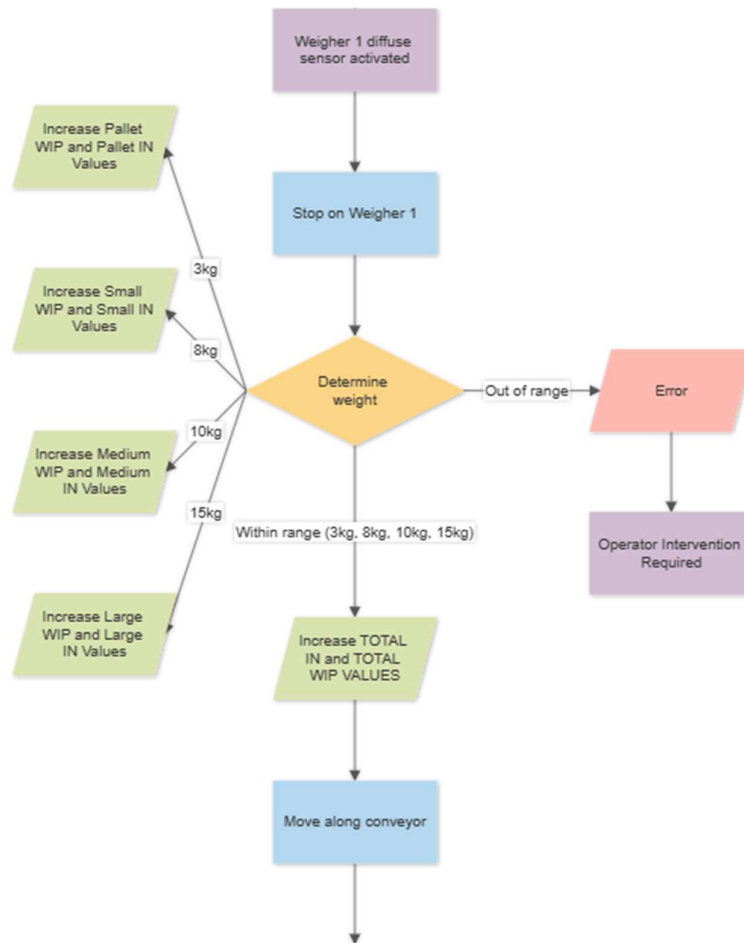


Figure 9 - Operational Flow Chart pt.2

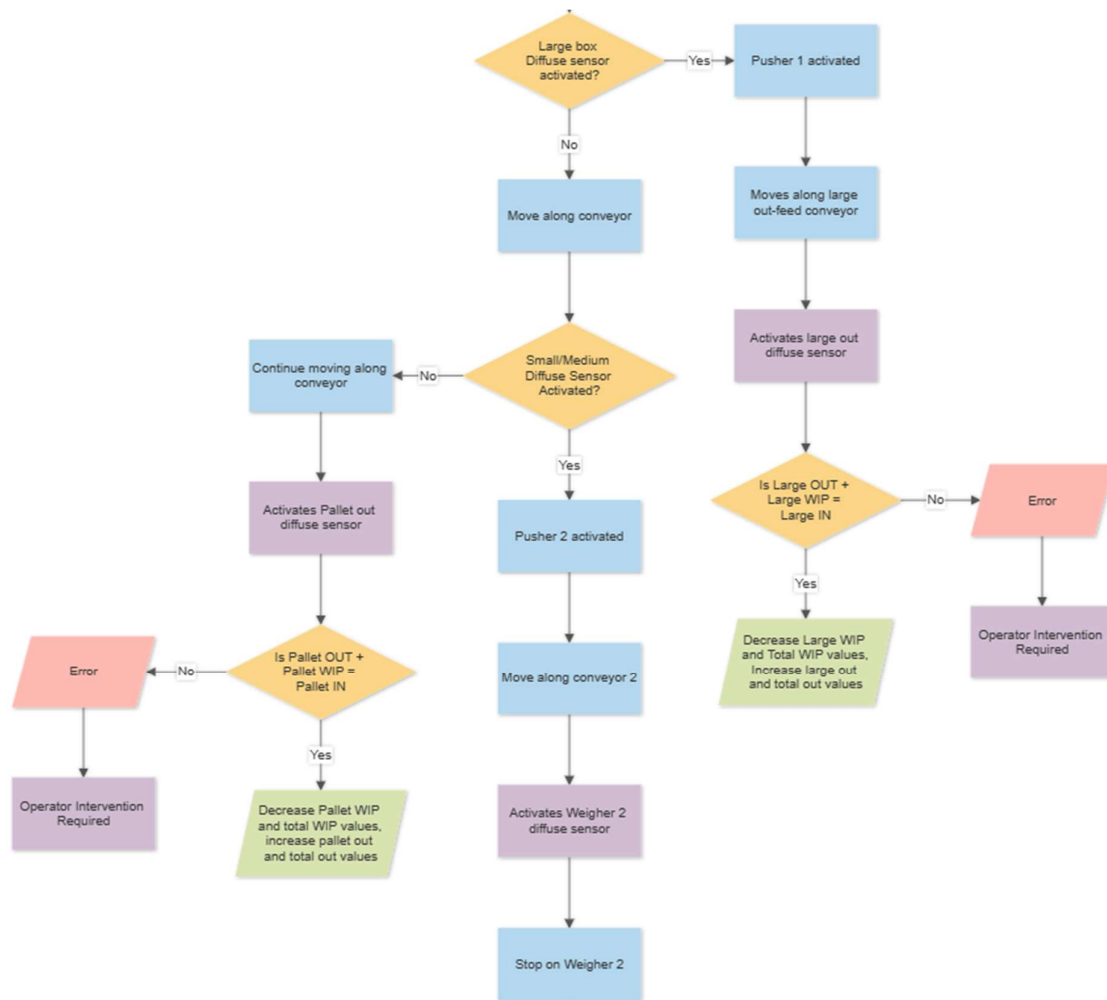


Figure 10 - Operational Flow Chart pt.3

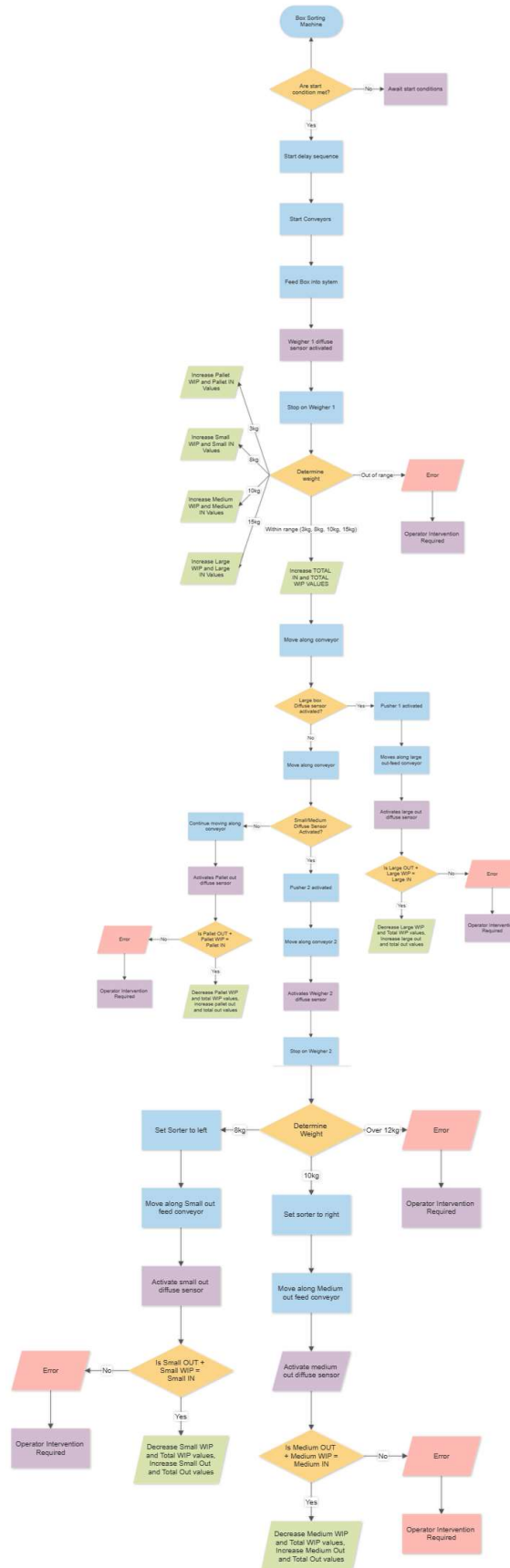


Figure 11 - Operational Flow Chart (complete)

4 Ladder Logic Program

4.1 Network 1: Connection to Factory IO

This network contains the Function Block which allows Siemens TIA Portal to communicate with Factory IO.

4.2 Network 2: Sequence Start Conditions

The conditions which must be achieved to enable starting sequence of the conveyor. It ensures there are no alarms present in order to operate once the Start button has been pressed.

4.3 Network 3: Sequence Start Warning

Once the start sequence is activated, there is a warning siren and beacon for 2 seconds before any machinery starts to move.

4.4 Network 4: Conveyor start time delay sequence

Each conveyor (beginning with the furthest) starts in sequence, 500ms after each other, to limit the total current draw on the system during startup. It starts with the conveyor furthest away to allow the system to run off when restarting and help prevent blockages.

4.5 Network 5: Conveyors

These are the enabling conditions for each conveyor, this network is programmed this way to easily control the starting and stopping of the weighing and feed conveyors during weighing operations.

4.6 Network 6: Pushers

Both Pushers are controlled in this network, when the system is operational, the activation of a diffuse sensor positioned before a pusher, activates a Pulse timer and a delay on timer before the pusher actuator can be actuated. The Pulse timer keeps the input signal from the diffuse sensor high until the pusher has had time to actuate fully. The delay timer ensures the part has continued to travel in front of the pusher before actuating.

4.7 Network 7: Light Stacks

All the light stacks and HMI replicated lights are controlled from this network.

If the system is running (FLAG is high), the green stack lights are illuminated.

If there is a warning condition in the system, the yellow stack lights are illuminated.

If there is an alarm condition in the system, or any of the safety devices are not healthy, the red stack lights are illuminated.

4.8 Network 8: Weigher 1 Part present

When any box is detected by the diffuse sensor situated on weigher 1, the weigh conveyor and the conveyor feeding it are stopped for 1 second using a pulse timer.

4.9 Network 9: Convert Weigher 1 Value

The "Real" Voltage input from the weigher is converted to a "DINT" value, which is then scaled to give a Kilogram reading which is the same as the box being weighed.

4.10 Network 10: Determine Weigher 1 Weight

Once Weigher 1 has stopped, a combination of a TON timer and a pulse timer, are used to ensure the box has finished moving and is stable, ready for accurate weighing.

Then a series of "IN RANGE" Comparators check to determine the weight of the box currently on the weigher, and which of the 4 categories it fits into.

When this process is complete, it restarts the weigh conveyor and the infeed conveyor.

4.11 Network 11: Weigher 2 Part Present

When a box is detected by the diffuse sensor situated on weigher 2, the weigh conveyor and the conveyor feeding it are stopped for 1 second using a pulse timer.

4.12 Network 12: Convert Weigher 2 Value

The "Real" Voltage input from the weigher is converted to a "DINT" value, which is then scaled to give a Kilogram reading which is the same as the box being weighed.

4.13 Network 13: Determine Weigher 2 Weight

Once Weigher 2 has stopped, a combination of a TON timer and a pulse timer, are used to ensure the box has finished moving and is stable, ready for accurate weighing.

Then a series of "IN RANGE" Comparators check to determine what the weight of the box currently on the weigher is, and which of the 3 categories it fits into - Small, Medium or Overweight.

Small and medium restart the weigh conveyor, the in-feed conveyor and sets the pop-up sorter to the corresponding direction. Left for Small or Right for Medium.

Overweight triggers an alarm condition as there are only two known weights that should be present on this weigher requiring sorting.

4.14 Network 14: In count

A Diffuse sensor counts the total amount of boxes entering the system.

Outputs from weigher 1 feed into count UP function blocks, which count the amount of each size box that has passed over weigher 1 and entered the system. They are reset to 0 using a reset button displayed on the HMI.

4.15 Network 15: WIP Count

This network uses Count up/down function blocks to count the WIP for each size package. the count UP input comes from the weigher 1 outputs, the count DOWN inputs come from a diffuse sensor on the output chute for each size respectively, this difference is known as WIP or work in progress. They are reset to 0 using a reset button displayed on the HMI. There is also an ADD function block which adds the total from each size to create an overall system total WIP.

4.16 Network 16: Out Count

The count UP inputs for each function block come from a diffuse sensor on the output chute for each size respectively, this counts the number of boxes that have left the system. They are reset to 0 using a reset button displayed on the HMI. There is also an ADD function block which adds the total from each size to create an overall system total output.

4.17 Network 17: Warnings

This network contains the logic for system warnings. The warnings as defined in the system strategy, are controlled using comparators and defined setpoints to trigger warning outputs. There is also a master warning that is activated if any of the warning bits are set to high.

4.18 Network 18: Alarms

This network contains the logic for system Alarms. The alarms as defined in the system strategy, are controlled using comparators and defined setpoints to trigger alarm outputs. There is also a master alarm that is activated if any of the alarm bits are set to high.

4.19 Network 19: Check Counters

Comparators which compare the "OUT" count values against the "IN" count values for each parcel size, counting UP if the "OUT" Value exceeds the "IN" Value.

4.20 Network 20: Defaults

A Series of values which are to be used as default setpoints when a button is pressed on the HMI, this is to save time on initialisation of the simulation, as these values are not retained in the memory after the PLC is stopped.

4.21 Network 21: LCD Displays

Converts various "Dint" or "UInt" Values from Input devices such as weighers, or calculated count function blocks like totalisers and converts them to "Real" Outputs for the LCD displays in Factory IO.

5 Alarm/Warning Strategy

5.1 Error Checking

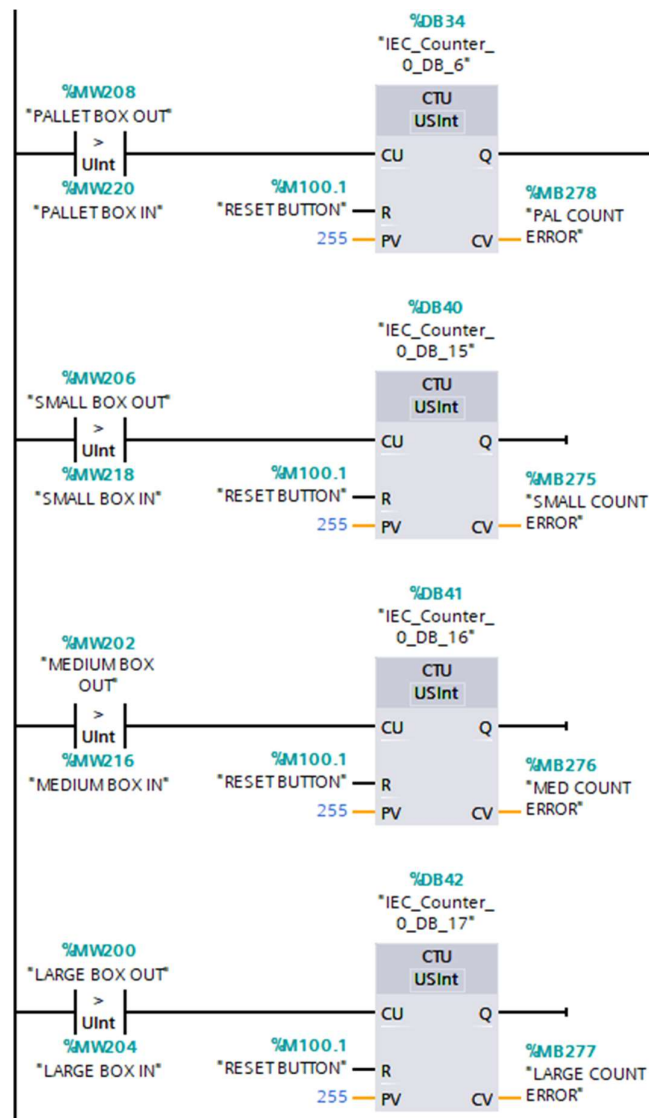


Figure 12 - Error Checking Ladder Logic

The ladder logic in Figure 12 calculates differences between the OUT counters and IN counters, recording each instance and providing an output for each size.

5.2 Warnings

The warning strategy dictates that a warning condition will be displayed once the setpoint is reached.

Warnings 1, 2, 3 and 4 - Package did not complete traverse for each size / Lost package counter for each package size.

The purpose of this warning is to ensure that boxes complete their cycle and are not lost somewhere in the system (fallen off conveyors, jammed, etc).

The warning logic is shown in Figure 13, the setpoint warning level was determined by testing the system and determining the maximum amount of each size box that could be 'in process' in the system and then adding to each value.

The values for this are as follows:

Pallet Box = 4, Small Box = 7, Medium Box = 7, Large Box = 3, Total Boxes = 9.

Warnings 5, 6, 7 and 0 - Counter warning number exceeded for each counter.

The purpose of this warning is to ensure that the amount of each package exiting the system, is always less than or equal to the amount entering the system. By checking each size, the system can identify if a box has been sorted incorrectly. This check is shown in Figure 12.

The setpoint for all these warnings is 2. The reason for this low setpoint value is to minimize disruption/cost caused by incorrect sorting and allow operator rectification. The warning logic and setpoint are shown in Figure 14.

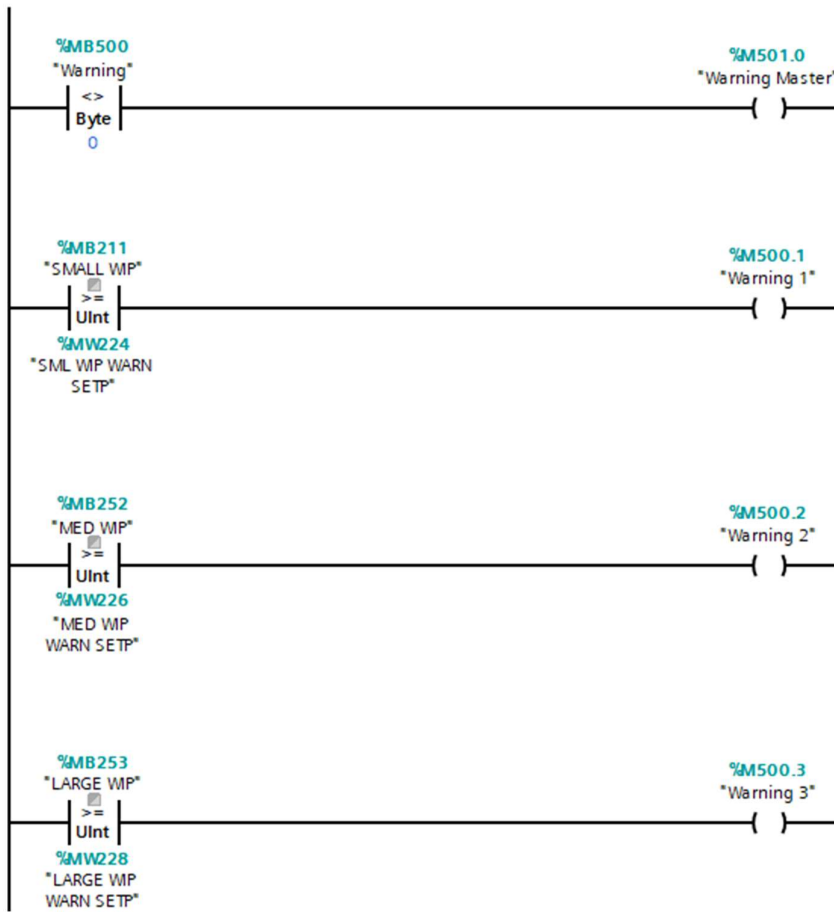


Figure 13 - Warnings 1

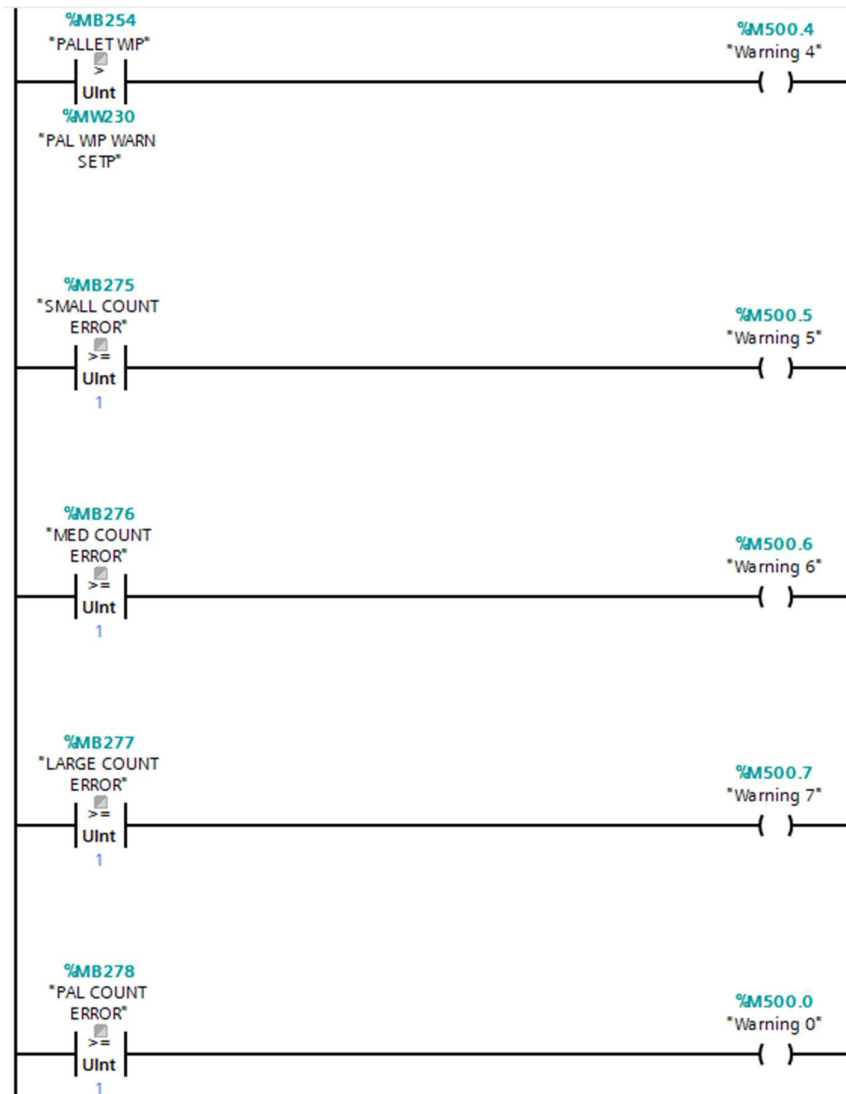


Figure 14 - Warnings 2

5.3 Alarms

The alarm strategy dictates that the system will stop immediately with the activation of any alarm. This is achieved by removing the "FLAG" output from the logic in network 2. The operator will then need to rectify the fault and confirm a reset, before restarting the system, they will not be able to rectify the fault and restart the system without acknowledging the alarm.

Alarm Master - Emergency Stop activated.

Any activation of a safety device such as an e-stop or safety door, will activate the alarm master output. This is shown in Figure 15.

Alarms 0,1,2,3 and 4 - Max lost package alarm number exceeded for each sorter.

This alarm logic is the same as the warning logic for the same conditions, with an additional 1 count triggering an alarm state.

Alarm 5 - Counter alarm number exceeded for each counter/sorter.

This alarm logic is the same as the warning logic for the same conditions, with an additional 1 count triggering an alarm state.

Alarm 6 – Weigher 2 overweight

As shown in Figure 18, the presence of a box outside of the range small or medium would trigger an overweight alarm, possible causes for this could be an incorrect box (large) or multiple boxes being present on the weigher at the same time and this would require immediate rectification, and cannot be allowed to continue.

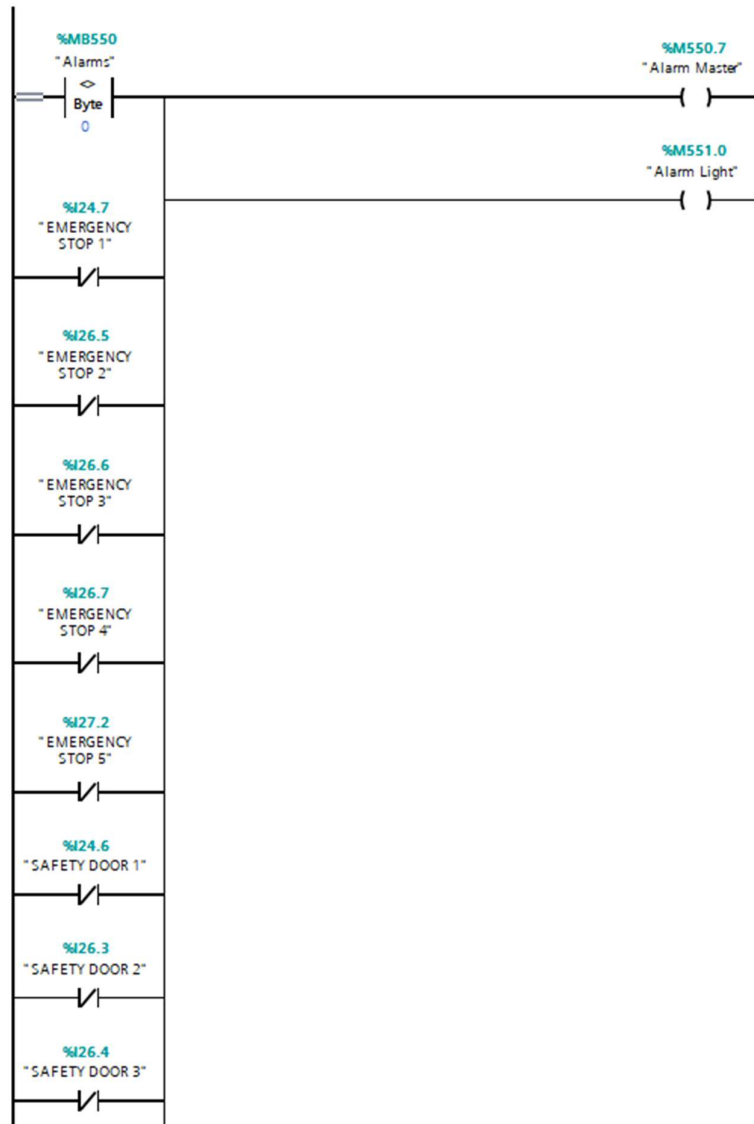


Figure 15 - Alarms 1

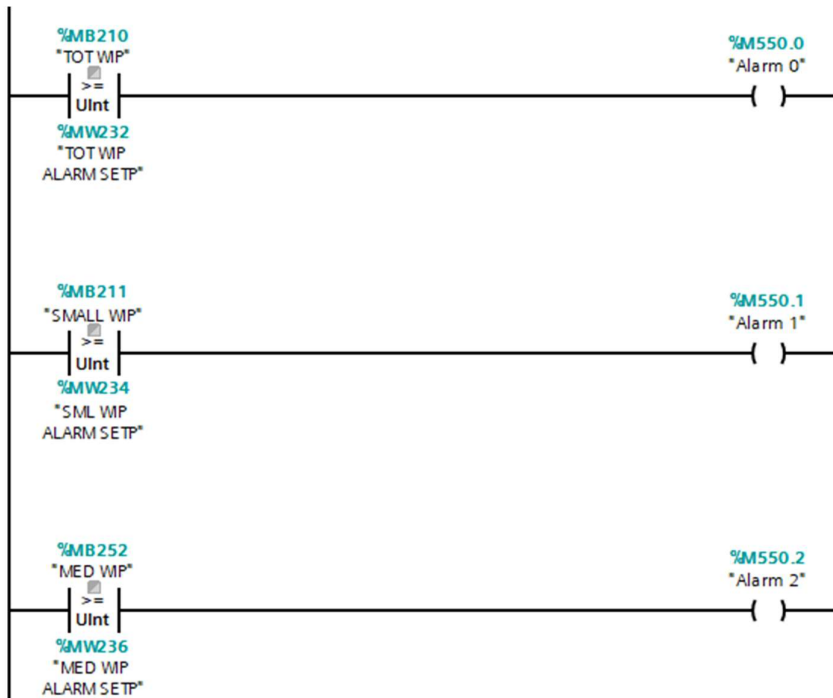


Figure 16 - Alarms 2

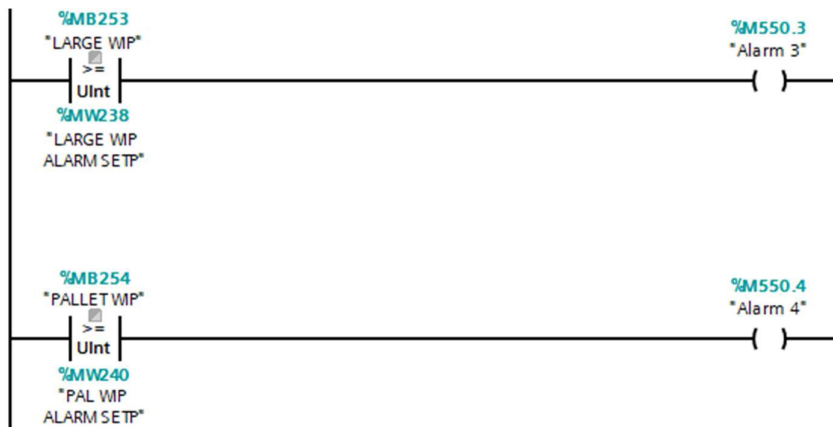


Figure 17 - Alarms 3

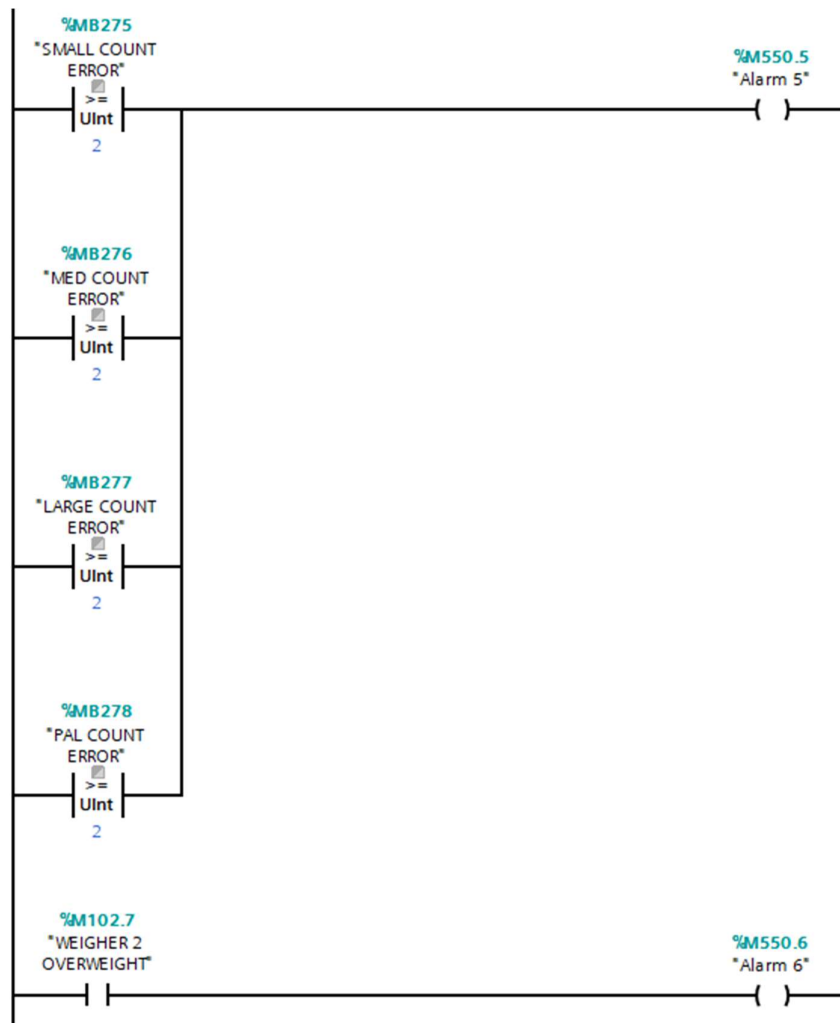


Figure 18 - Alarms 4

6 Conclusion

6.1 Major challenges

One of the major challenges I encountered was the learning curve associated with TIA Portal. Being unfamiliar with the software, I had to invest time and effort into understanding its programming concepts, syntax, and overall structure. It required patience and perseverance to navigate through the various menus and functions. However, I was determined to overcome this hurdle, and with the help of online resources, tutorials, and documentation, I gradually began to grasp the fundamentals of TIA Portal.

Another significant challenge arose when configuring and integrating the different components of the box sorting machine. Setting up the sensors, calibrating them, and ensuring their seamless interaction with the conveyor system demanded meticulous attention to detail and timing. Synchronizing the movements of multiple actuators added

complexity to the programming process. Along the way, I encountered issues such as unexpected behaviour and counting errors, which required diligent debugging and troubleshooting. These challenges pushed me to think critically and creatively, and I developed a deeper understanding of the machine's mechanical and electrical components.

However, with each challenge I faced, I experienced a sense of accomplishment when I overcame it. The successful completion of each step in the programming process reinforced my confidence and expanded my programming skills. It was truly rewarding to witness the box sorting machine come to life and perform its intended functions.

6.2 Troubleshooting

One issue that I encountered was during programming of the out counting function, it became evident that I was not capturing every box out of the system and totalling them correctly. And it was creating discrepancies between the IN, WIP and OUT counters as shown in Figure 19.

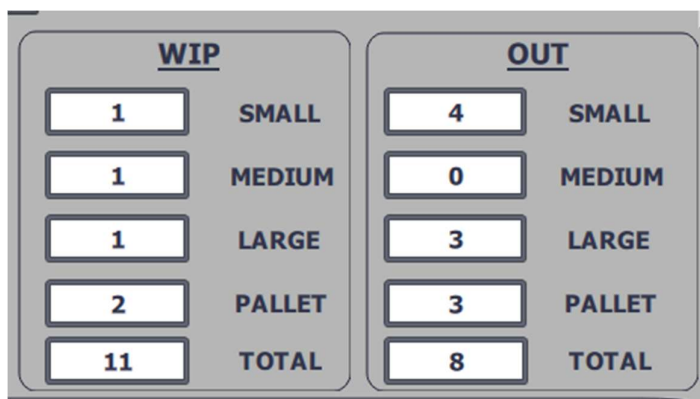


Figure 19 - WIP and OUT counters displayed on HMI.

To overcome this, I set up a trace to understand if the boxes were activating their respective diffuse sensors correctly. This is shown in Figure 20.

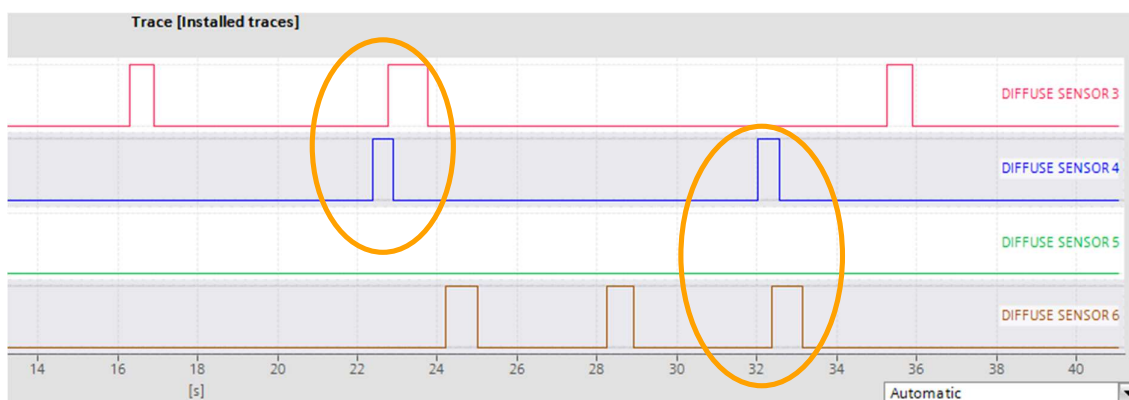


Figure 20 - Trace of diffuse sensors during cycle

From the trace I could see that the multiple diffuse sensors were occasionally being activated at the same time. Due to the method I used to program the out-count block shown in Figure 21, it could only record one of these activations and it would miss the others, to overcome this I used 4 separate count up function blocks - 1 for each size (Figure 22), 3 ADD function blocks (Figure 23), 1 to add the small and medium out counts, 1 to add the pallet and large counts, and then 1 to add these values together.

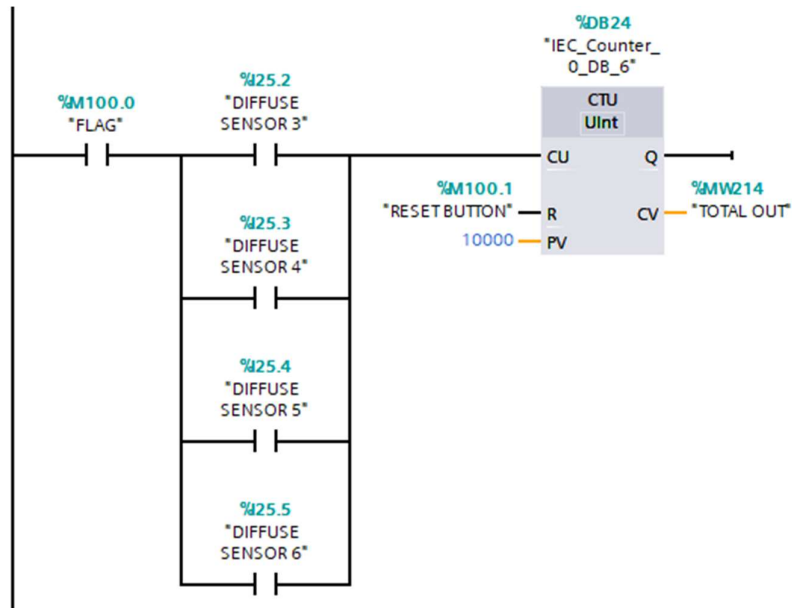


Figure 21 - Previous OUT count logic

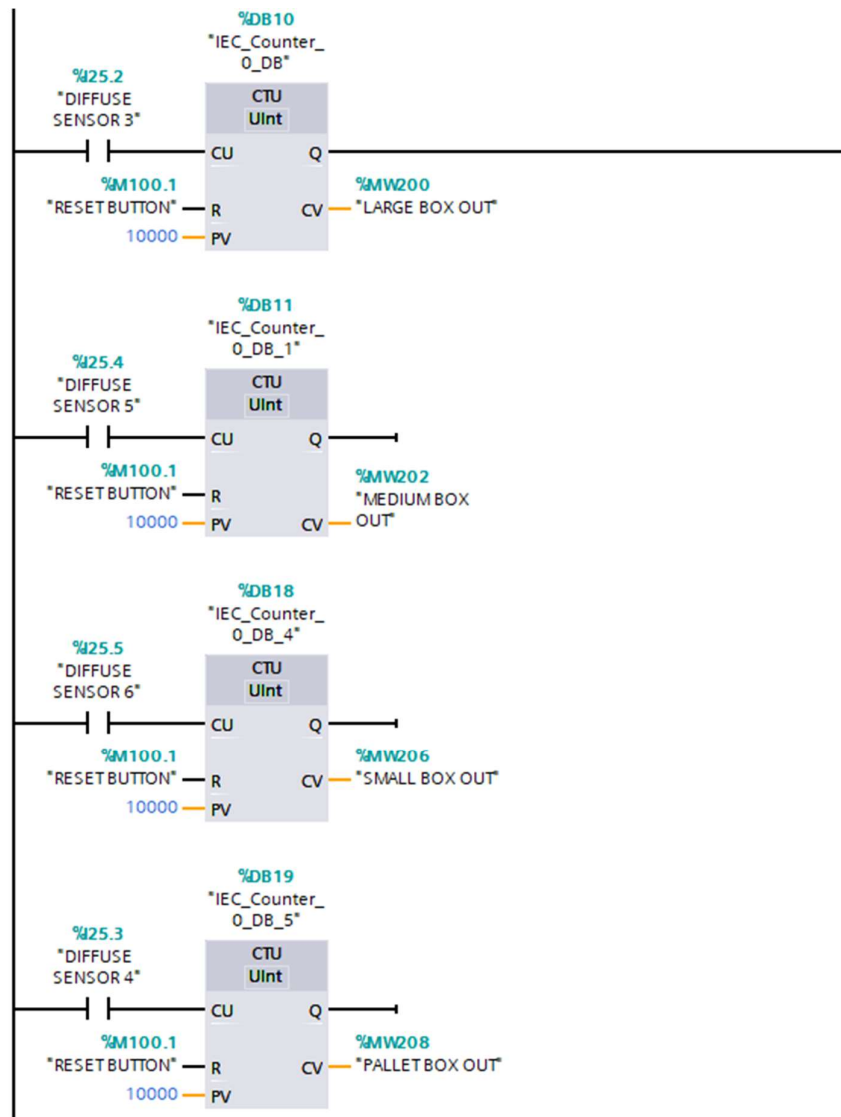


Figure 22 - Improved OUT count logic 1

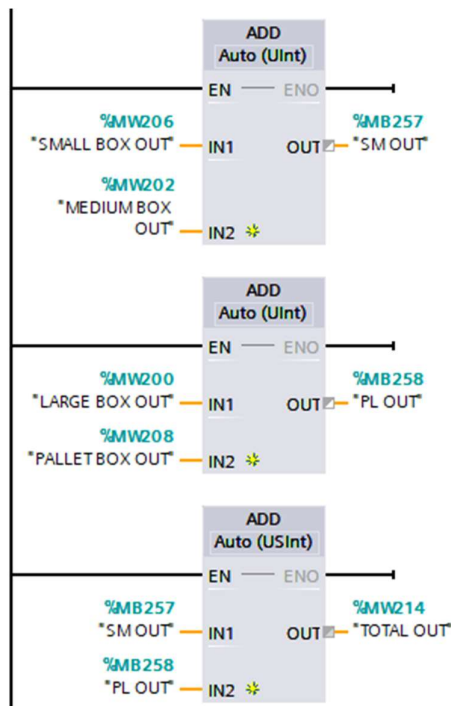


Figure 23 - Improved count logic 2

This was a very good learning curve, and the trace tool is a very good feature of TIA portal, I could see many benefits for this feature in real-world fault-finding scenarios.

6.3 Improvements

If I were to complete this project again with more time and more freedom with regards to component selection etc. or if I was designing this project for an industrial application for a real company, I would make the following improvements.

1. Improved Layout - I would layout the system in a more efficient manner, with a smaller footprint, possibly u-shaped, with shorter conveyors to decrease WIP waste and collection points which were closer together to eliminate transport waste in line with LEAN manufacturing principles.
2. Less components - I would use less components to make the system more compact and to reduce costs.
3. Dry cycle Functions – I would add a dry cycle function controlled by a maintenance/test mode to simulate the system running without any product being introduced into the system.
4. Single cycle function – I would also add a single cycle function to aid in fault finding activities.
5. Eco-mode – I would be interested to see if there is any value in adding an 'eco' function to the system, which would shut the conveyors down if there were no boxes

in process and none had entered in a pre-determined time. This would have to consider start-up currents, delays when restarting, electricity costs, frequency of activation etc. In a real-world condition, this work would include some root cause analysis which would ask the question why boxes are not being fed into the machine? and can this cause be rectified instead, so that the machine is better utilised.

6. I/O Display on HMI – this would show all the Inputs and Outputs on the HMI, this could aid fault finding in real-world operations.
7. Troubleshooting page on HMI – with a list of common faults associated with the alarms, the symptoms, causes and how to rectify.
8. Runtime counters – this would record the total operation time of each conveyor and actuator, this would be used for preventative maintenance purposes.
9. Smoother transfer options – in a real-world application, some of the transfer motions used are too aggressive, and could damage fragile packages, I would instead use a smoother option such as a diverting conveyor, sorting table, or pick and place robot.
10. Warning strategy - stop the in-feed conveyor and allow the remainder of the system to operate if there were any warnings present. I would argue that this is beneficial as it would stop issues such as lost / incorrectly sorted boxes being compounded and would give the system an opportunity to self-correct without leading to an alarm condition. It could also be argued that this could slow down the output of the machine and that warnings could still be investigated whilst the machine is running and continuing to process new entries.

6.4 Summary

In reflecting on my experience of using TIA Portal for the first time to program a box sorting machine, I can say that it has been an incredibly transformative journey filled with both triumphs and challenges. As a newcomer to TIA Portal, I was initially daunted by the task ahead, but I embraced it as an opportunity for personal and professional growth.

Through this experience, I also gained a greater appreciation for the power and versatility of TIA Portal. Its user-friendly interface, extensive programming capabilities, and comprehensive diagnostic tools proved indispensable in the development of a robust control system. TIA Portal's seamless integration with hardware devices and simulation software made the process more efficient, and its advanced features allowed me to customize the machine's behaviour according to specific requirements.

Moreover, I realized the value of collaboration and seeking assistance when needed. Engaging with fellow programmers, participating in online forums, and leveraging available

resources played a vital role in overcoming obstacles and expanding my knowledge. The willingness of others to share their experiences and insights was invaluable, and it reinforced the importance of being part of a supportive community.

In conclusion, my journey of using TIA Portal for the first time to program a box sorting machine has been a truly transformative experience. The challenges I faced along the way tested my perseverance and problem-solving skills, but they also provided opportunities for growth and learning. Through it all, I have developed a deep appreciation for the intricacies of automation programming and the immense potential of TIA Portal in achieving efficient and reliable control systems.

7 Bibliography

- [1] Siemens, "S7-1500 Product Catalogue," 2023. [Online]. Available:
<https://mall.industry.siemens.com/mall/en/WW/Catalog/Products/10204162?tree=CatalogTree>.
- [2] Rockwell Automation, "1756 User Manual," 2023. [Online]. Available:
https://literature.rockwellautomation.com/idc/groups/literature/documents/um/1756-um001_-en-p.pdf.
- [3] Mitsubishi Electric, "MELSEC Q series QCPU User's Manual," 2023. [Online]. Available:
<https://dl.mitsubishielectric.com/dl/fa/document/manual/plc/sh080483eng/sh080483engay.pdf>.
- [4] Omron, "NX7 Machine automation controller datasheet," 2023. [Online]. Available:
https://assets.omron.eu/downloads/datasheet/en/v11/p141_nx7_machine_automation_controller_datasheet_en.pdf.
- [5] Schneider Electric, "Modicon M340 Processors Setup Manual," 2019. [Online]. Available:
https://download.schneider-electric.com/files?p_enDocType=User+guide&p_File_Name=35012676_K01_000_14.pdf&p_Doc_Ref=35012676K01000.
- [6] Siemens, "S7-1200 Product Catalogue," 2023. [Online]. Available:
<https://mall.industry.siemens.com/mall/en/WW/Catalog/Products/10045647?tree=CatalogTree>.

- [7] Beckhoff, "CX5100 Manual," 2022. [Online]. Available:
https://download.beckhoff.com/download/Document/ipc/embedded-pc/embedded-pc-cx/cx5100_en.pdf.
- [8] R. Langmann and L. F. Rojas-Peña, "A PLC as an Industry 4.0 component," *13th International Conference on Remote Engineering and Virtual Instrumentation (REV)*, pp. 10-15, 2016.
- [9] H. Salih, H. Abdelwahab and A. Abdallah, "Automation design for a syrup production line using Siemens PLC S7-1200 and TIA Portal software," *2017 International Conference on Communication, Control, Computing and Electronics Engineering (ICCCCEE)*, 2017.
- [1 K. T. Erickson, *Programmable Logic Controllers: An Emphasis on Design and*
0] *Application*, 3rd ed., Dogwood Valley Press, Jan 2016.
- [1 Siemens, "Simatic S7-1500," 2023. [Online]. Available:
1] <https://www.siemens.com/global/en/products/automation/systems/industrial/plc/simatic-s7-1500.html>.
- [1 Siemens, "Simatic S7-1200," 2023. [Online]. Available:
2] <https://www.siemens.com/global/en/products/automation/systems/industrial/plc/s7-1200.html>.
- [1 Rockwell Automation, "Allen Bradley 1756-L71," 2023. [Online]. Available:
3] <https://www.rockwellautomation.com/en-us/products/details.1756-L71.html>.
- [1 Mitsubishi Electric, "Programmable Controllers MELSEC Q Series," 2023. [Online].
4] Available: <https://www.mitsubishielectric.com/fa/products/cnt/plcq/items/>.
- [1 Omron, "NX7 Sysmac Controller," 2023. [Online]. Available:
5] <https://industrial.omron.co.uk/en/products/nx7#>.
- [1 Schneider Electric, "Modicon M340," 2023. [Online]. Available:
6] <https://www.se.com/uk/en/product-range/1468-modicon-m340/>.
- [1 Beckhoff, "CX1540 Embedded PC with Intel Atom processor," 2023. [Online]. Available:
7] <https://www.beckhoff.com/en-gb/products/ipc/embedded-pcs/cx5100-intel-atom/cx5140.html>.

[1 M. O. A. Ephrem Ryan Alphonsus, "A review on the applications of programmable logic
8] controllers (PLCs)," *Renewable and Sustainable Energy Reviews*, vol. 60, pp. 1185-
1205, 2016.

[1 H. Jack, Automating Manufacturing Systems with PLCs, 7.0 ed., 2010.
9]

8 Appendices

8.1 Appendix 1: Ladder Logic Program – Project 7.pdf

Project7 / 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

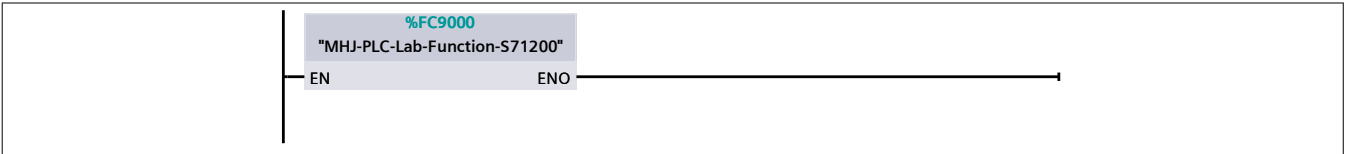
Title	"Main Program Sweep (Cycle)"	Author		Comment	
Family		Version	0.1	User-defined ID	

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			

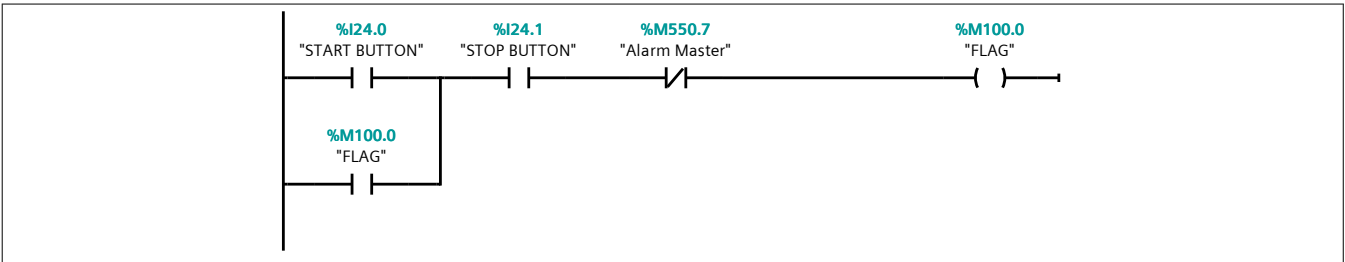
Network 1: Connection to Factory IO

This network contains the Function Block which allows Siemens TIA Portal to communicate with Factory IO.



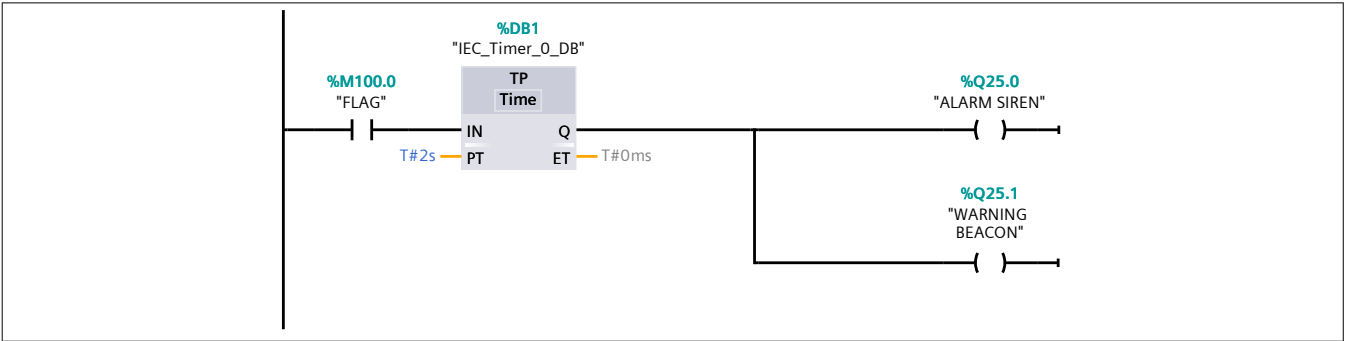
Network 2: Sequence Start Conditions

The conditions which must be achieved to enable starting sequence of the conveyor. It ensures there are no alarms present in order to operate once the Start button has been pressed.



Network 3: Sequence Start Warning

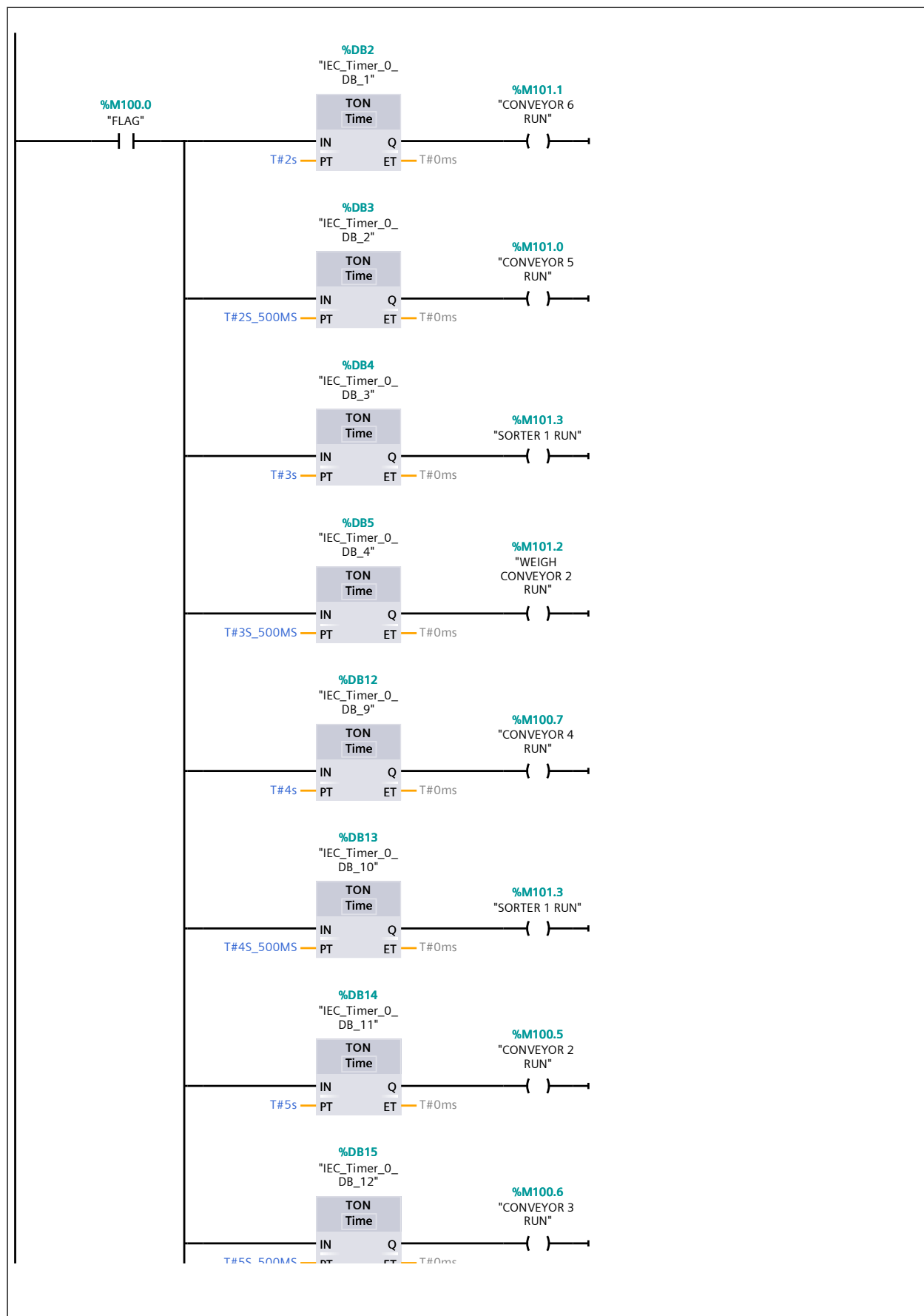
Once the start sequence is activated, there is a warning siren and beacon for 2 seconds before any machinery starts to move.



Network 4: Conveyor start time delay sequence

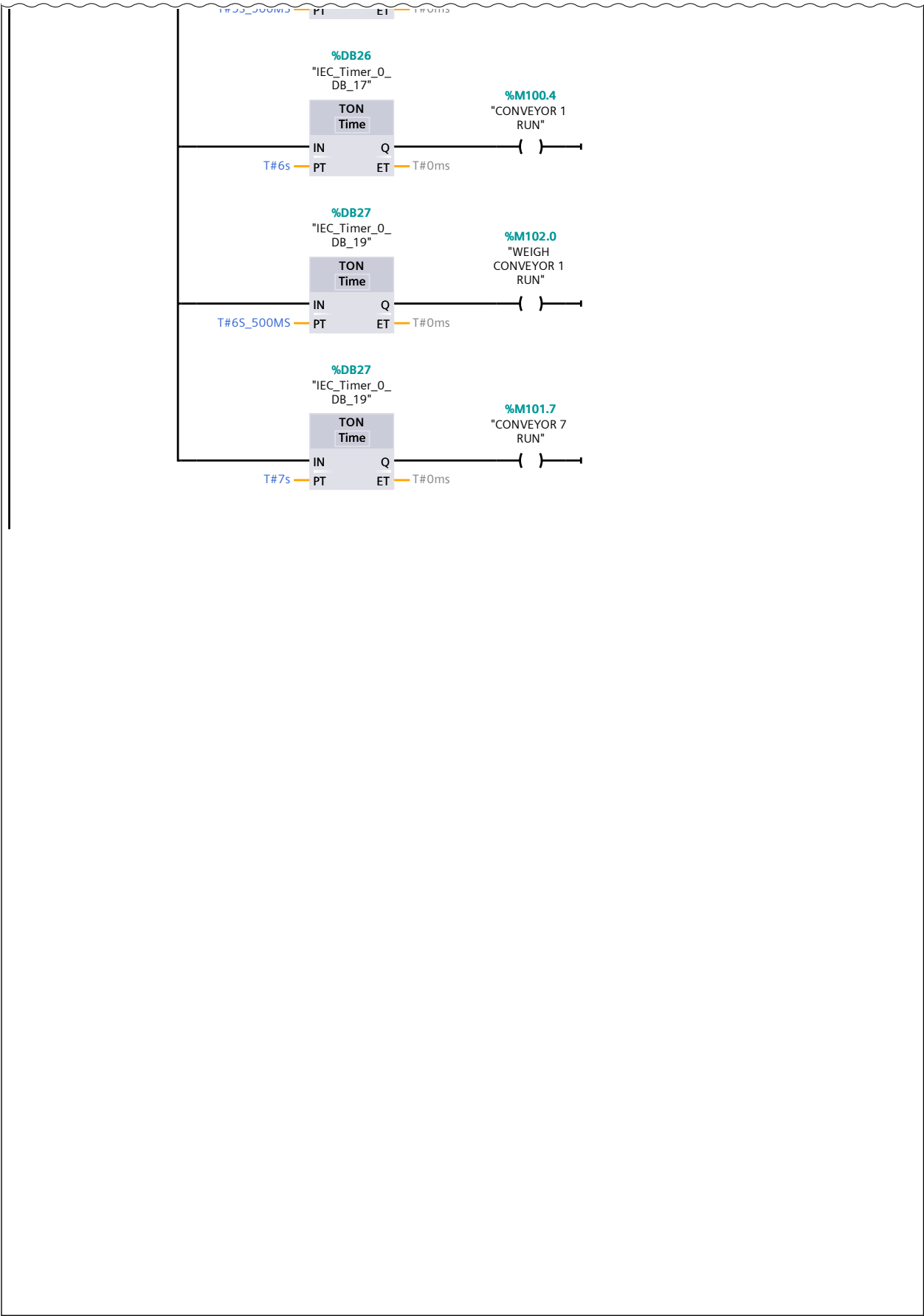
Each conveyor (beginning with the furthest) starts in sequence, 500ms after each other, to limit the total current draw on the system during startup. It starts with the conveyor furthest away to allow the system to run off when restarting and help prevent blockages.

Network 4: Conveyor start time delay sequence (1.1 / 2.1)



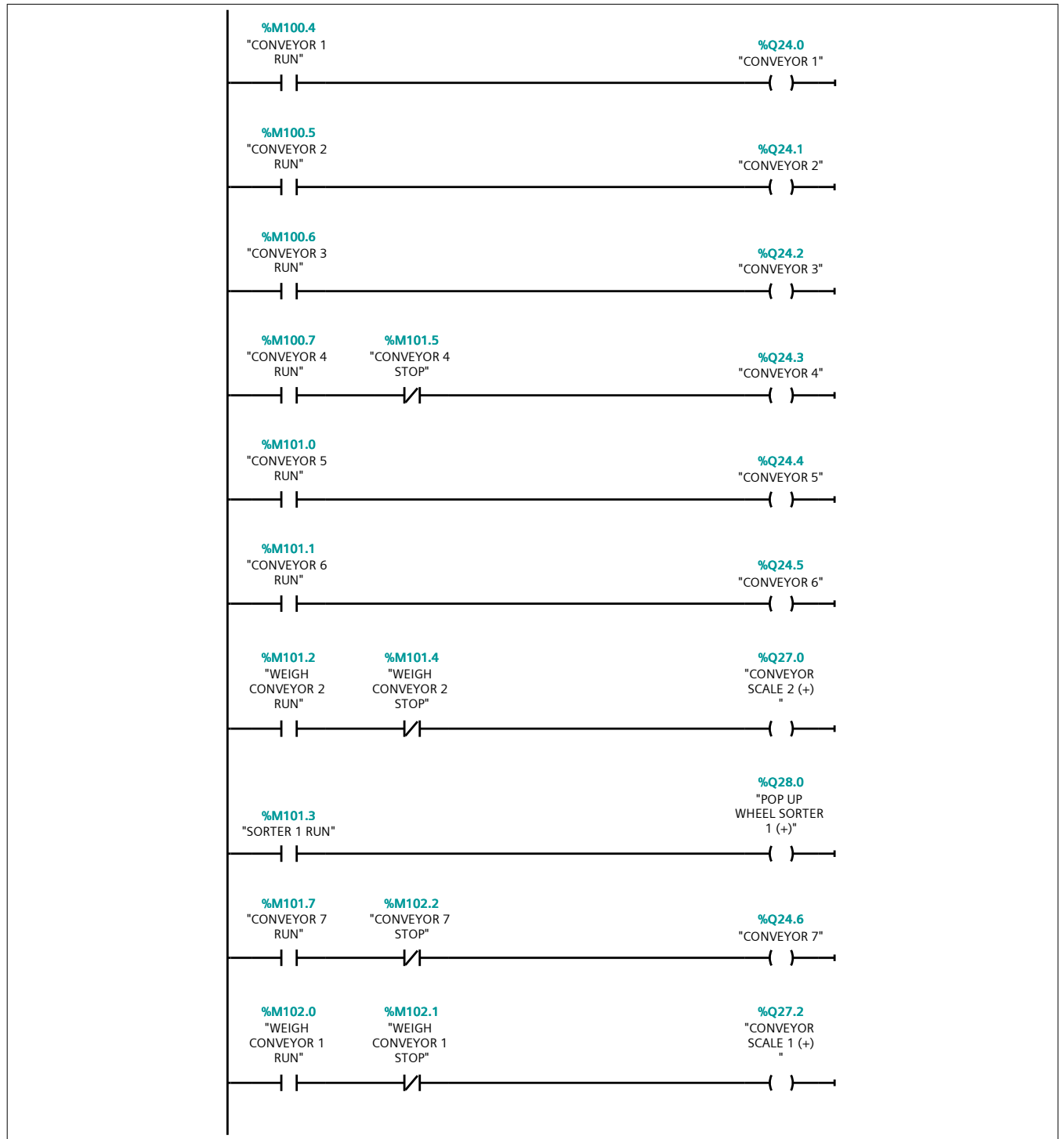
Network 4: Conveyor start time delay sequence (2.1 / 2.1)

1.1 (Page1 - 3)



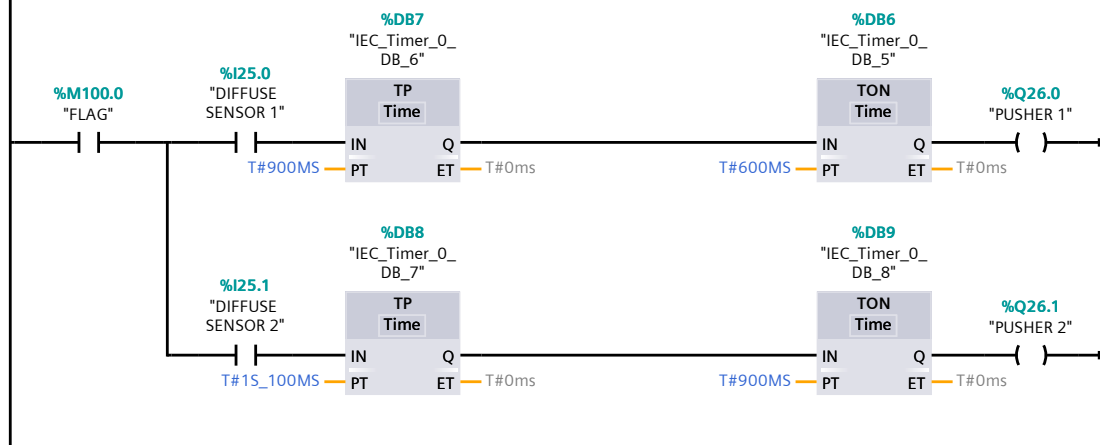
Network 5: Conveyors

These are the enabling conditions for each conveyor, this network is programmed this way to easily control the starting and stopping of the weighing and feed conveyors during weighing operations.



Network 6: Pushers

Both Pushers are controlled in this network, when the system is operational, the activation of a diffuse sensor positioned before a pusher, activates a Pulse timer and a delay on timer before the pusher actuator can be actuated. The Pulse timer keeps the input signal from the diffuse sensor high until the pusher has had time to actuate fully. The delay timer ensures the part has continued to travel in front of the pusher before actuating.



Network 7: Light Stacks

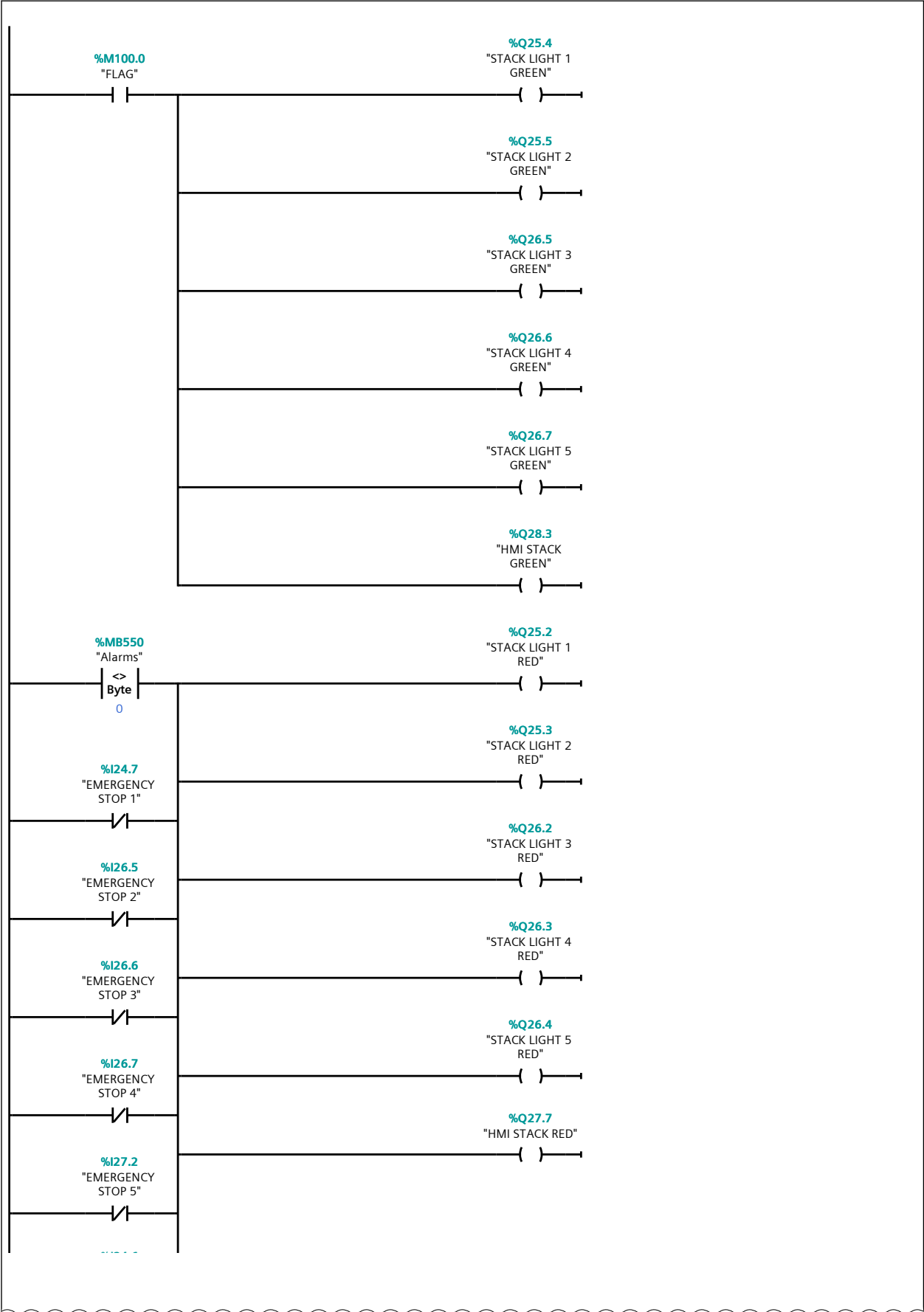
All the light stacks and HMI replicated lights are controlled from this network.

If the system is running (FLAG is high), the green stack lights are illuminated.

If there is a warning condition in the system, the yellow stack lights are illuminated.

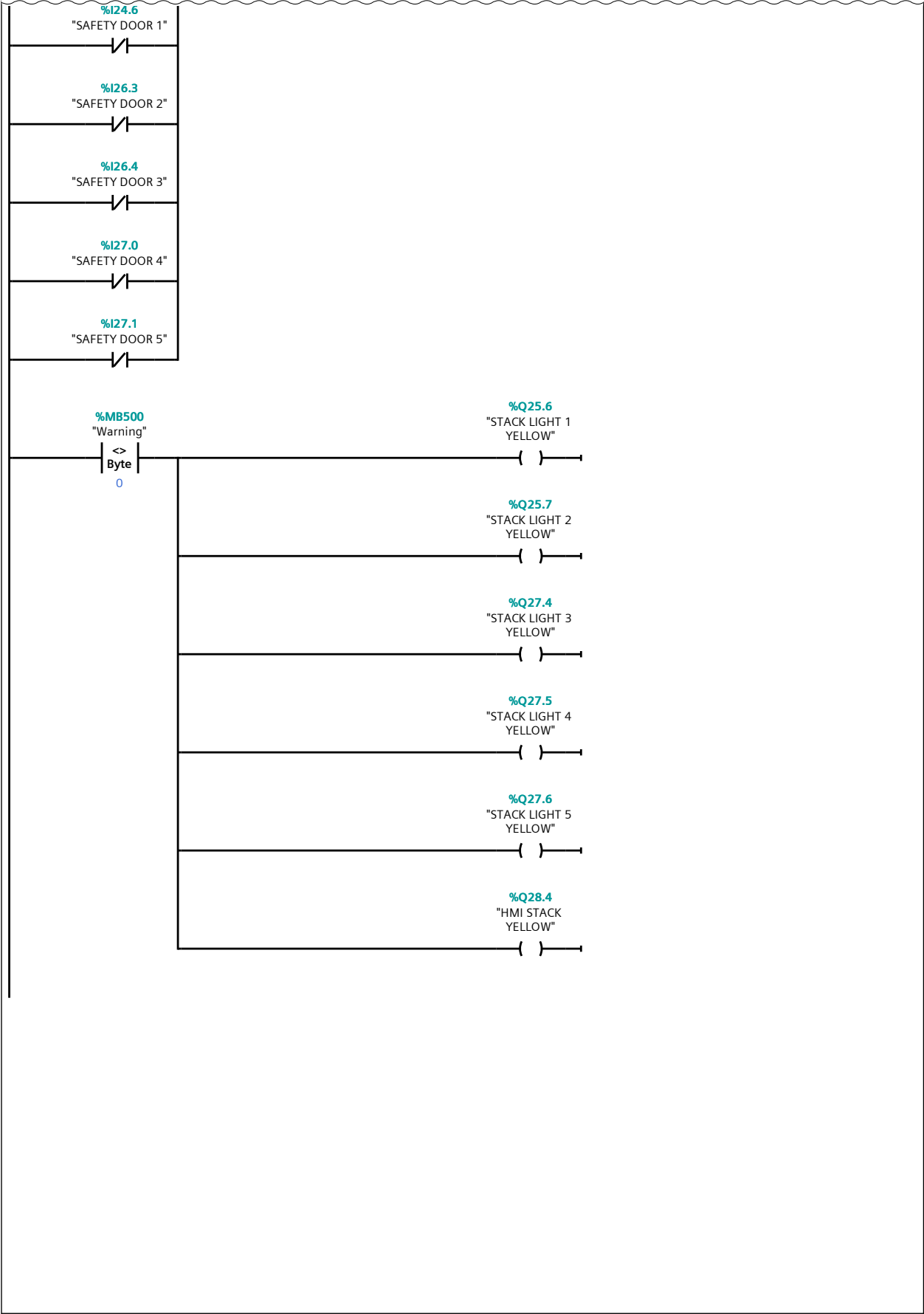
If there is an alarm condition in the system, or any of the safety devices are not healthy, the red stack lights are illuminated.

Network 7: Light Stacks (1.1 / 2.1)



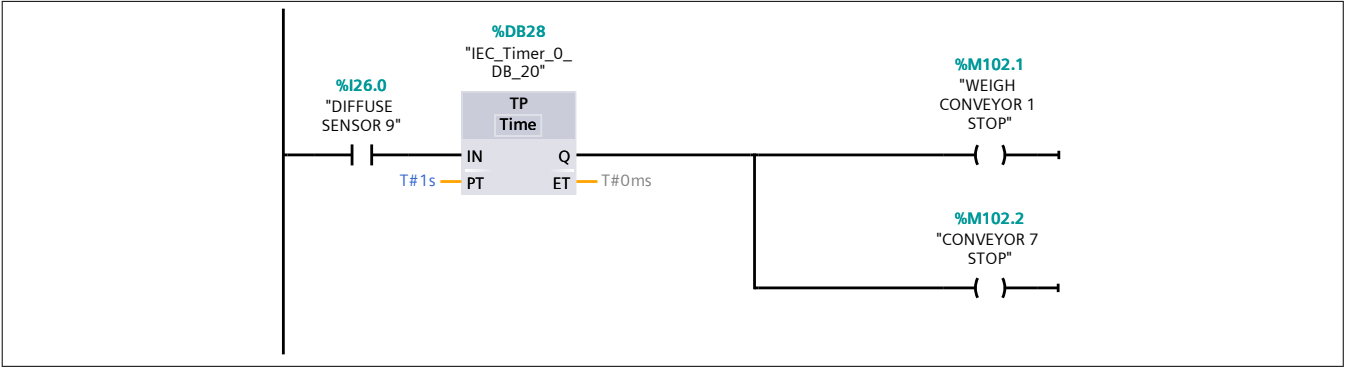
Network 7: Light Stacks (2.1 / 2.1)

1.1 (Page1 - 7)



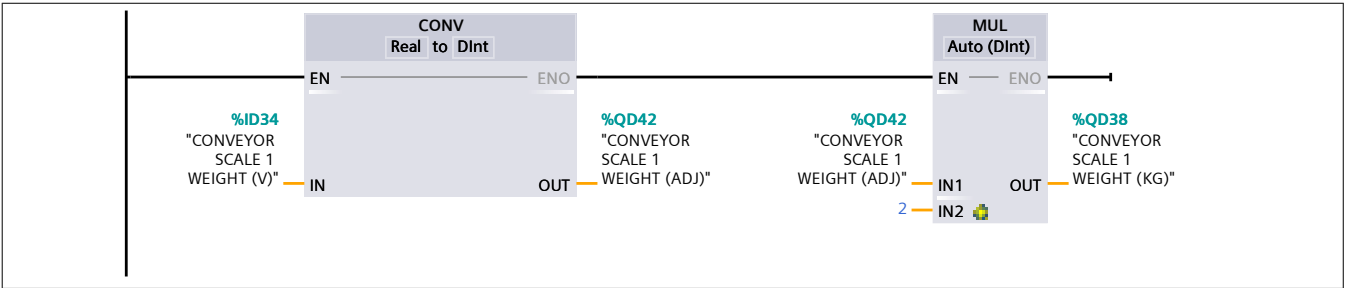
Network 8: Weigher 1 Part Present

When any box is detected by the diffuse sensor situated on weigher 1, the weigh conveyor and the conveyor feeding it are stopped for 1 second using a pulse timer.



Network 9: Convert Weigher 1 Value

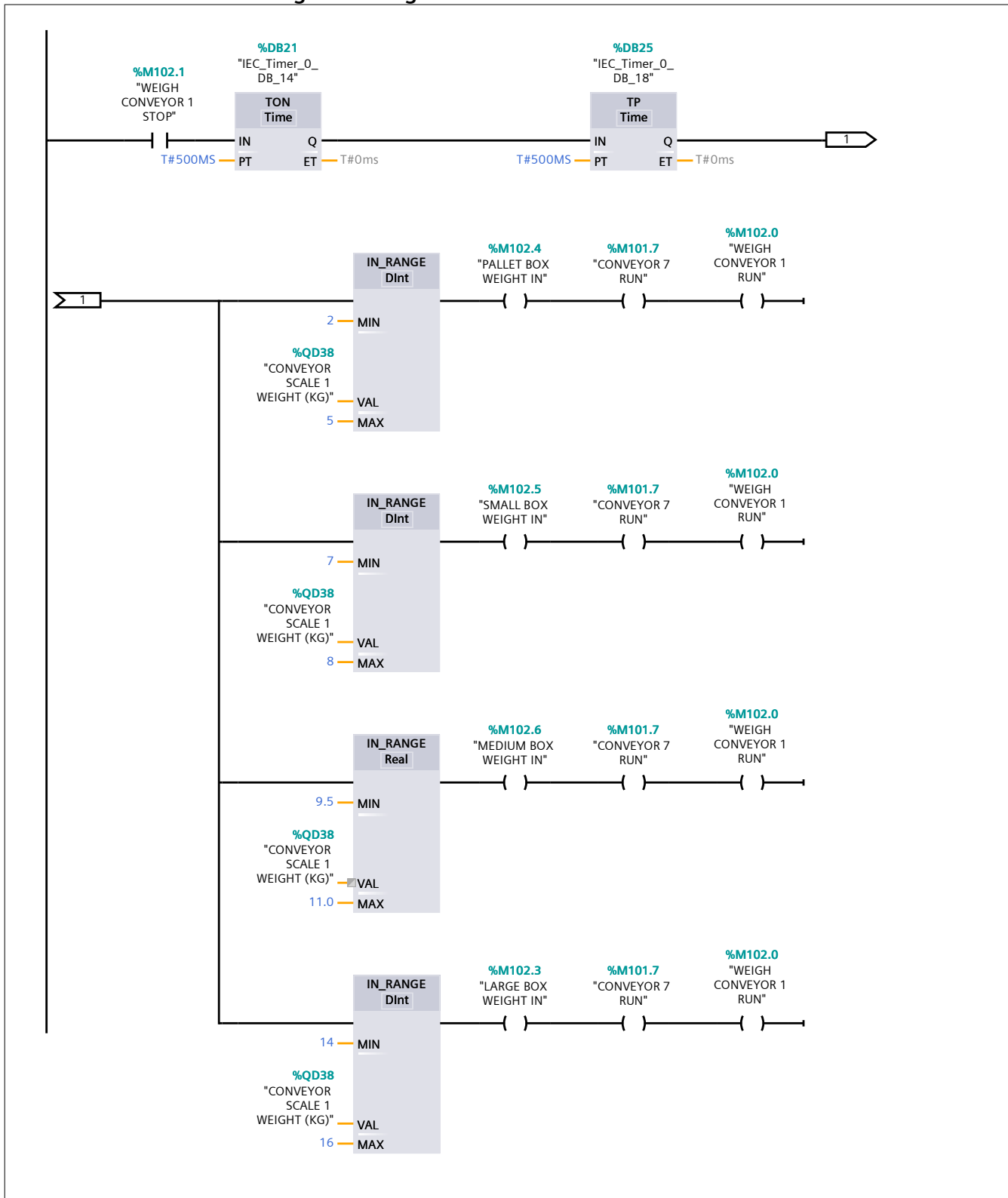
The "Real" Voltage input from the weigher is converted to a "DINT" value, which is then scaled to give a Kilogram reading which is the same as the box being weighed.



Network 10: Determine Weigher 1 Weight

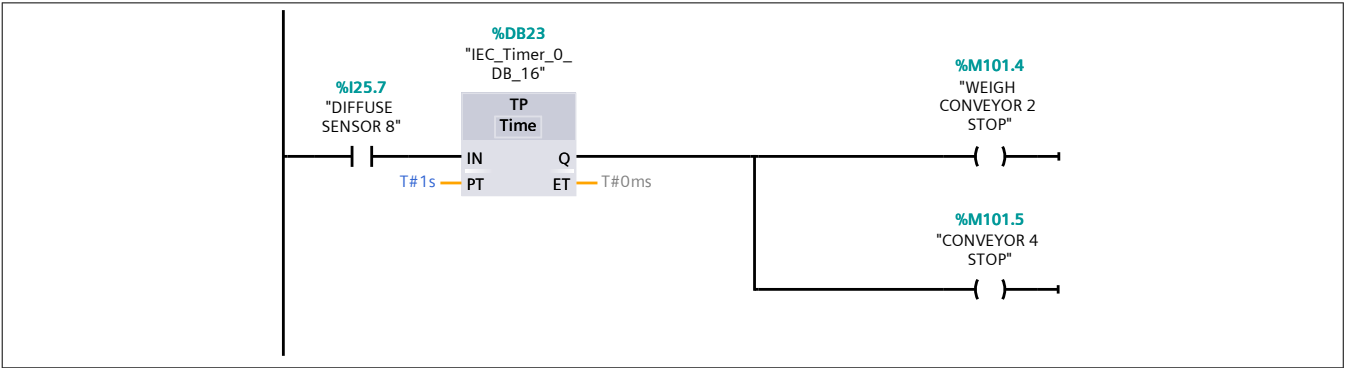
Once Weigher 1 has stopped, a combination of a TON timer and a pulse timer, are used to ensure the box has finished moving and is stable, ready for accurate weighing. Then a series of "IN RANGE" Comparators check to determine the weight of the box currently on the weigher, and which of the 4 categories it fits into. When this process is complete, it restarts the weigh conveyor and the infeed conveyor.

Network 10: Determine Weigher 1 Weight



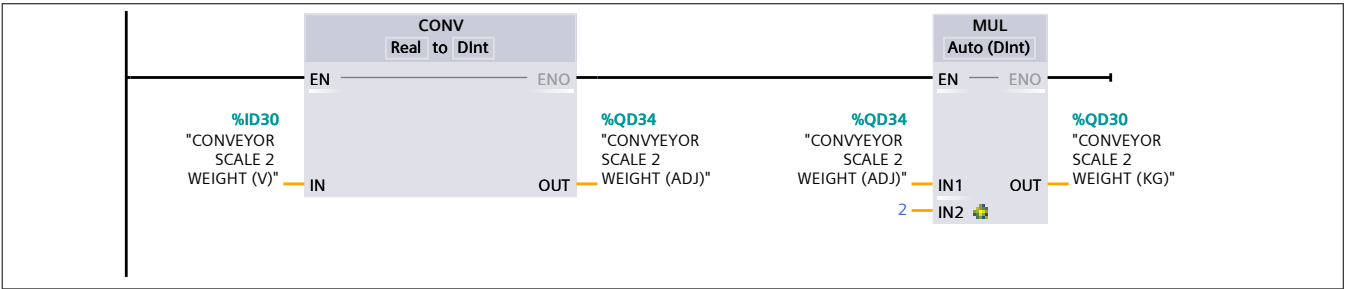
Network 11: Weigher 2 Part Present

When a box is detected by the diffuse sensor situated on weigher 2, the weigh conveyor and the conveyor feeding it are stopped for 1 second using a pulse timer.



Network 12: Convert Weigher 2 Value

The "Real" Voltage input from the weigher is converted to a "DINT" value, which is then scaled to give a Kilogram reading which is the same as the box being weighed.



Network 13: Determine Weigher 2 Weight

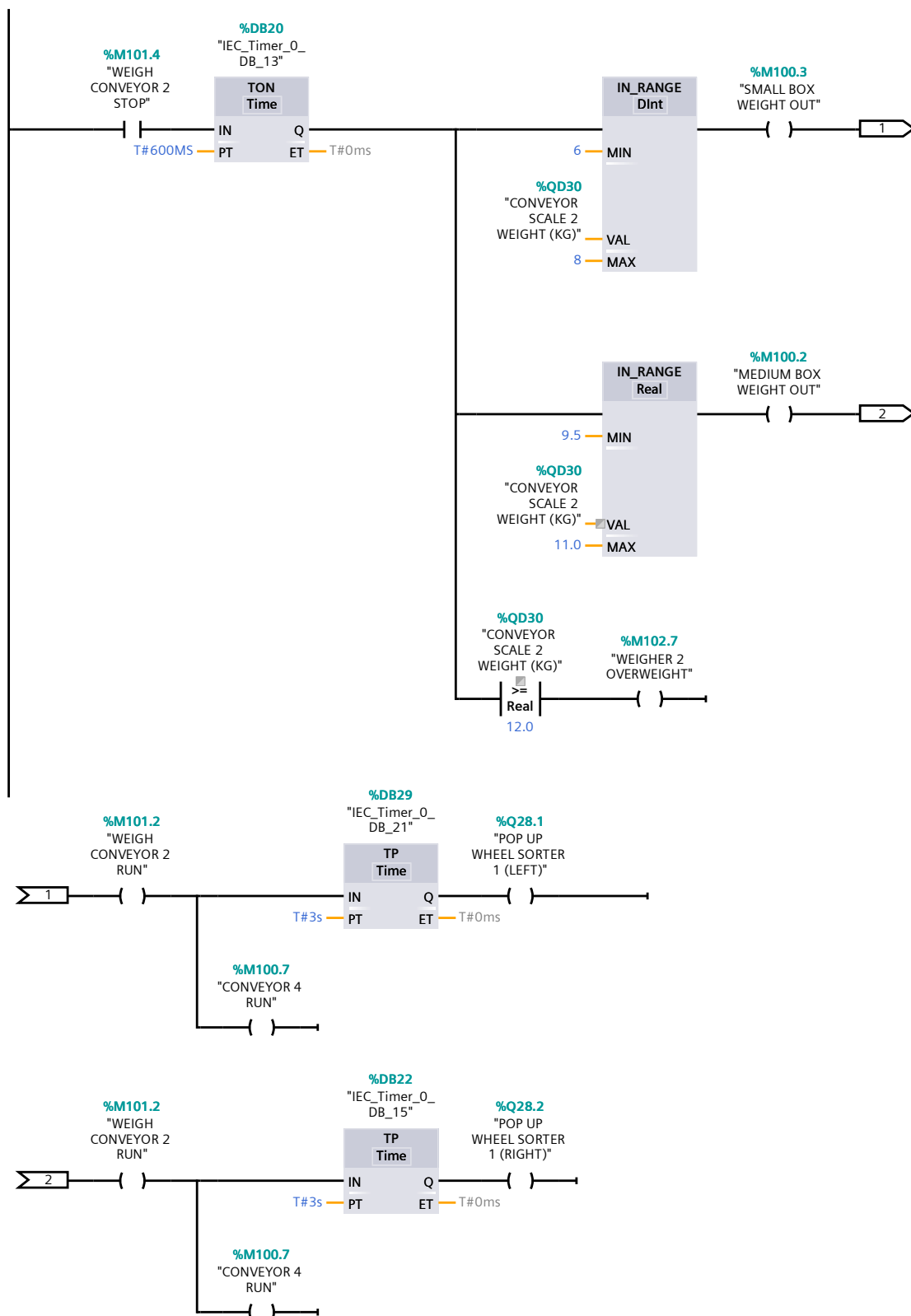
Once Weigher 2 has stopped, a combination of a TON timer and a pulse timer, are used to ensure the box has finished moving and is stable, ready for accurate weighing.

Then a series of "IN RANGE" Comparators check to determine what the weight of the box currently on the weigher is, and which of the 3 categories it fits into - Small, Medium or Overweight.

Small and medium restart the weigh conveyor, the in-feed conveyor and sets the pop-up sorter to the corresponding direction. Left for Small or Right for Medium.

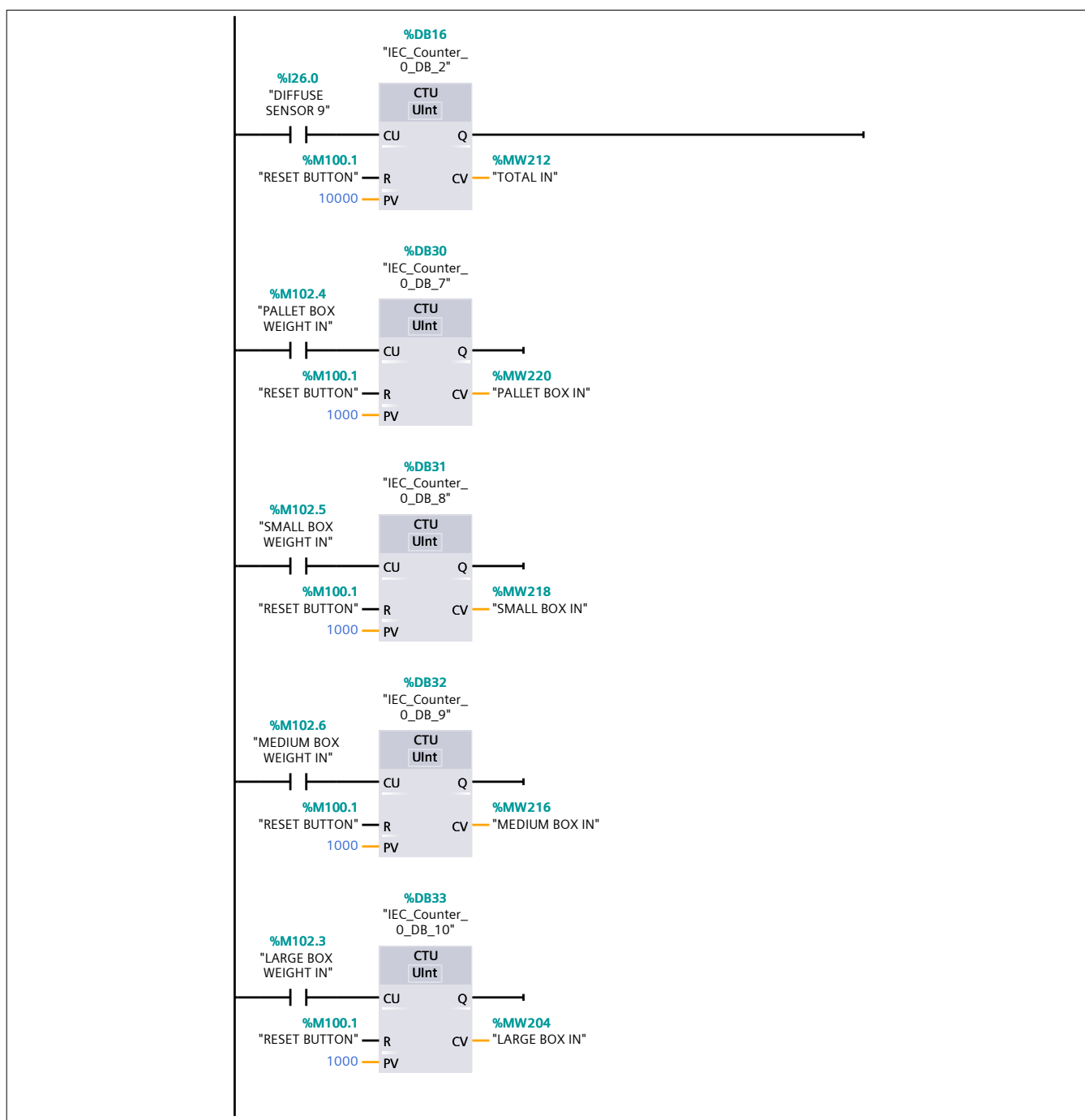
Overweight triggers an alarm condition as there are only two known weights that should be present on this weigher requiring sorting.

Network 13: Determine Weigher 2 Weight



Network 14: IN Count

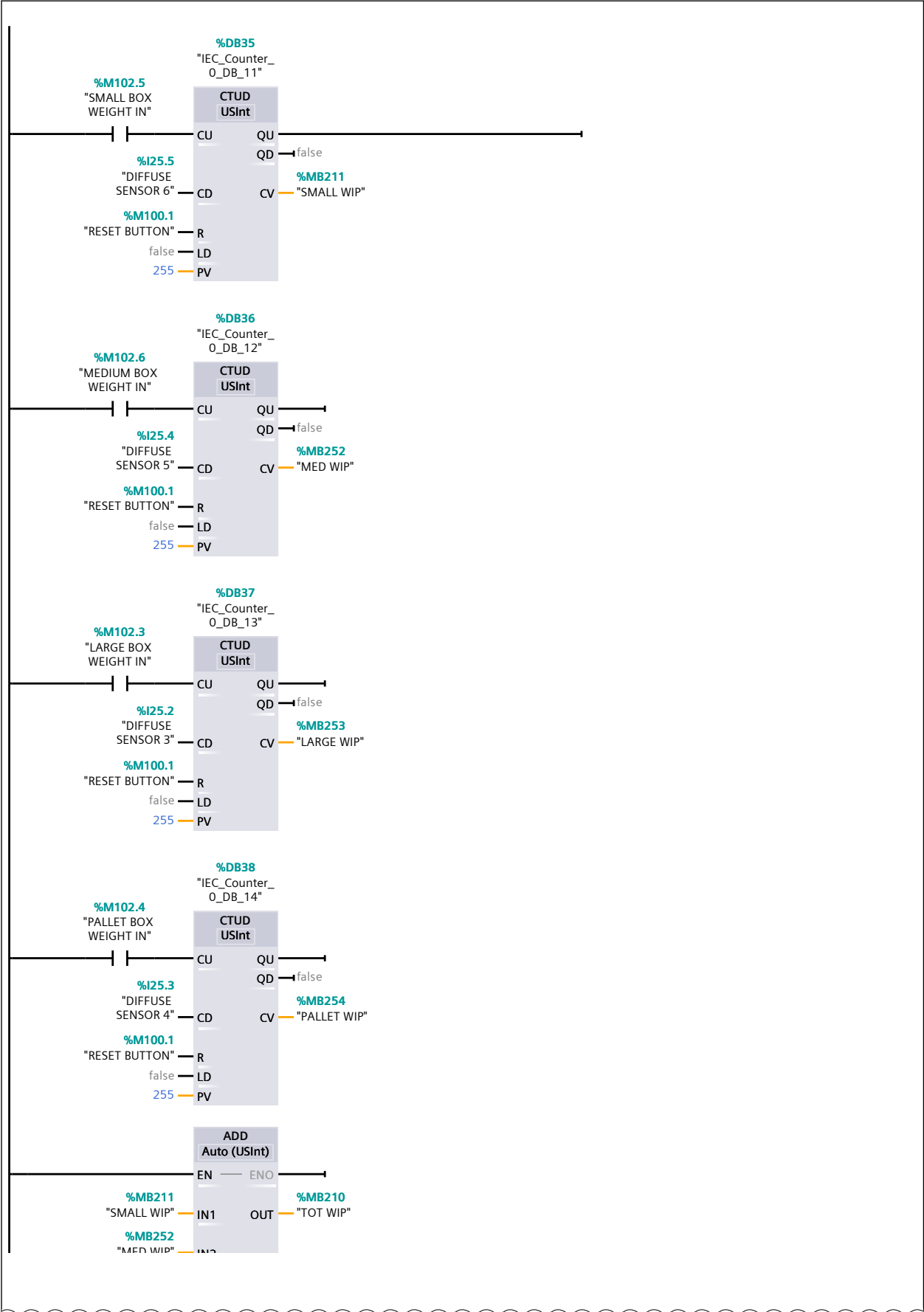
A Diffuse sensor counts the total amount of boxes entering the system. Outputs from weigher 1 feed into count UP function blocks, which count the amount of each size box that has passed over weigher 1 and entered the system. They are reset to 0 using a reset button displayed on the HMI.



Network 15: WIP COUNT

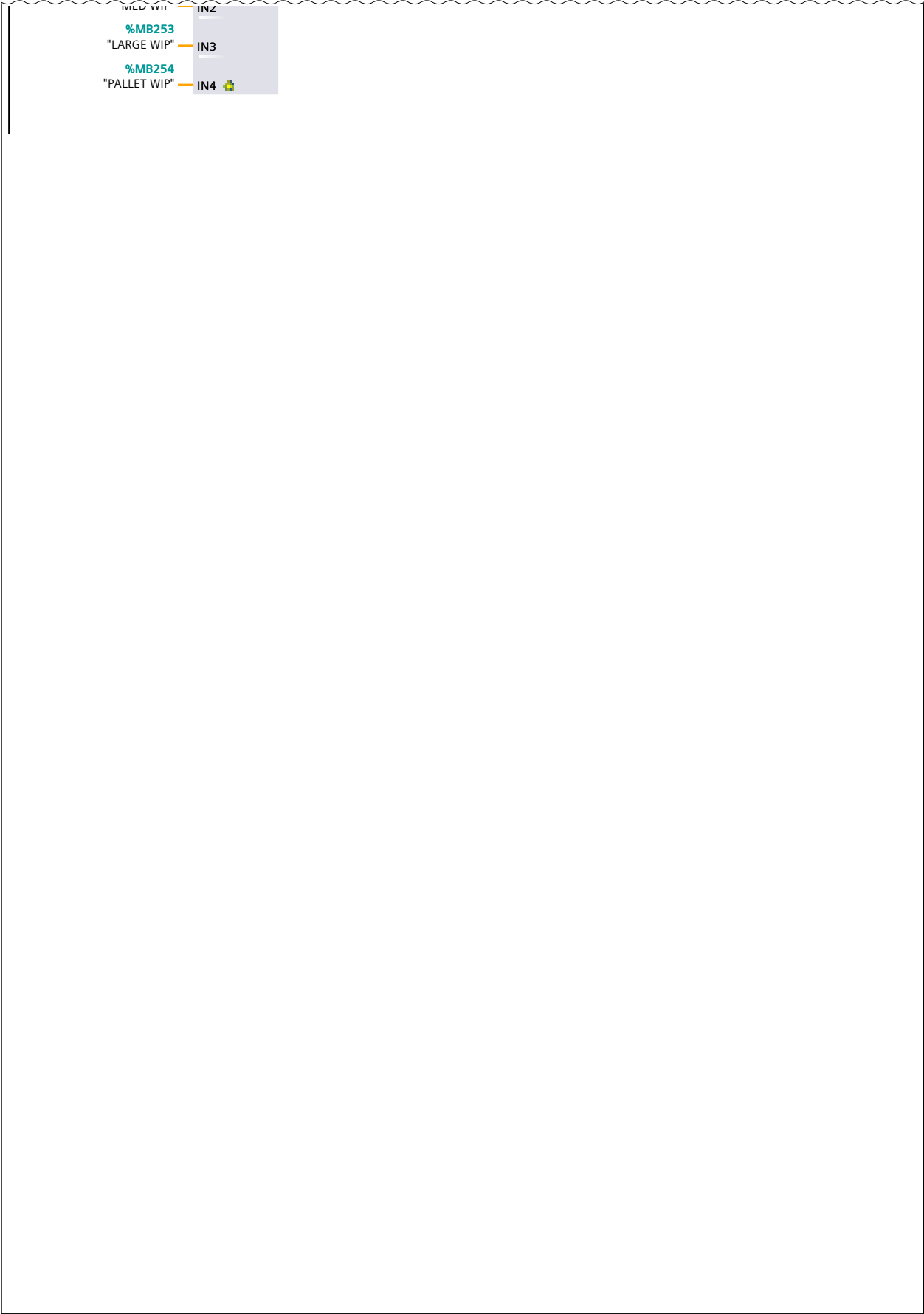
This network uses Count up/down function blocks to count the WIP for each size package. the count UP input comes from the weigher 1 outputs, the count DOWN inputs come from a diffuse sensor on the output chute for each size respectively, this difference is known as WIP or work in progress. They are reset to 0 using a reset button displayed on the HMI. There is also an ADD function block which adds the total from each size to create an overall system total WIP.

Network 15: WIP COUNT (1.1 / 2.1)



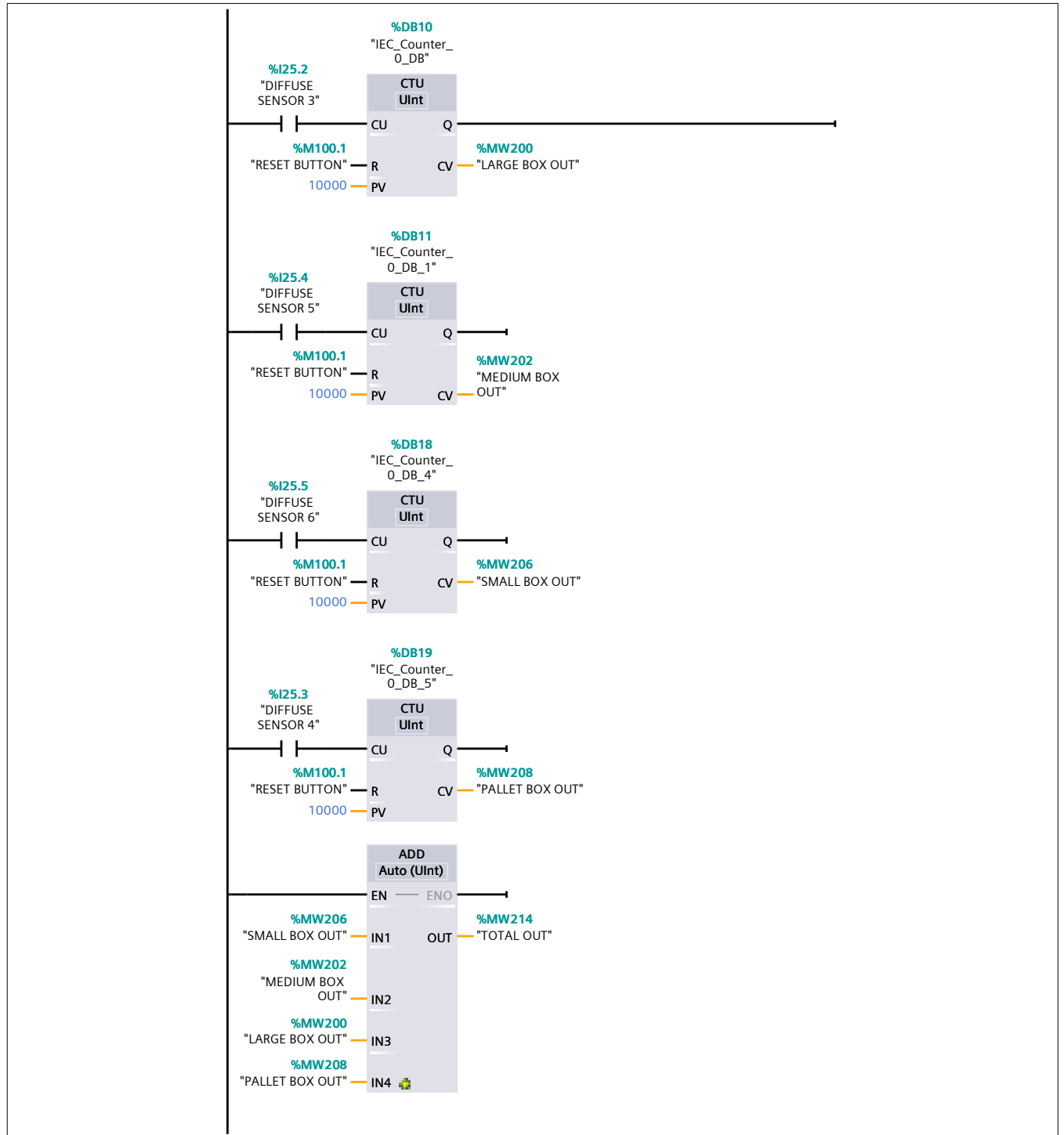
Network 15: WIP COUNT (2.1 / 2.1)

1.1 (Page1 - 14)



Network 16: OUT Count

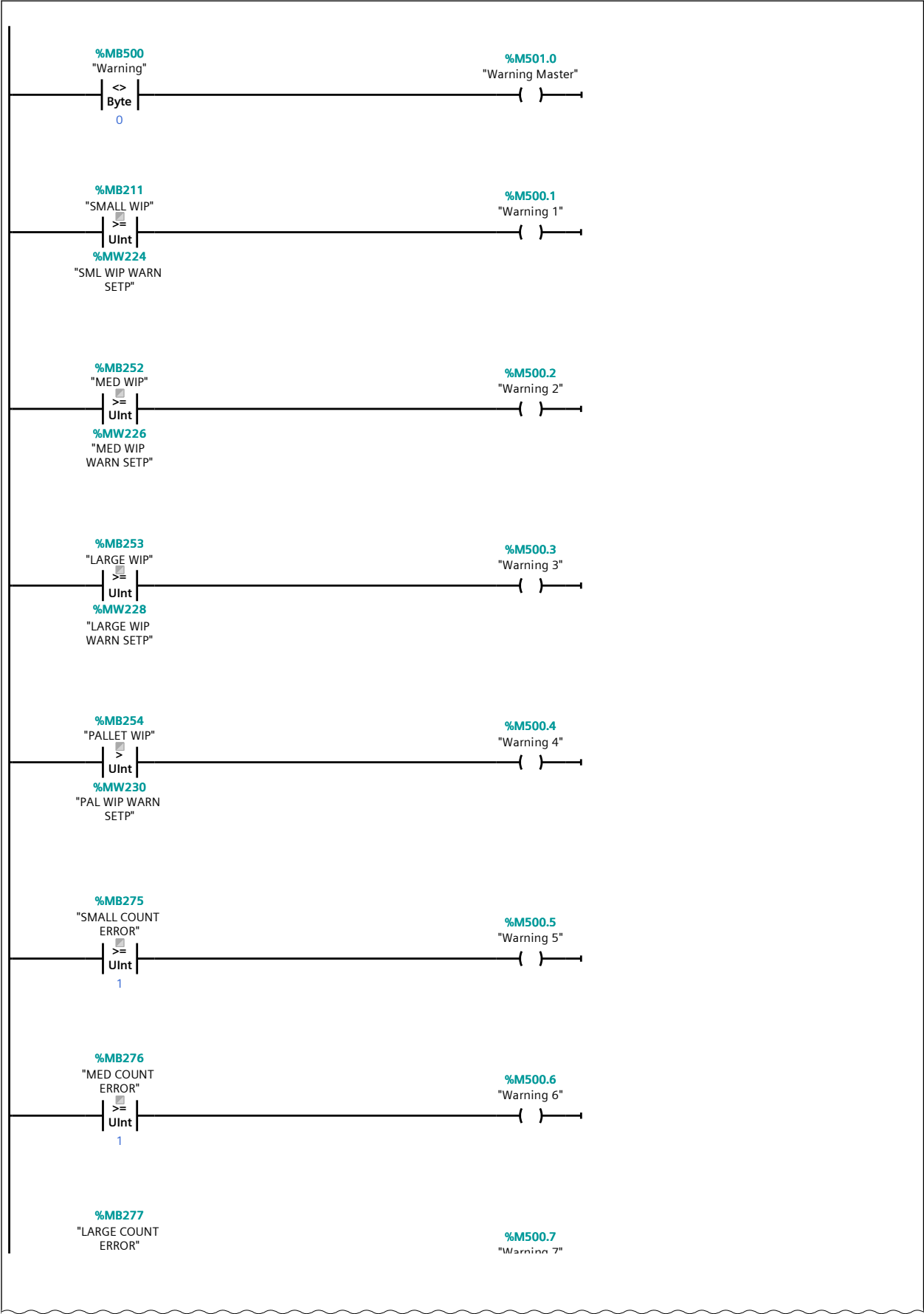
The count UP inputs for each function block come from a diffuse sensor on the output chute for each size respectively, this counts the number of boxes that have left the system. They are reset to 0 using a reset button displayed on the HMI. There is also an ADD function block which adds the total from each size to create an overall system total output.



Network 17: Warnings

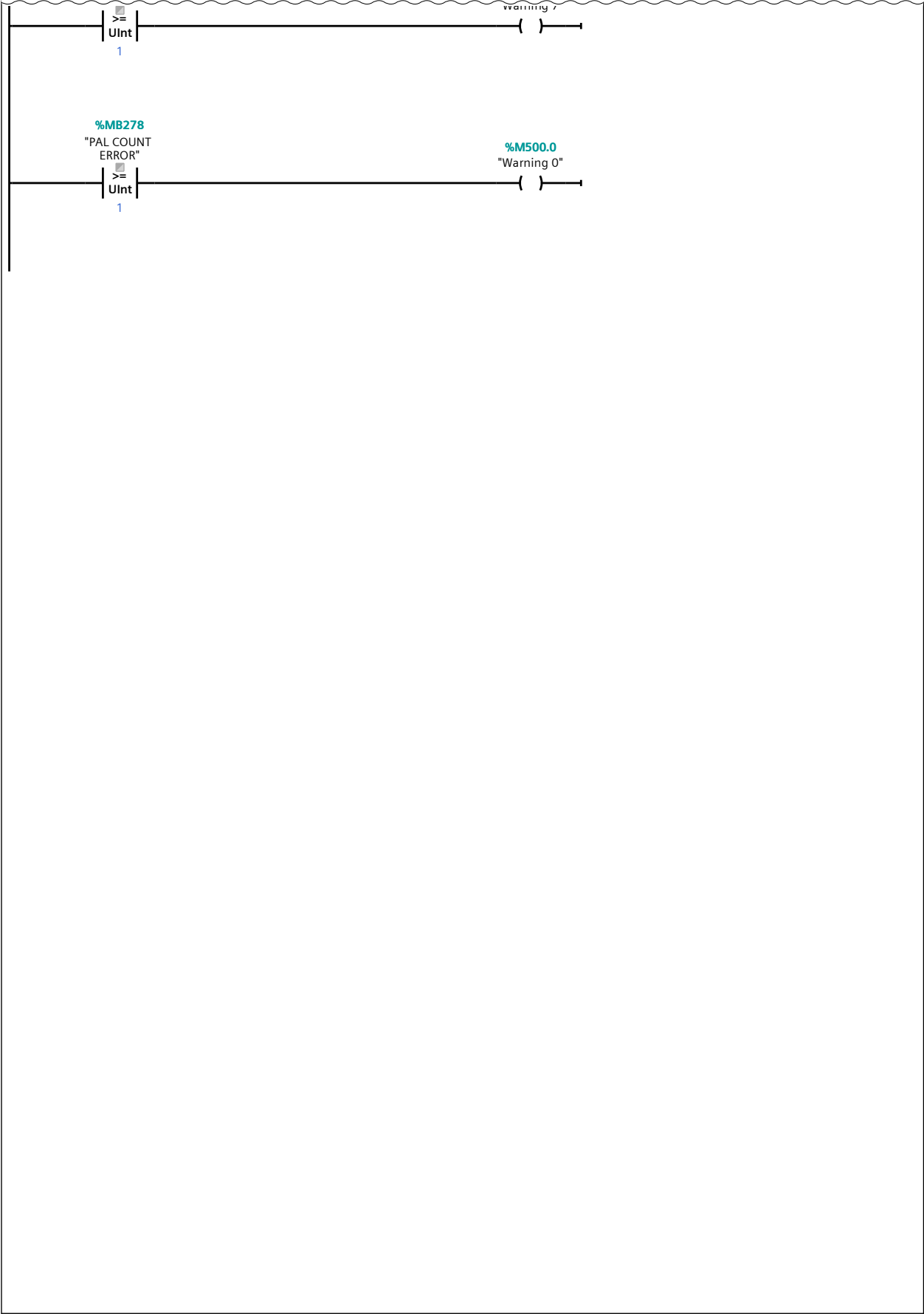
This network contains the logic for system warnings. The warnings as defined in the system strategy, are controlled using comparators and defined setpoints to trigger warning outputs. There is also a master warning that is activated if any of the warning bits are set to high.

Network 17: Warnings (1.1 / 2.1)



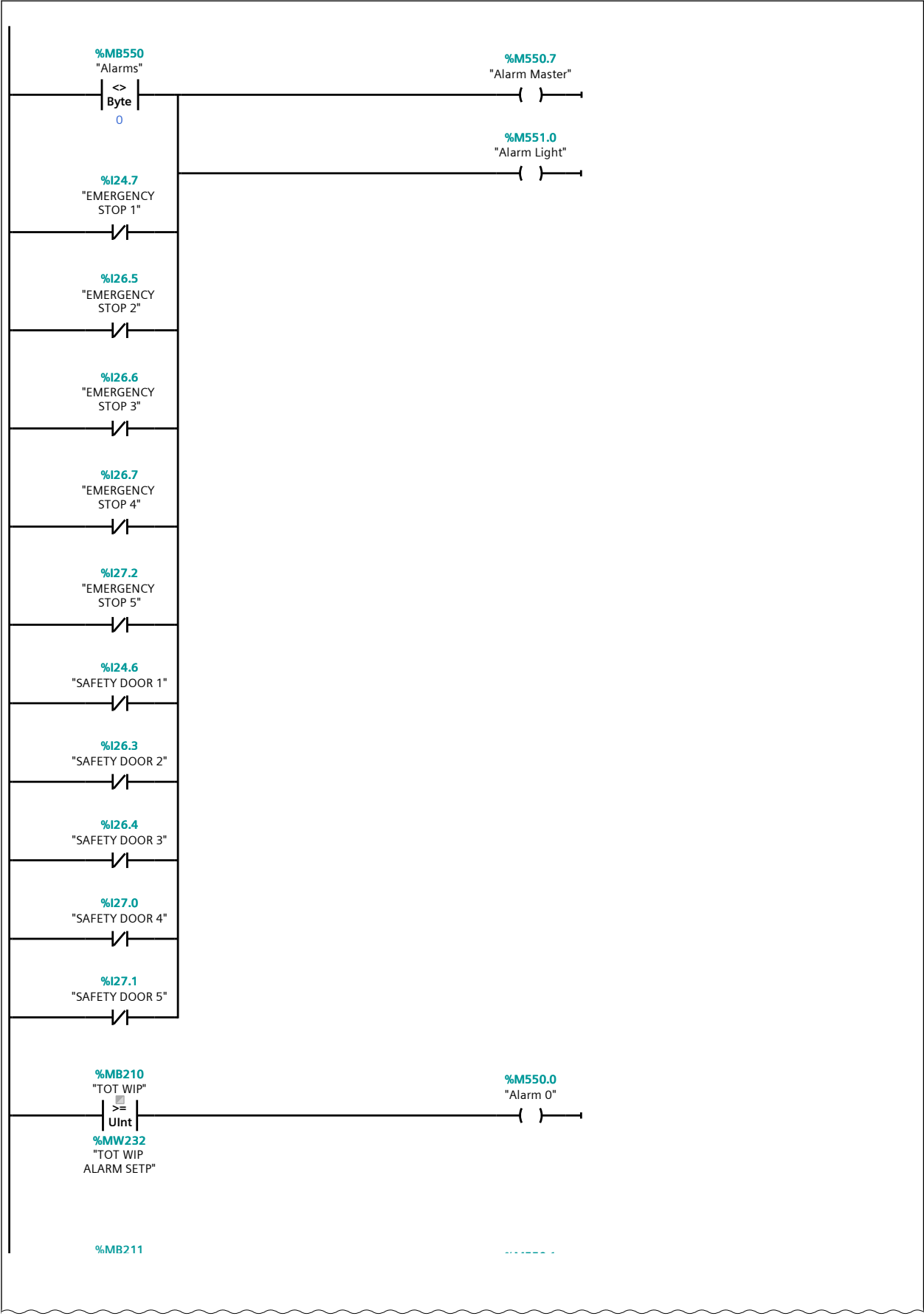
Network 17: Warnings (2.1 / 2.1)

1.1 (Page1 - 17)



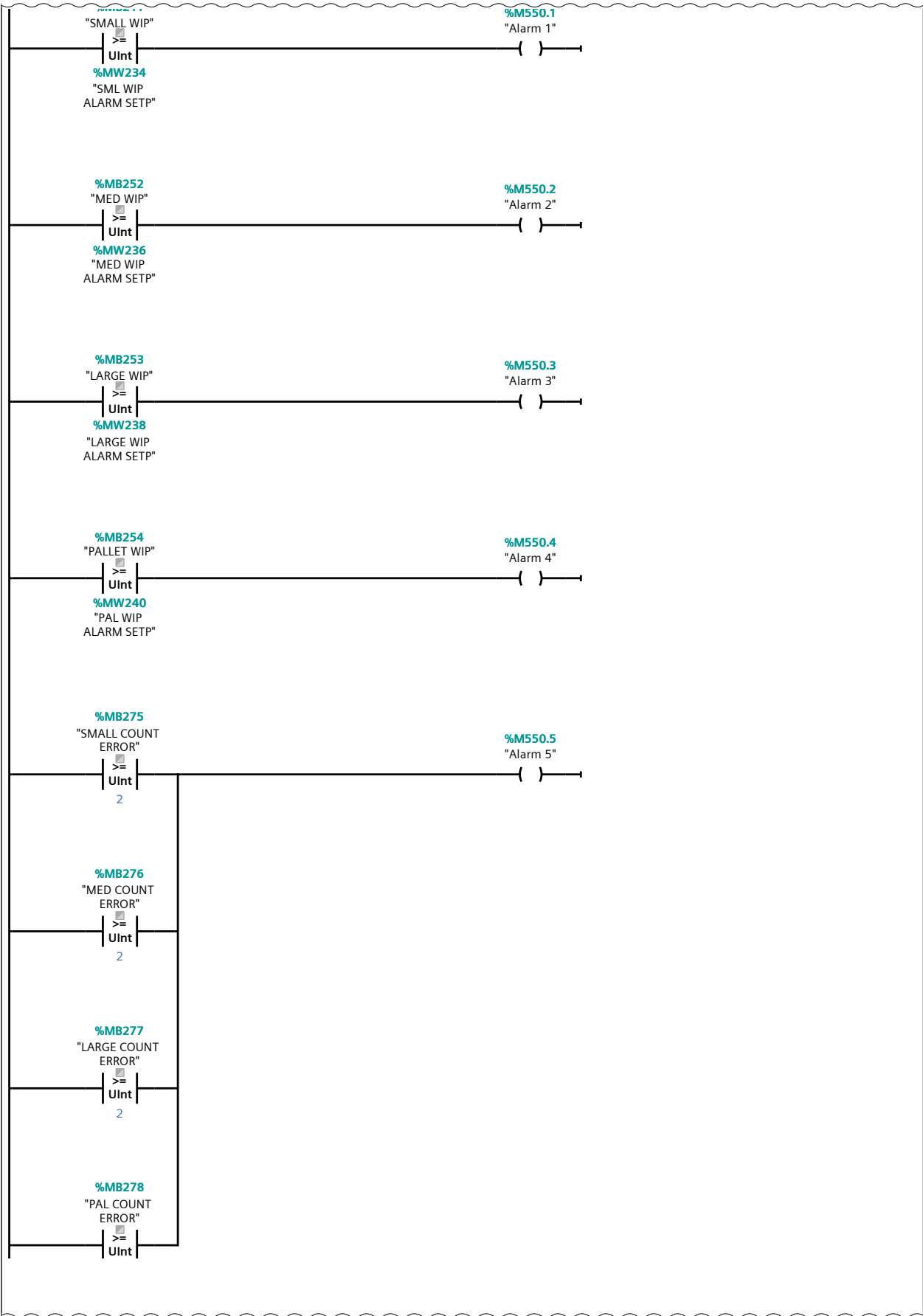
Totally Integrated Automation Portal		
Network 18: Alarms This network contains the logic for system Alarms. The alarms as defined in the system strategy, are controlled using comparators and defined setpoints to trigger alarm outputs. There is also a master alarm that is activated if any of the alarm bits are set to high.		

Network 18: Alarms (1.1 / 3.1)



Network 18: Alarms (2.1 / 3.1)

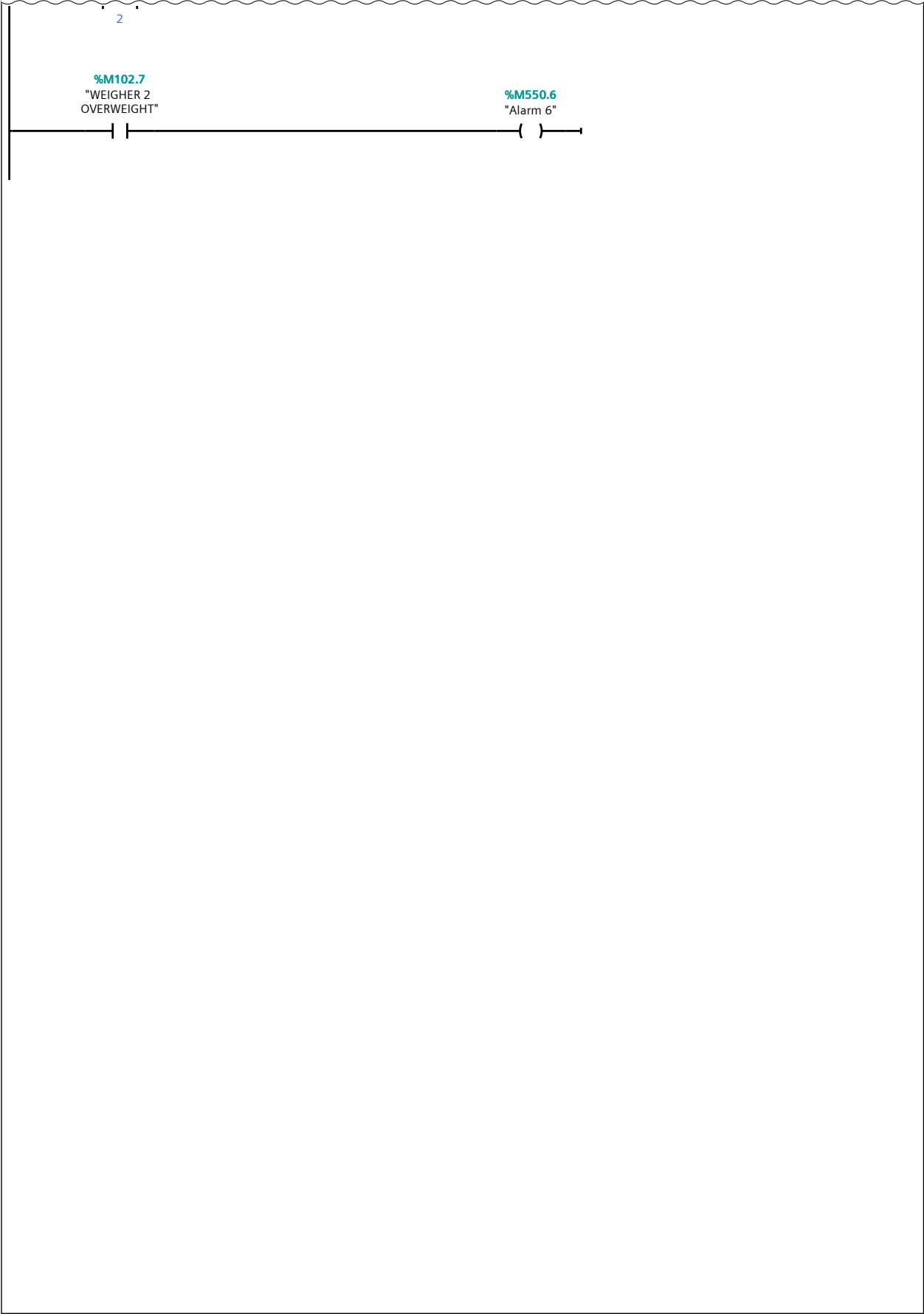
1.1 (Page1 - 20)



3.1 (Page1 - 22)

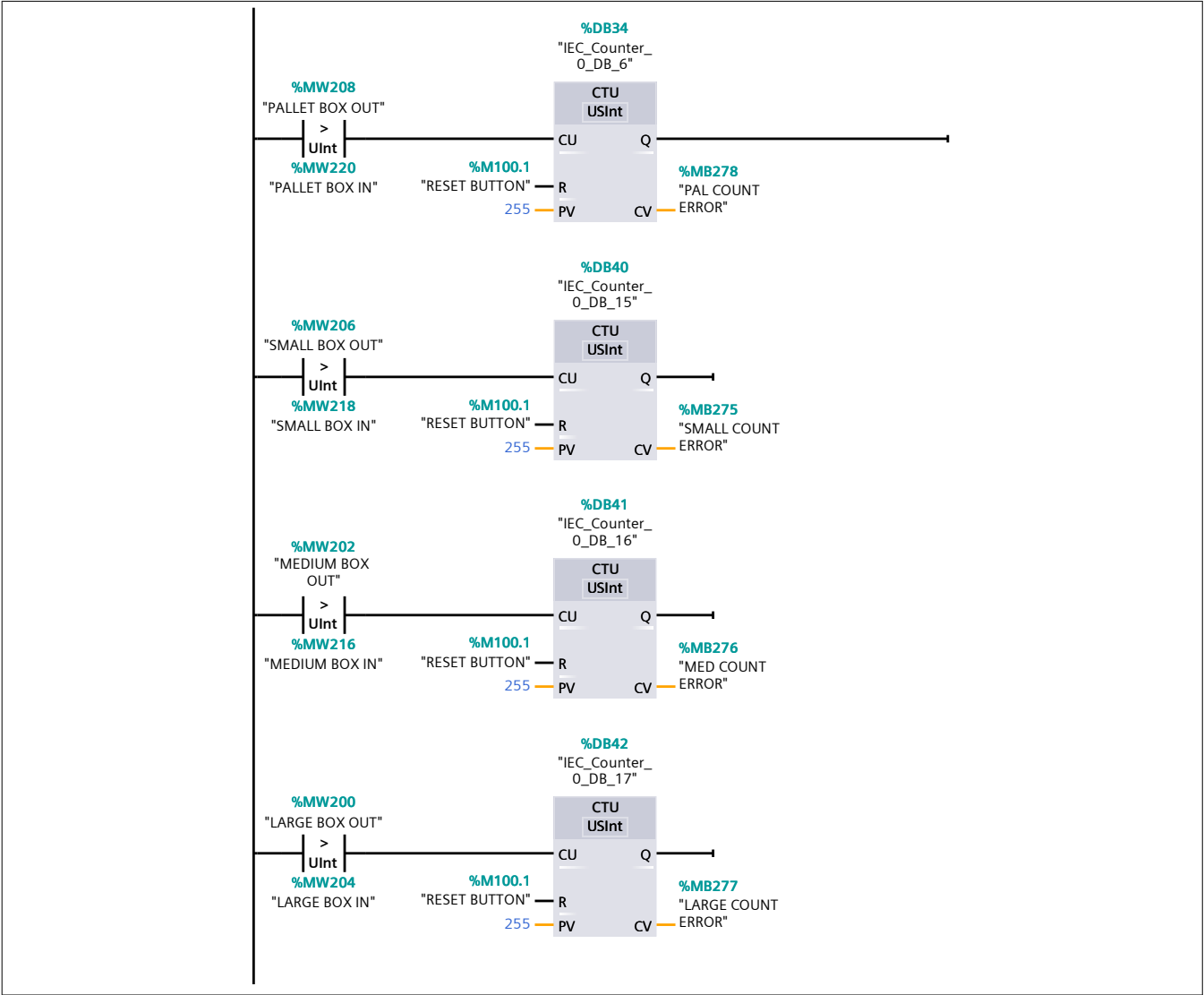
Network 18: Alarms (3.1 / 3.1)

2.1 (Page1 - 21)



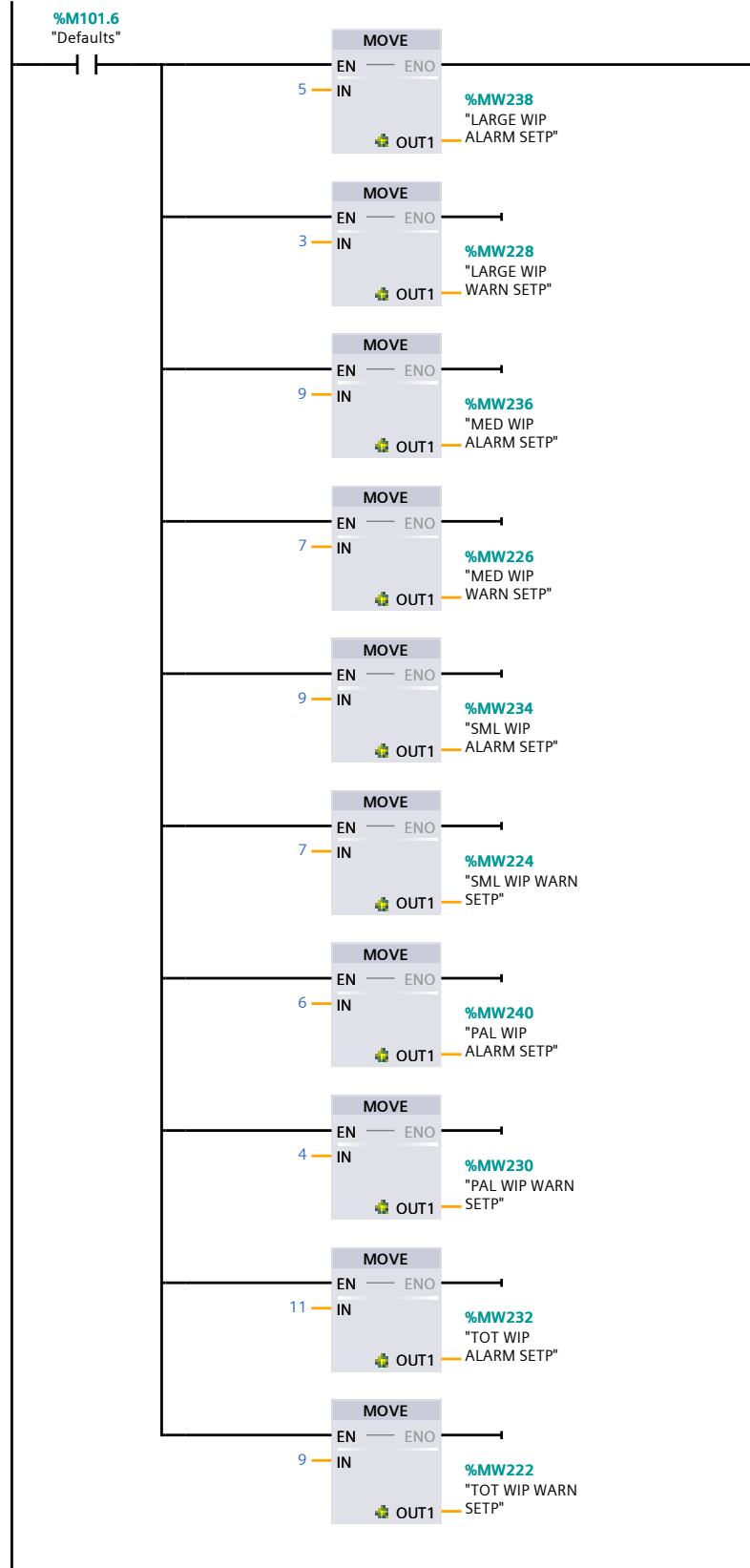
Network 19: Check Counters

Comparators which compare the "OUT" count values against the "IN" count values for each parcel size, counting UP if the "OUT" Value exceeds the "IN" Value.



Network 20: Defaults

A Series of values which are to be used as default setpoints when a button is pressed on the HMI, this is to save time on initialisation of the simulation, as these values are not retained in the memory after the PLC is stopped.



Network 21: LCD DISPLAYS

Converts various "Dint" or "UInt" Values from Input devices such as weighers, or calculated count function blocks like totalisers and converts them to "Real" Outputs for the LCD displays in Factory IO.

