A Review on Modular Mechatronic System (mMs)

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Abstract

Sequential processing is commonly carried out in industrial practices. Programmable Logic Control (PLC) is used to operate such sequential operation. Assumption University of Thailand is providing a laboratory course in Mechatronics Engineering where a modular Mechatronic system (mMs) is introduced and a study of its sequential operation is made. The mMs and PLC are from Bosch Rexroth, Germany. The mMs includes three stations: Station 1 - The Magazine Station, Station 2 - The Pneumatic Processing Station and Station 3 - The Storage Station. This review article will be beneficial to readers interested in getting the quick concept in sequential processing with the Bosch Rexroth mMs. The readers will be able to save their time on initial steps such as sensors and actuators addresses, 'how to set parameters' and 'the sequential flow of the mMs'. Sequential plans written with sequential flow chart (SFC) for three different stations are summarized. After completing laboratory training with the use of the mMs and PLC, one will be able to write programs to control mMs with different equipment and will be more confident in facing problems in various industries in the future.

Keywords: *Sequential processing, programmable logic control, sequential flow chart, Mechatronics Engineering.*

1. Introduction

Most of the products in a particular industry are manufactured in a sequential order. For example, in a carbonated drink industry the sequential processing is concerned with the following tasks:

1. Start the conveyor belt. Clean and empty bottles are transported along the conveyor belt.
2. To fill carbonated water into a bottle, a sensor is used to detect the presence of the bottle. If the bottle is detected:
    a. Yes: go to step 3.
    b. No: wait at step 2.
3. Stop the conveyor belt at the appropriate location.
4. Fill in carbonated water.
5. To fill water to a specific level, a simple timer can be used. If the timer value is reached:
    a. Yes: go to step 6.
    b. No: wait at step 5.
6. Continue the conveyor belt and stop at the position to fill the bottle's cap.
7. To fill the bottle's cap, sensors are used to detect the presence of the bottle and the cap. If both are detected:
    a. Yes: go to step 8.
    b. No: wait at step 7.
8. Continue the conveyor belt and stop at the packing position.
9. Continue to another sequential process if other processes are required.

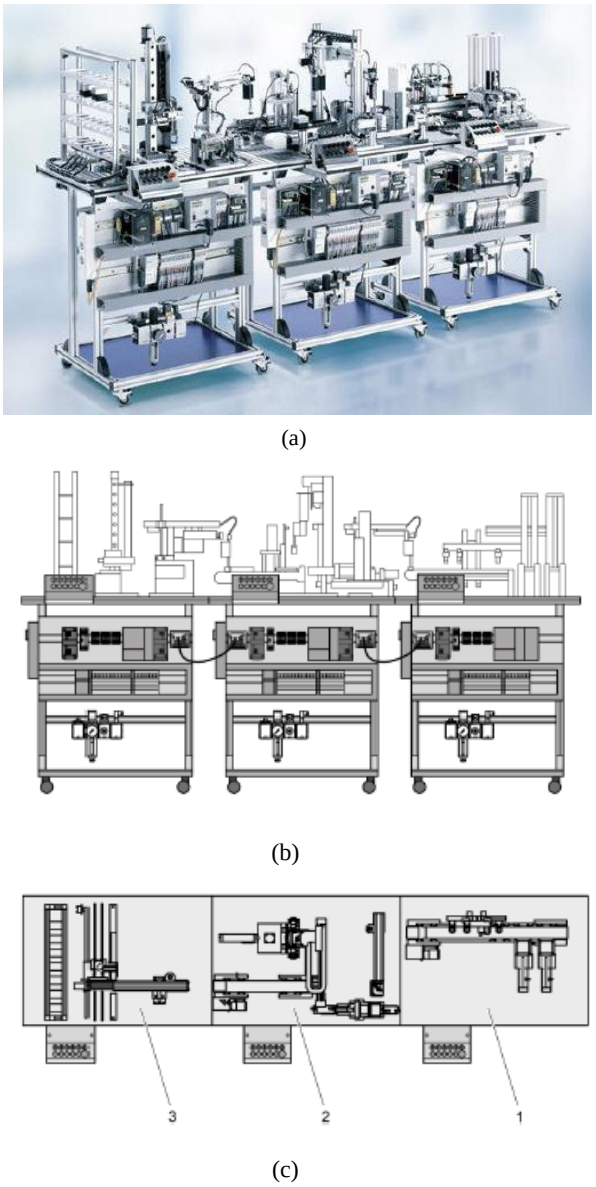
These kinds of industries are using programmable logic control (PLC) to control their sequential process applications. Hence, it is important for the ones studying in the field of Industrial and Mechatronics Engineering to understand and gain an experience in writing PLC programs to control sequential processes.

Behary *et al*. (2004) designed and implemented a program on sugar boiling process in batch vacuum pans. They used a Function Block Diagrams (FBD) and Sequential Flow Chart (SFC) as the main programming languages for his PLC. Aoki *et al*. (2000) have shown how to convert a state flow diagram to a sequential path in PLC. They illustrated how to automatically generate the motion sequence in the PLC. However, they claimed that the solutions found are not always optimal, and further research needs to be carried out. A modular Mechatronic system (mMs) is studied as a laboratory course in the School of Mechatronics Engineering at Assumption University. The objective of this paper is to provide basic guidelines to the ones who are interested in the details of such laboratory training. The readers will be able to visualize the entire system along with the sequential processes and they will be able to save time in setting up the equipment, like profibus address, inline modules, etc., with the help of this review paper.

The basic components of the mMs are summarized in section 1. Section 2 focuses on the entire mMs which includes the three stations, PLC, profibus coupler, maintenance unit and emergency stop relays. Section 3 discusses Station 1 - the Magazine Station. Section 4 discusses Station 2 - the Pneumatic press station and section 5 discusses Station 3 - the Storage Station. Conclusion of the paper is presented in section 6.

2. The Modular Mechatronic System

The modular Mechatronic system (mMs) from Bosch Rexroth AG (2002, 2005 and 2006) includes three stations: Station 1- the Magazine Station, Station 2 - the Pneumatic Press Station and Station 3 - the Storage Station. Figure 1 shows the diagram of the three mMs stations combined together.



(a)

(b)

(c)

Fig. 1. The modular Mechatronic system: (a) Overview; (b) Front view; and (c) Top view.

The mMs is a unit provided in order to learn how to write programs to control sequential processes. The details for each station are summarized in Tables A1-A3 in Appendix A and Figures B1-B4 in Appendix B.

Each station includes a programmable Logic Control (PLC), a profibus coupler, a maintenance unit, emergency stop relays and main operation components.

2.1 Programmable Logic Controller

PLC IndraControl L20 by Rexroth is used as a main controller in this case study. Figure 2 shows the PLC unit, which includes a PLC: onboard and profibus modules.

Fig. 2. PLC IndraControl L20 unit.

The onboard module includes:

- Digital inputs: 8 inputs, 24V DC;
- Digital outputs: 8 outputs, 24V DC, 500 mA;
- Ethernet: RJ45, female connector, 8-pin;
- RS232: D-Sub male connector, 9-pin.

2.2 The Profibus Coupler

The profibus is used to operate sensors and actuators via a centralized controller in production automation applications. The mMs's profibus coupler is shown in Fig. 3 and has the following characteristics:

- Maximum of 63 inline modules;
- 192 bytes/station.

The profibus's DIP switches represent:

- Switches 1-7 – profibus address in binary (0-127);
- Switch 8 – data errors in the inline:
  - ✓ ON: stopped data transfer;
  - ✓ OFF: restarted data transfer;
- Switches 9-10 must be "OFF".

The addresses of each station will be shown in the latter sections.

2.3 Emergency Stop Relays

For safety reasons, there are 3 emergency stop relays at each station. The emergency stop relay is used to control the air flow to each station. PNOZ will not allow the air to flow for two cases:

a) PLC fails to send a signal to enable QX0.4.

b) Pneumatic pressure is not in the range between 5 to 6 Bar.

Fig. 3. Bus coupler.

The PNOZ circuit diagram is illustrated in Fig. 4.

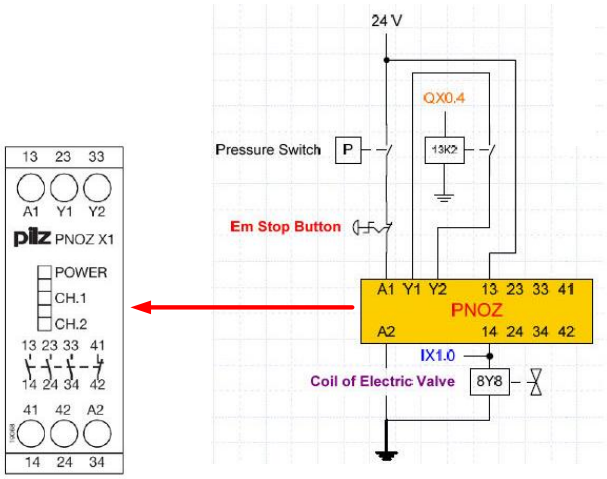


Fig. 4. Emergency stop relays.

2.4 The Maintenance Unit

The maintenance unit is served to prevent an unauthorized adjustment of the 'set' pressure. The other purpose is to prevent the condensed moisture to get into the system. Figure 5 shows the maintenance unit which is included at all three stations. Table 1 lists out the maintenance unit's components.

Table 1. The maintenance unit components.

Item	Description
1	Mechanical shut-off cock
2	Pressure reducer
3	Pressure switch
4	Electric valve for emergency stop
5	Water separator
6	Manometer

Fig. 5. Maintenance unit.

Concerning the pressure switch, the operational pressure for mMs stations is minimum 5 Bar and maximum 6 Bar. The pressure switch is shown in Fig. 6, where:

a) Status LED: ON – activated pressure switch;
b) Adjustment screw: to increase or decrease the switching pressure (read pressure from manometer);
c) Locking screw: to lock or unlock the adjustment of pressure switch.

If the pressure is not in the switching range, the PNOZ will disable the air to get into the system.

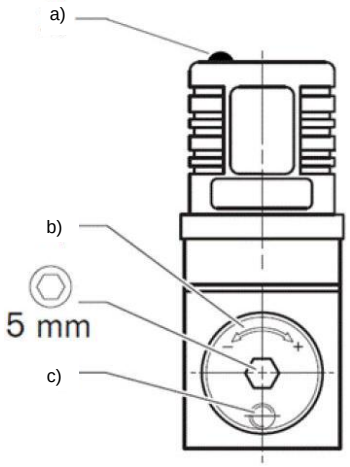


Fig. 6. Pressure switch.

3. The Magazine Station

In this section, mMs Station 1 - The Magazine Station, is defined. The overview diagram of the magazine station is shown in Fig. 7. The equipment of Station 1 is listed in Table 2.

The profibus and inline modules of Station 1 are given in Fig. 8.

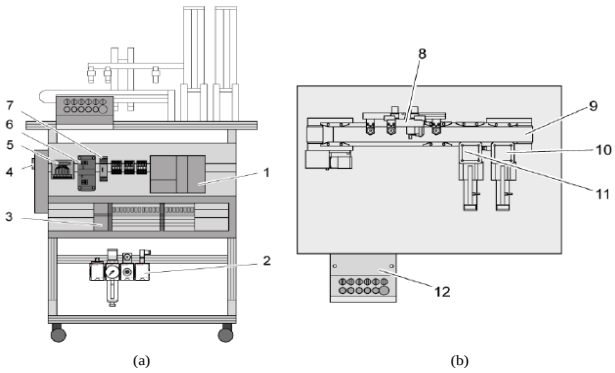


Fig. 7. The Magazine Station:
(a) Front view; and (b) Top view.

Table 2. The Magazine station's structure.

Item	Description
1	PLC
2	Maintenance unit
3	Profibus coupler
4	Main switch
5	Terminating plug on the transfer module
6	Power supply
7	Emergency stop relay
8	Testing unit
9	Conveyor belt
10	Separator magazine 1
11	Separator magazine 2
12	Control panel

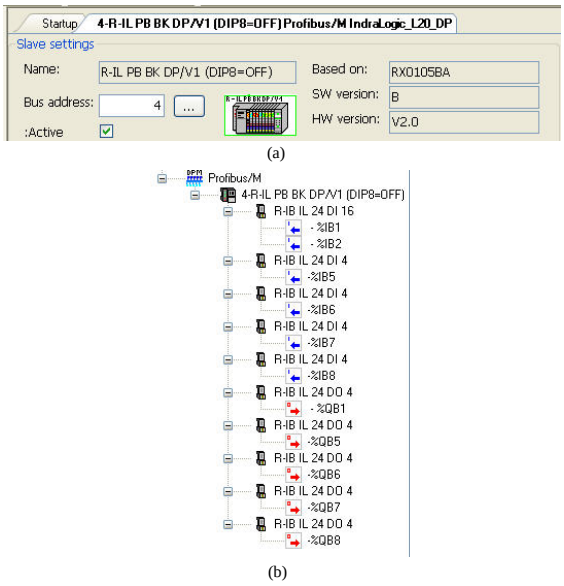


Fig. 8. Station 1 parameters:
(a) Profibus address; and (b) Inline module.

The input and output addresses of sensors and actuators are shown in Table A1. The sequential operation of Station 1 is shown in a flow chart diagram in Fig. B1.

4. The Pneumatic Processing Station

In this section, mMs Station 2 - The Pneumatic Processing Station is defined. The overview diagram of the pneumatic processing station is shown in Fig. 9. The equipment of Station 2 is listed in Table 3.

The profibus and inline modules of Station 2 are given in Fig. 10. The input and output addresses of sensors and actuators are shown in Table A2. The sequential operation of Station 2 is shown in a flow chart diagram in Figs. B2 and B3.

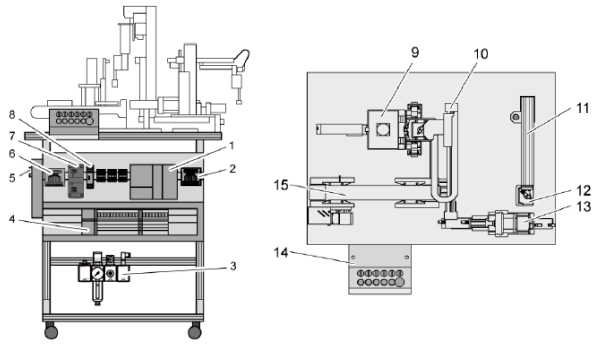


Fig. 9. The Pneumatic Processing Station:
(a) Front view; and (b) Top view.

Table 3. The Pneumatic processing station's structure.

Item	Description
1	PLC
2	Terminating plug on the transfer module
3	Maintenance unit
4	Profibus coupler
5	Main switch
6	Terminating plug on the transfer module
7	Power supply
8	Emergency stop relay
9	Pneumatic press
10	Portal
11	Handling device
12	Turning unit
13	Pins unit
14	Control panel
15	Conveyor belt

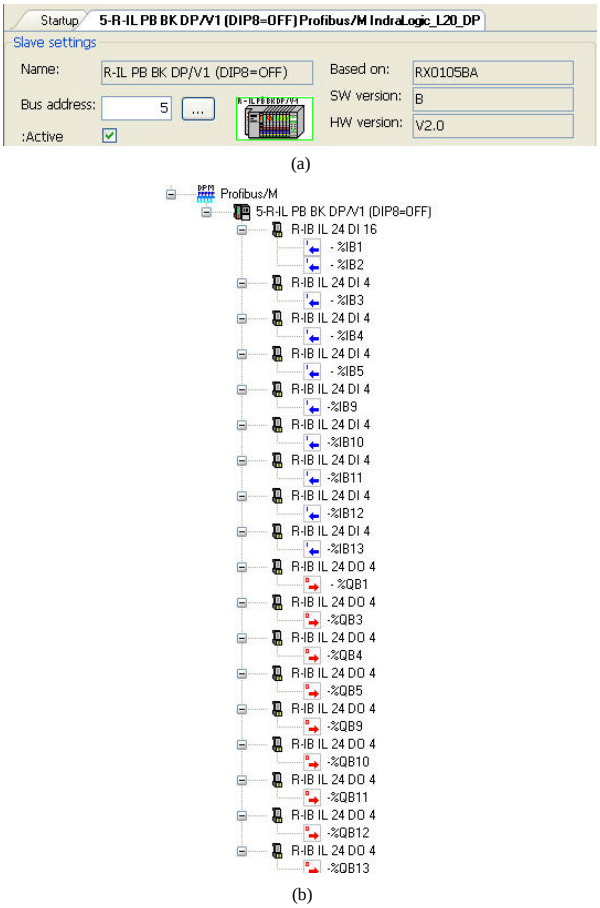


Fig. 10. Station 2 parameters:
(a) Profibus address; and (b) Inline module.

5. The Storage Station

In this section, mMs Station 3 - The Storage Station is defined. The overview diagram of the pneumatic processing station is shown in Fig. 11. The equipment of Station 3 is listed in Table 4.

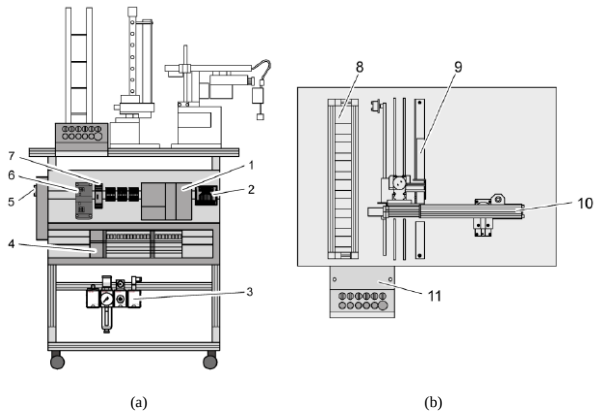
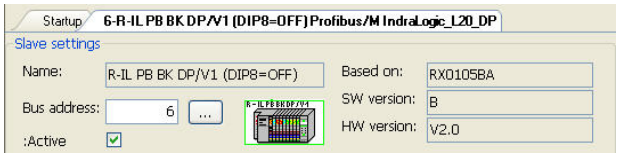


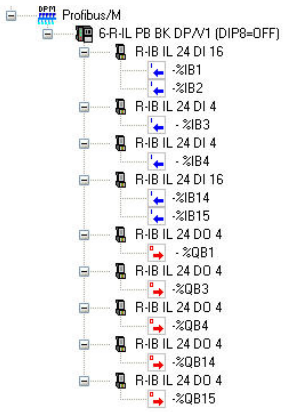
Fig. 11. The Storage Station:
(a) Front view; and (b) Top view.

Table 4. The Storage station's structure.

Item	Description
1	PLC
2	Terminating plug on the transfer module
3	Maintenance unit
4	Profibus coupler
5	Main switch
6	Power supply
7	Emergency stop relay
8	High bay racking
9	Cartesian robot
10	Handling device
11	Control panel



(a)



(b)

Fig. 12. Station 3 parameters:
(a) Profibus address; and (b) Inline module.

The profibus and inline modules of Station 3 are given in Fig. 12. The input and output addresses of sensors and actuators are shown in Table A3. The sequential operation of Station 3 is shown in a flow chart diagram in Fig. B4.

6. Concluding Remarks

Most of the operations in various industries are based on sequential processes. This article gives a preview of mMs which includes three stations operating in a sequential manner (from Station 1 to Station 2 and then to Station 3) in the Mechatronics Laboratory II experiments at Assumption University of Thailand. There are three sequential processes which can be performed individually on each station.

The goal of this paper is to give the readers some basic guidelines so they will be able to perform the initial setting of the mMs, like profibus and inline modules. Details of mMs components on each station have been provided. An operational sequence has been included in a flow chart. With this flow chart, one will be able to quickly grasp the flow of a program and will be able to write such a program much easier.

The experiments which can be conducted with the mMs and PLC are quite useful in providing comprehensive knowledge of the industrial sequential processes. In addition, the said experiments include a practice with SFC language in PLC. With this knowledge, the engineering professionals and students will be more confident and will be able to use PLC. It will be helpful for their professional career.

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Appendix A: Input and Output Addresses

Table A1. The Magazine Station.

Control Panel	
Items	***Address***
i_Emergency_Stop_Relay_OK	IX1.0
i_Switch_Manual_S0	IX1.1
i_Switch_Auto_S0	IX1.2
i_Start_Button_SH10	IX1.3
i_Stop_Button_SH11	IX1.4
i_Quit_Button_SH12	IX1.5
i_Button_SH6	IX1.6
i_Emergency_Stop_Button_S8	IX1.7
i_S1_Switch	IX2.0
i_S2_Switch	IX2.1
i_S3_Switch	IX2.2
i_S4_Switch	IX2.3
i_S5_Switch	IX2.4
q_Start_Button_SH10_Lamp	QX1.0
q_Stop_Button_SH11_Lamp	QX1.1
q_Quit_Button_SH12_Lamp	QX1.2
q_Button_SH6_Lamp	QX1.3
Conveyor belt	
Items	***Address***
i_Light_Pushbutton_B1	IX5.0
q_Motor_Conveyor_Belt_Clockwise_K1	QX5.0
q_Motor_Conveyor_Belt_Counter_Clockwise_K2	QX5.1
Separating Magazine1	
Items	***Address***
i_Cylinder_Extended_Magazine1_B1	IX6.0
i_Cylinder_Retracted_Magazine1_B2	IX6.1
i_Magazine1_Empty_S3	IX6.2
q_Retract_Cylinder_Magazine1_Y1	QX6.0
q_Extend_Cylinder_Magazine1_Y2	QX6.1
Separating Magazine2	
Items	***Address***
i_Cylinder_Extended_Magazine2_B1	IX7.0
i_Cylinder_Retracted_Magazine2_B2	IX7.1
i_Magazine2_Empty_S3	IX7.2
q_Retract_Cylinder_Magazine2_Y1	QX7.0
q_Extend_Cylinder_Magazine2_Y2	QX7.1
Onboard	
Items	***Address***
i_Station2_Coupled	IX0.2
i_Ackn_from_Station2	IX0.3
q_Station1_Finished	QX0.0
q_Ackn_to_Station2	QX0.1
q_Emergency_Stop_Relay	QX0.4
Testing Unit	
Items	***Address***
i_Workpiece_Present_B1	IX8.0
i_Contour_Depth_OK_B2	IX8.1
i_Workpiece_Light_B3	IX8.2
i_Workpiece_Metal_B4	IX8.3
q_Extend_Cylinder_Testing_Unit_Y2	QX8.0
q_Retract_Cylinder_Testing_Unit_Y1	QX8.1

Table A2. The Pneumatic Press Station.

Control Panel	
Items	***Address***
i_Emergency_Stop_Relay_OK	IX1.0
i_Switch_Manual_S0	IX1.1
i_Switch_Auto_S0	IX1.2
i_Start_Button_SH10	IX1.3
i_Stop_Button_SH11	IX1.4
i_Quit_Button_SH12	IX1.5
i_Referencing_Run_SH6	IX1.6
i_Emergency_Stop_Button_S8	IX1.7
i_S1_Switch	IX2.0
i_S2_Switch	IX2.1
i_S3_Switch	IX2.2
i_S4_Switch	IX2.3
i_S5_Switch	IX2.4
q_Start_Button_SH10_Lamp	QX1.0
q_Stop_Button_SH11_Lamp	QX1.1
q_Quit_Button_SH12_Lamp	QX1.2
q_Referencing_Run_SH6_Lamp	QX1.3
Conveyor belt	
Items	***Address***
i_Light_Pushbutton_B1	IX5.0
q_Motor_Conveyor_Belt_Clockwise_K1	QX5.0
q_Motor_Conveyor_Belt_Counter_Clockwise_K2	QX5.1
Handling Device	
Items	***Address***
i_Home_Position_B1	IX3.0
i_Vertical_Cylinder_Down_B2	IX3.1
i_Vertical_Cylinder_Up_B3	IX3.2
i_Z_Axis_Retracted_B4	IX3.3
i_Z_Axis_Extended_B5	IX4.0
q_Vertical_Cylinder_Up_Y1	QX3.0
q_Suction_On_Y2	QX3.1
q_Extend_Z_Axis_Y3	QX3.2
q_Motor_Clockwise_K1	QX3.3
q_Motor_Counter_Clockwise_K2	QX4.0
Onboard	
Items	***Address***
i_Station1_Finished	IX0.0
i_Ackn_from_Station1	IX0.1
i_Station1_Coupled	IX0.2
i_Ackn_from_Station3	IX0.4
i_Station3_Coupled	IX0.5
i_Converter_Unit_Channel_A	IX0.6
i_Converter_Unit_Channel_B	IX0.7
q_Station2_Finished	QX0.0
q_Ackn_to_Station3	QX0.3
q_Emergency_Stop_Relay	QX0.4
q_Ackn_to_Station1	QX0.6
Pin Station	
Items	***Address***
i_Clamping_Cylinder_Extended_B1	IX10.0
i_Clamping_Cylinder_Retracted_B2	IX10.1
i_Pin_Cylinder_Extended_B3	IX10.2
i_Pin_Cylinder_Retracted_B4	IX10.3
q_Extend_Clamping_Cylinder_Y1	QX10.0
q_Extend_Pin_Cylinder_Y2	QX10.1
Portal	
Items	***Address***
i_Cylinder_Up_B1	IX11.0
i_Cylinder_Down_B2	IX11.1
i_Shuttle_Right_B3	IX11.2
i_Shuttle_Left_B4	IX11.3
q_Cylinder_Lower_Y1	QX11.0
q_Shuttle_Left_Y2	QX11.1
q_Suction_On_Y3	QX11.2
Press Station	
Items	***Address***
i_Protective_Door_Up_B1	IX12.0
i_Protective_Door_Down_B2	IX12.1
i_Ejector_Extended_B3	IX12.2
i_Ejector_Retracted_B4	IX12.3
i_Push_Button_Right_SH5	IX13.0
i_Push_Button_Left_SH6	IX13.1
q_Open_Protective_Door_Y1	QX12.0
q_Close_Protective_Door_Y2	QX12.1
q_Extend_Ejector_Y3	QX12.2
q_Retract_Ejector_Y4	QX12.3
q_Push_Button_Right_SH5_Lamp	QX13.0
q_Push_Button_Left_SH6_Lamp	QX13.1
q_Lift_Pressing_Cylinder_Y5	QX13.2
q_Lower_Pressing_Cylinder_Y6	QX13.3
Turning Unit	
Items	***Address***
i_Turning_Unit_Horizontal_B1	IX9.0
i_Turning_Unit_Vertical_B2	IX9.1
q_Turning_Unit_Horizontal_Y2	QX9.0
q_Turning_Unit_Vertical_Y1	QX9.1

Table A3. The Storage Station.

Control Panel	
Items	***Address***
i_Emergency_Stop_Relay_OK	IX1.0
i_Switch_Manual_S0	IX1.1
i_Switch_Auto_S0	IX1.2
i_Start_Button_SH10	IX1.3
i_Stop_Button_SH11	IX1.4
i_Quit_Button_SH12	IX1.5
i_Referencing_Run_SH6	IX1.6
i_Emergency_Stop_Button_S8	IX1.7
i_S1_Switch_High_Bay_Racking_Empty	IX2.0
i_S2_Switch	IX2.1
i_S3_Switch	IX2.2
i_S4_Switch	IX2.3
i_S5_Switch	IX2.4
q_Start_Button_SH10_Lamp	QX1.0
q_Stop_Button_SH11_Lamp	QX1.1
q_Quit_Button_SH12_Lamp	QX1.2
q_Referencing_Run_SH6_Lamp	QX1.3
Handling Device	
Items	***Address***
i_Home_Position_B1	IX3.0
i_Vertical_Cylinder_Down_B2	IX3.1
i_Vertical_Cylinder_Up_B3	IX3.2
i_Z_Axis_Retracted_B4	IX3.3
i_Z_Axis_Extended_B5	IX4.0
q_Vertical_Cylinder_Up_Y1	QX3.0
q_Suction_On_Y2	QX3.1
q_Extend_Z_Axis_Y3	QX3.2
q_Motor_Clockwise_K1	QX3.3
q_Motor_Counter_Clockwise_K2	QX4.0
High Bay Racking Horizontal Axis	
Items	***Address***
i_Gap_Reached_B10	IX15.0
i_Stop_Left_S11	IX15.1
i_Stop_Right_S13	IX15.2
i_Transfer_Position_Reached_B15	IX15.3
q_Horizontal_Direction_Initial_Position_K1	QX15.0
q_Horizontal_Direction_Transfer_K2	QX15.1
High Bay Racking Vertical Axis	
Items	***Address***
i_Postion_Reached_Vertical_B1	IX14.0
i_Stop_Down_S2	IX14.1
i_Stop_Up_S4	IX14.2
i_Cylinder_Extended_B6	IX14.3
i_Cylinder_Retracted_B7	IX14.4
q_Motor_Vertical_Axis_Clockwise_K3	QX14.0
q_Motor_Vertical_Axis_Counter_Clockwise_K4	QX14.1
q_Cylinder_Y1	QX14.2
Onboard	
Items	***Address***
i_Station2_Finished	IX0.0
i_Station2_Coupled	IX0.2
i_Ackn_from_Station2	IX0.3
i_Converter_Unit_Channel_A	IX0.6
i_Converter_Unit_Channel_B	IX0.7
q_Ackn_to_Station2	QX0.1
q_Emergency_Stop_Relay	QX0.4

Appendix B: Flow Charts

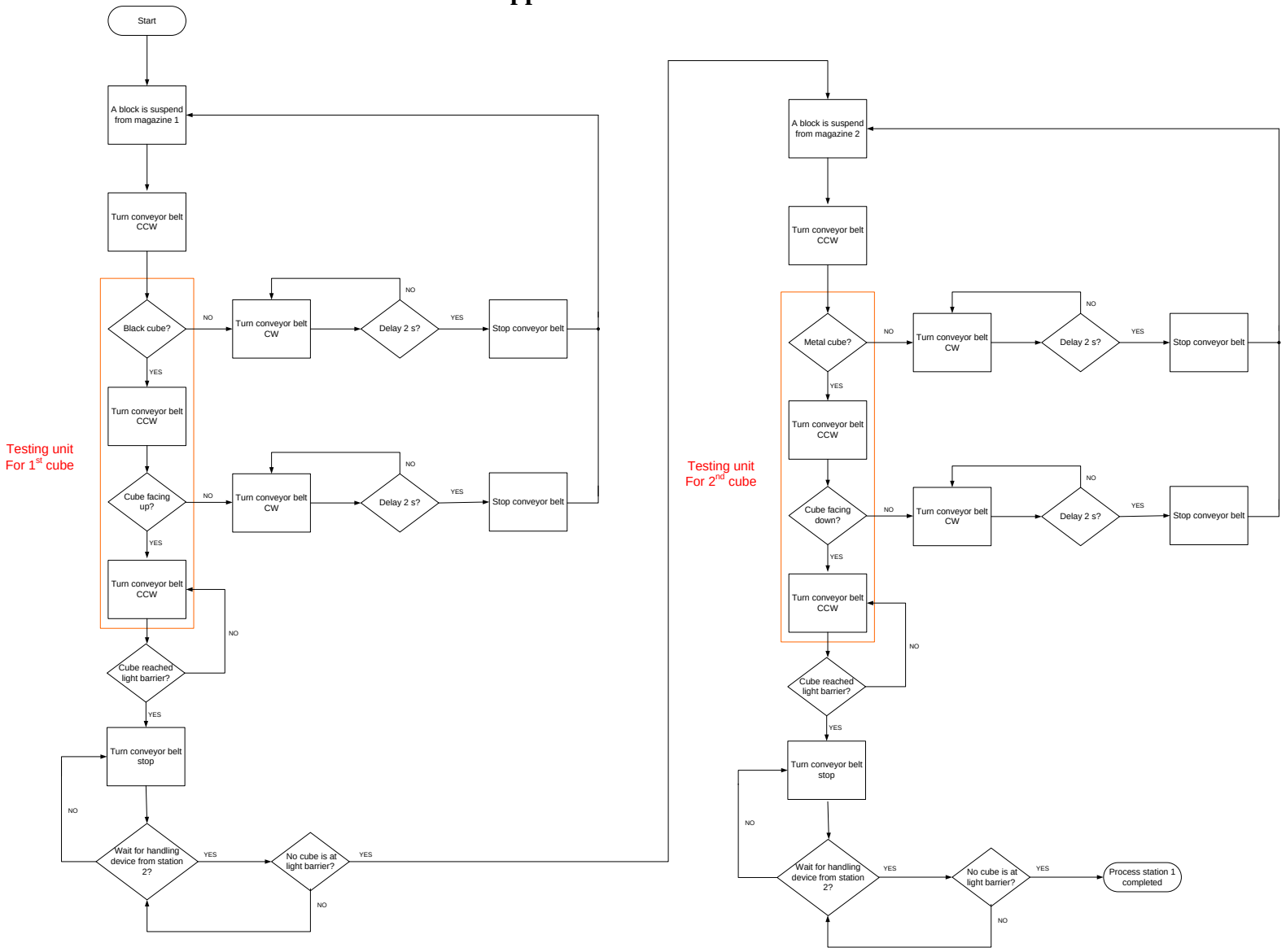

Fig. B1. Flow chart for Station 1 process.

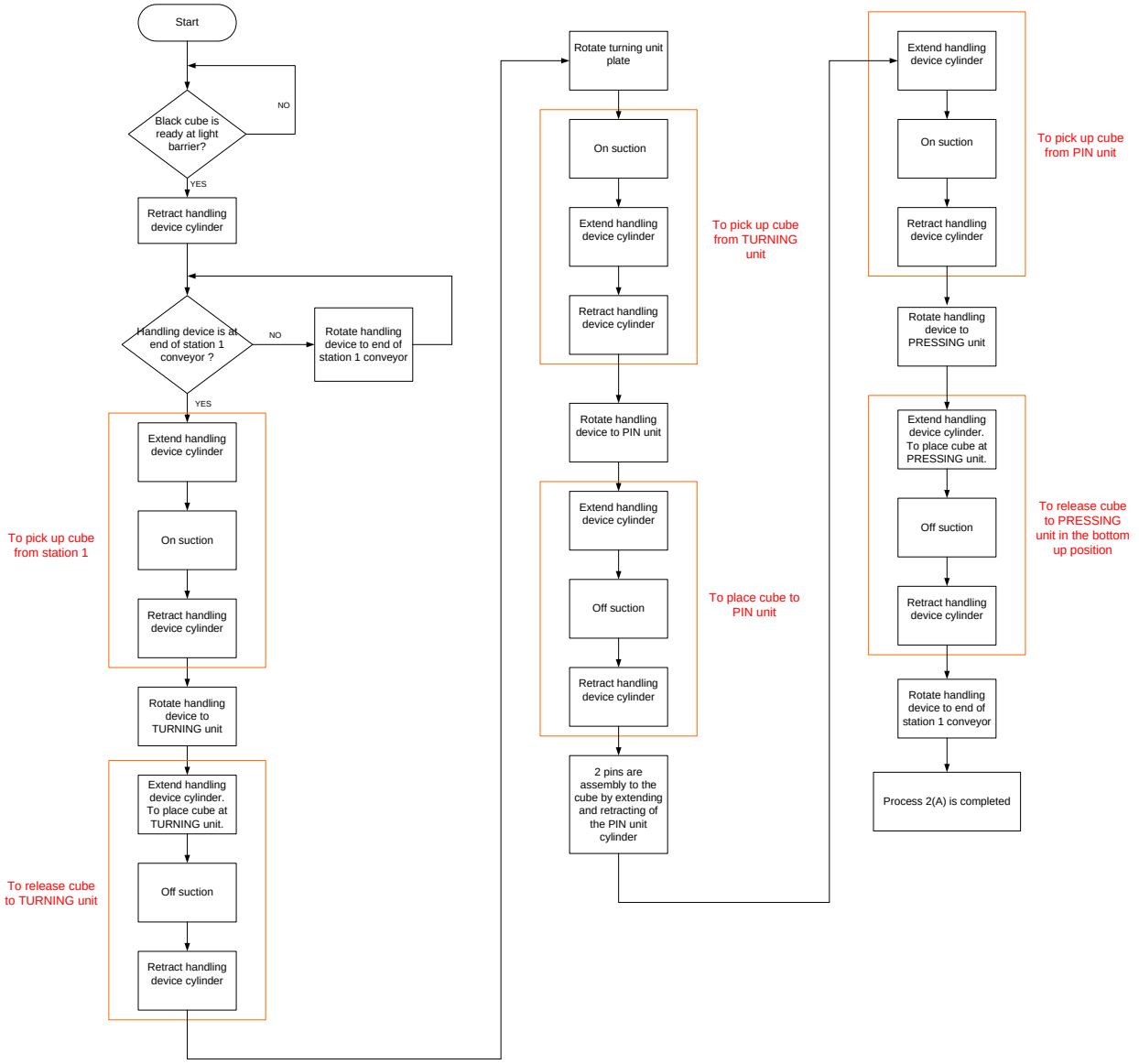

Fig. B2. Flow chart for Station 2 process (part 1).

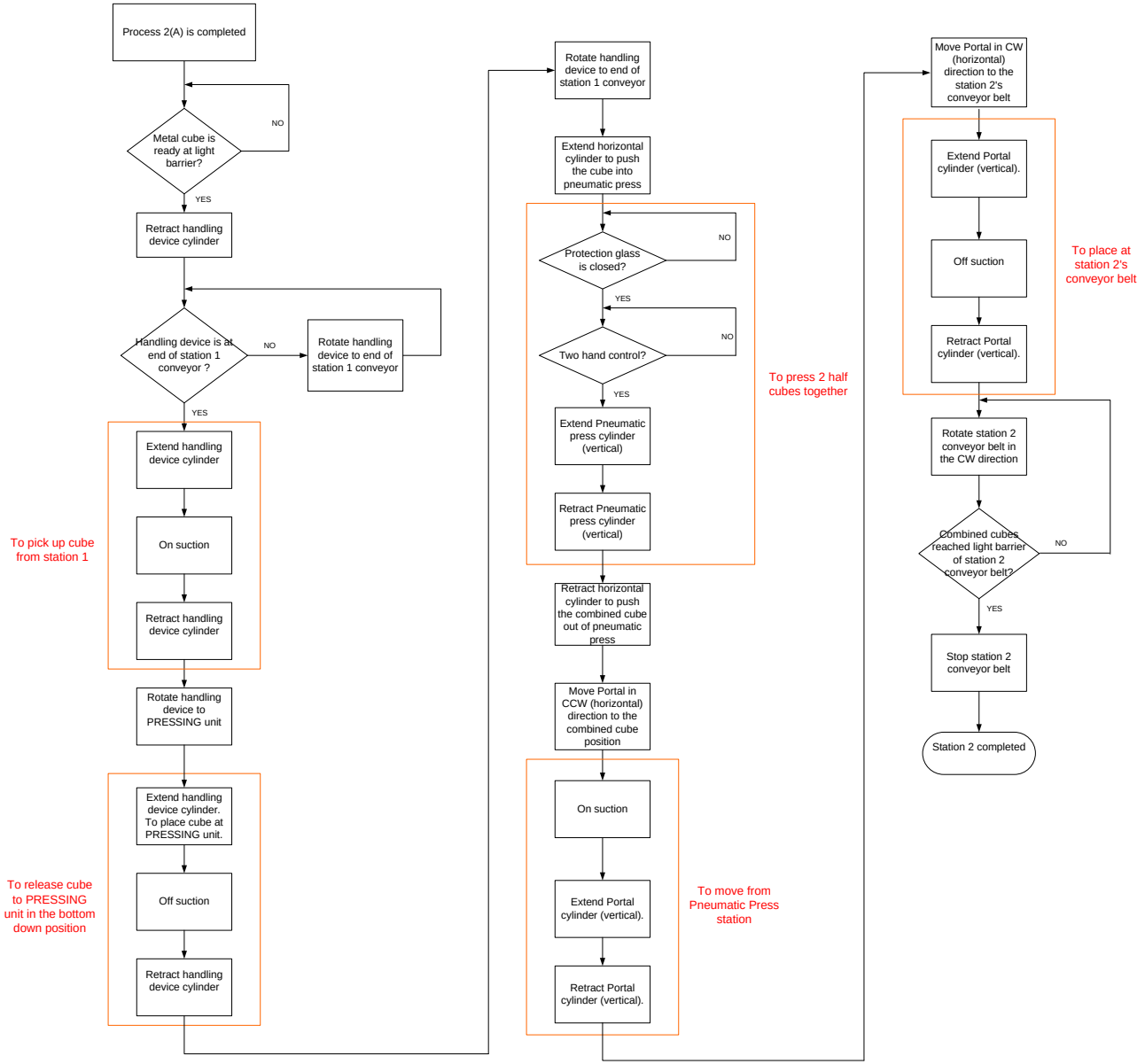

Fig. B3. Flow chart for Station 2 process (part 2).

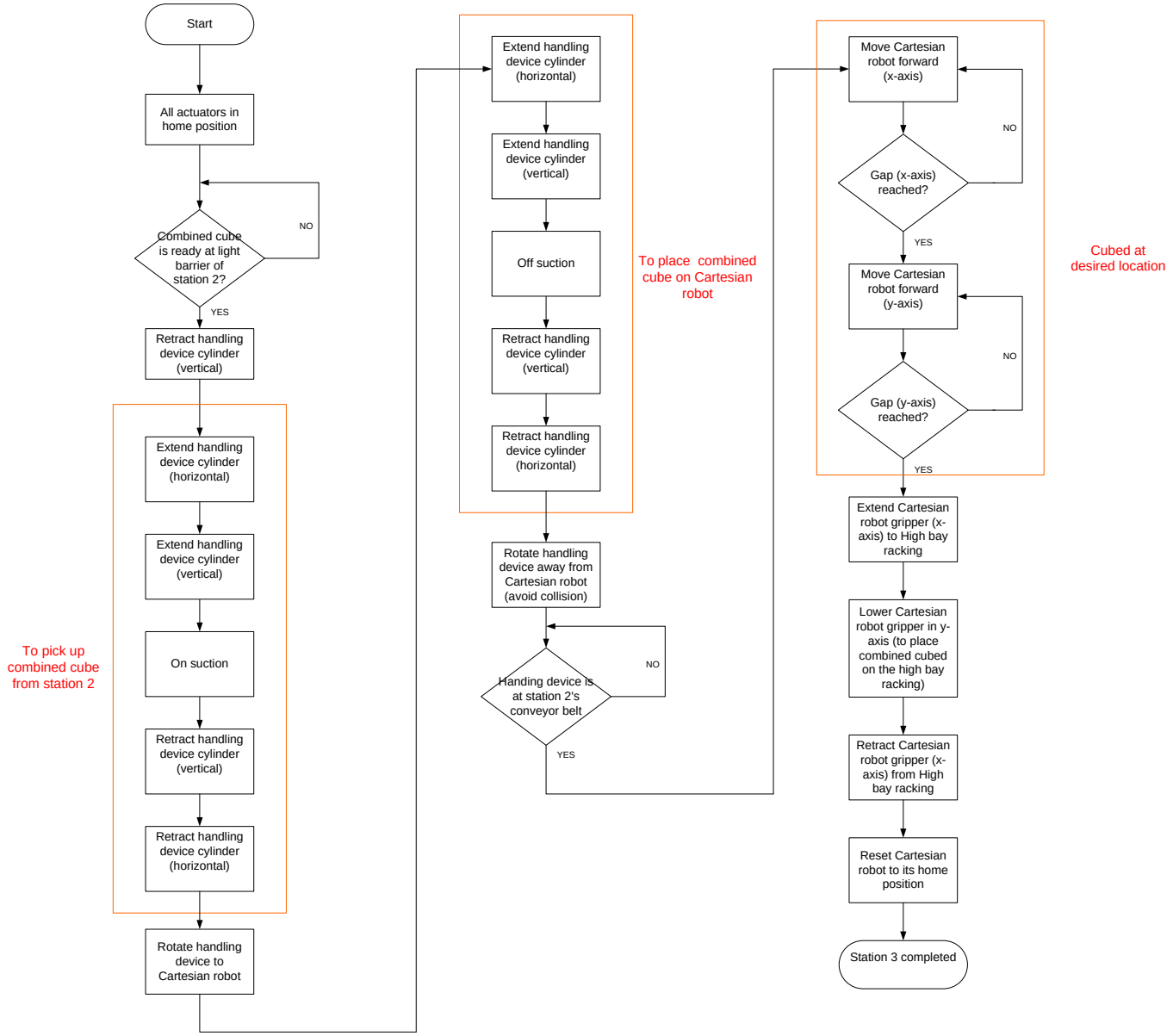

Fig. B4. Flow chart for Station 3 process.