



APPLIED PLC CONTROL SYSTEM

Module code: ACDA6000, Lecturer: Dr Gary Jones

ABSTRACT

This article displays the PLC control system implemented to operate a conveyor belt to allow different sized objects to be sorted into storage bins dependant on their size characteristics.

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Introduction

A Programmable Logic Controller (PLC) is an industrial computer control system that continuously monitors the state of input devices and makes decisions based upon a custom program to control the state of output devices. PLC's are modular, this allows the user to mix and match input and output devices to suit the application. [1]

This document details a PLC control system designed to sort aluminium pucks dependant on diameter and height. There are two different heights, tall and short, and there are three different diameters, narrow, medium and large.

The aluminium pucks are manually placed on the conveyor belt by the operator, the pucks that are narrow and both tall and short are to be ejected into storage bin one by cylinder one. The pucks that are of medium diameter and short in height are ejected into storage bin two by cylinder two. The pucks that are of large diameter and short height are to be ejected into storage bin three by cylinder three. The pucks that are of medium diameter and tall height are to continue to travel to the end of the conveyor into storage bin four. The pucks that are of large diameter and tall in height are to be stored in a container at the start of the conveyor belt, this will require the conveyor belt to be reversed.

As well as the control system logic to ensure the above functions are achieved, there will be a HMI display that provides a visual indication that the system is running, the speed of the conveyor belt, a counter display that indicates the number of pucks that have been sorted and indication of any error or warning fault conditions.

The root screen of the HMI is to include an emergency stop button and the facility to display alternate screens which can be used to interrogate warnings or errors should they occur. If an error is to occur, the system must stop immediately and should not be able to be restarted until the operator has manually removed the error and re-set the master error flag.

This system is to be designed and implemented using Siemens TIA software with a Siemens S7-1200 PLC. The physical operational hardware is the LJ Create industrial control work cell.

Operational problems

Warning and error indications and also automatic system stop functions are built into a program to prevent damage to the machinery, components and operators. These will range from flashing lights to indicate a warning state to limit switches or emergency stop buttons that when operated completely stop a process to ensure it is safe, an error function will require an operator to manually allow the process to restart by re-setting the master error indication. All warnings and errors will be displayed on a HMI. Below is a table detailing both warning and errors applicable to this operation.

Warning table:

Description	Problem that could occur	Preventative measure
Air pressure low	Cylinder's may not operate if air pressure is too low	Monitor air pressure using an external pressure transducer
Storage bins 80% of capacity	Storage bins are nearly too full, if pucks keep filling, the pucks could back up onto the conveyor and cause a blockage	An alarm at 80% would ensure sufficient time for an operator to empty the storage bins before they get to full
Motor temperature high	Motor could overheat	Install thermocouple on motor and monitor, alarm to alert operator if motor temperature goes above set point
Optical 1 sensor fault	Pucks may travel along conveyor belt without being detected	Install a second low level sensor so the system has redundancy
Counter fault	Storage bins may display incorrect quantities of pucks being stored	Install a weight measurement device in the storage bins, this can be used as a second counter
Motor vibration high	Motor could fall out of alignment and cause the conveyor belt to misalign	Install vibration monitoring devices on the motor, set an alarm point if vibration levels get to high
Conveyor belt slippage	Timings could be effected if the conveyor belt slips	Install tension gauge on the conveyor belt, set an alarm point if the tension becomes slack
Conveyor roller temperature high	Bearings on rollers could warp and cause vibration/ misalignment of the conveyor belt	Install temperature monitoring device on the roller bearing, set an alarm point if temperature gets to high
No material on conveyor belt	Conveyor belt may continue to operate when not required	Use a timer that will stop the conveyor belt if no operation has happened for 5 minutes

Table 1 - Warning

Error table:

Description	Problem that could occur	Preventative measure
Emergency stop	Any emergency situation, entrapment, blockage etc.	Emergency stop function on HMI which immediately stops the entire process
Storage bins full	Storage bins at full capacity, pucks could back up or spill onto conveyor belt causing a blockage	Error set point automatically sets master error which causes a trip on the conveyor running
Conveyor belt speed outside parameters	Pucks may have past the point they need to be ejected if belt is too fast or not reach the point of ejection if too slow	Monitor the conveyor belt speed, if the speed increases or decreases by +/- 2mm/s, a signal resets the conveyor running signal and stops the process before any blockages or miss timings occur
Cylinder fault	Cylinder does not extend, pucks not ejected correctly	Monitor cylinder in position, if the signal does not change state, an error flag is set that stops the conveyor running to avoid pucks being sorted into the wrong storage bins
Cylinder not retracted	Cylinder does not retract, pucks build up on conveyor belt	Monitor cylinder in position, if the signal does not return after 500ms, a timer sets the master error which stops the conveyor belt
Air pressure critically low	Cylinders may not operate	Install pressure switch on the air supply, if the air pressure gets to a level where it will not operate the cylinders, a signal switches the error signal which would trip the conveyor running signal
Foreign object on conveyor belt	Obstruction on conveyor belt could cause a blockage or equipment not operating correctly	Install a scan camera that monitors the conveyor belt, if a product is not within parameters, a signal from the camera is sent to an error bit which sets a conveyor trip signal

Table 2 - Error table

Software review and timing diagrams

A timing diagram is a model that focuses on showing how objects interact with each other during a period of time. The primary purpose of the diagram is to show the changing conditions along a linear time axis. [2]

Below are the timing diagrams for this program, each section shows the PLC network run and then the timing diagram for that network. The timing diagrams are shown for normal operation and for an error or reset condition if that network features that function.

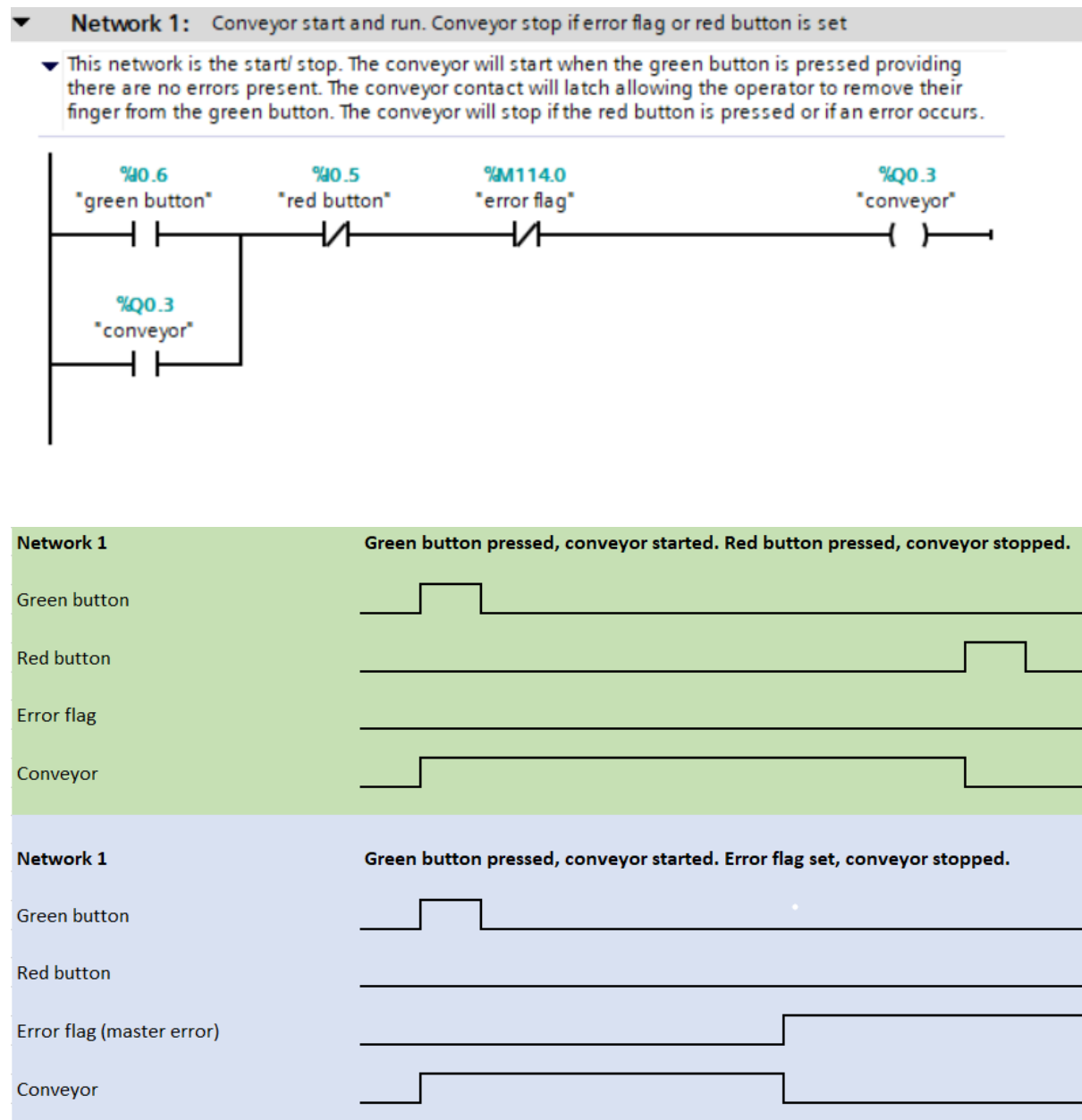


Figure 1 - Network 1 timing diagram

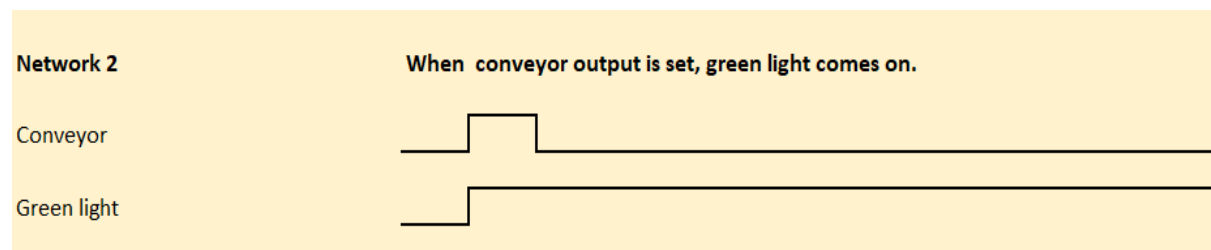
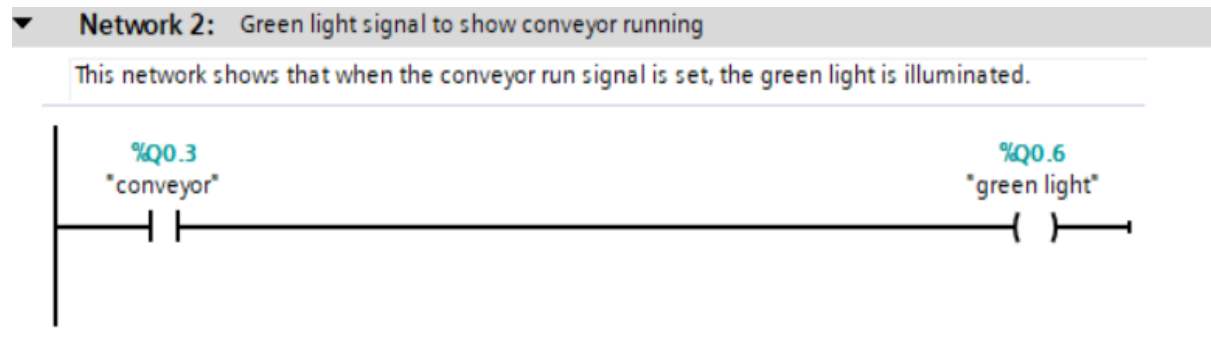


Figure 2 - Network 2 timing diagram

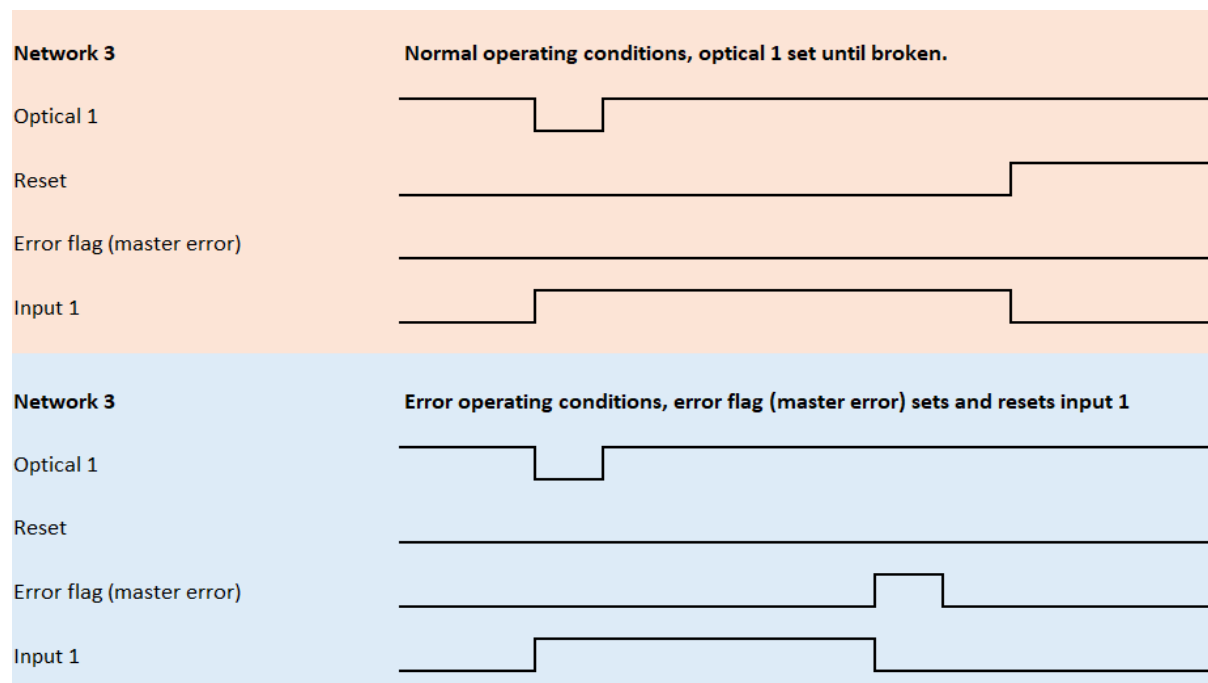
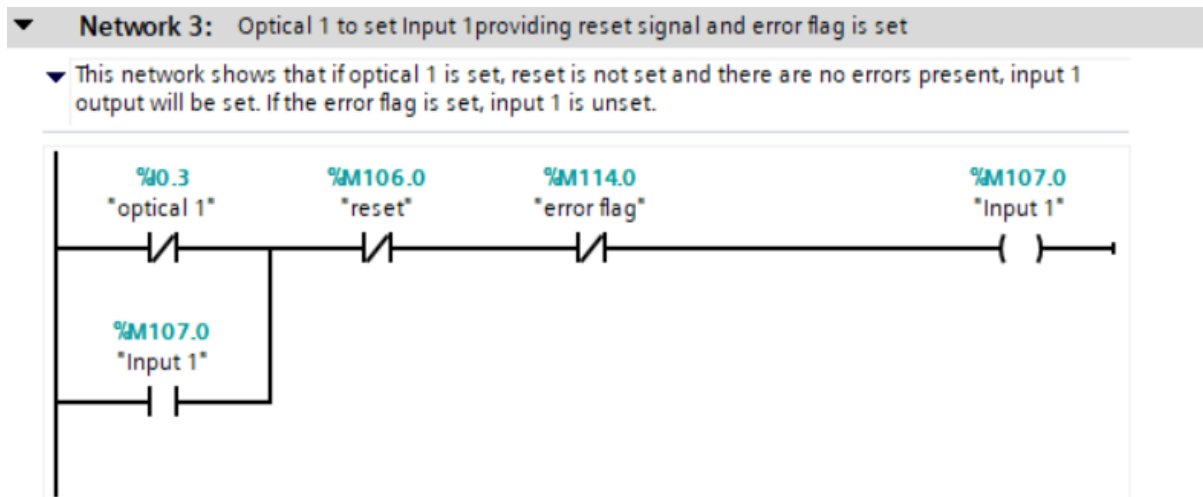


Figure 3 - Network 3 timing diagram

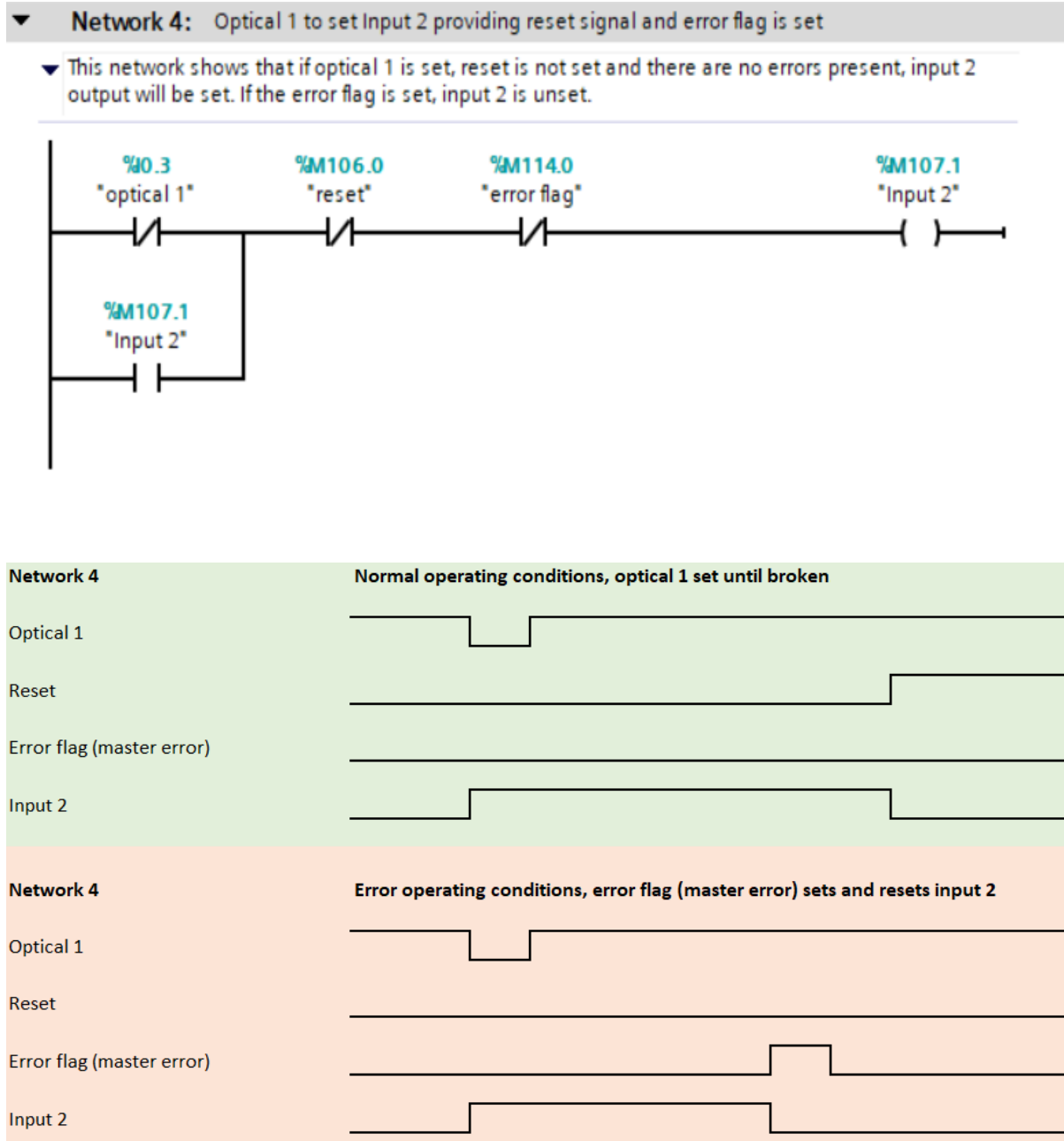


Figure 4 - Network 4 timing diagram

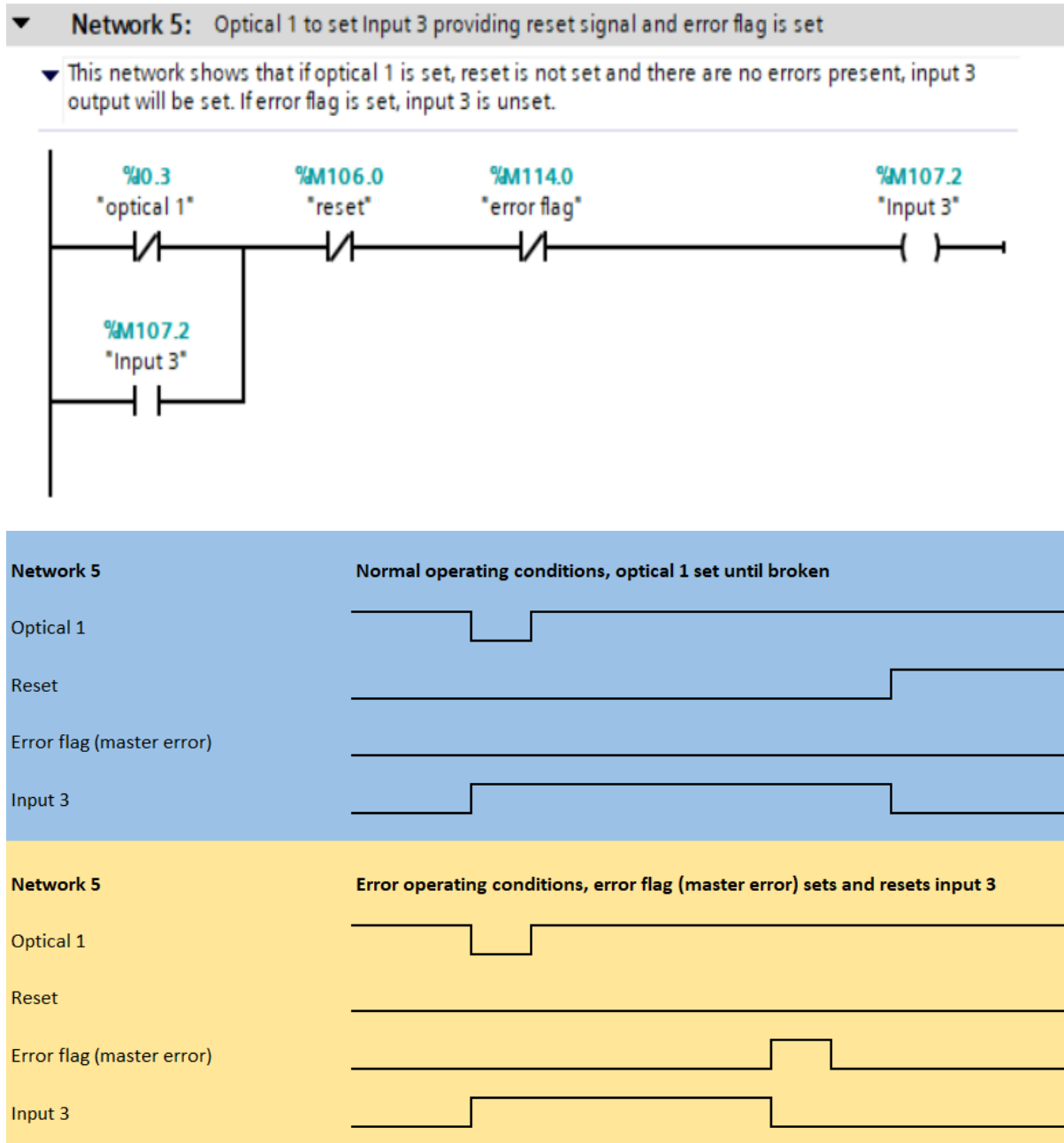


Figure 5 - Network 5 timing diagram

Network 6: Optical 2 set until broken

- ▼ This network shows that optical 2 output is set if reset is not set and optical 2 is set. If reset is set, optical 2 output is unset.

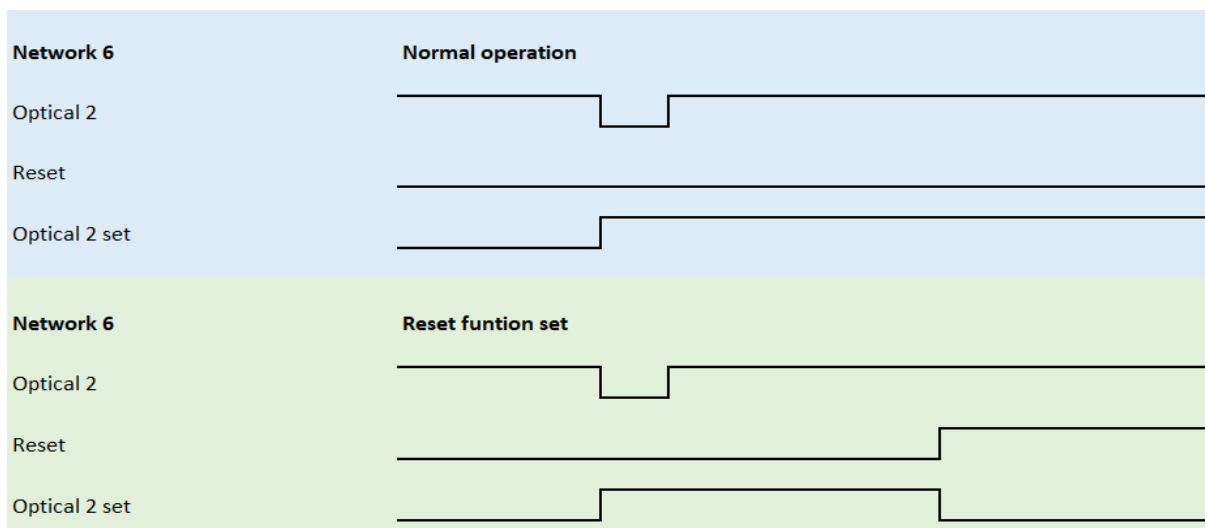
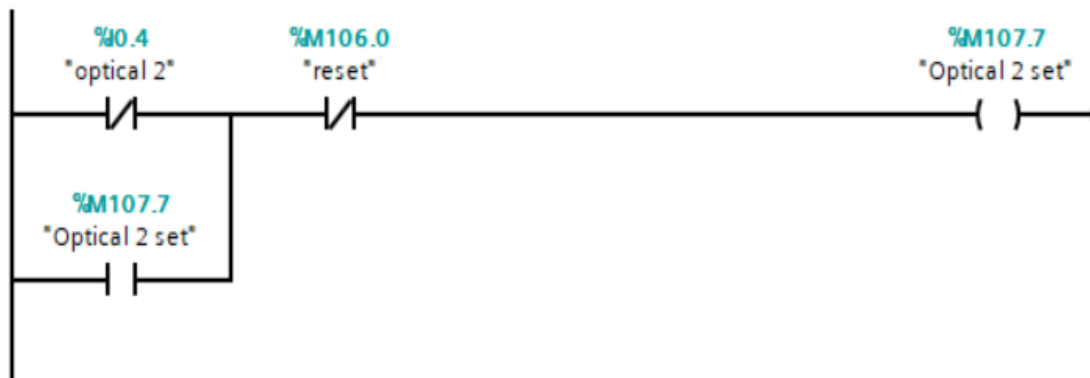


Figure 6 - Network 6 timing diagram

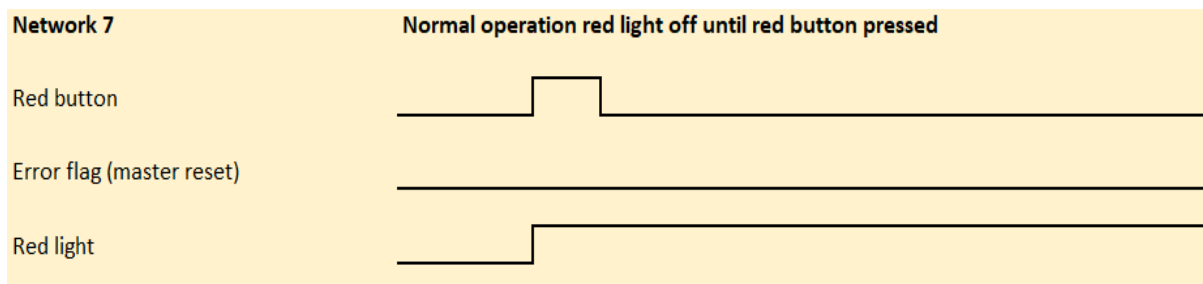
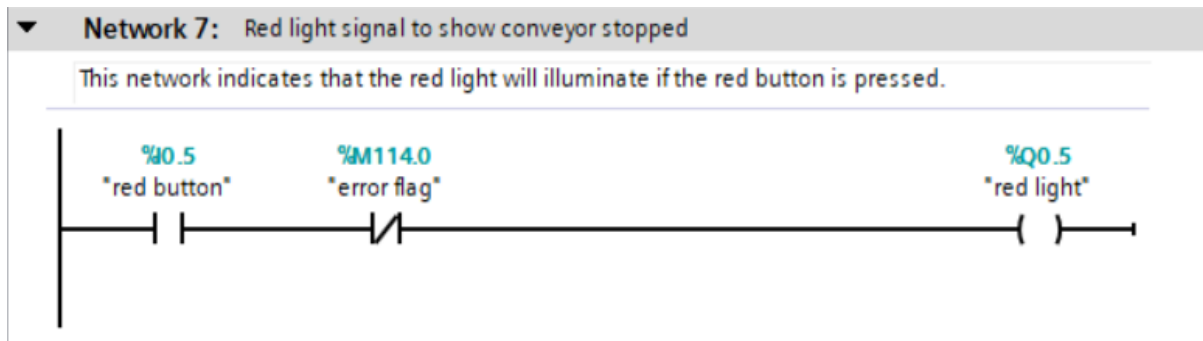


Figure 7 - Network 7 timing diagram

▼ **Network 8:** Pucktime is the time the puck is travelling through optical 1

- ▼ This network contains a time accumulator. The timer measures the accumulated time the puck is travelling through optical 1 sensor. The elapsed time is then output as pucktime. This is used to determine whether the puck is narrow, medium or large in diameter. The timer is reset when the reset signal is set. If reset is set, the pucktime output is unset.

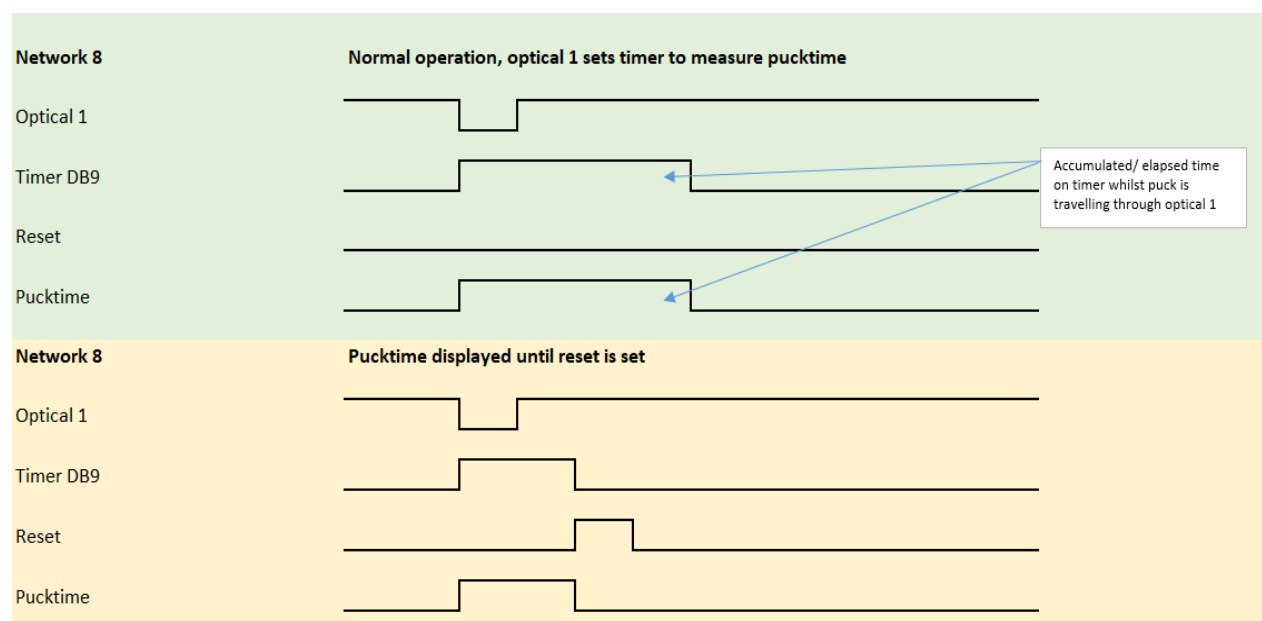
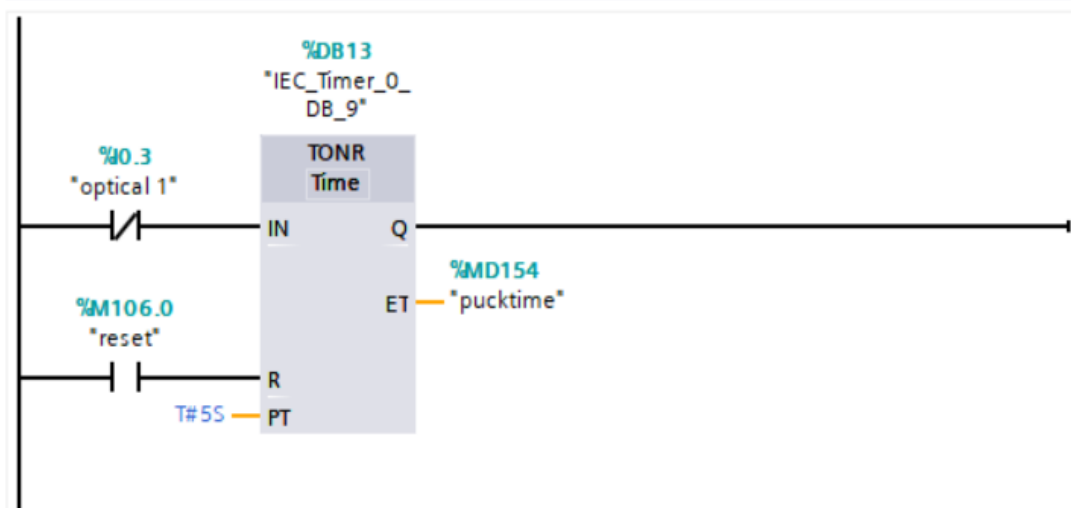


Figure 8 - Network 8 timing diagram

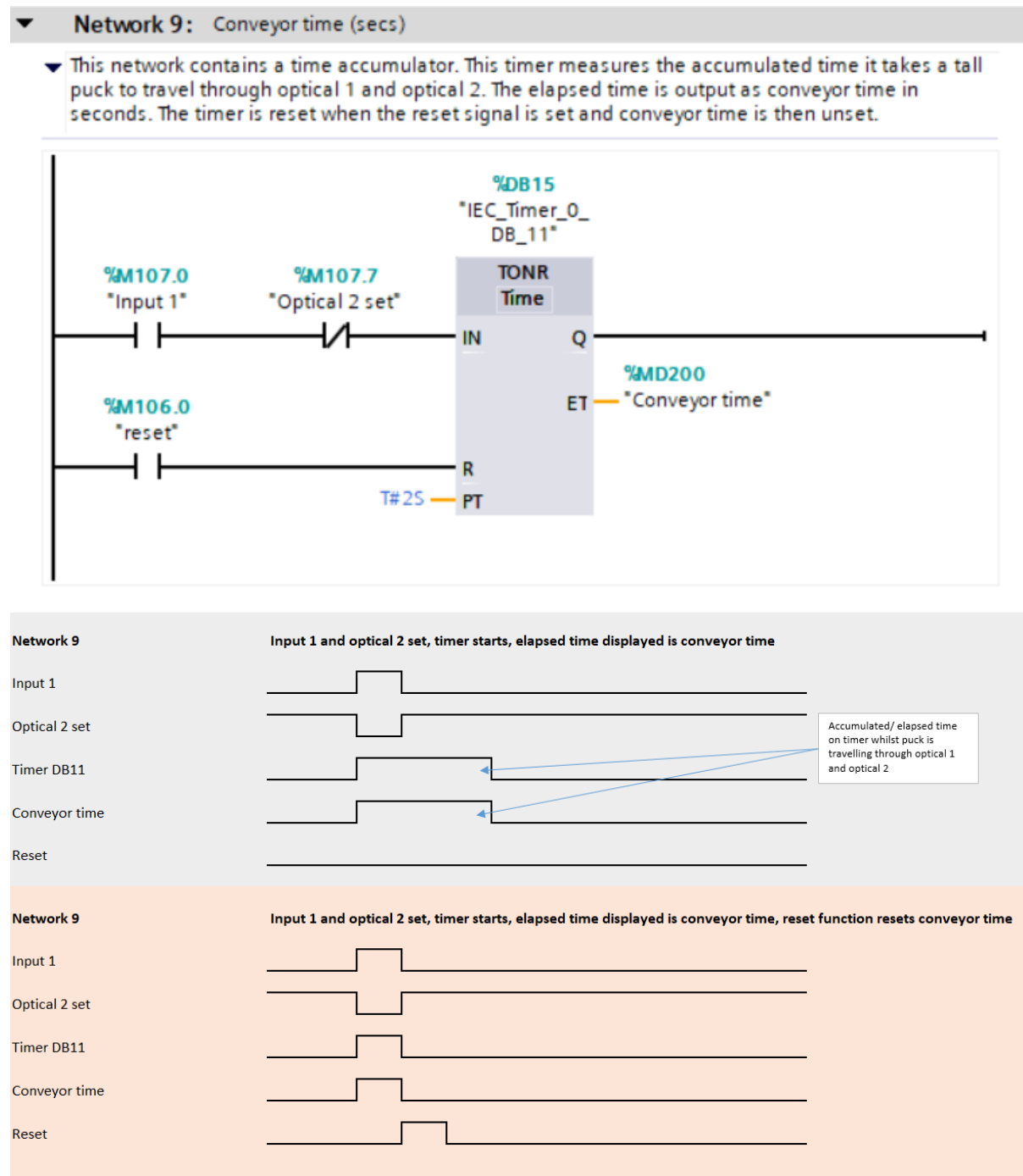


Figure 9 - Network 9 timing diagram

Network 10: Conveyor speed (mm/s). Time between sensor 1 and 2 converted to large integer

- ▼ This network contains a time conversion function. When input 1 is set and tall puck is set, the time conversion function converts the conveyor speed in seconds to a 32 bit integer. The numeric value output from the time conversion is the conveyor count, the conveyor count is divided by 50000 in a divide function to output the conveyor speed in mm/s.

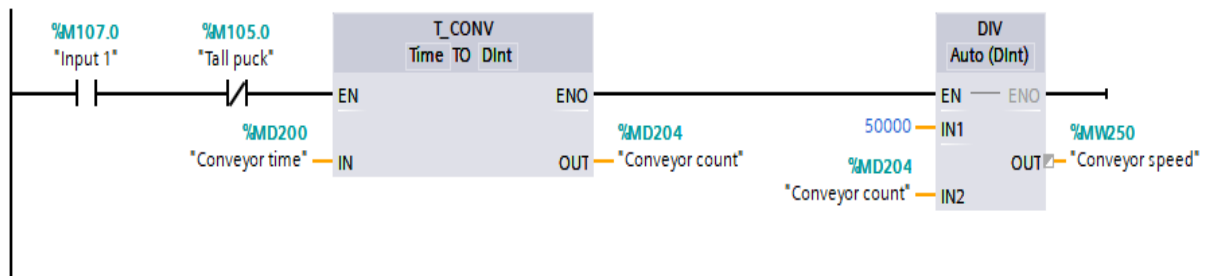
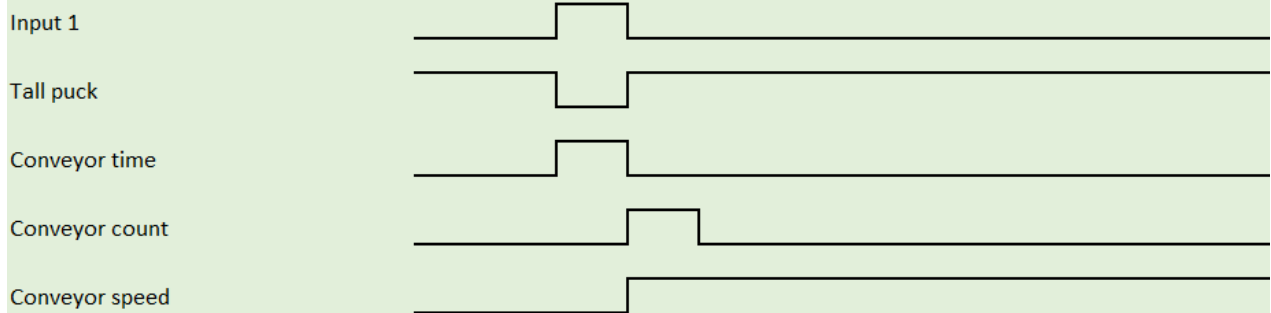
**Network 10****Time between sensor 1 and 2 converted from time to integer**

Figure 10 - Network 10 timing diagram

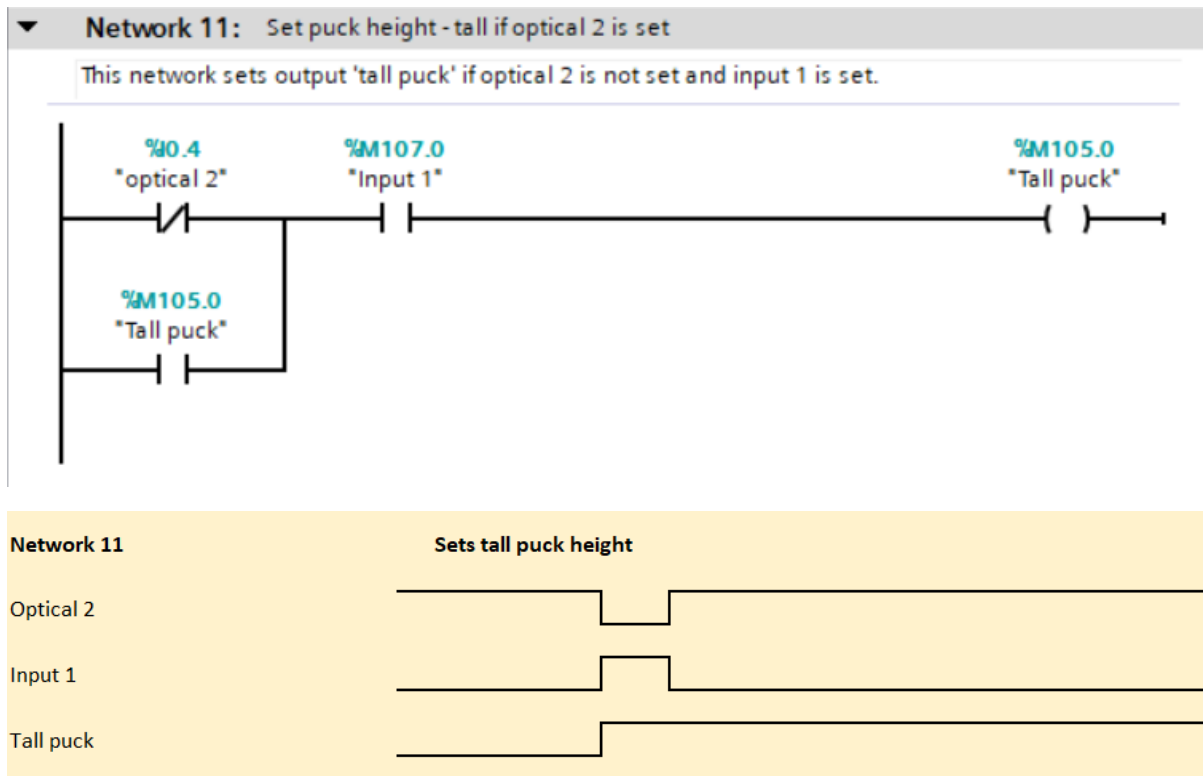


Figure 11 - Network 11 timing diagram

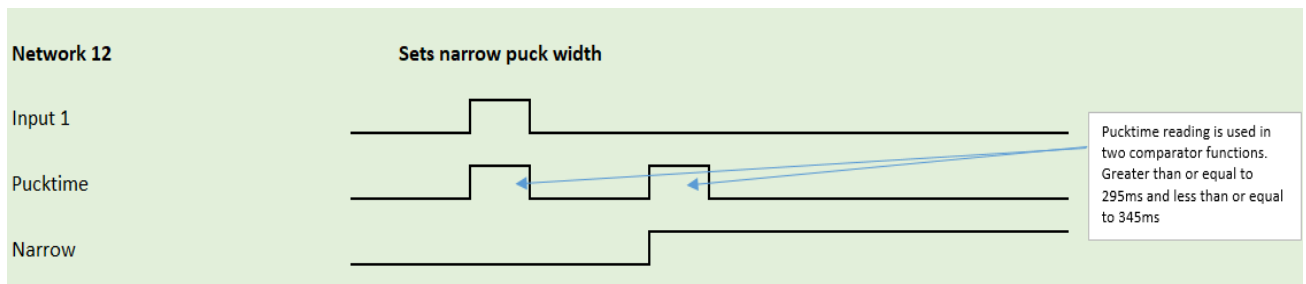
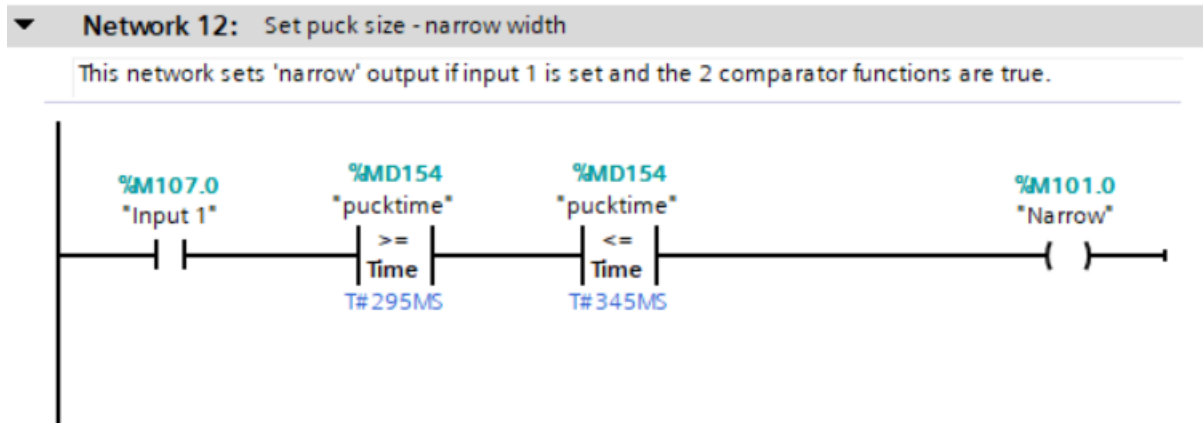


Figure 12 - Network 12 timing diagram

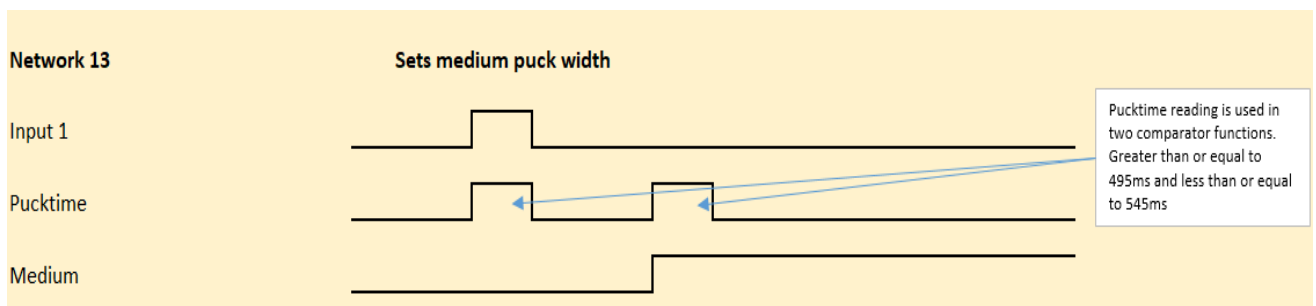
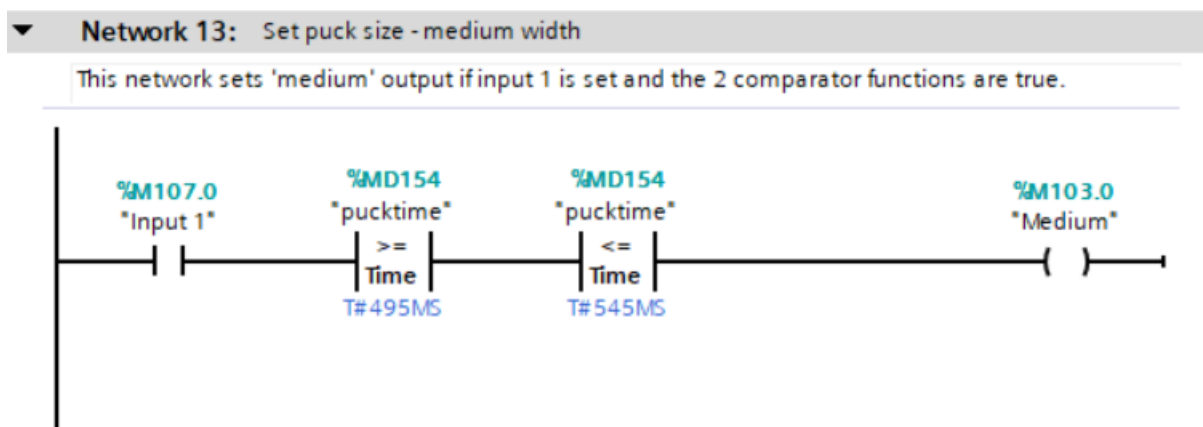


Figure 13 - Network 13 timing diagram

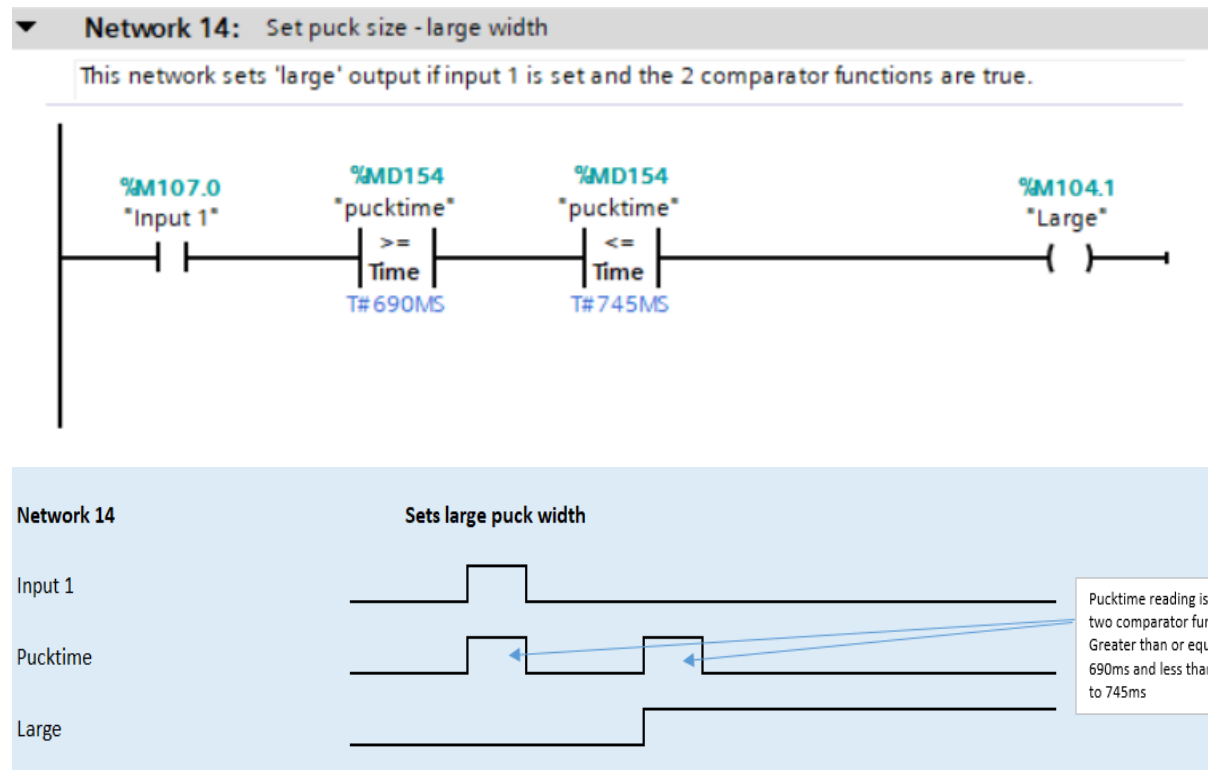


Figure 14 - Network 14 timing diagram

Network 15: Operate cylinder 1 - Tall and short narrow to storage bin 1

- ▼ This network contains an on delay timer. 2500ms after input 1 is set and if 'narrow' is set cylinder 1 will output.

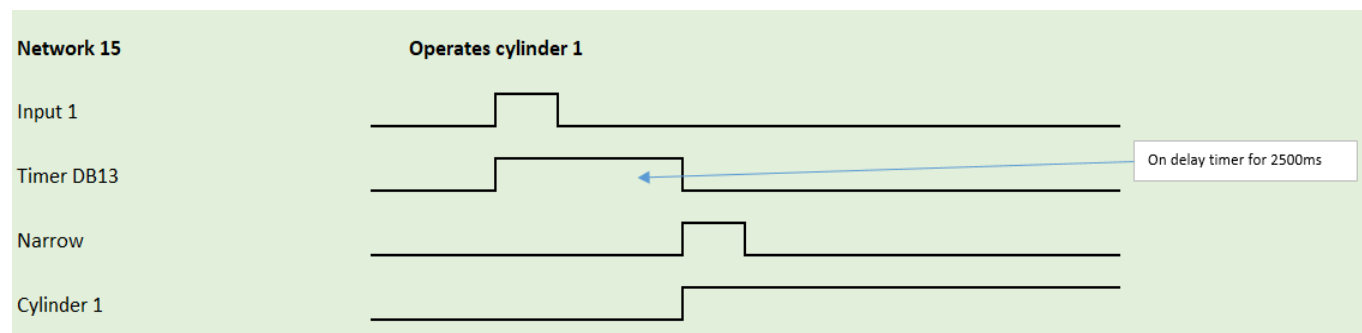
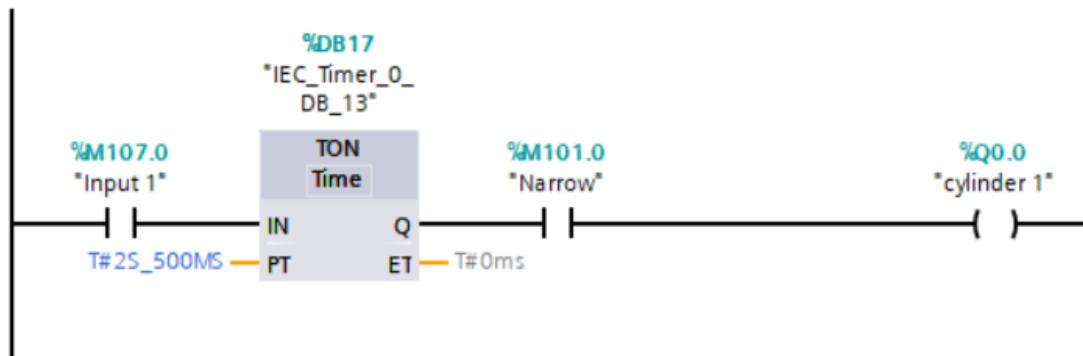
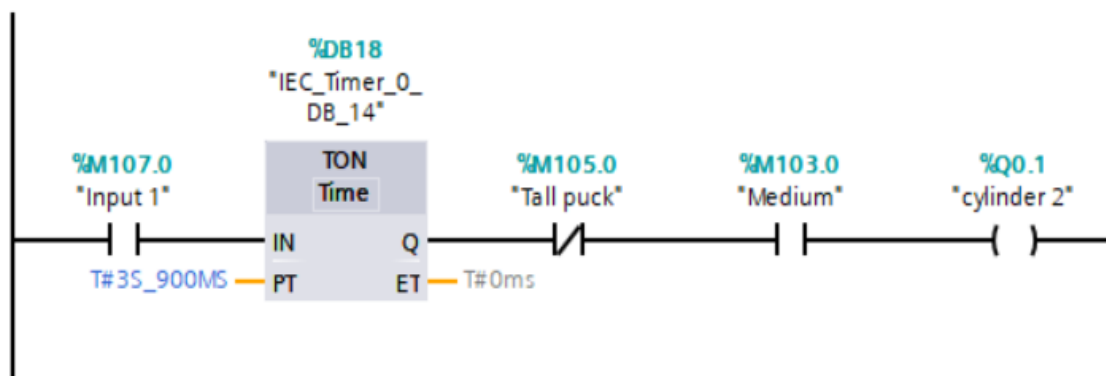


Figure 15 - Network 15 timing diagram

Network 16: Operate cylinder 2 - short medium pucks to storage bin 2

- ▼ This network contains an on delay timer. 3900ms after input 1 is set and if 'medium' and 'tall puck' is set cylinder 2 will output.



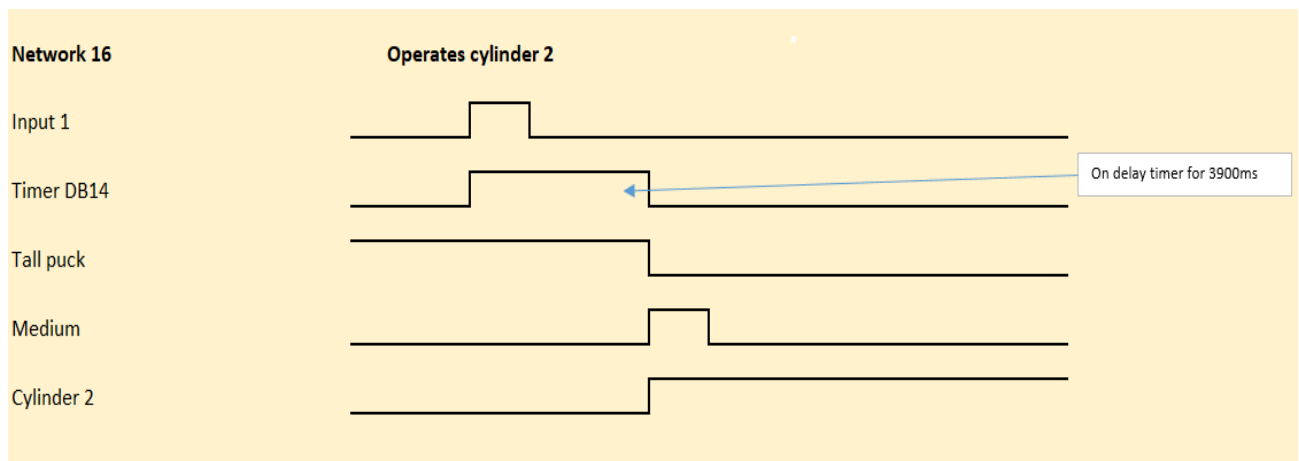


Figure 16 - Network 16 timing diagram

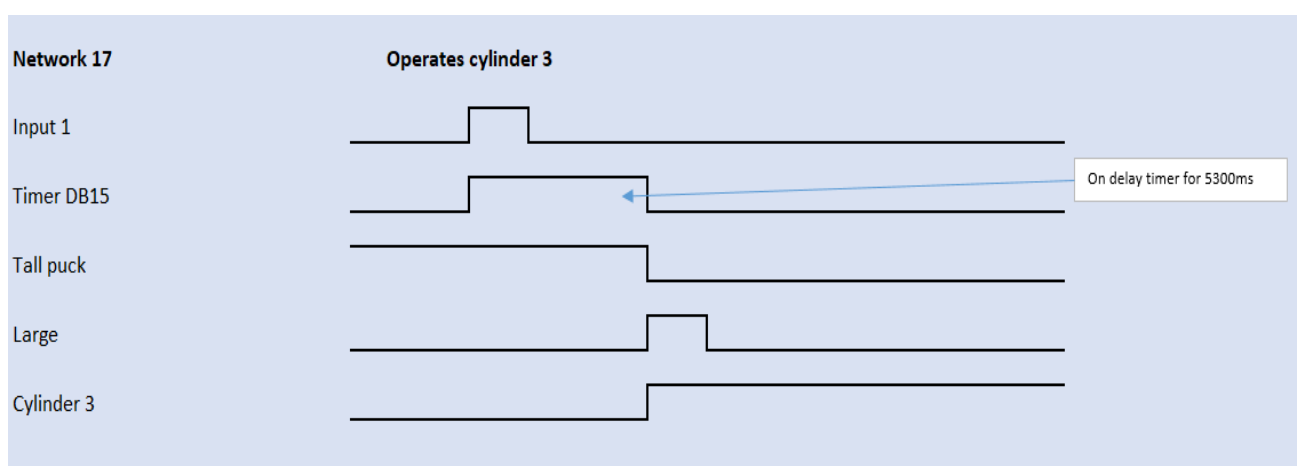
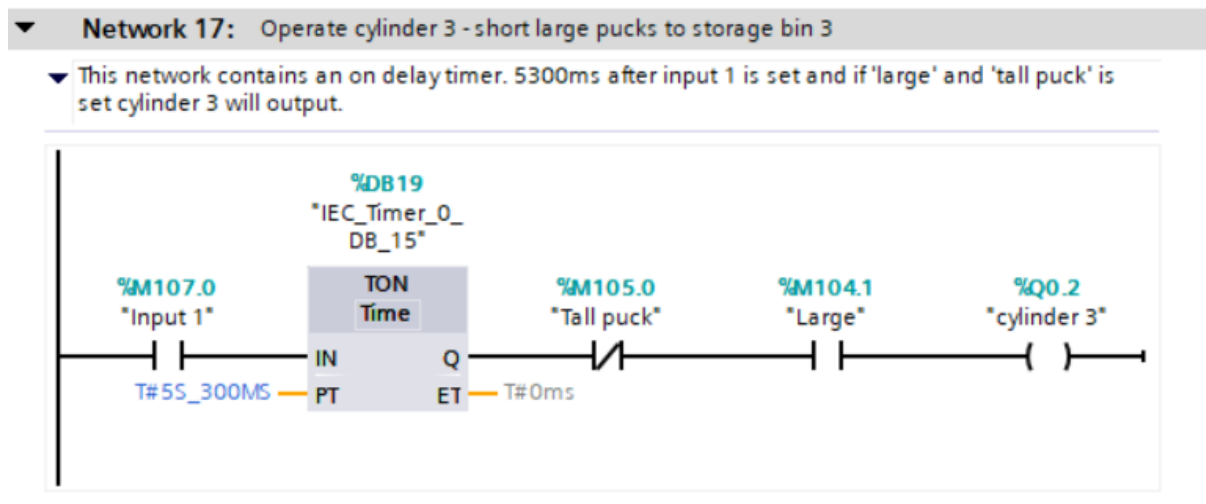


Figure 17 - Network 17 timing diagram

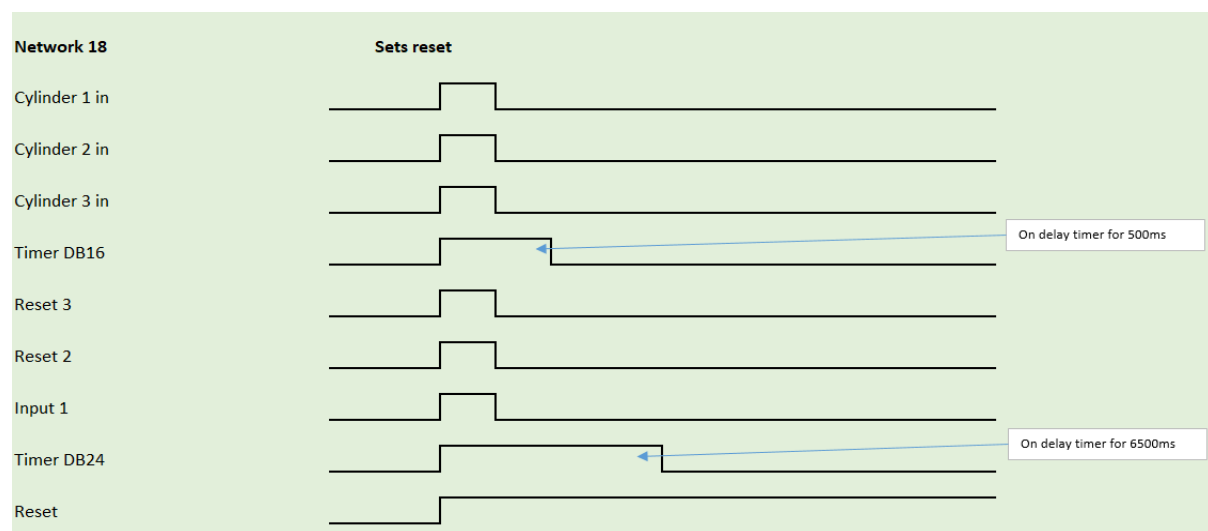
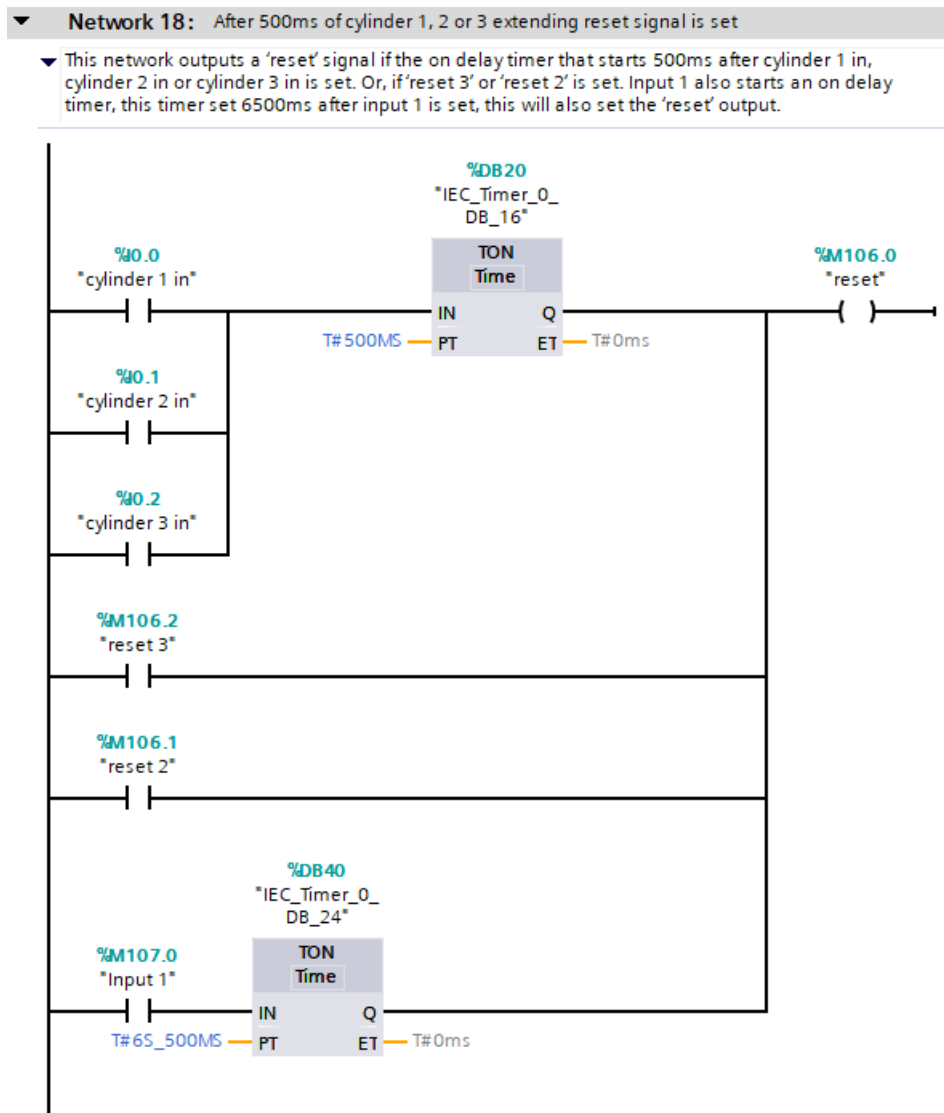


Figure 18 - Network 18 timing diagram

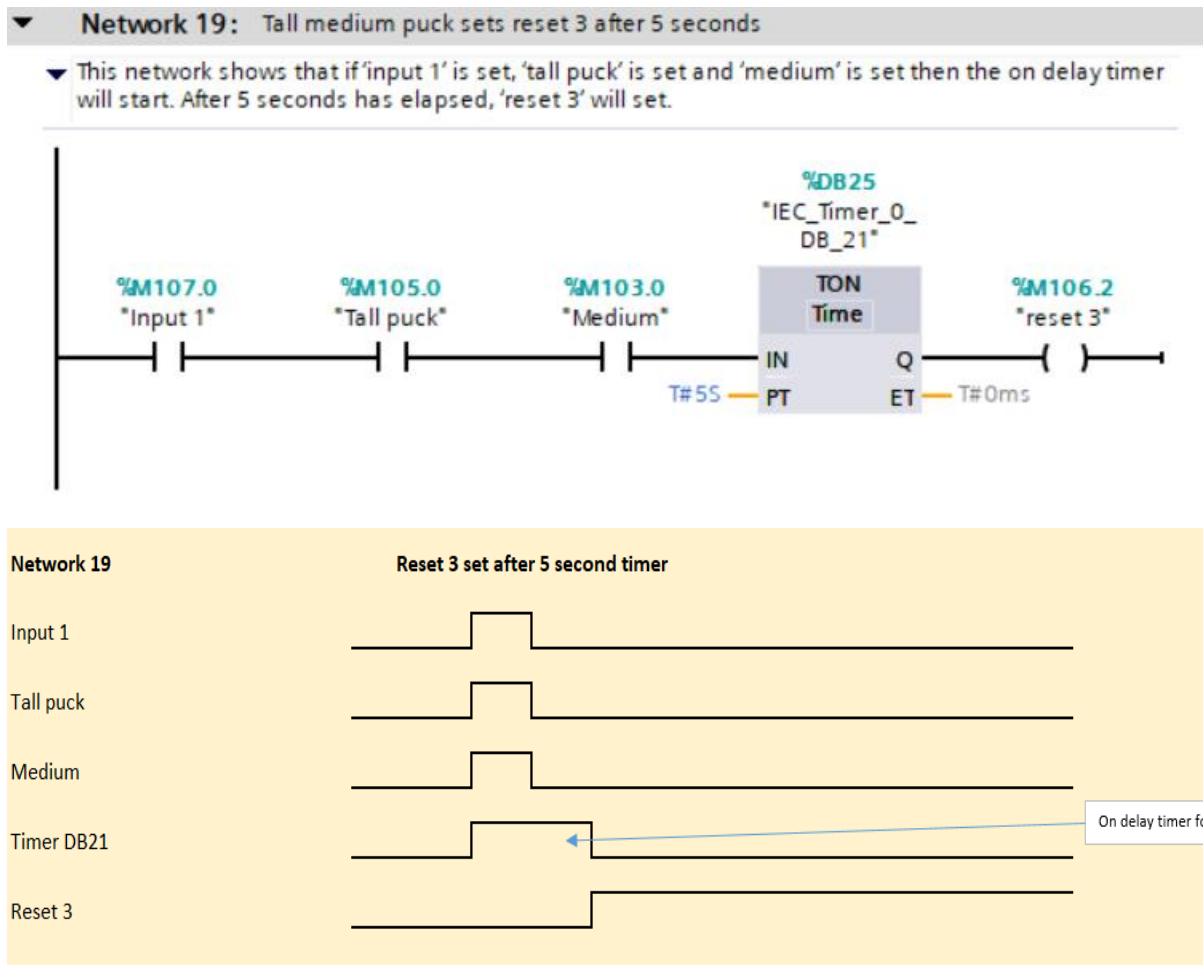


Figure 19 - Network 19 timing diagram

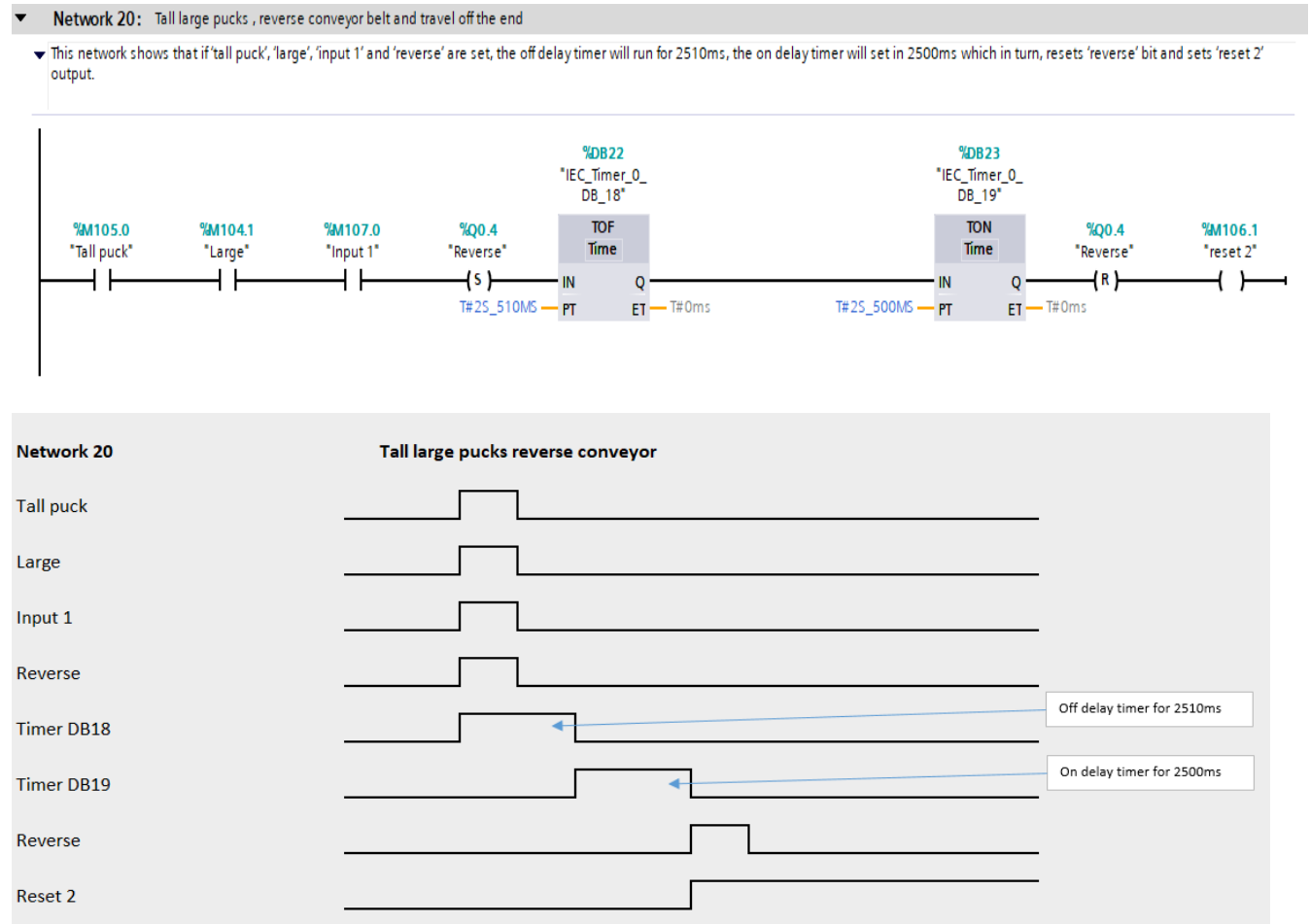


Figure 20 - Network 20 timing diagram

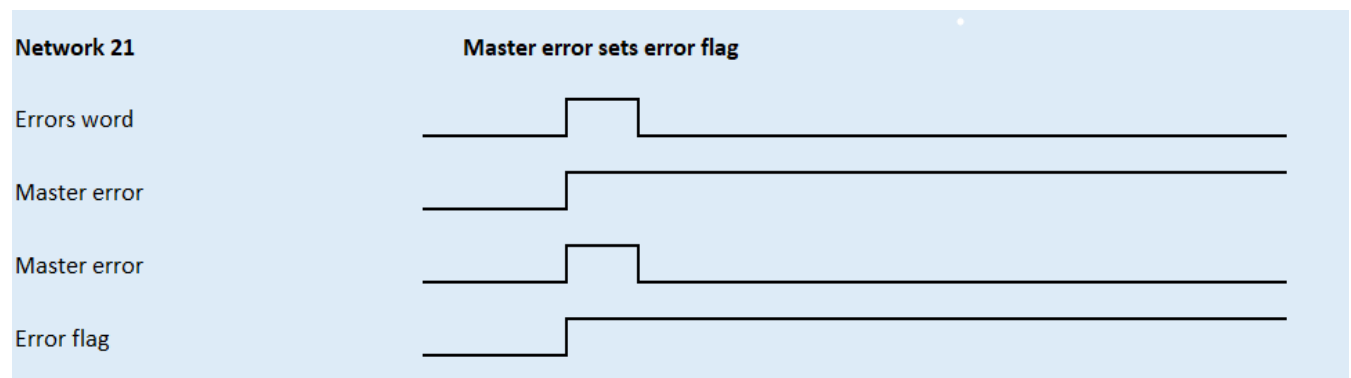
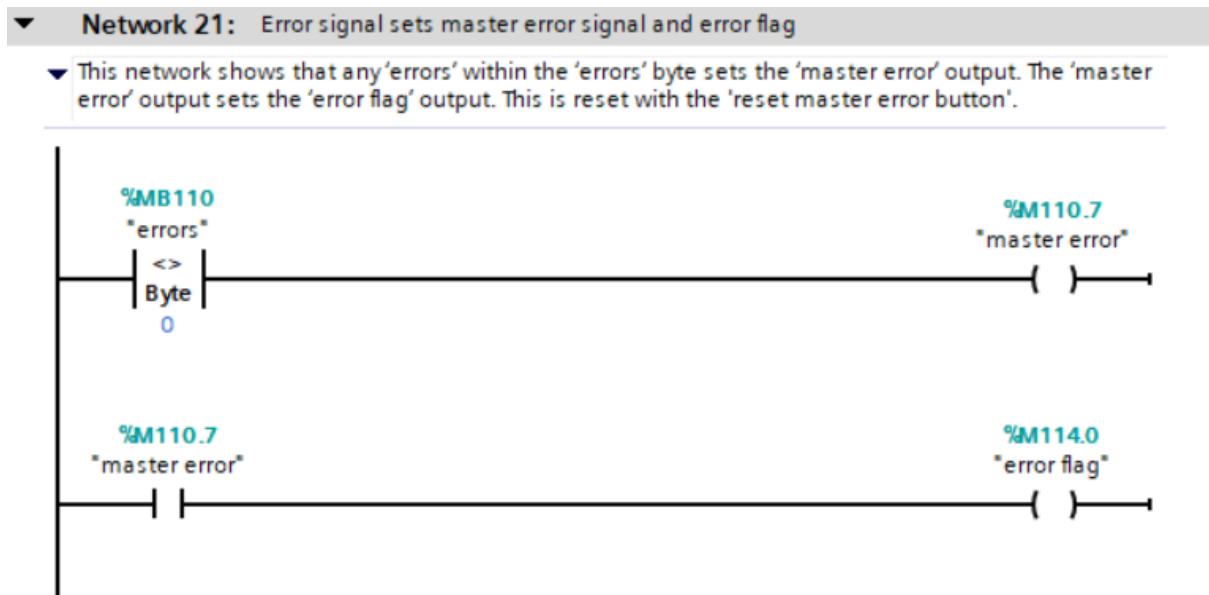


Figure 21 - Network 21 timing diagram

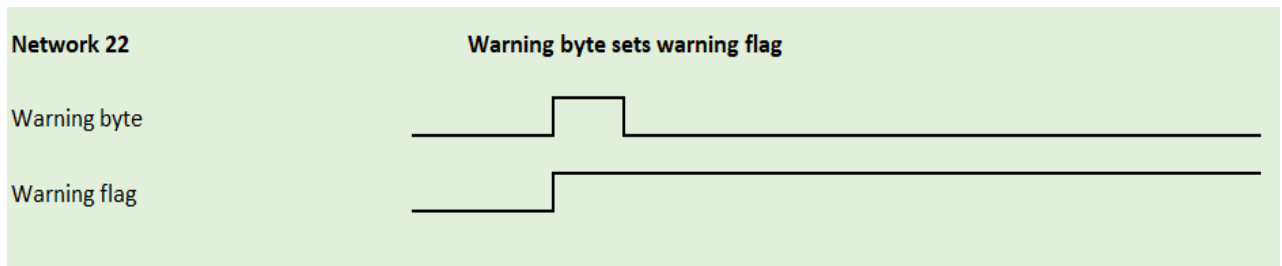
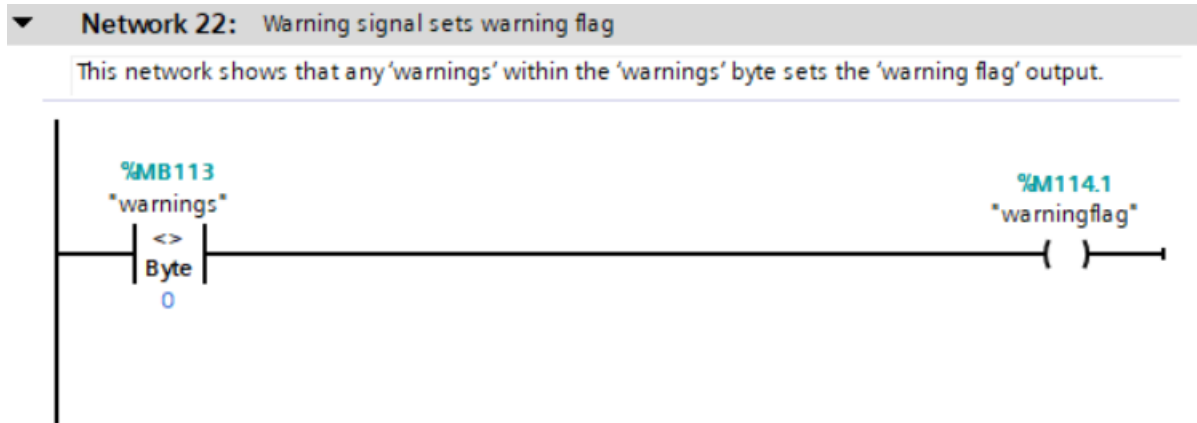


Figure 22 - Network 22 timing diagram

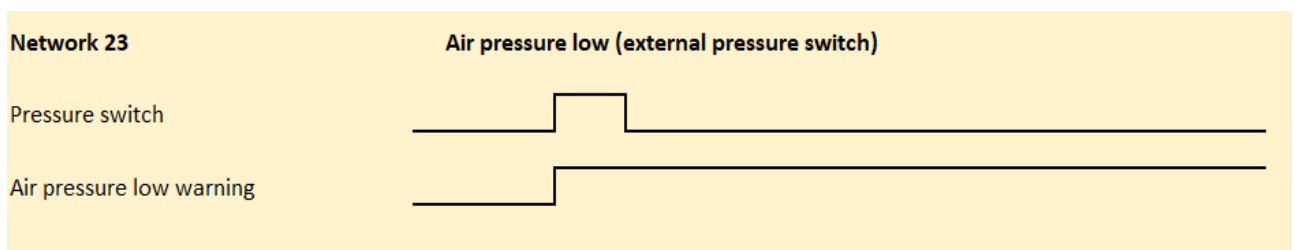
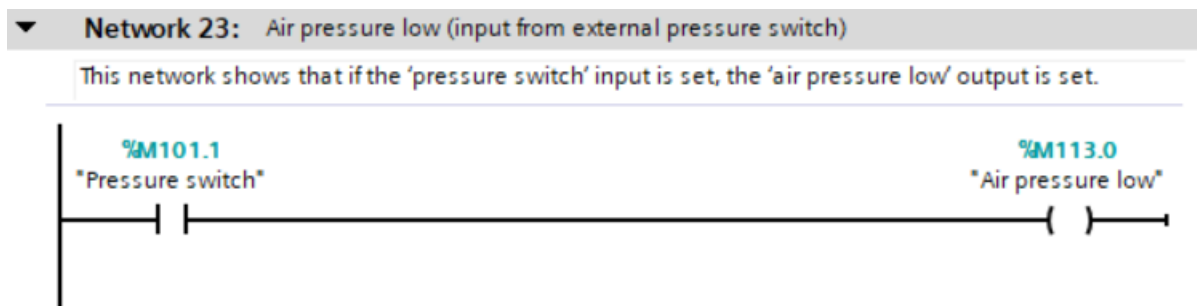
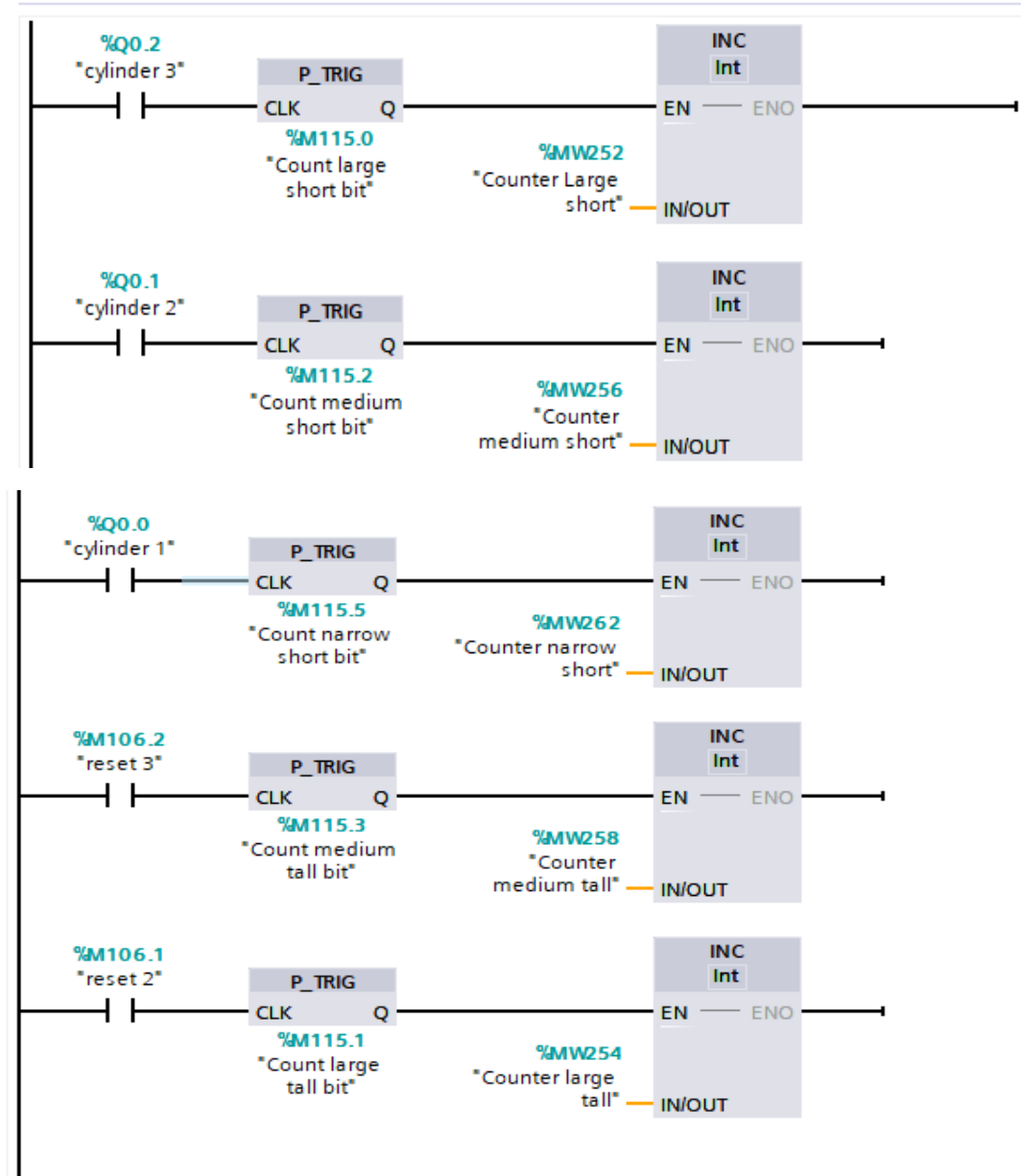


Figure 23 - Network 23 timing diagram

Network 24: Counters

- ▼ This network shows that if 'cylinder 3' is set, the associated positive trigger bit sets which in turn sets the incremental counter to an additional count. This is replicated for each individual input in this network, each input has an associated positive trigger and associated incremental counter. These counter functions are used to count the pucks in each individual storage bin.



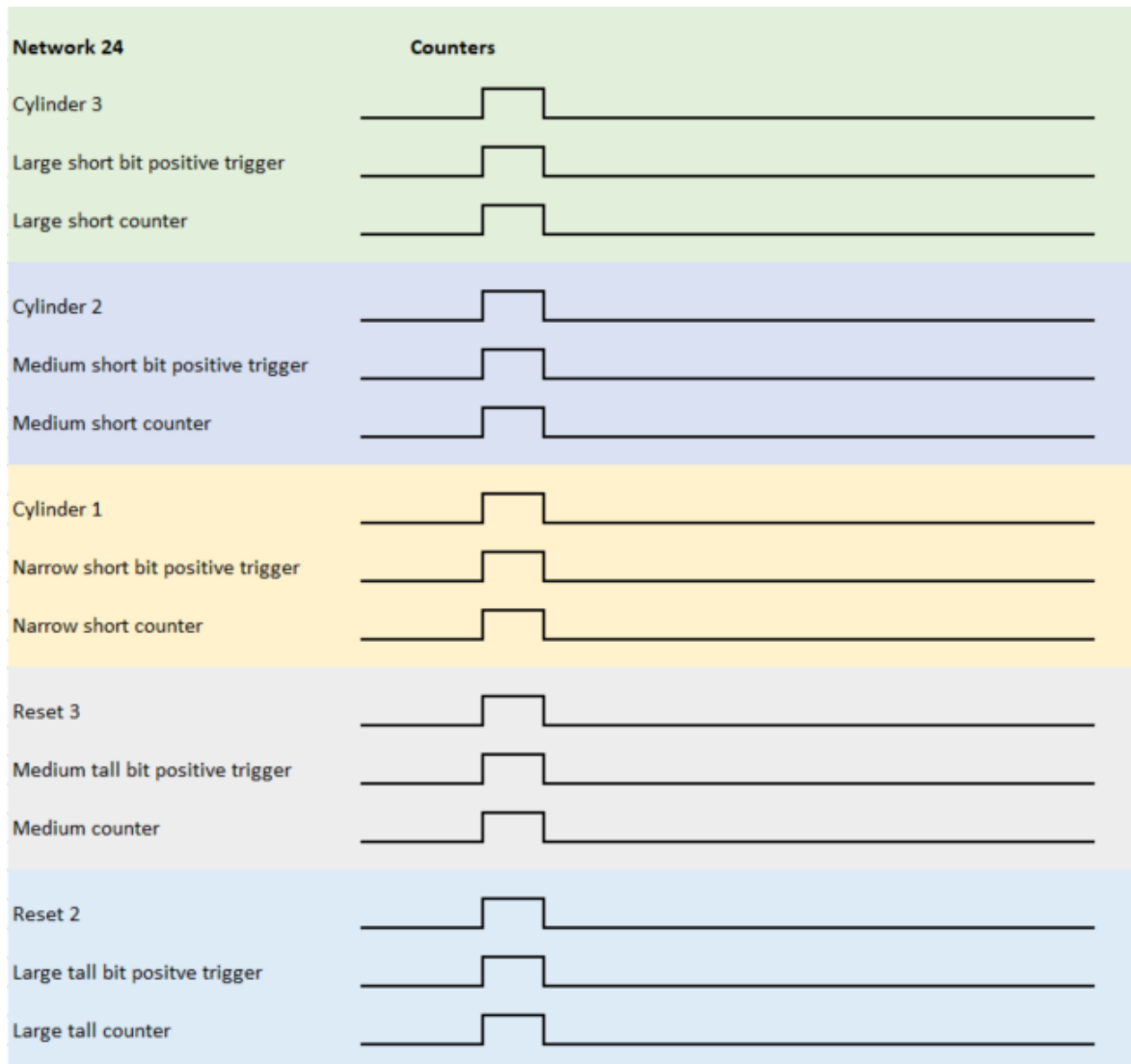
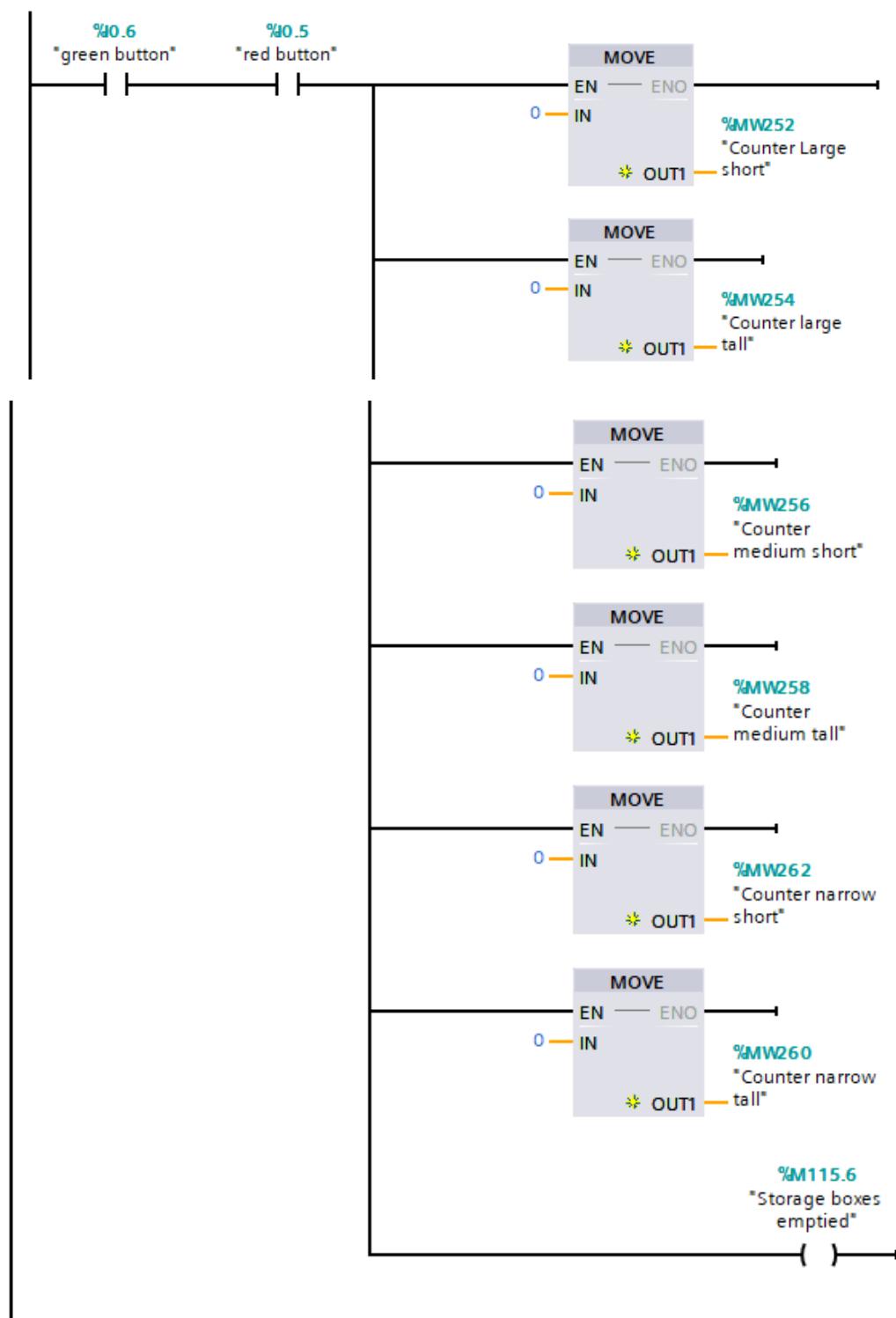


Figure 24 - Network 24 timing diagram

Network 25: Reset all counters when green and red buttons are set simultaneously

- ▼ This network shows that by pressing/ setting the green and red buttons/ inputs simultaneously all of the counters are reset to zero. This is done by using a move function as it moves the value of the output to the desired value set at the input. This process also sets the 'storage bins emptied' output.



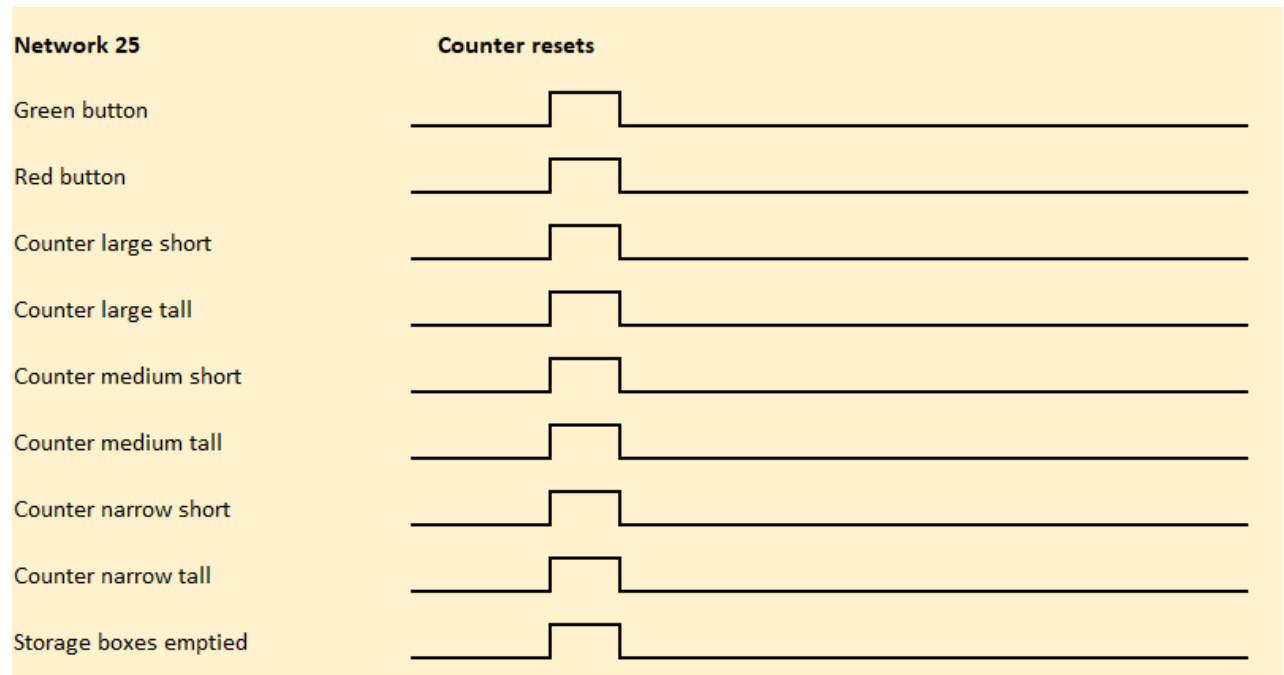
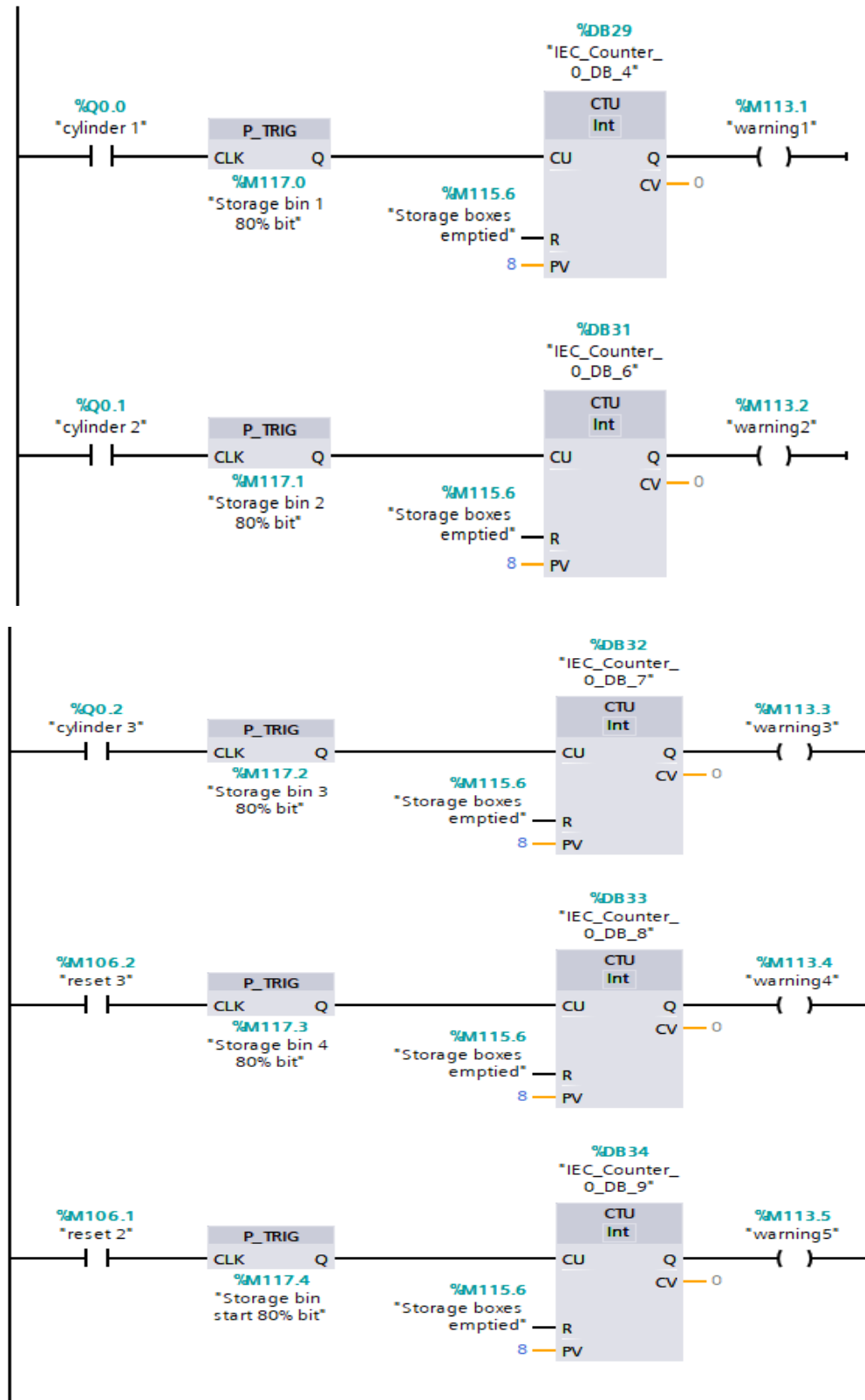
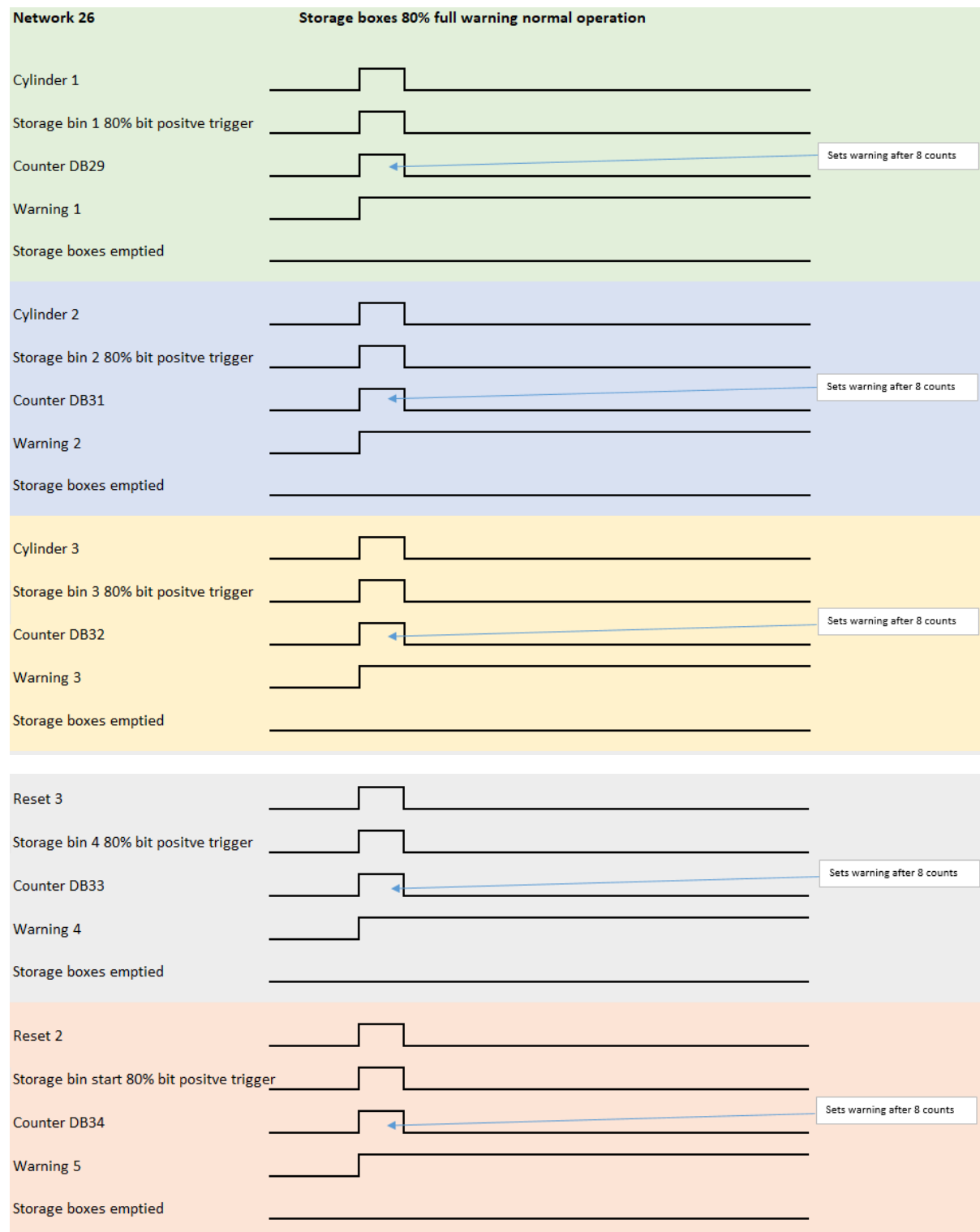


Figure 25 - Network 25 timing diagram

Network 26: Storage boxes 80% full warning

- ▼ This network shows that when an input within this network is set, the associated positive trigger is set which in turn sets an input to the count up counter. The counters have input PV value of 8. This means that when the counter gets to 8 counts, the output is set. The output signal is the associated warning tag. There are 5 separate inputs, positive triggers, counter and warning outputs, this means that it is easy to identify which storage bin is at 80% capacity. When the 'storage boxes emptied' signal is set, the warning signal is unset and resets the counter value to zero.





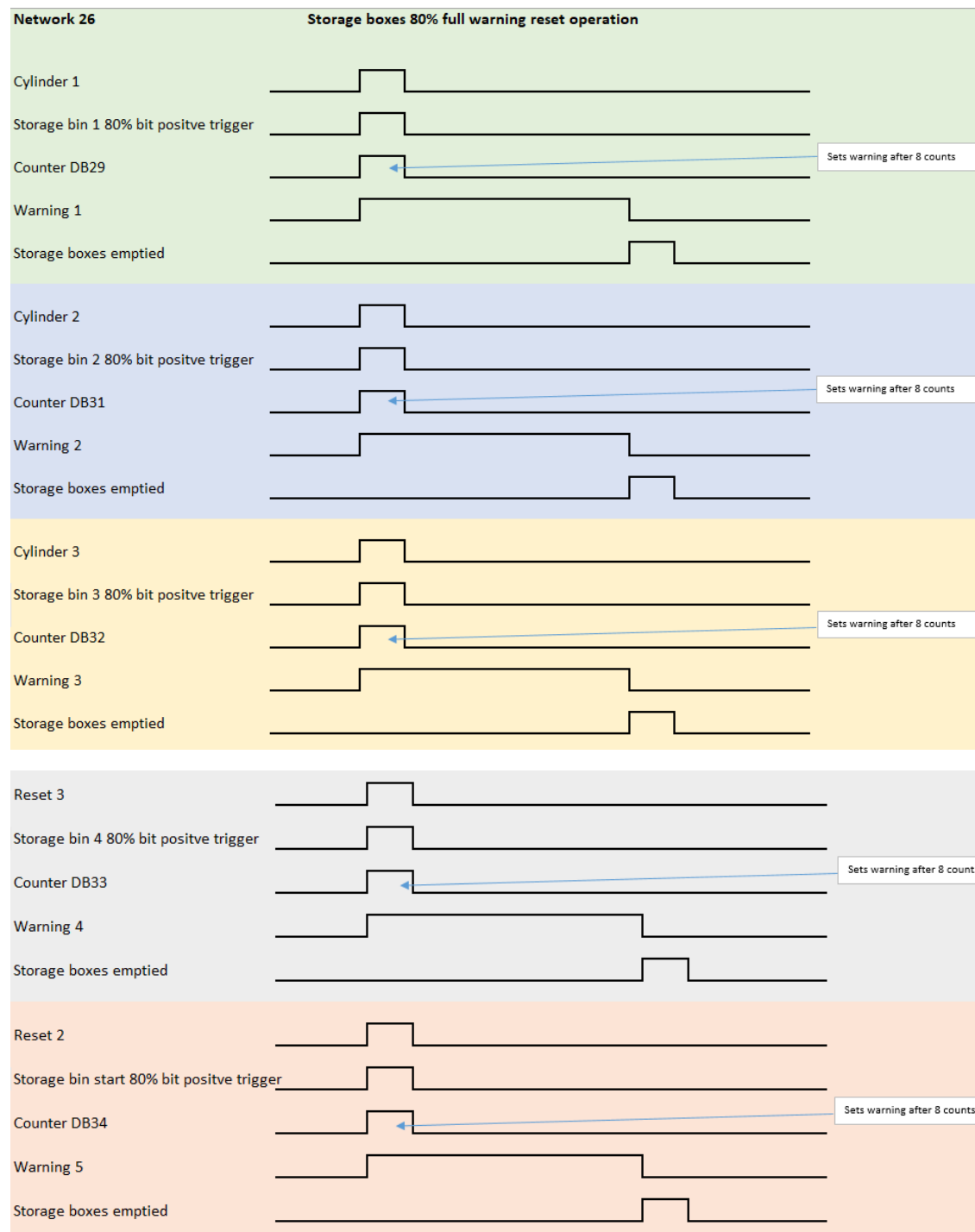
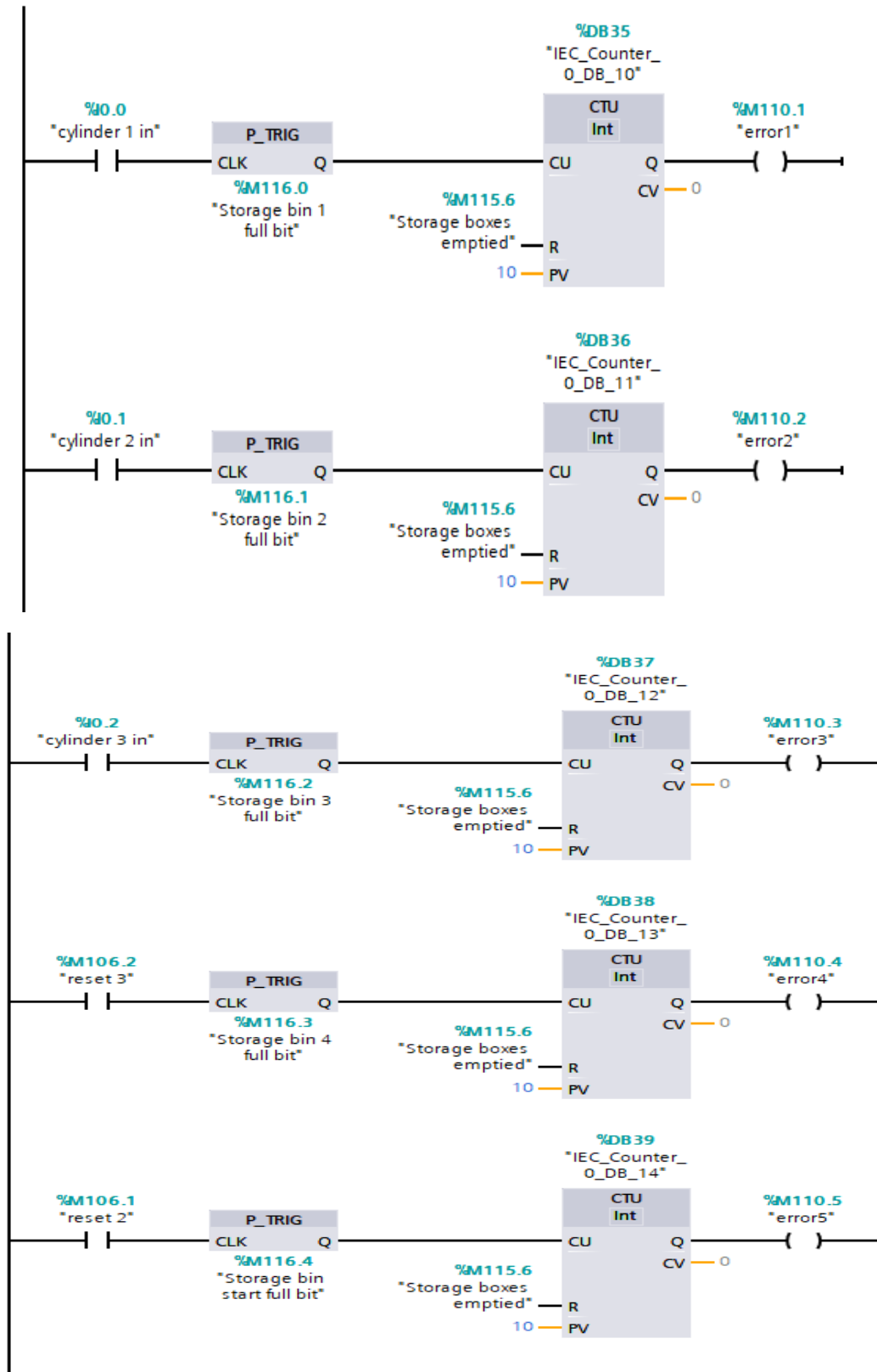


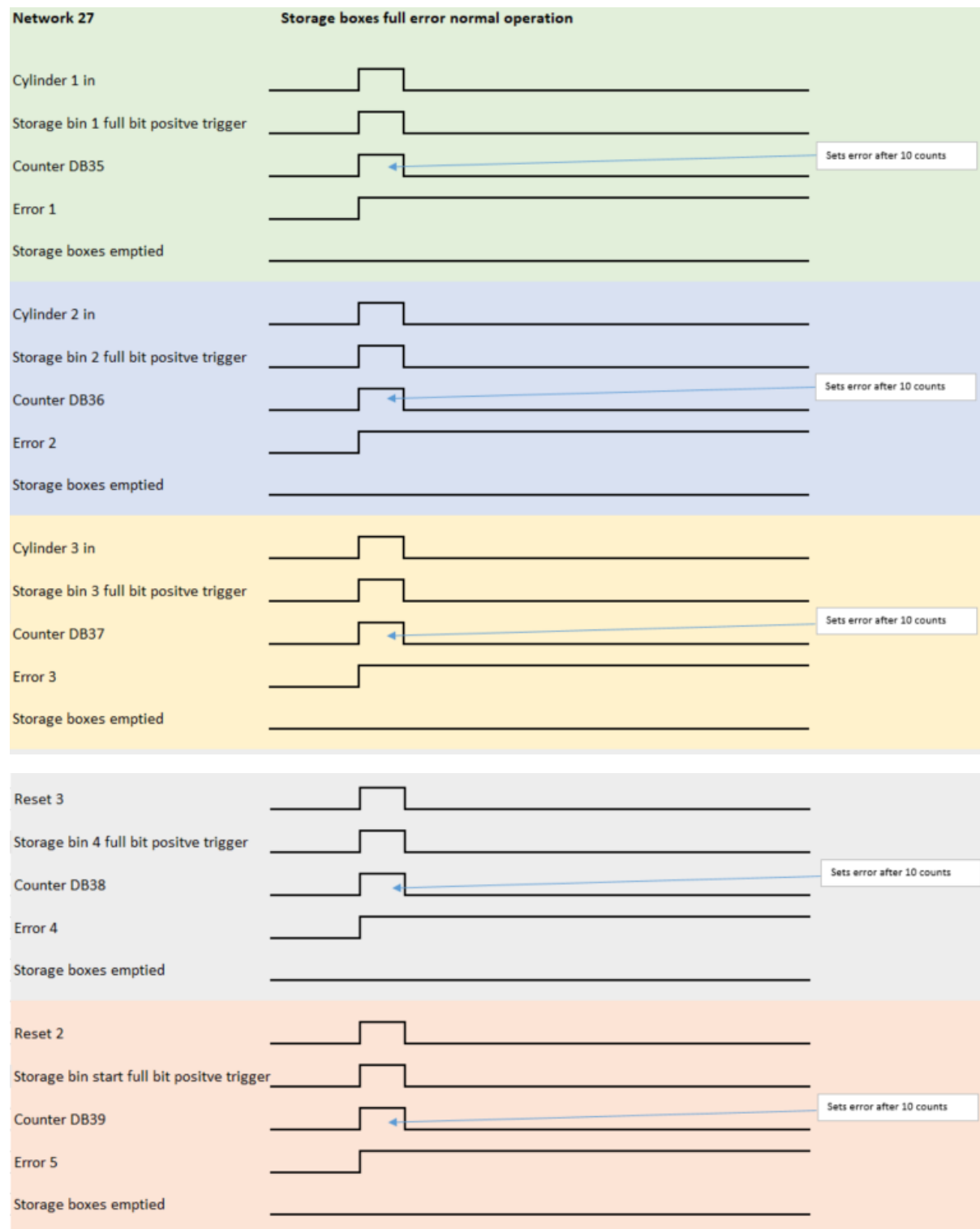
Figure 26 - Network 26 timing diagram

This timing diagram shows that when the 'storage boxes emptied' signal is set, the warning signal is unset and resets the counter value to zero.

Network 27: Storage boxes full error

- ▼ This network shows that when an input within this network is set, the associated positive trigger is set which in turn sets an input to the count up counter. The counters have input PV value of 10. This means that when the counter gets to 10 counts, the output is set. The output signal is the associated error tag. There are 5 separate inputs, positive triggers, counter and warning outputs, this means that it is easy to identify which storage bin is at full capacity. When the 'storage boxes emptied' signal is set, the error signal is unset and resets the counter value to zero.





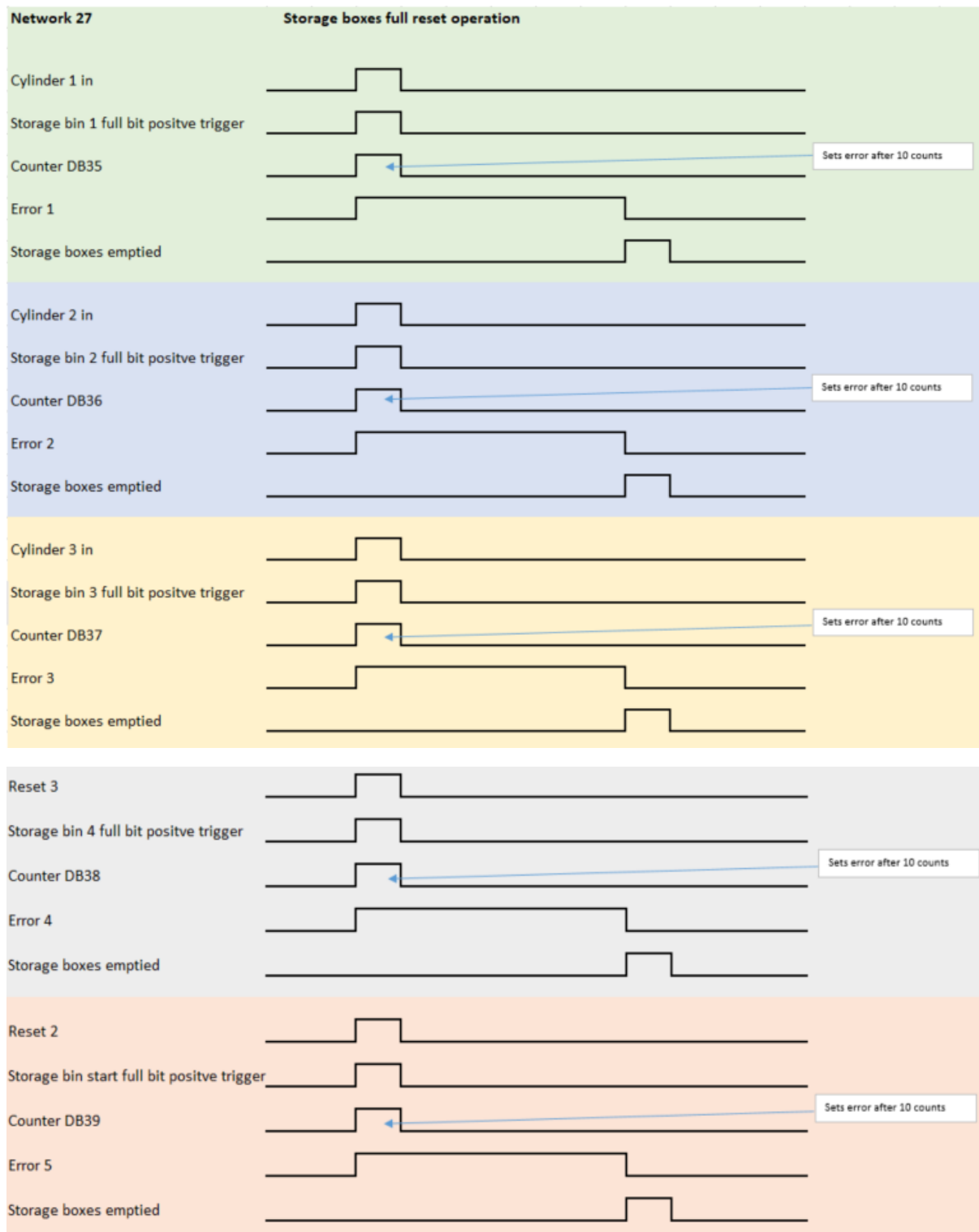


Figure 27 - Network 27 timing diagram

This timing diagram shows that when the 'storage boxes emptied' signal is set, the error signal is unset and resets the counter value to zero.

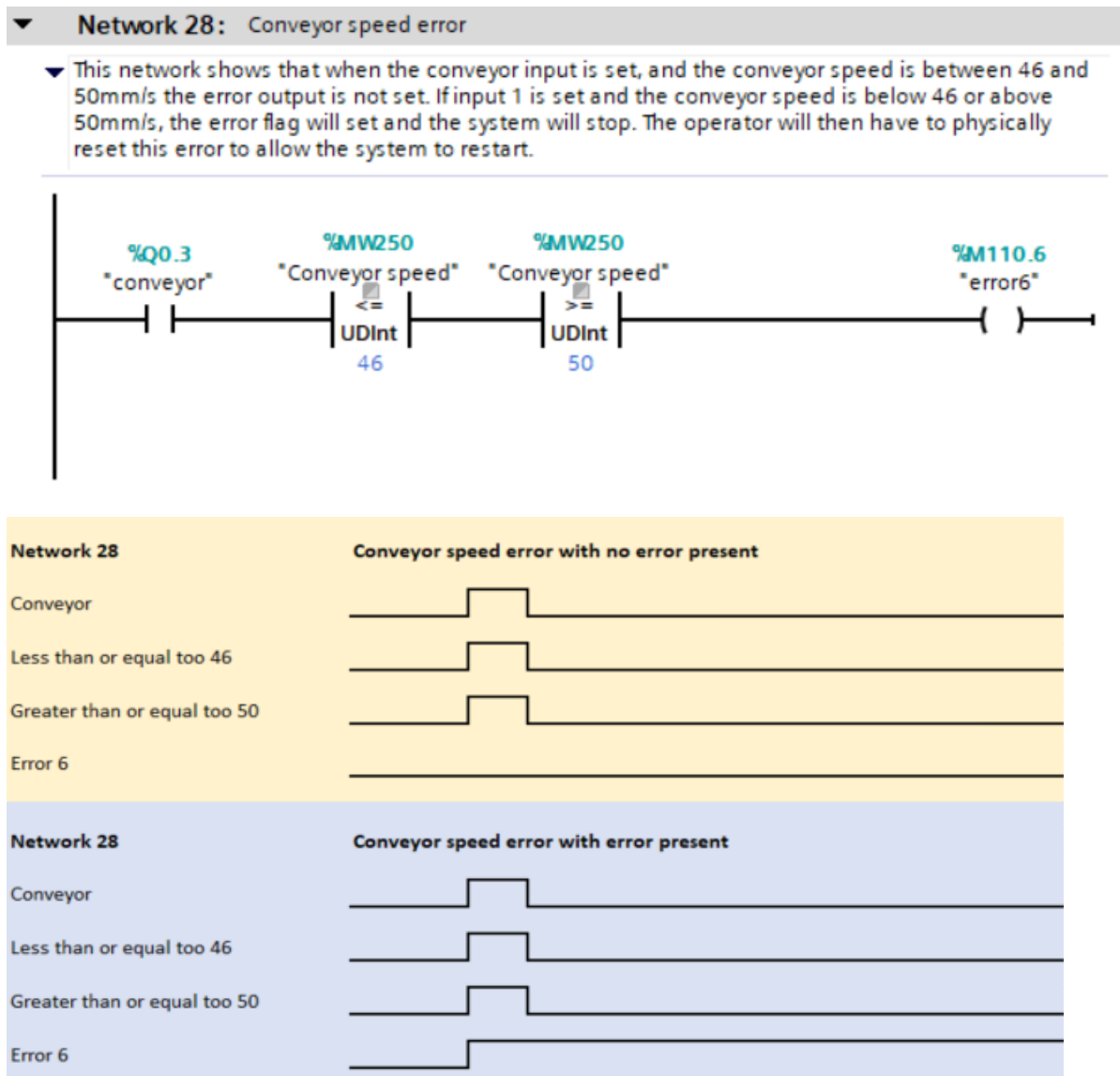


Figure 28 - Network 28 timing diagram

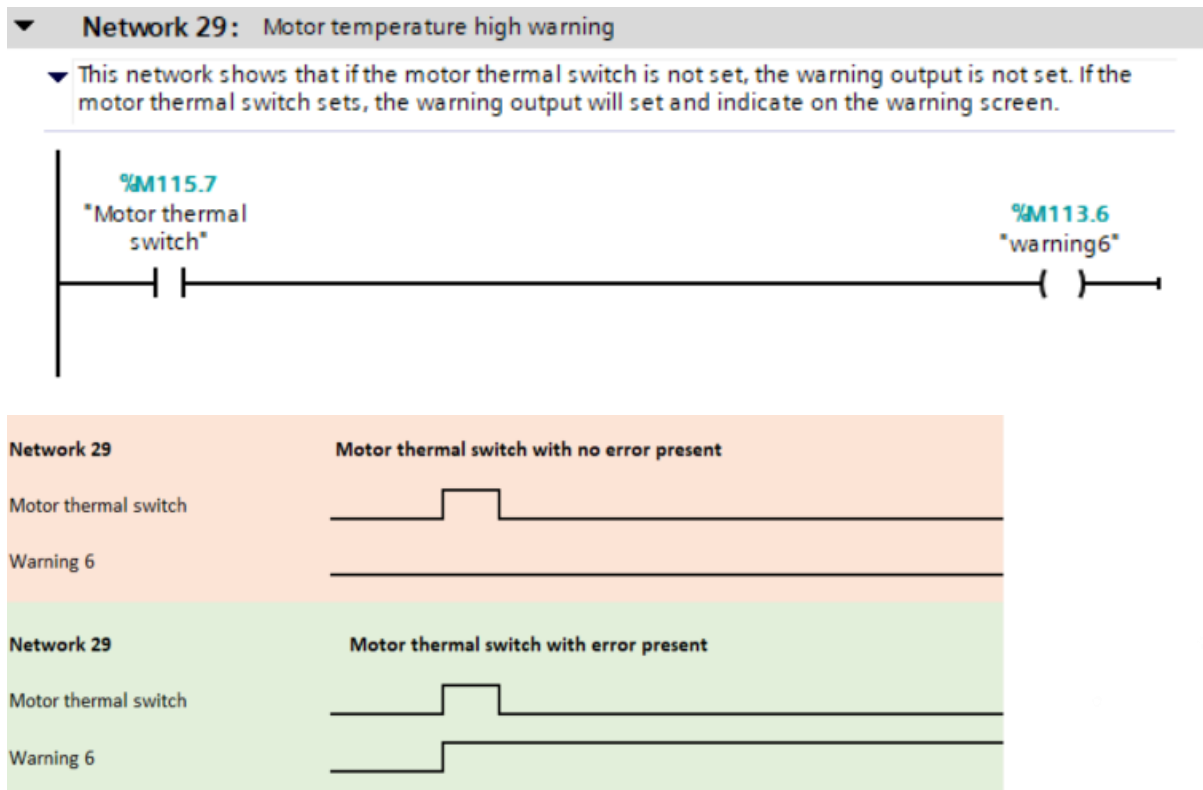


Figure 29 - Network 29 timing diagram

The areas of interest within the timing diagrams for an operator is the switching points. The switching points indicate which stage of the program the system has operated too. This would be critical if the operator needed to fault find to see where the last system operation was and how to rectify the problem.

User screens

The user screens documented below are intentionally designed to be basic and understandable. The HMI will be used by an operator to control and monitor the process and therefore needs to be simplistic and not cause confusion should an error or warning occur.

This system comprises of 5 screens, a root screen, process overview screen, warning screen, error screen and an engineer's screen.

Root screen

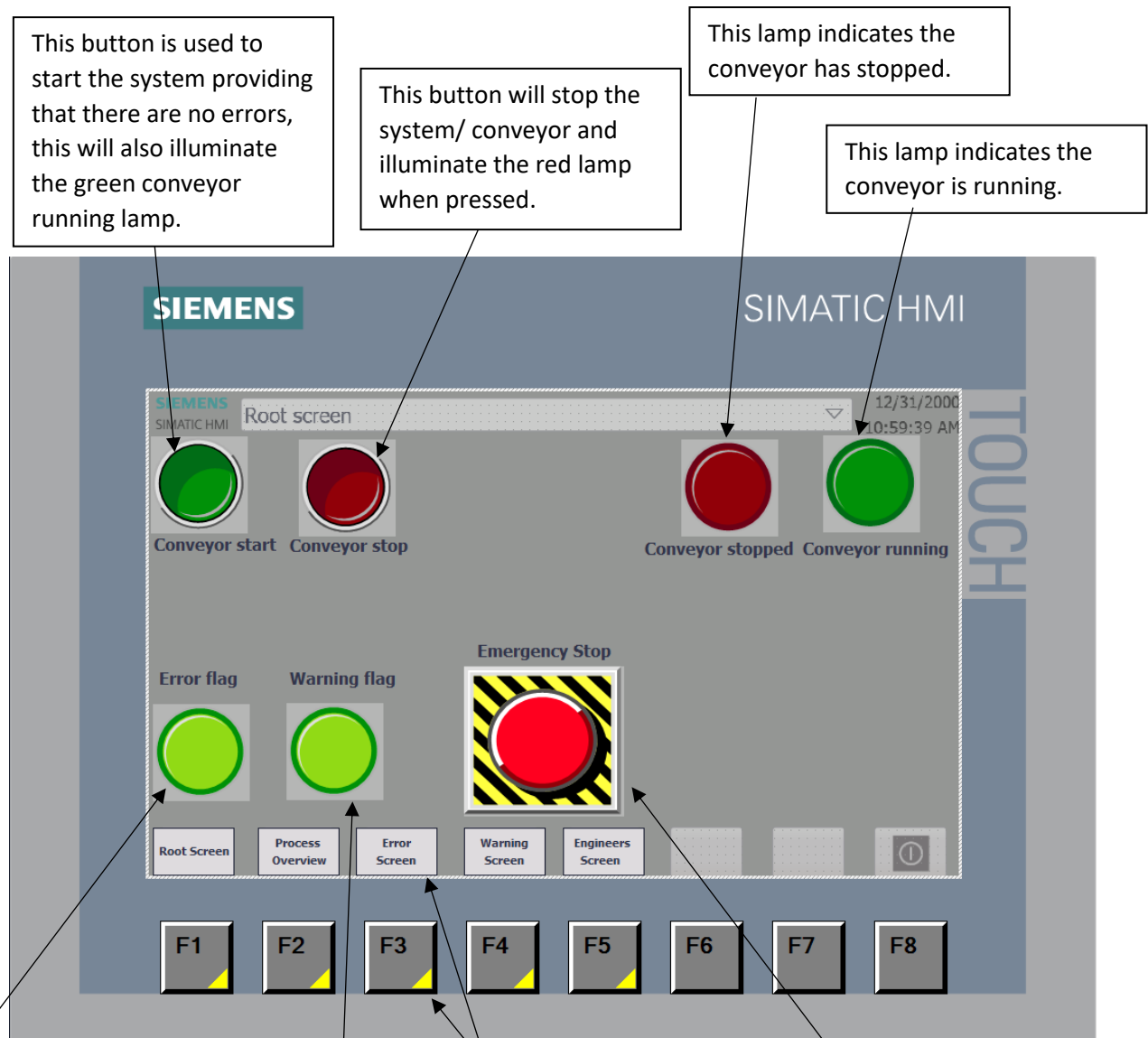


Figure 30 - Root screen

Process overview screen

This screen is designed to represent the system that is being operated. This screen gives an overview of component parts and how they appear in the physical system.

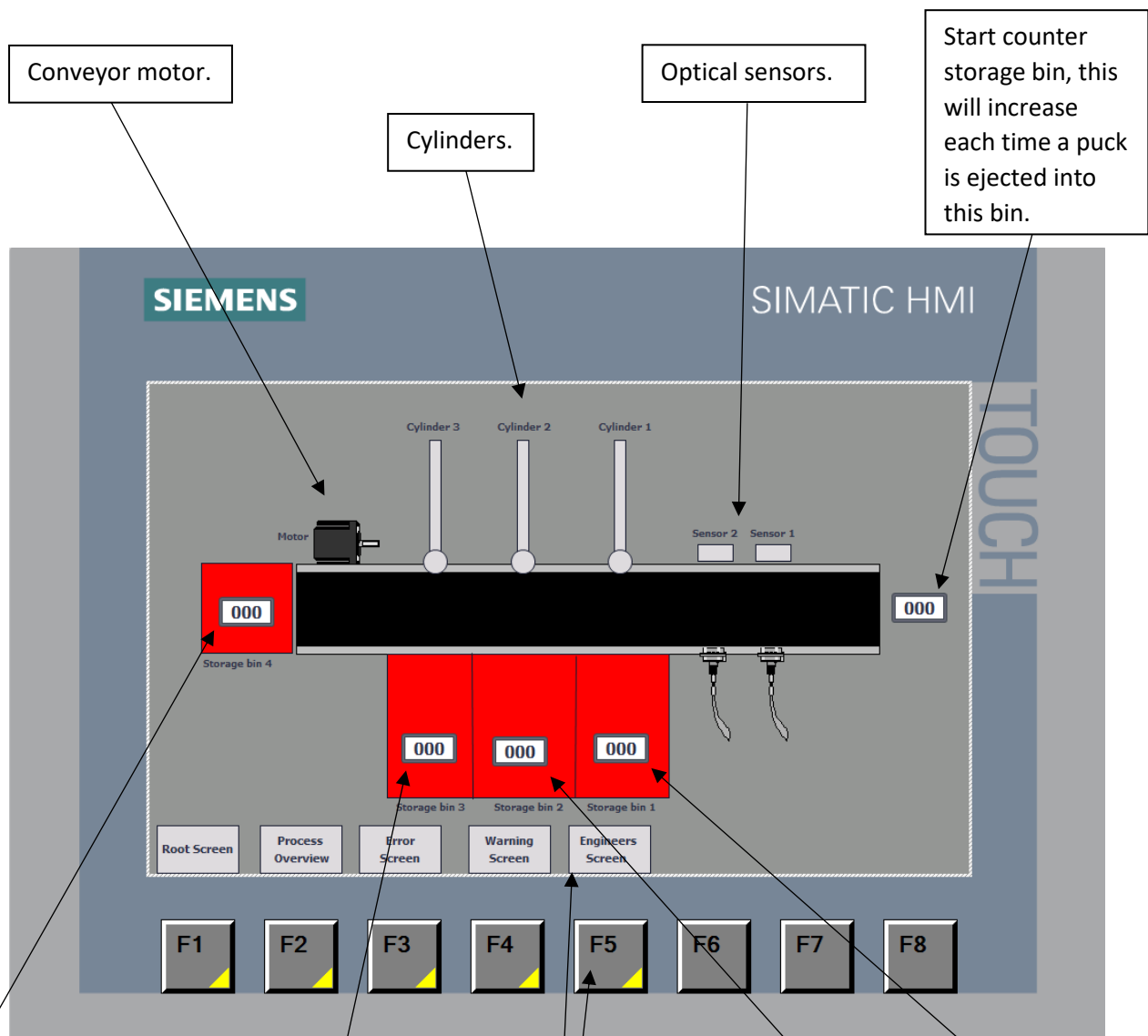


Figure 31 - Process overview screen

Storage bin 4 counter, this will increase each time a puck is ejected into this bin.

Storage bin 3 counter, this will increase each time a puck is ejected into this bin.

The function buttons will navigate the operator to the screen displayed above each button respectively. These are repeated on each screen.

Storage bin 2 counter, this will increase each time a puck is ejected into this bin.

Storage bin 1 counter, this will increase each time a puck is ejected into this bin.

Warning screen

This screen is designed to indicate warnings that arise from deviation of the parameters of the program. Though warnings do not automatically stop the process, they should be investigated to ensure that the issue does not lead to an error. Warnings may be indication to the operator that system stop is required.

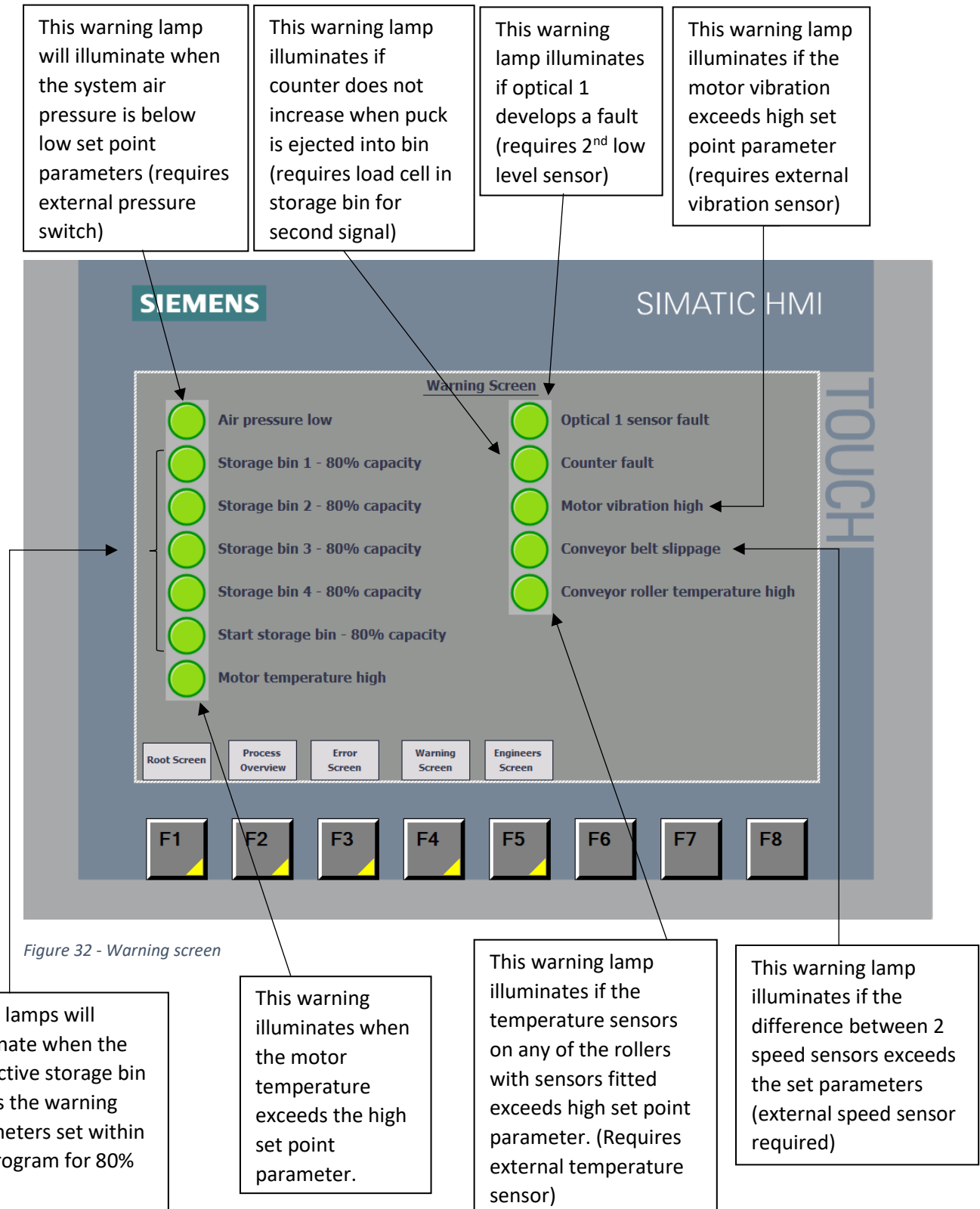


Figure 32 - Warning screen

Error screen

This screen is designed to display errors that have arisen from deviation of the parameters of the program. The error function stops the system automatically and requires an operator to physically reset the error before the system can resume normal operation.

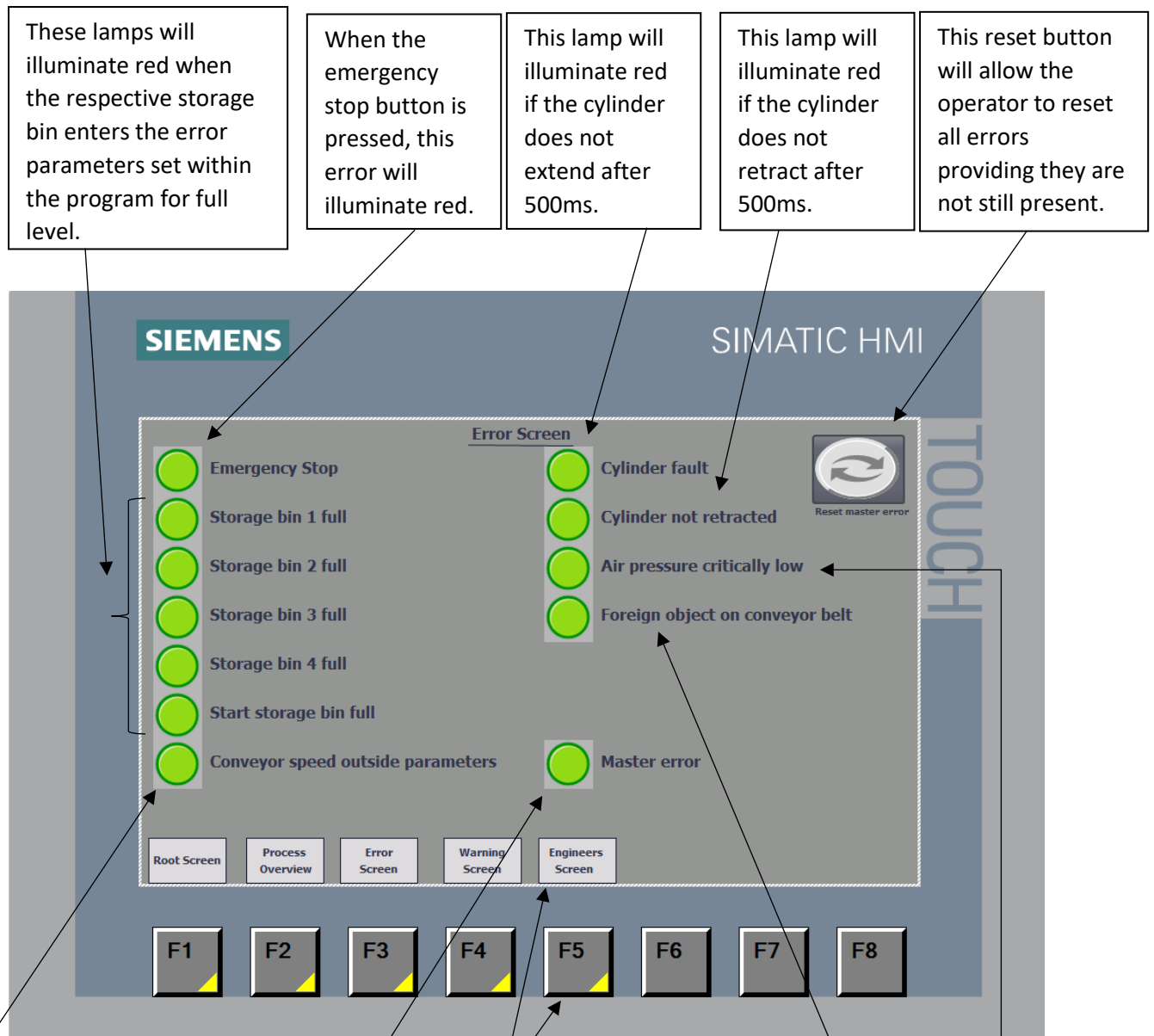


Figure 33 - Error screen

This lamp will illuminate red when the conveyor speed is above or below the error parameters.

This lamp will illuminate red if any of the errors are set.

The function buttons will navigate the operator to the screen displayed above each button respectively. These are repeated on each screen.

This lamp will illuminate red if a foreign object is detected on the conveyor belt (external scan camera required)

This lamp will illuminate red if the system air pressure exceeds the low low parameter set point.

Engineers screen

This screen has been made available for engineers, it doesn't include any information required for operation unless there is a fault, where an engineer may need to interrogate the system. The screen is intentionally quite empty to allow engineers to add I/O signals if required for fault finding.

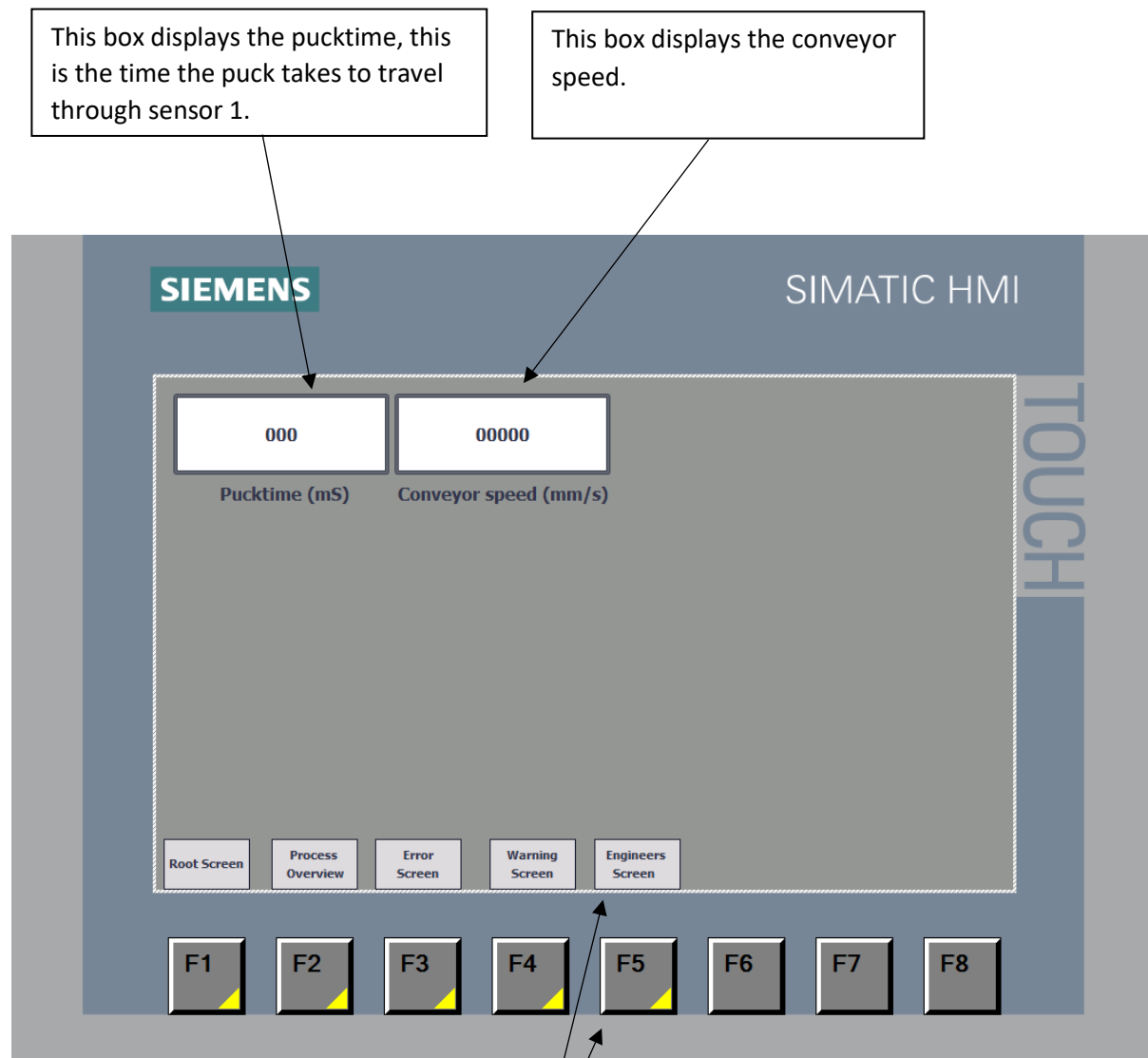


Figure 34 - Engineers screen

Alarm audit document and check procedure

Warnings



Figure 35 - Warnings audit and check

Errors

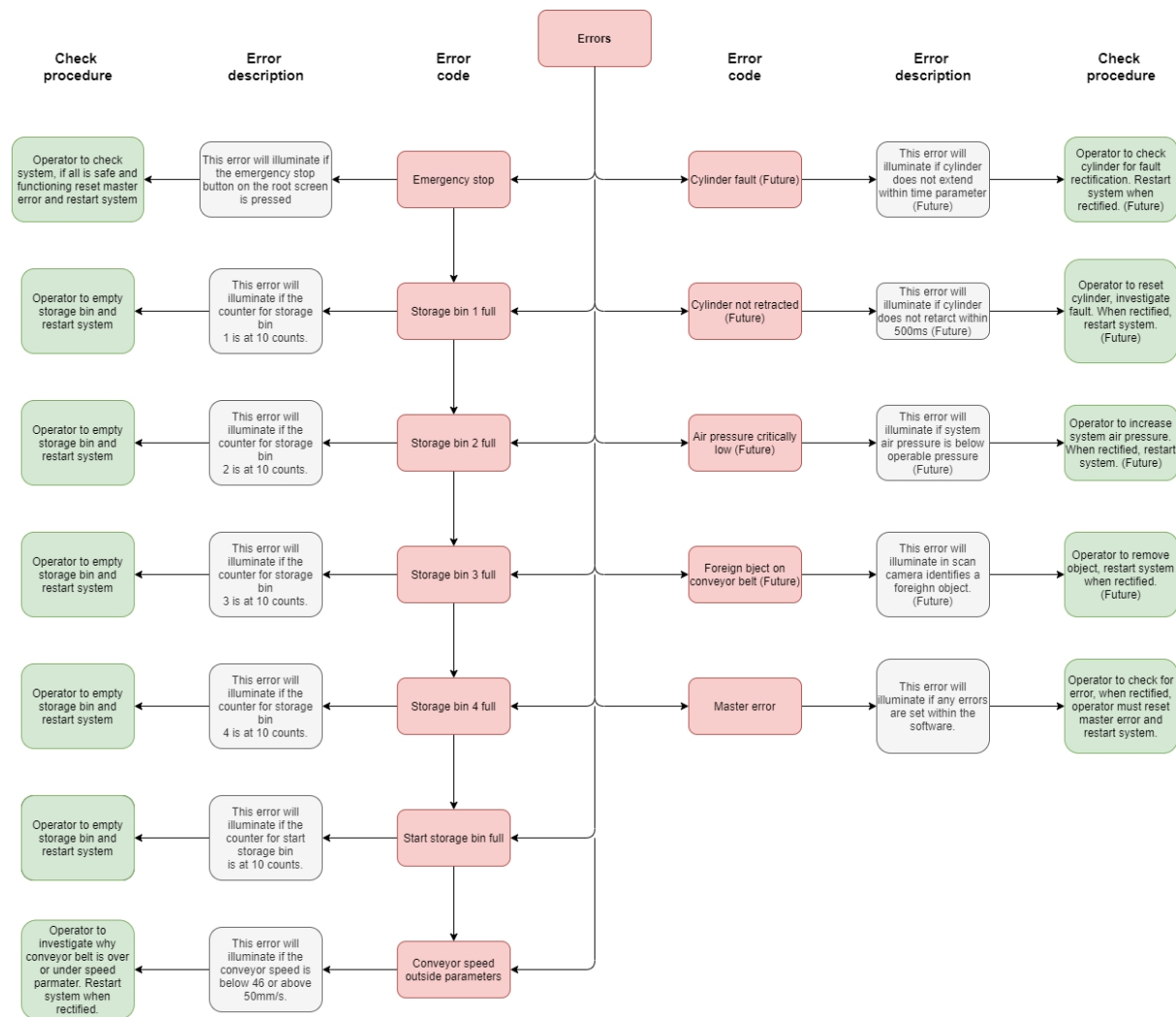


Figure 36 - Errors audit and check

Operational flow chart

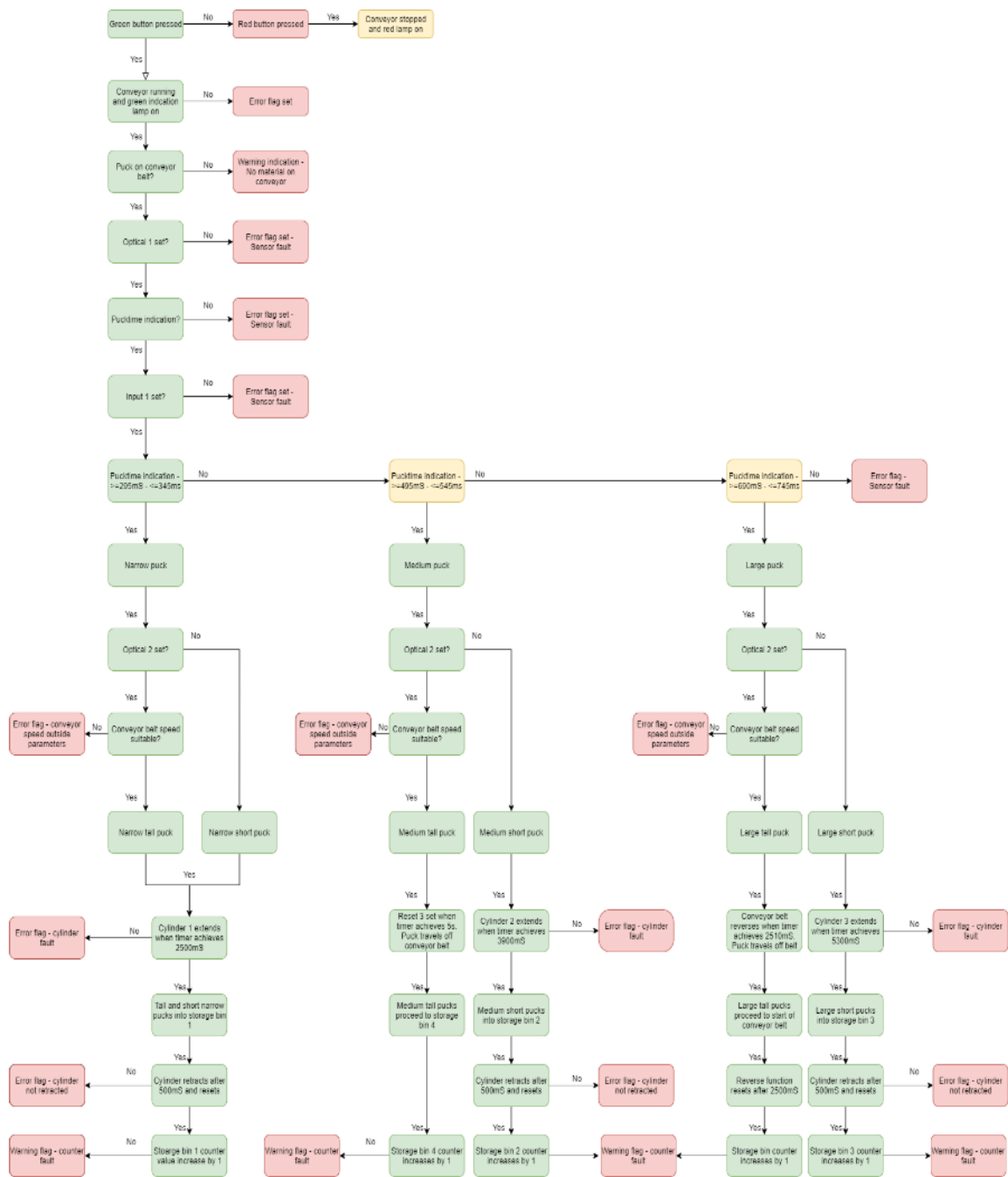


Figure 37 - Operational flow chart

System block diagram

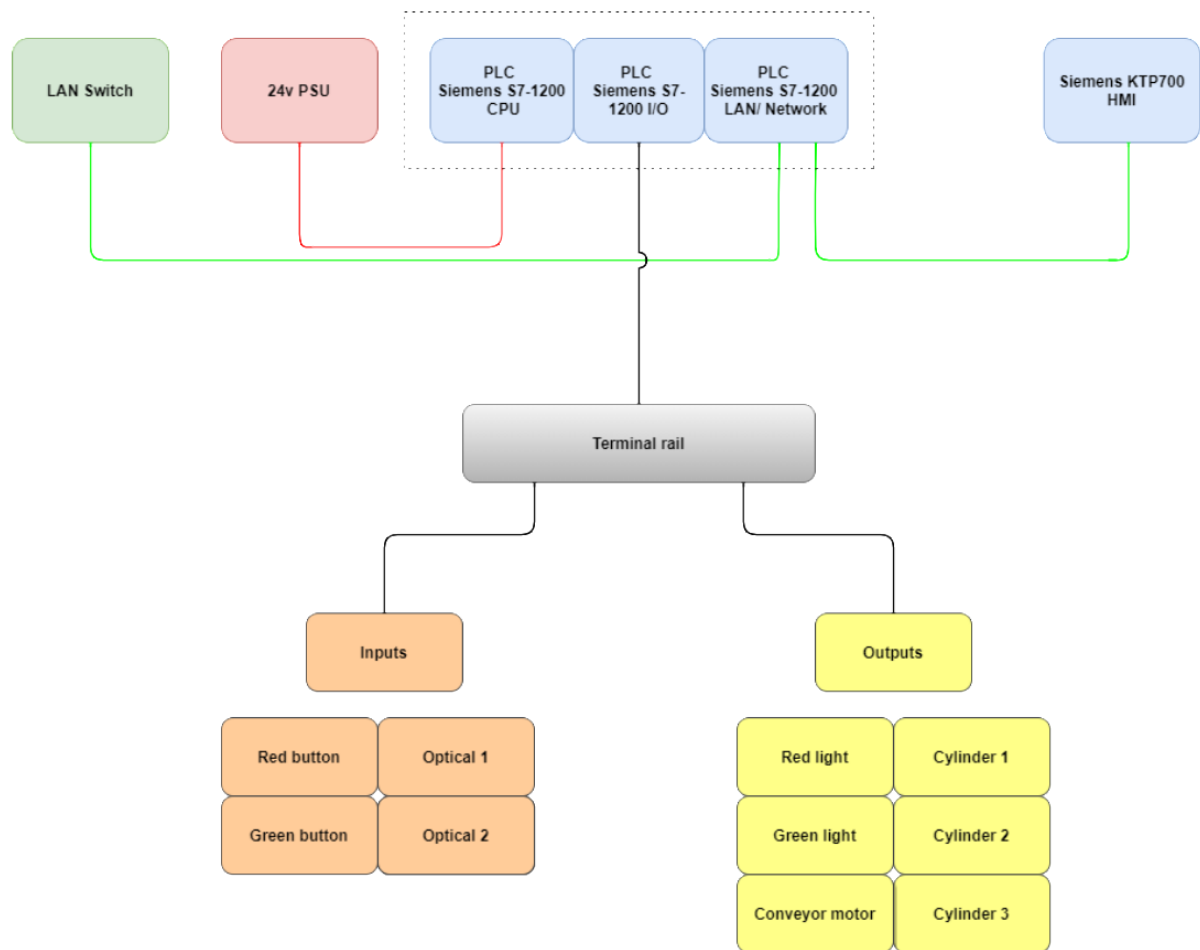


Figure 38 - Block diagram

Improvements

An improvement to the system would be an alarm log screen. This would document when a warning or error occurs and log down the date and time the event took place. This would allow an engineer to trend the alarms to see if a particular error or warning persists, this could then be used to modify the software to allow a better, safer and more reliable process.

A sounder could be added to the system, this would give an audible alarm which would alert an operator to a warning.

The error and warning indication lamps on the root screen are just indication in this program. Changing the indication lamps so that they incorporate a push button that if it was pressed would navigate the operator to the appropriate warning or error screen would be an improvement.

Real time, live monitoring on the HMI would be an improvement, this would indicate actual process operations in real time.

Other improvements include additional field equipment, some of these items have been captured on the alarm and error screens but haven't been developed to be functional;

1. External pressure switch to set error alarm if the air pressure drops below an inoperable level,
2. Additional low level sensor in case of fault with original sensor , this would allow dual redundancy,
3. Weight sensors in storage bins as secondary indication of counter,
4. Vibration monitoring of conveyor belt motor,
5. Temperature monitoring of conveyor belt motor,
6. Additional speed monitoring device/ encoder to monitor belt slippage,
7. Temperature monitoring on conveyor rollers,
8. Tension monitoring on conveyor in case of overloading belt,
9. Scan camera above conveyor belt to monitor for foreign objects.

The above external equipment would be an improvement to the system as it would allow there to be more warnings before the system gets to the error stage, this would be advantageous as it would allow the system to be more efficient because there will be less down time as warnings can be rectified whilst the system is functioning.

References

- [1] "industrial-automation-resources/plc-automation-tutorials/what-plc/," Amci, [Online]. Available: <https://www.amci.com/industrial-automation-resources/plc-automation-tutorials/what-plc/>. [Accessed 18 May 2020].
- [2] "uml-timing-diagram," [Online]. Available: <https://www.lucidchart.com/pages/uml-timing-diagram>. [Accessed 13 May 2020].