Chapter II: Grafcet

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1 History

In 1975, the French Association for Economic and Technical Cybernetics (AFCET) established a standardization commission with the aim of defining tools capable of describing sequential automation systems.

In 1977, AFCET proposed the GRAFCET representation tool. The name "GRAFCET" is an acronym for **"Graphe Fonctionnel de Commande Étapes/Transitions"** (Functional Control Graph for Steps/Transitions).

In 1982, the French National Agency for the Development of Automated Production (ADEPA) standardized GRAFCET with the **AFNOR C03190** French standard. In 1987, it became an international standard, **IEC 848**.

2 Definition of a Grafcet

Grafcet is designed to represent logical automation systems, meaning systems in which the information is binary (All-Or-Nothing logic, TOR in French).

A grafcet is a graph consisting of two types of elements: steps and transitions. Directed arcs connect either a step to a transition or a transition to a step.

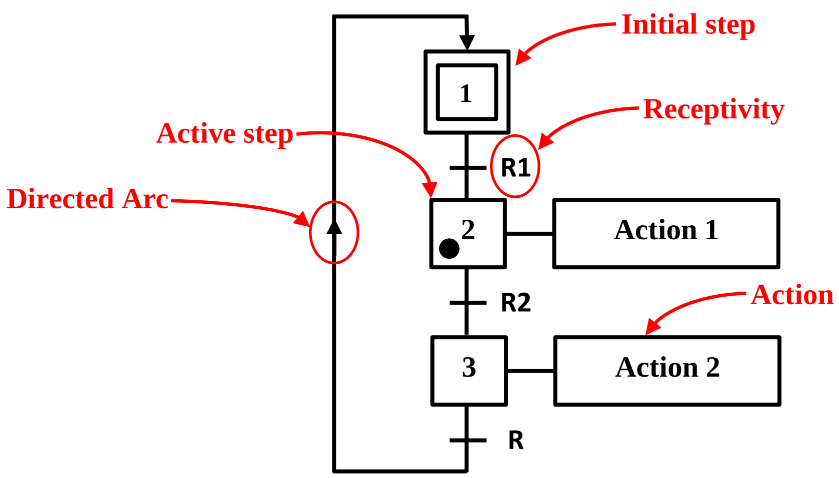


Figure 2.1. Representation of the Basic Elements of a Grafcet

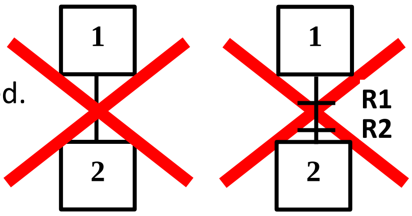
2.1 Steps

A step is represented by a square and can have two states: active or inactive. Steps that must be active at the start are represented by a double square and are referred to as **initial steps**. Actions, which are the outputs of the grafcet, are associated with the steps.

2.2 Transition

A transition is represented by a line. Each transition is associated with a **receptivity**, which is a function of the **input variables** of the grafcet.

2.3 Syntax Rules



1. The alternation between steps and transitions must be respected.
2. Two steps should never be directly connected.
3. Two transitions should never be directly connected.

2.4 Different Types of Transitions

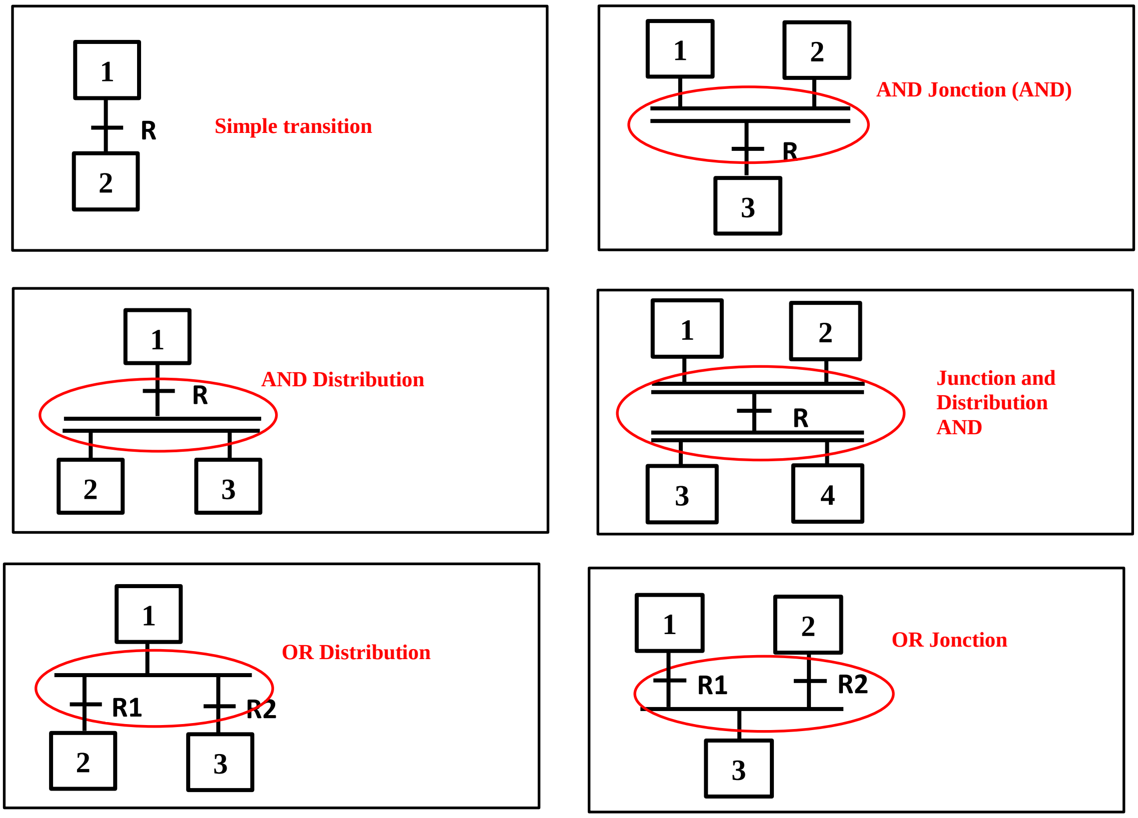


Figure 2.2. Representation of Different Types of Transitions

3 Evolution of a Grafcet

A grafcet has dynamic behavior governed by rules that define the causes and effects of transition crossing.

3.1 Initial Situation

The initial situation of a grafcet characterizes the initial behavior of the control part, corresponding to the steps that are active at the beginning of operation (activation of the initial steps).

3.2 Crossable Transition

A transition is crossable if and only if the following two conditions are met:

1. All steps preceding the transition are active (the transition is said to be validated).
2. The receptivity of the transition is true.

Crossable Transition If: (Transition is validated) + (Receptivity is true)

3.3 Rules for the Evolution of a Grafcet

Rule 1: Any crossable transition is crossed immediately.
Rule 2: Multiple simultaneously crossable transitions are crossed simultaneously.
Rule 3: When a step must be simultaneously activated and deactivated, it remains active.

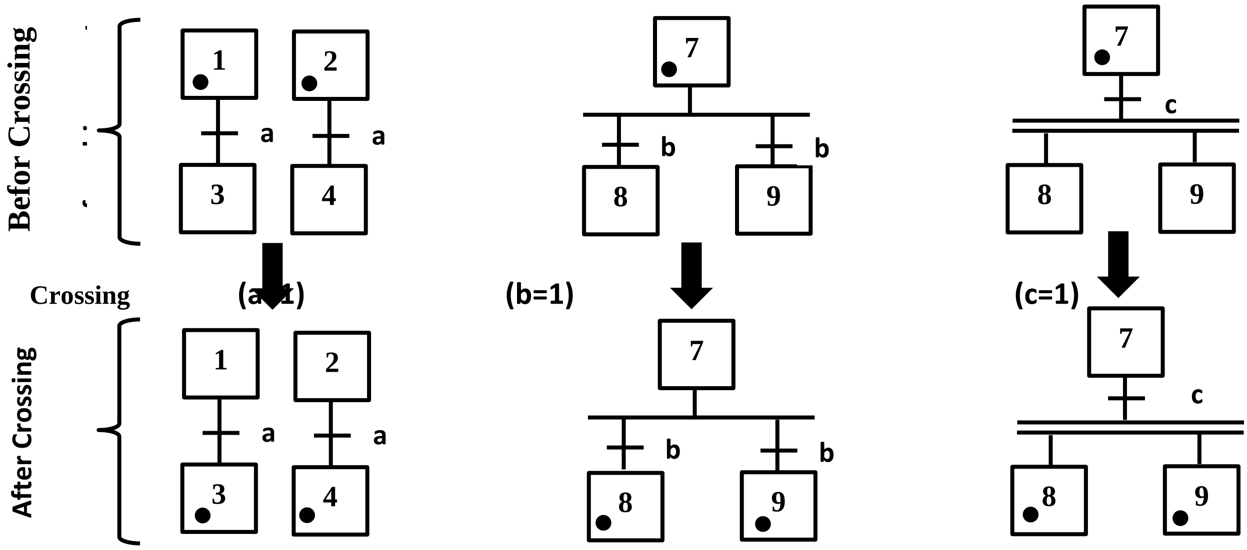


Figure 2.3. Illustration of Simultaneous Transition Crossing

4 Examples

4.1 Example 1

A cart moves between points **a** and **b** (see Figure 4). When the cart is at point **a**, the operator can request the loading of the cart by pressing the load request button. The cart then travels to point **b**, where the loading is carried out by opening a hopper. Once the loading is complete, the hopper closes, and the cart returns to point **a**, where its load is used. The cart will depart again when a new loading is requested by the operator.

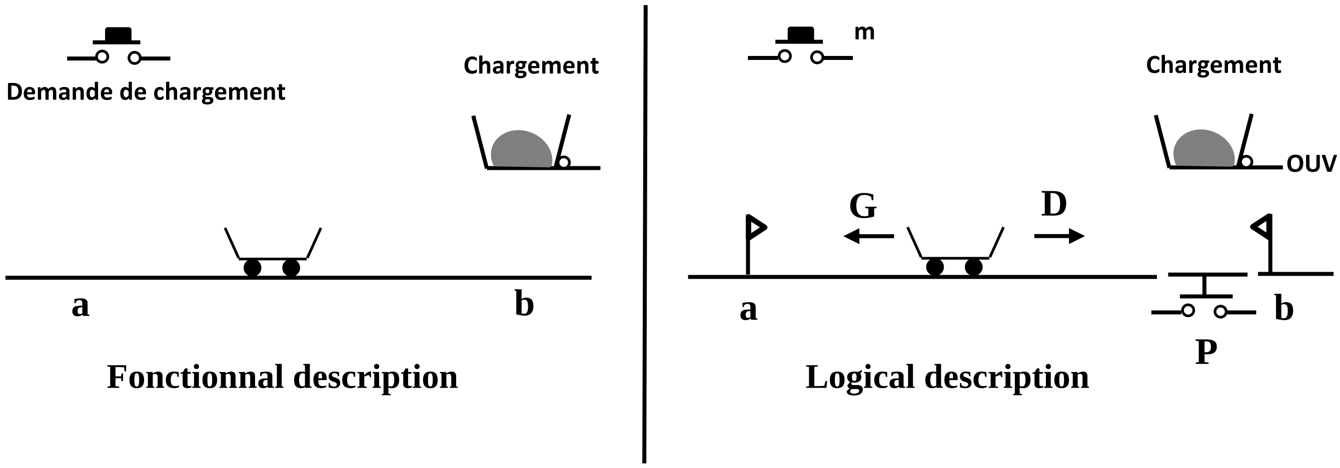
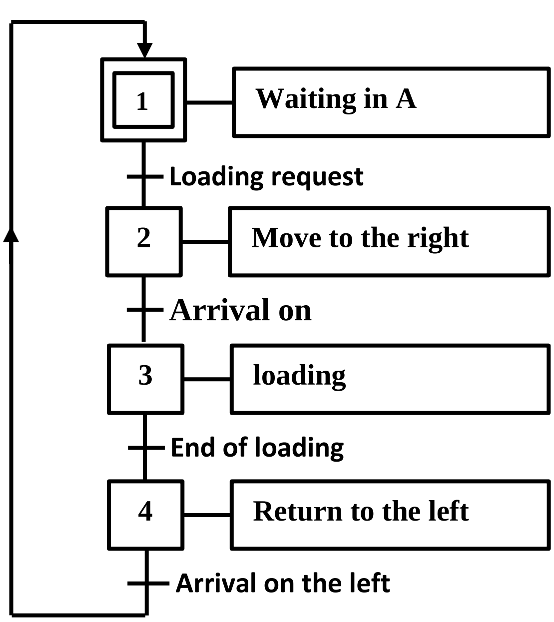
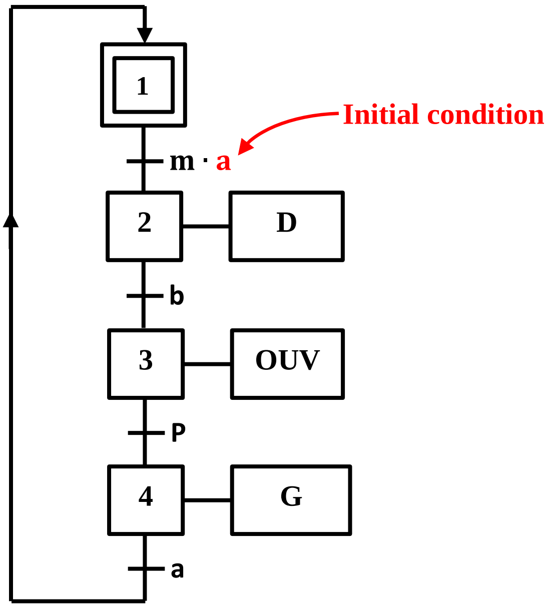
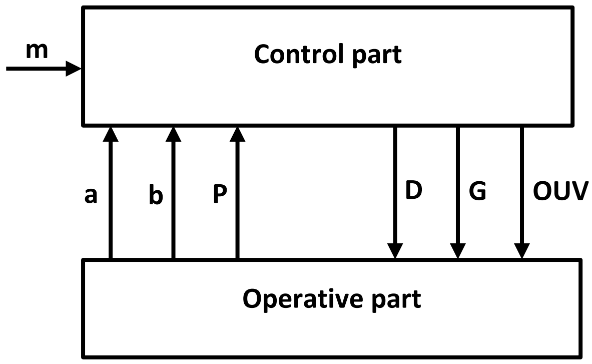
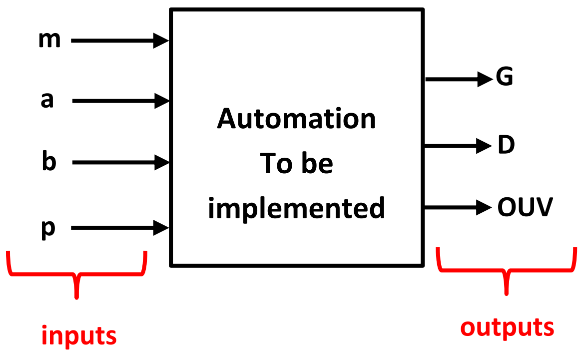


Figure 2.4. Functional and Logical Description of the Loading System









4.2 Example 2

After the start cycle command (DCY), the drill descends at High Speed (DGV) to position S2, then at Low Speed (DPV) to position S3. From S3 to S1, the drill ascends at High Speed (RGV). The parts to be drilled are supplied and secured manually. The drilling motor (M) continuously rotates the drill bit.

The cycle can only start if the drill is in the upper position (**S1 = 1**) and a part is present on the vise (**P = 1**).

DGV: High-Speed Descent
DPV: Low-Speed Descent
RGV: High-Speed Ascent

Describe the system's operation using a Grafcet.

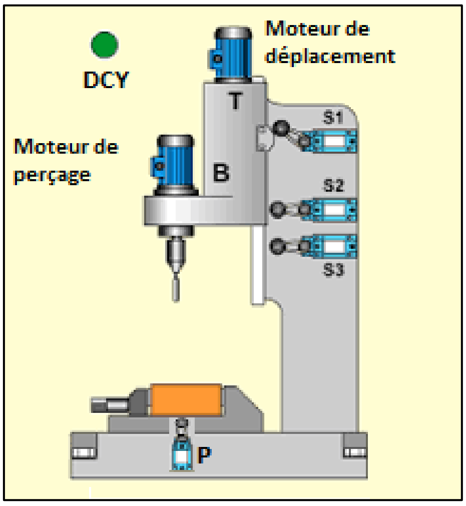
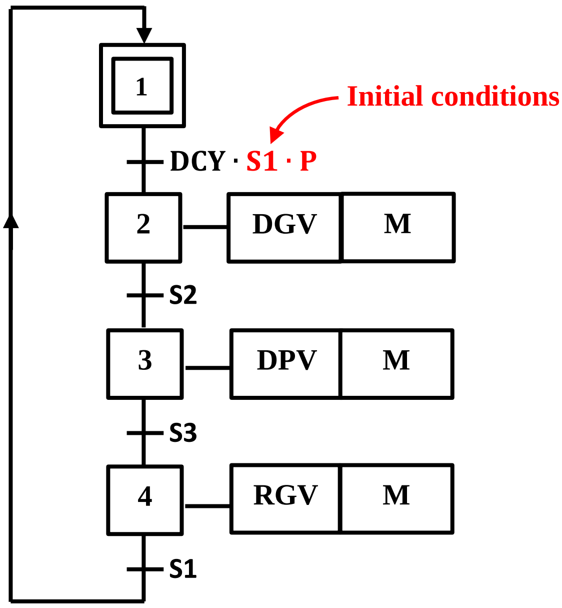
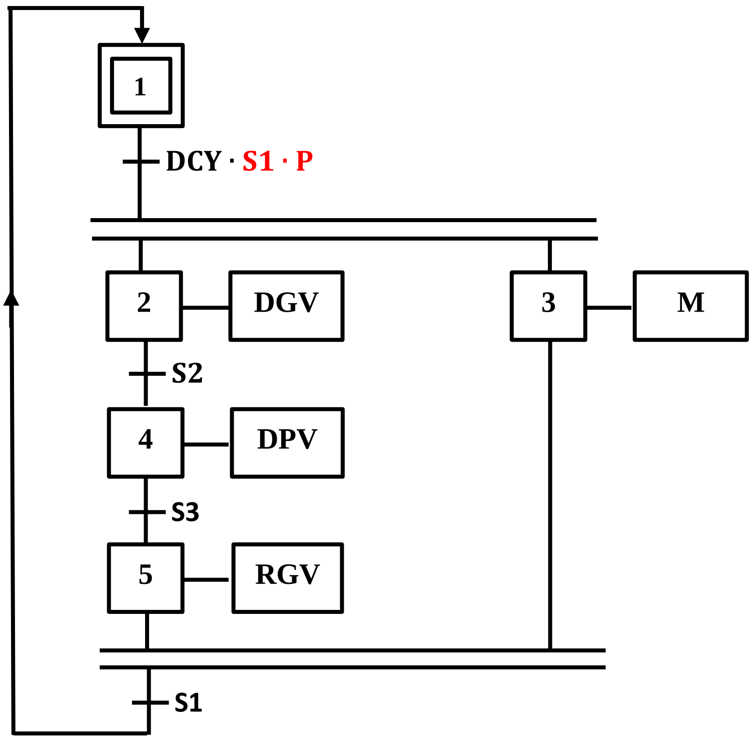


Figure 2.5

Solution :



The motor **M** runs as long as one of the steps **X_2, X_3**, or **X_4** is active. The Grafcet above can be modified by introducing an **AND distribution** after the receptivity **DCY** and an **AND junction** after step 5.



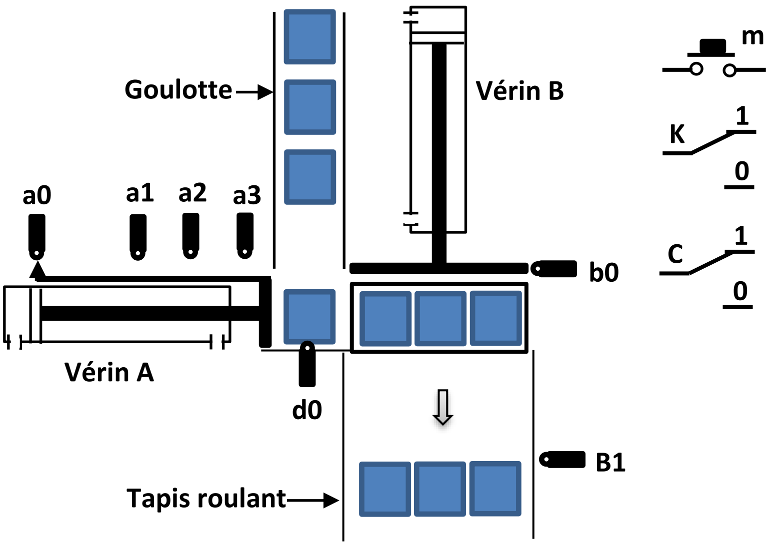
4.3 Example 3

Pieces arrive in a chute in a line and must be arranged in groups of three on a conveyor belt that transports them to the next operation.

- The **push button m** allows the cycle to start.

- **K = 1**: The system operates cycle by cycle.
- **K = 0**: The system operates continuously.
- **C = 1**: The system sends one centered part onto the conveyor belt.
- **C = 0**: The system sends three parts onto the conveyor belt.

The cycle can only start if **Cylinder A** is in position $\mathbf{a_0}$ ($\mathbf{a_0 = 1}$) and **Cylinder B** is in position $\mathbf{b_0}$ ($\mathbf{b_0 = 1}$).

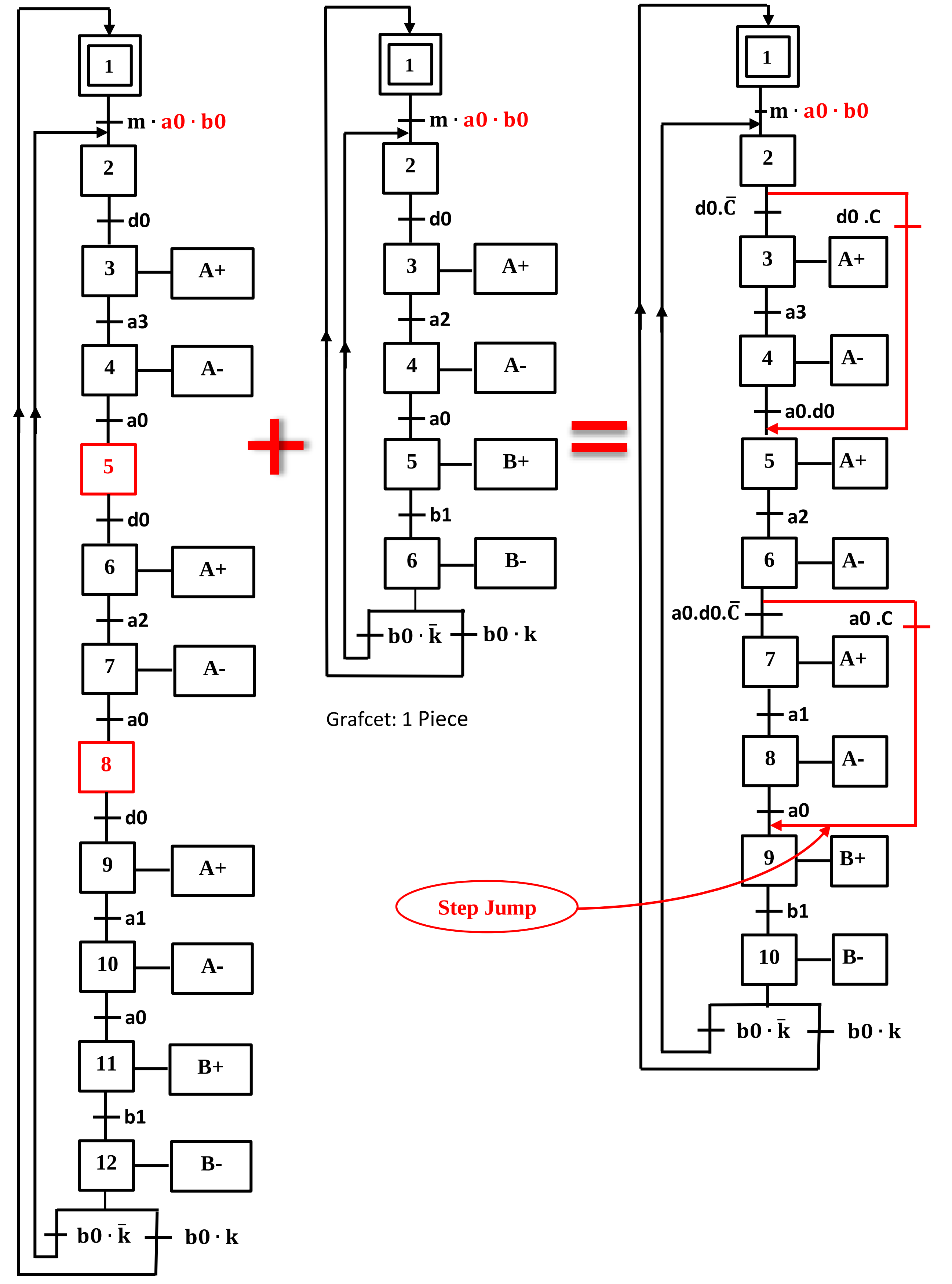


Cylinder A and Cylinder B: Double-acting cylinders
- **A+**: Cylinder A rod moving outward
- **A-**: Cylinder A rod moving inward
- **B+**: Cylinder B rod moving outward
- **B-**: Cylinder B rod moving inward

$\mathbf{a_0, a_1, a_2, a_3, d_0, b_0, b_1}$: Binary inputs (All-Or-Nothing logic)
m, k, c: Binary inputs (All-Or-Nothing logic)

Figure 2.6

Solution :

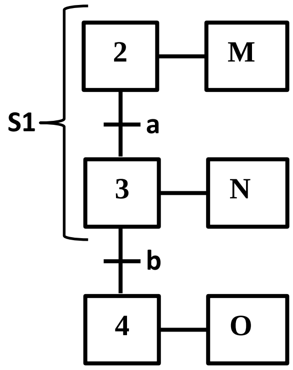


Grafcet: 1 Piece

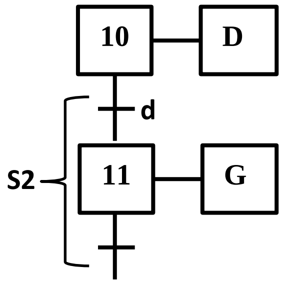
Grafcet: 3 Pieces

5 Waiting for and Blocking an Event

5.1 Waiting for an Event



Grafcet 1



Grafcet 2

Grafcet 2 can only execute sequence **S2 = {step 11}** if Grafcet 1 has completed the execution of sequence **S1 = {step 2, step 3}**.

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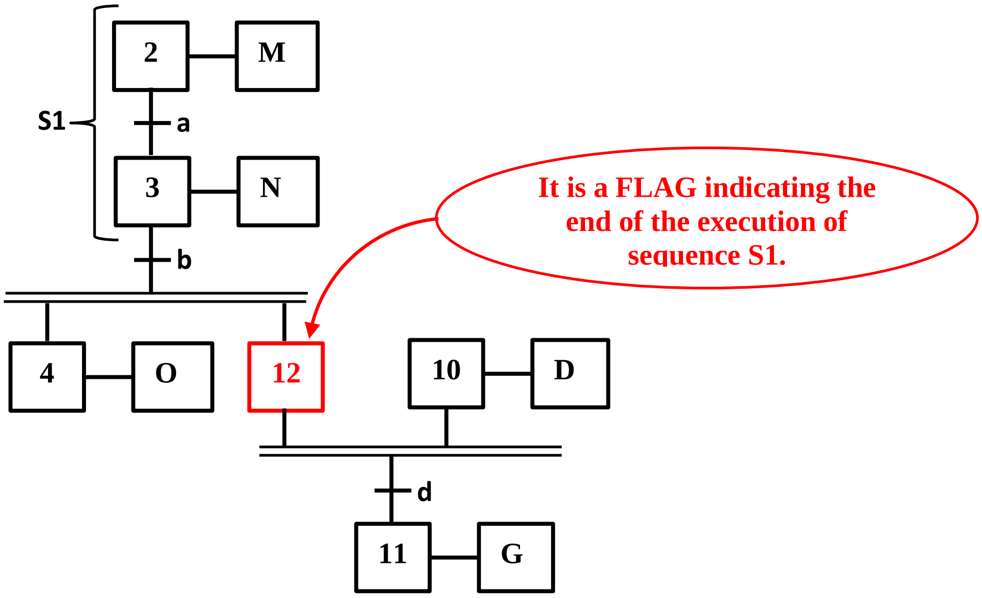
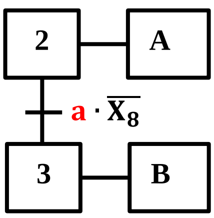
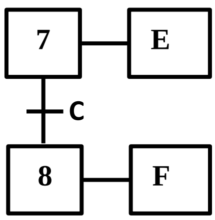


Step 11 can only be executed if Step 10 is active and after the execution of sequence **S1**.

5.2 Blocking an Event



Grafcet 1



Grafcet 2

Step 3 of Grafcet 1 cannot be executed if Grafcet 2 is currently executing Step 8. The variable **X** is used to represent the state of a step:

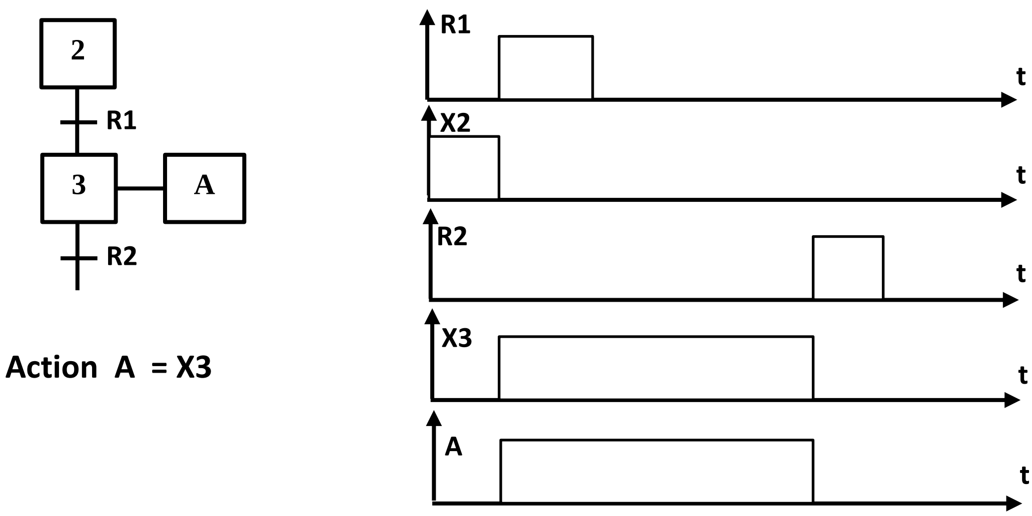
- **X_8 = 1**: This means that Step 8 is active.
- **X_8 = 0**: This means that Step 8 is inactive.

6 Different Types of Actions

The actions associated with a step can vary in nature and complexity. They may be conditional or unconditional, delayed or time-limited, memorized or non-memorized.

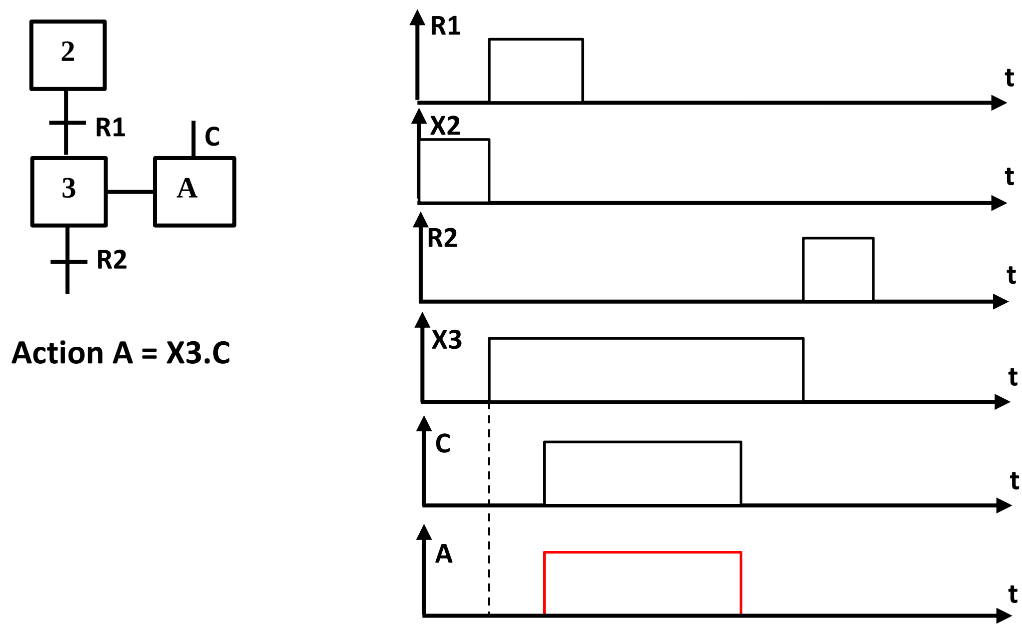
6.1 Unconditional Continuous Action

The action command is issued continuously as long as the step to which it is associated remains active.



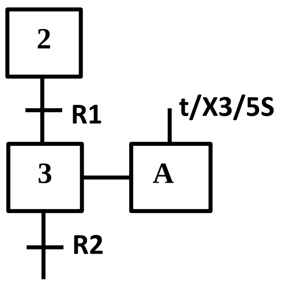
6.2 Conditional Continuous Action

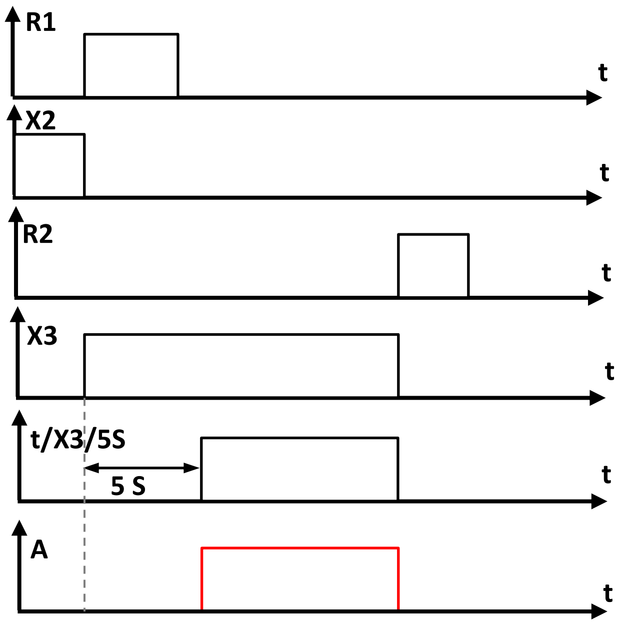
This is a continuous action whose execution depends on a logical condition.
Action **A** is executed if **X3·C = 1**.



6.3 Delayed Conditional Continuous Action

This is a conditional continuous action where the condition includes a delay, allowing the action to be postponed relative to the activation of the step it is associated with.

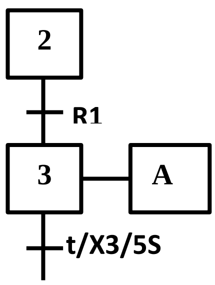


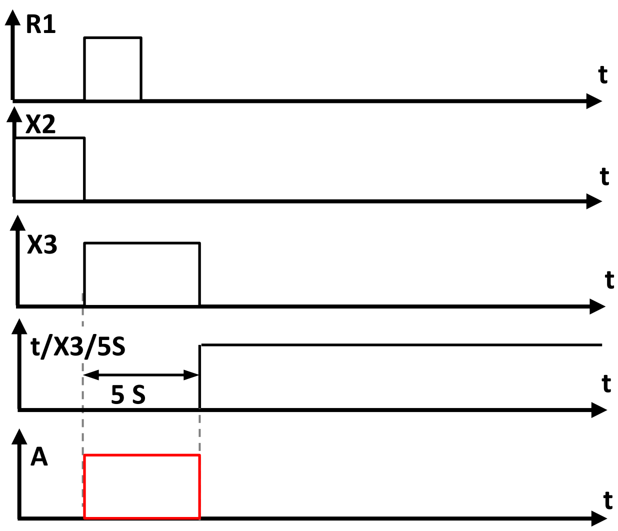


Action A = X3 . t/X3/5S

6.4 Delayed Continuous Action

This is a conditional continuous action where the command remains continuous for a certain period starting from the activation of the step it is associated with.



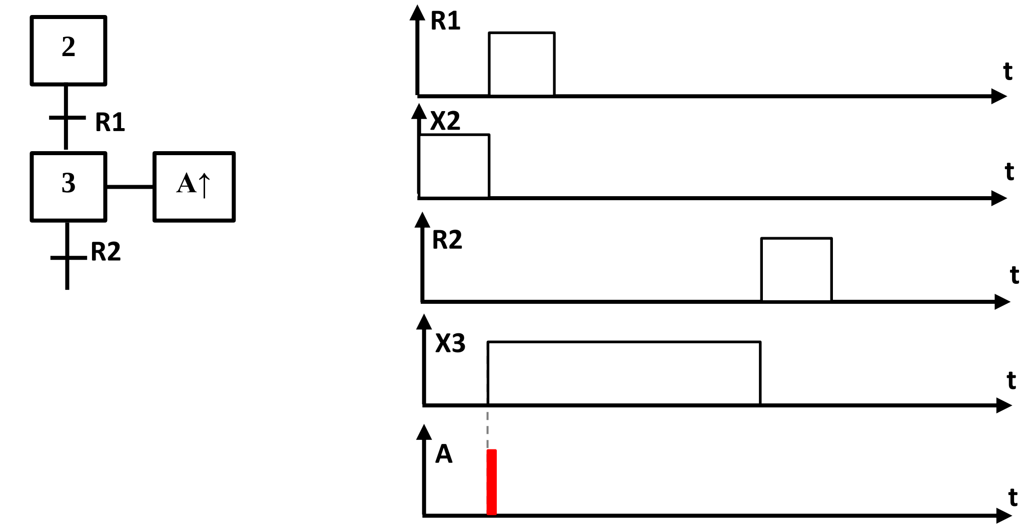


Action A = X3

6.5 Unconditional Pulse Action

The action command is brief and is triggered on the rising edge of the activation of the step it is associated with.

Action **A** is executed for a very short time as soon as $\mathbf{X_3 = 1}$. This type of action is commonly used to increment or decrement a counter.



6.6 Conditional Pulse Action

This is a pulse action whose command depends on a logical condition.

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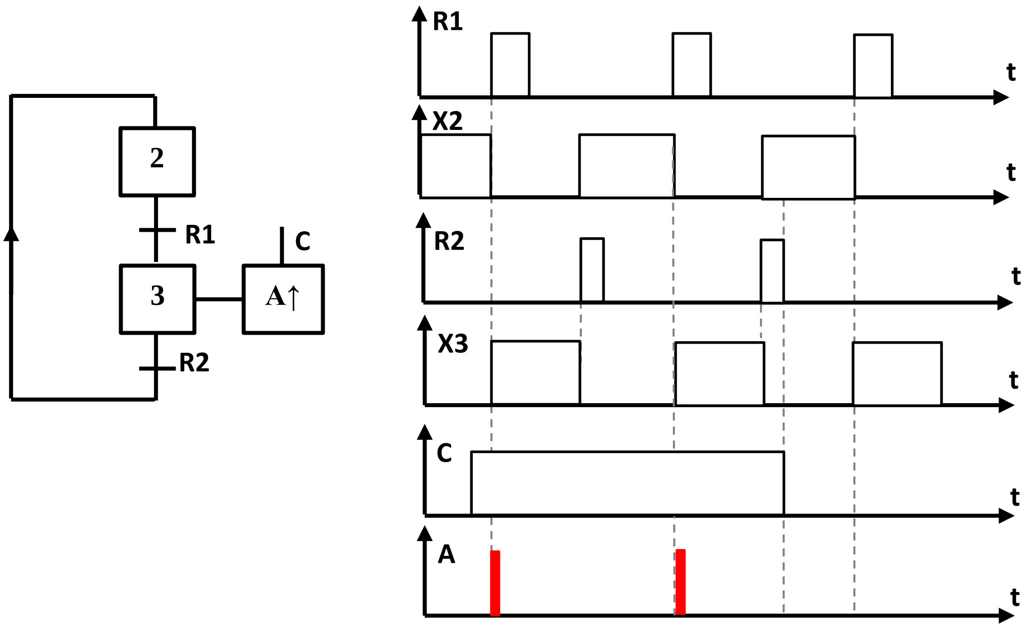
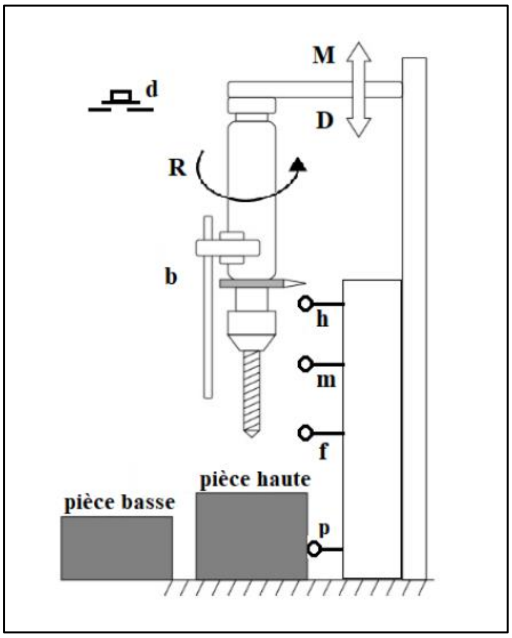


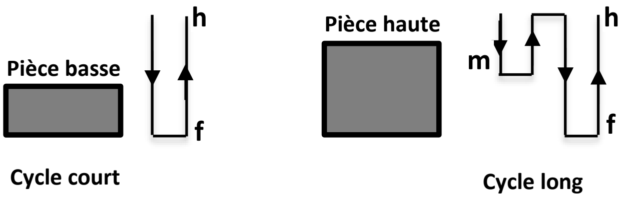
7 Exercises :

Exercise 1:

A drill performs a drilling cycle controlled by the input variables **d**, **h**, **m**, **f**, **b**, and **p**.



d: Cycle start push button
h: Upper limit switch contact
m: Midpoint switch contact
f: End-of-course switch contact
b: Piece height contact
p: Piece presence contact
M: Ascending motor
D: Descending motor
R: Rotation motor



M, D, and R:

- **1** → Motor running
- **0** → Motor stopped

When the drill is at mid-course (**m = 1**):

- **If the piece is low → b = 0**
- **If the piece is high → b = 1**

The cycle begins when the push button **d** is pressed. The drill must be in the upper position, and a piece must be present. The pieces to be drilled can be of two types: **high piece** or **low piece**.
The description of the two cycles, short and long, is shown in the figure above. Before starting a new cycle, the drilled piece must be removed and replaced.

- **Describe the operation of the automation system using a Grafcet.**

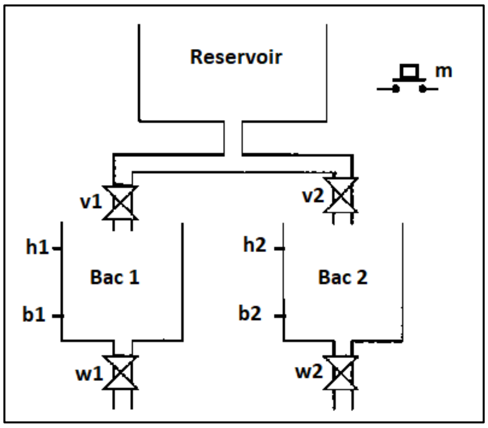
Exercise 2:

The system shown in the figure above consists of two tanks that are used similarly.

- **If the level is below b_1 → b_1 = 0**
- **If the level is above b_1 → b_1 = 1**

When the push button **m** is pressed, both tanks are filled by opening valves **V1** and **V2**. As soon as one tank is full, for example, **tank 1**, its filling is stopped, and its content is used. Once **tank 1** is empty, the valve is closed.

Filling can only begin when both tanks are empty. Filling is triggered by pressing the push button **m**.



$$v_i = \begin{cases} 1 & \text{valve open} \\ 0 & \text{valve closed} \end{cases}$$

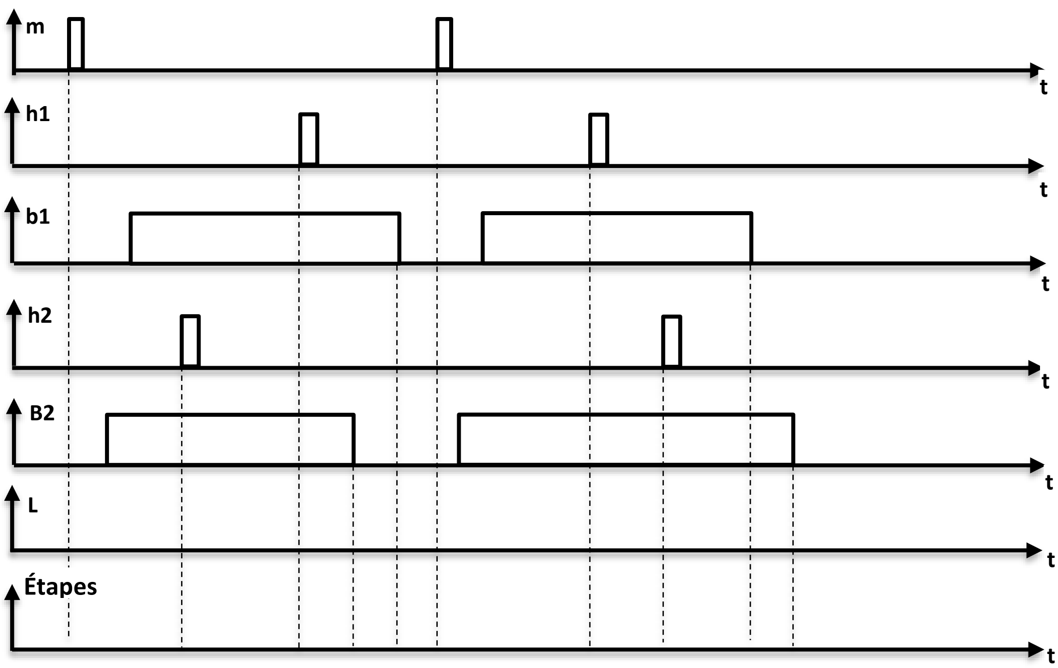
$$w_i = \begin{cases} 1 & \text{valve open} \\ 0 & \text{valve closed} \end{cases}$$

Describe the operation of this control system using a Grafcet.

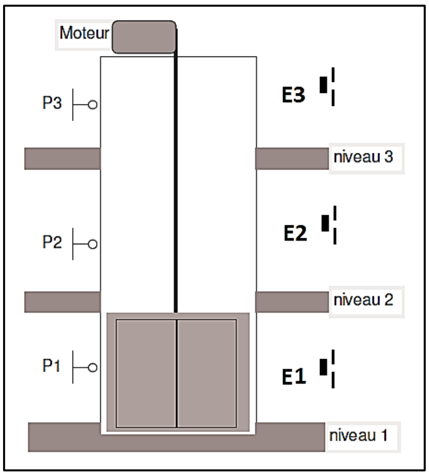
Exercise 3:

We consider the system from the previous exercise, with the addition of a lamp **'L'**, which lights up if **tank 2 is empty** and **tank 1 is not yet empty**.

- Describe the system using a Grafcet.
- For the timing diagram provided in the figure below, indicate the sequence of stable states and the timing diagram for the variable **'L'**.



Exercise 4:



A lift is programmed to regularly serve the three levels of a building. The lift is called using the buttons **E1**, **E2**, and **E3**. When the lift is called, the system commands the closing of the doors, followed by the movement of the lift to the requested level. Once it arrives, the doors open.
Initially, the lift doors are open.

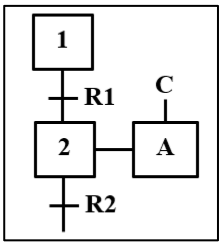
- **MO**: Lift ascent
- **DE**: Lift descent
- **OU**: Door opening
- **FE**: Door closing
- **E1, E2, E3**: Lift call buttons
- **a**: Door open sensor
- **b**: Door closed sensor
- **P1, P2, P3**: Position sensors for the lift (level 1, level 2, level 3)

Remarks: The doors open when the lift reaches the desired floor. It is assumed that the three call buttons are never pressed simultaneously.

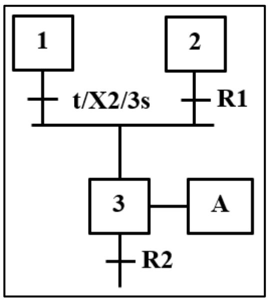
Provide the Grafcet for the process.

Exercise 5:

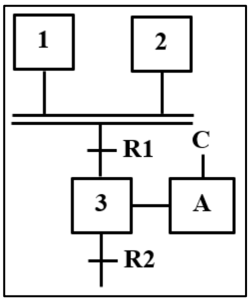
Draw the timing diagrams for the missing signals for the three Grafcets (1), (2), and (3).



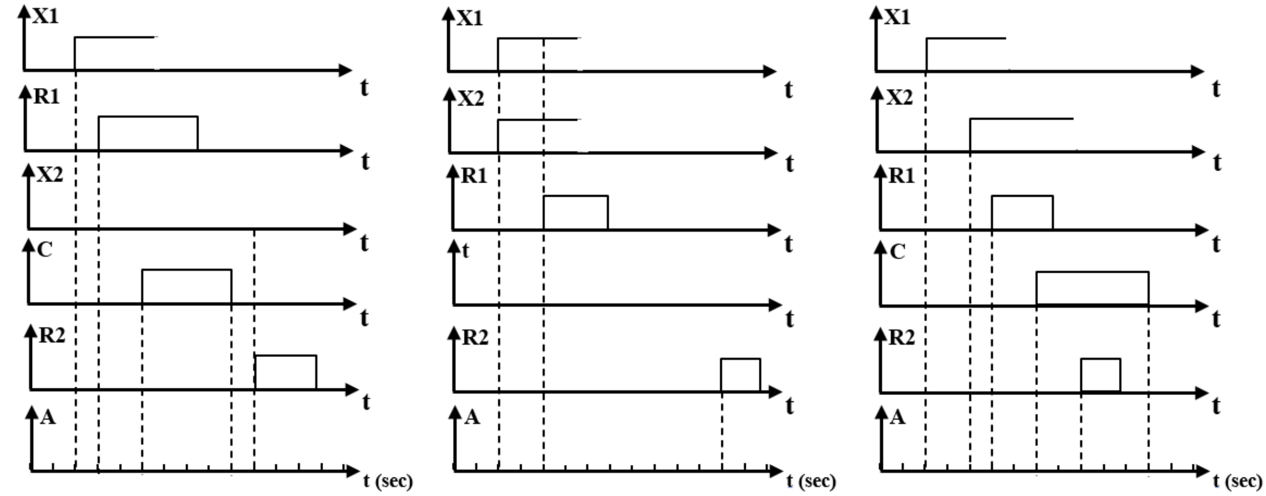
(1)



(2)



(3)



(1) (2) (3)

Exercise 6:

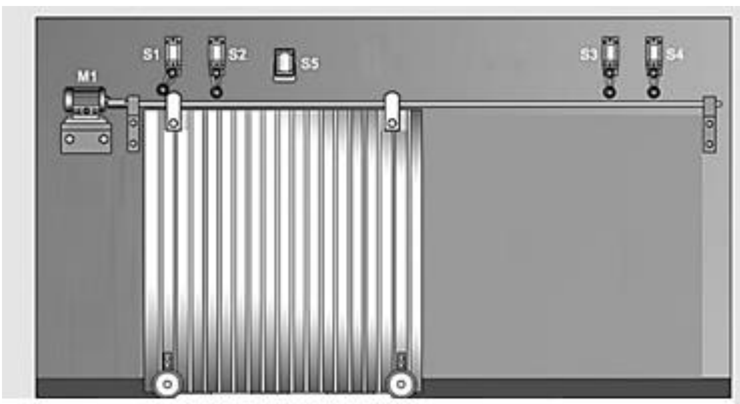
A sliding door moves along a rail via motor **M1**, which allows the door to move right and left at both low and high speeds.

- If a person is detected by the presence sensor **S5**, the door first opens at **high speed (GVD)** from **S1** to **S3**, then at **low speed (PVD)** from **S3** to **S4**.
- At the end of the opening, the door remains open for 15 seconds.

After the 15-second period:

- If no one is detected again, the door closes first at **high speed (GVG)** from **S4** to **S2**, then at **low speed (PVG)** from **S2** to **S1**.
- If a new person is detected, the door remains open for another 15 seconds.
- Initially, the door is closed.

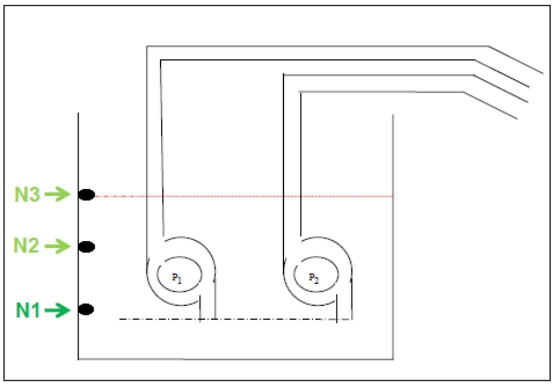
Describe the system using a Grafcet.



Exercise 7:

A sump is used to collect rainwater, which gradually infiltrates into the ground around the cavity of the sump. To prevent water overflow in the event of excessive inflow, two pumps, **P1** and **P2**, and a water level detector have been installed as shown in Figure 1. The desired operation is as follows:

- If the water level **N** is below **N1** (all three contacts **N1**, **N2**, and **N3** are released), neither pump operates.
- Suppose the level **N** rises. When **N** reaches **N2**, pump **P1** starts.
- If the level drops, **P1** stops when **N** reaches **N1**.
- If the level continues to rise, **P2** starts when **N** reaches **N3**.
- When both pumps are operating and the level **N** drops to **N2**, **P2** stops, but **P1** continues to operate.



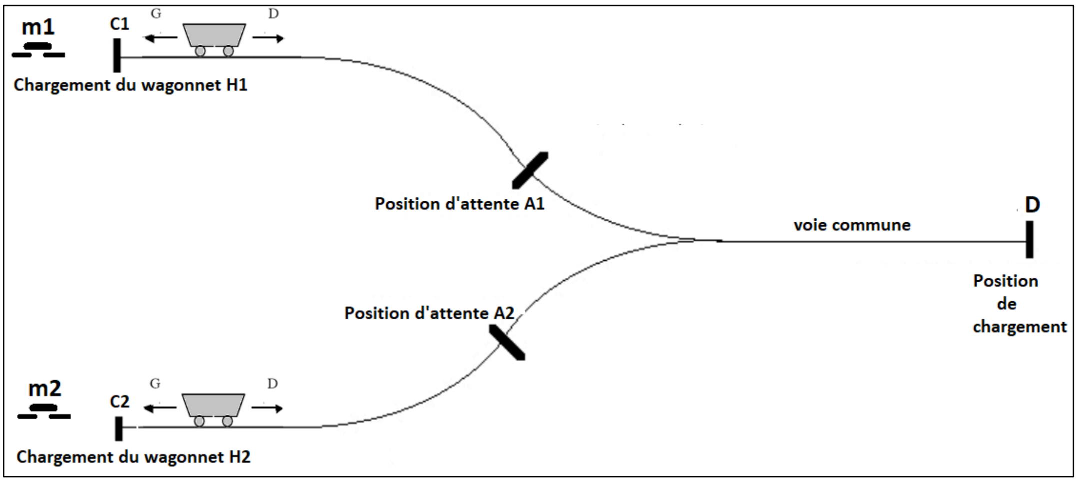
Describe the system using a Grafcet.

Exercise 8:

Describe the operation of the sump system from the previous exercise using a Grafcet, ensuring the pumps alternate operation.

Exercise 9:

Two wagons, **H1** and **H2**, transport materials from loading points **C1** and **C2**, respectively, to point **D**.



C1, C2, and D =

- **1**: Wagon present
- **0**: Otherwise

If wagon **H1** is at **C1** and the push button **m1** is pressed, a cycle **C1 → D → C1** begins.

- Wait at **A1** until the common area shared by the two wagons is free.
- Mandatory waiting at **D** for a duration of 100 seconds. Wagon **H2** operates identically.

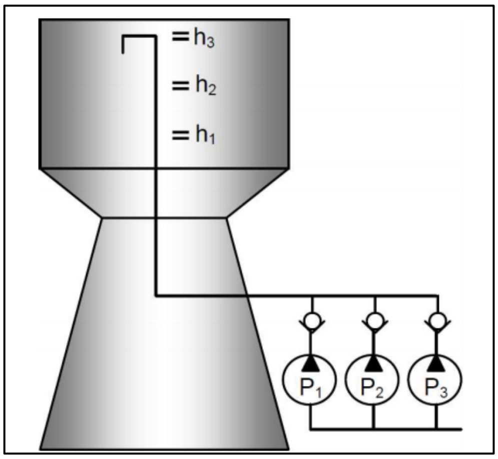
Describe the control system using a Grafcet.

Exercise 10:

A water tower is supplied by three pumps **P1**, **P2**, and **P3**, depending on the state of three level detectors **h1**, **h2**, and **h3**.

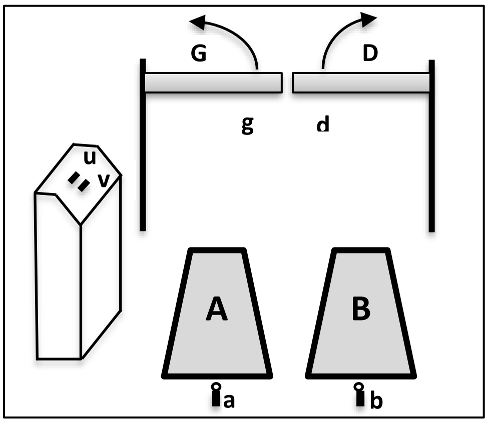
- A level detector is in state **1** if it is submerged.
- A switch **m** enables the operation of the system.
- Pump **Pi** operates if the switch **m** is activated and the level detector **hi** is not submerged.

Develop two Grafcets for the system: The first using conditional actions.



Exercise 11:

On considère le système de commande d'une barrière automatique de parking payant. La barrière est composée de deux parties la barrière G peut s'ouvrir seulement et laisser passer les motos.



a = 1: Vehicle on plate A
b = 1: Vehicle on plate B
u = 1: Insertion of a 50DA coin
v = 1: Insertion of a 100DA coin
g = 1: Left barrier closed
d = 1: Right barrier closed
G = 1: Left barrier open (and remains open)
D = 1: Right barrier open (and remains open)

The two barriers can open together to allow a car to pass. On the ground, two plates detect the presence of vehicles. The system's inputs and outputs are represented in the figure above. On the left side, there is a toll station with two slots for 50 DA and 100 DA coins.

- To open the left barrier, there must only be a motorcycle on plate **A**, and a 50 DA coin must be inserted. The barrier closes when there is no longer a vehicle on plate **A**.
- To open both barriers, there must be a vehicle detected on both plates **A** and **B**, and either a 100 DA coin or two 50 DA coins must be inserted. The barriers close when there are no vehicles on plates **A** and **B**. It is assumed that a car that first presses plate **A** must also press plate **B** within a delay not exceeding one second.
- Initially, both barriers are closed.

Describe the operation of this control system using a Grafcet.

Exercise 12:

This is a system used in beverage production plants and describes part of the process ensuring the filling and capping of bottles. The system consists of:

- A conveyor belt for moving the bottles.
- A filling station **P1**, controlled by the solenoid valve **EV**.
- A capping station **P2**, controlled by a double-acting press cylinder **V1**.
- The bottling line is initiated by activating the switch **DCY**.
- The motor **M** advances the conveyor by one step until the "conveyor in position" sensor (**FCTP**) is triggered. A bottle is then present at each station:
  - **P1** (detected by the empty bottle sensor **PBV**)
  - **P2** (detected by the full bottle sensor **PBP**)
- **Vh** and **Vb** are sensors for the upper and lower positions, respectively.
- The filling and capping operations are performed simultaneously for the two bottles.

Capping is performed in two steps:

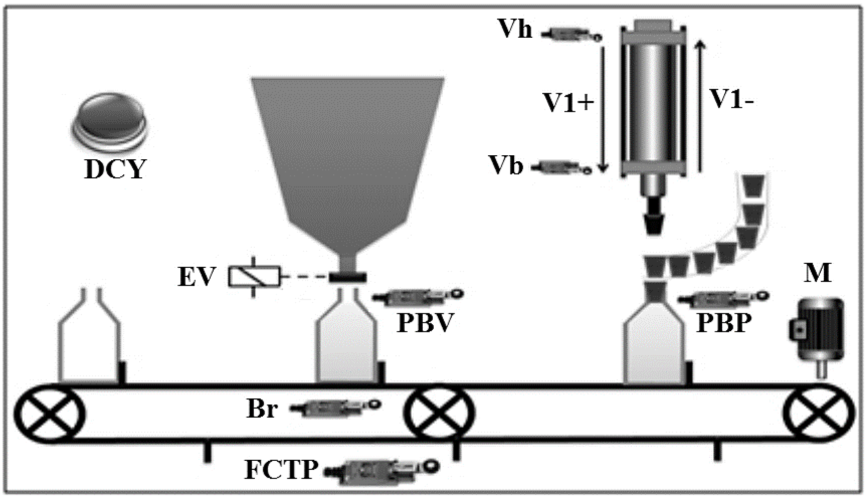
1. Lowering the press cylinder **V1**.
2. Raising **V1** after the cap has been pressed.

Filling is performed in two steps:

1. Opening the solenoid valve **EV**.
2. Closing **EV** after the bottle is filled, with the filled bottle sensor (**BR**) controlling the fill level.

- Initially, the press cylinder **V1** is in the upper position.
- The system operates continuously.

Describe the operation of this control system using a Grafcet.



Exercise 13:

Parts arrive in a line through a chute and must be placed on a conveyor belt (**TR**). The system is equipped with two double-acting cylinders:

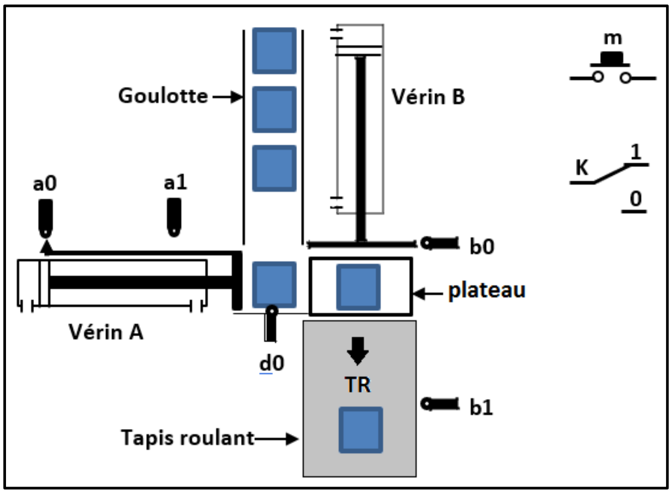
- Cylinder **A** is used to load the part onto the platform.
- Cylinder **B** is used to place the part on the conveyor belt.

The action **A+** controls the rod of cylinder **A** to extend outward, and the action **A-** controls the rod of cylinder **A** to retract inward.

The action **B+** controls the rod of cylinder **B** to extend outward, and the action **B-** controls the rod of cylinder **B** to retract inward.

The action **TR** controls the conveyor belt.

- The push button m allows the cycle to start.
- The sensor d0 detects the arrival of a new piece.
- a0, a1, b0, and b1 are binary sensors used to detect the positions of the cylinders.
- K: Mode selector:
  If K = 1, the system operates cycle by cycle.
  If K = 0, the system operates continuously (no need to press the m button to start a new cycle).



System Operation

Pressing the push button **m** starts the operation cycle. Once a piece is detected by sensor **d0**, the rod of cylinder **A** moves to place the piece on the platform and then returns to its initial position. Next, the rod of cylinder **B** moves towards the outlet to place the piece on the conveyor belt.

Once the piece is in position (**b1**), the system simultaneously commands the return of cylinder **B** and starts the conveyor belt **TR** for a duration **T** of 4 seconds. When cylinder **B** returns to position **b0** and the duration **T** has elapsed, the cycle restarts.

The cycle can only begin if cylinder **A** is in position **a0** and cylinder **B** is in position **b0**.

1. Determine the inputs and outputs of the system.
2. Describe the operation of the control system using a Grafcet to ensure mixed operation modes: cycle-by-cycle and continuous.