



## Design of an Automatic Filling Unit for LPG Cylinders with Valve

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### Article information

#### Article history:

Received: November, 08, 2025

Accepted: February, 14, 2026

Available online: June, 14, 2026

#### Keywords:

Conveyor,  
Carousel,  
Filling line,  
UNITY PRO XL,  
Lucidchart

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#### DOI:

<https://doi.org/10.53523/ijoirVol13I1ID620>

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### Abstract

This paper addresses the chronic underperformance of a manual liquefied petroleum gas (LPG) cylinder filling line at an industrial plant (Plant X). We present the complete design of a novel, fully automatic filling system specifically engineered for LPG cylinders equipped with a tap-type safety valve, a prevalent standard in the regional market for which existing automation solutions are inadequate. Our methodological contribution is a structured engineering approach that begins with a root-cause analysis using functional analysis tools (Ishikawa, Octopus, and FAST diagrams) to diagnose systemic failures. This analysis directly informs the technical design phase, where we provide detailed sizing calculations for the core subsystems: a double-drive chain conveyor (capacity: 7500 m<sup>3</sup>/h) and a 12-station rotating carousel framework (throughput:  $\geq 500$  cylinders/hour). The system's automation logic, formalized using GRAFCETs and implemented for a Schneider M340 PLC, ensures sequential control for filling, weight verification, leak testing, and sealing without manual intervention. The proposed design offers a fivefold increase in hourly production rate (from ~300 to 500-1500 cylinders/hour) and reduces the required operators from sixteen to five. Projected performance indicates the system would enable the plant to meet its daily target of 5,000 cylinders, generating a return on investment within 2 years and 7 months.

## 1. Introduction

In a liquefied petroleum gas (LPG) cylinder filling plant, cylinder handling is a vital process for ensuring quality and compliance with cylinder filling standards [1-3]. Receiving its gas from the national LPG distribution company, plant X has a filling and handling center for LPG cylinders of different sizes (6 kg, 12.5 kg and 35 kg). The center uses two LPG filling systems, one mechanical and one electromechanical. The introduction of automatic systems in the LPG filling field has enabled us to improve product quality by optimizing production, with a lower production cost [4-6]. Setting up an automatic or semi-automatic system is not enough to increase product quality or the production index. Several factors need to be considered to achieve this result. Adapting the system to bottle types and ease of handling are among the parameters to be assessed when setting up a filling system in a filling center, and these vary according to the requirements and objectives of the company owning the filling center [7-9].

Cameroonian legislation on LPG packaging recommends the use of LPG cylinders, especially in 12.5 kg format, with a safety valve [10]. The electromechanical system in place at plant X is semi-automatic. One part is fully automatic for valve cylinders. The other part, filling cylinders with taps, still requires the intervention of an operator [11-13]. The installation of the electromechanical system at plant X was intended to compensate for the poor performance of the pre-existing mechanical system on site, and to increase the production curve in order to meet the company's target of producing up to 5,000 12.5 kg bottles per day [14-16]. The first was faced with the problem of the format of the 12.5 kg cylinders, whose safety is provided by a tap, due to the automatic part designed for cylinders with a valve on one side, and the problem of compulsory intervention by operators, resulting in handling errors and repetitive stoppages in production. With a view to satisfying customer demand while complying with LPG packaging standards, the production department approached us with the desire to find a solution adapted to valve cylinders, as the company wished to comply with standards by producing only valve cylinders for all cylinder formats. The aim was to replace the mechanical system with a new gas filling line, while addressing the concern for cylinder safety. So this paper chose to work on the design of an automatic filling system for tap-type LPG cylinders.

The main objective of this paper is to set up a filling line that will improve productivity at plant X. This main objective is associated with the following specific objectives: to make LPG cylinder production more dynamic; to guarantee automatic filling of cylinders with taps; and to improve working conditions at plant X. The Ishikawa diagram is the external analysis tool which, together with the octopus diagram and the horned beast diagram as internal functional analysis tools, enabled us to determine the causes of the underperformance of the plant X filling center in relation to the objectives set by the company. Sizing the units of the new filling line is an important step in implementing the project to solve the problem [12]. To achieve this, the paper presents the methods and materials used to develop solutions to the problems identified. The work also presents the parts and automatic machines needed to set up the new production line, and the formulas for sizing the parts required for the project. Finally, the paper presents the sizing results and an estimate for the implementation of the proposed solution.

## 2. Material, Methods and Results

In order to better understand the problem and evaluate the proposal made in this paper, external analysis methods such as the Ishikawa diagram and internal functional analysis methods such as the octopus and horned beast diagrams are used. These methods are accompanied by grafquets, as they enable verification of a system's automatism. Sizing is used to determine the operating parameters and characteristics of the components in the filling line.

### 2.1. Results of Evaluations (Internal, External and Functional) and Analysis of Production Statistics

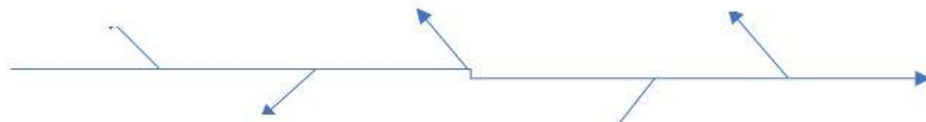
By analyzing the sectors involved in production, we can identify possible causes that could affect carousel performance, as shown in Figure (1).

**Method**

Incorrect filling  
Incorrect scale settings  
Wrong clamp connection

**Matter**  
Momentary absence of butane

**Environment**  
Insufficient space  
Power failure



**Material**

Compressor failure  
Dispenser failure  
Incorrect needle movement  
Incorrect display of values  
Hose leaks  
Conveyor failure  
Cylinder failure  
Centralization arm failure  
Housing malformation

**Workforce**

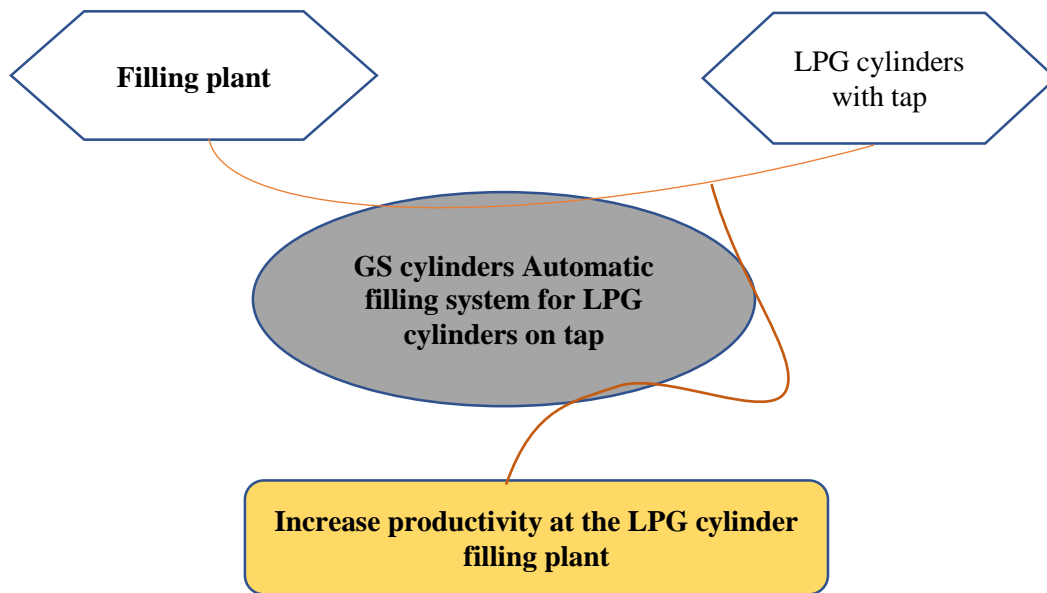
Repeated absences of operators  
Insufficient personnel  
Lack of commitment  
Abandonment of jobs and tasks

**Effects**

Production slowdown  
Poor plant performance

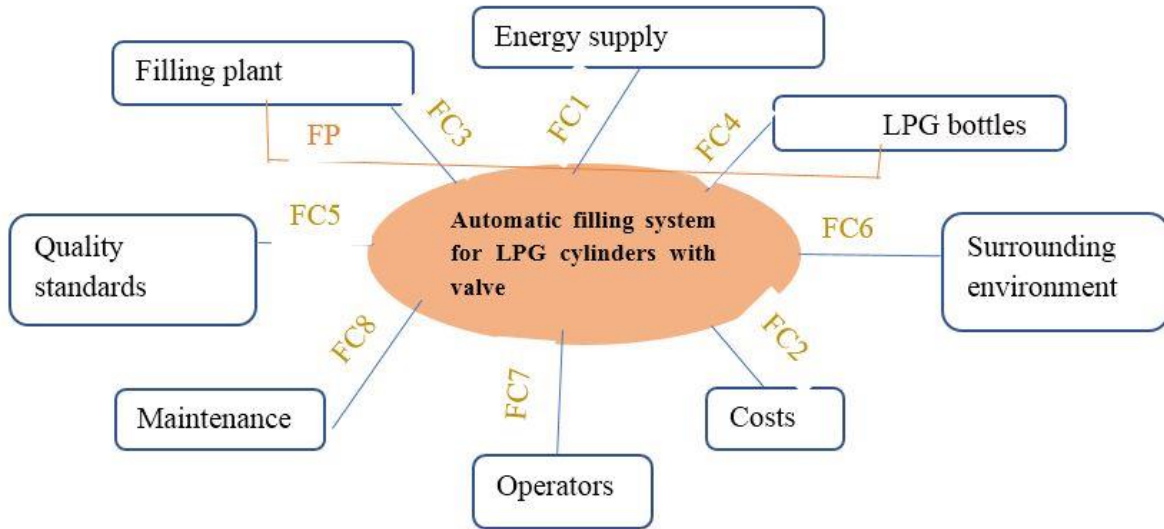
**Figure (1):** Ishikawa diagram results from the evaluation of the mechanical filling system.

Figure (1) shows the possible causes of the slowdown in the rate of gas cylinder filling at plant X. This only makes it possible to identify the factors that are causing problems for production, and to determine which are the most recurrent or the most dangerous for the filling of LPG cylinders. The results of the horned beast diagram are shown in Figure (2).



**Figure (1):** Results of the horn-and-beast diagram of the internal analysis of the new filling line.

Figure (2) shows the benefits of the new automatic filling line, which would be an important element in Plant X's ability to fill LPG cylinders on tap at improved output rates, thus boosting plant productivity. Consideration of the conditions in the filling hall reveals a correlation between the constraints to be considered when installing the new automatic filling system to replace the manual system, as shown in Figure (3).



**Figure (3):** Result of the Octopus diagram for functional analysis of the new LPG cylinder filling line.

Setting up a system in an environment always requires a functional analysis to compare the capabilities of the instruments with the realities of the environment in which they are to be installed. This analysis gives the results shown in Table (1), with the level of flexibility of each function.

**Table (1):** Constrained functions.

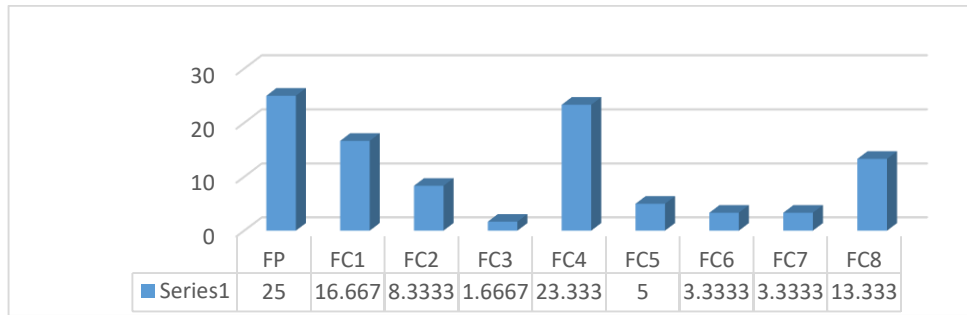
Functions	Criteria	Levels	Flexibilities
<b>FP</b>	Number of bottles per day	5,000 per day	F1
<b>FC1</b>	Type of feed	Low voltage	F0
<b>FC2</b>	Total cost	High	F1
<b>FC3</b>	Filling speed	Less than 1 minute	F2
<b>FC4</b>	Bottle compatibility	Good	F0
<b>FC5</b>	Respect of tares	Test	F2
<b>FC6</b>	Weather resistance	Good	F0
<b>FC7</b>	Ease of handling	Good	F1
<b>FC8</b>	Maintenance access	Good	F1

During an internal functional analysis, it is necessary to determine the major constraints in order to overcome problems of compatibility between the system and its environment, as shown in Table (2).

**Table (2):** Hierarchical ranking of constrained functions.

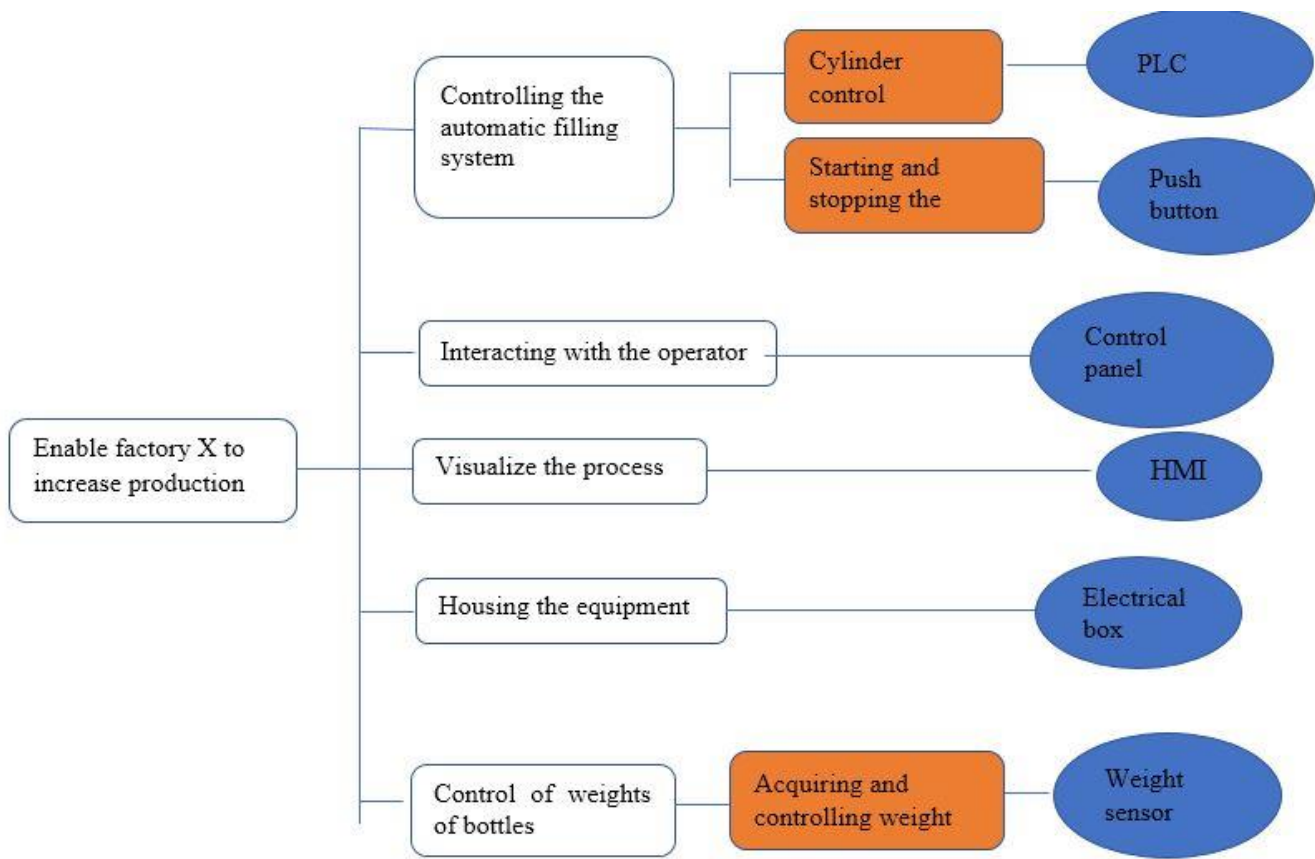
	<b>FP</b>	<b>FC1</b>	<b>FC2</b>	<b>FC3</b>	<b>FC4</b>	<b>FC5</b>	<b>FC6</b>	<b>FC7</b>	<b>FC8</b>	<b>WEIGHT</b>	<b>%</b>
<b>FP</b>	FP/0	FP/1	FP/2	FP/3	FP/1	FP/2	FP/3	FP/2	FP/1	15	25
<b>FC1</b>		FC1/0	FC1/2	FC1/1	FC4/1	FC1/2	FC1/2	FC1/2	FC1/1	10	16.67
<b>FC2</b>			FC2/0	FC2/1	FC4/1	FC2/1	FC2/2	FC2/1	FC8/1	5	8.33
<b>FC3</b>				FC3/0	FC4/2	FC3/1	FC6/2	FC7/1	FC8/2	1	1.67
<b>FC4</b>					FC4/0	FC4/3	FC4/3	FC4/2	FC4/1	14	23.33
<b>FC5</b>						FC5/0	FC5/2	FC5/1	FC8/2	3	5.1
<b>FC6</b>							FC6/0	FC7/1	FC8/2	2	3.33
<b>FC7</b>								FC7/0	FC8/1	2	3.33
<b>FC8</b>									FC8/0	8	13.33
										60	100

Based on the comparison of the constrained functions, it is estimated that the compatibility of the existing system is the major challenge to be met in order to solve the production problem of the filling plant. Figure (4) shows the level of importance of these functions.



**Figure (2):** Graphical representation of function hierarchies.

Through these methods, internal functional analysis enables a systemic approach to the search for technological solutions. These solutions enable the realization of service functions and, consequently, the satisfaction of needs. For this paper, we chose the FAST diagram method. The FAST diagram provides a rigorous translation of each of the service functions into a technical function, and then materially into constructive solutions. It is constructed from left to right, in a logic from why to how, as shown in Figure (5).



**Figure (5):** Automated FAST diagram of the proposed filling line.

From Figure (5), we can see that two major factors are responsible for the filling plant's underperformance in relation to the company's objectives. These are: The incessant and continuous intervention of the operators and the repetitive breakdowns of the mechanical filling line due to its ageing.

Plant X's daily target is to produce 800 6 kg bottles, 5,000 12.5 kg bottles and 60 35 kg bottles after 16 hours' production. As shown in Table (3), these targets were not met.

**Table (3):** Production reports from plant X.

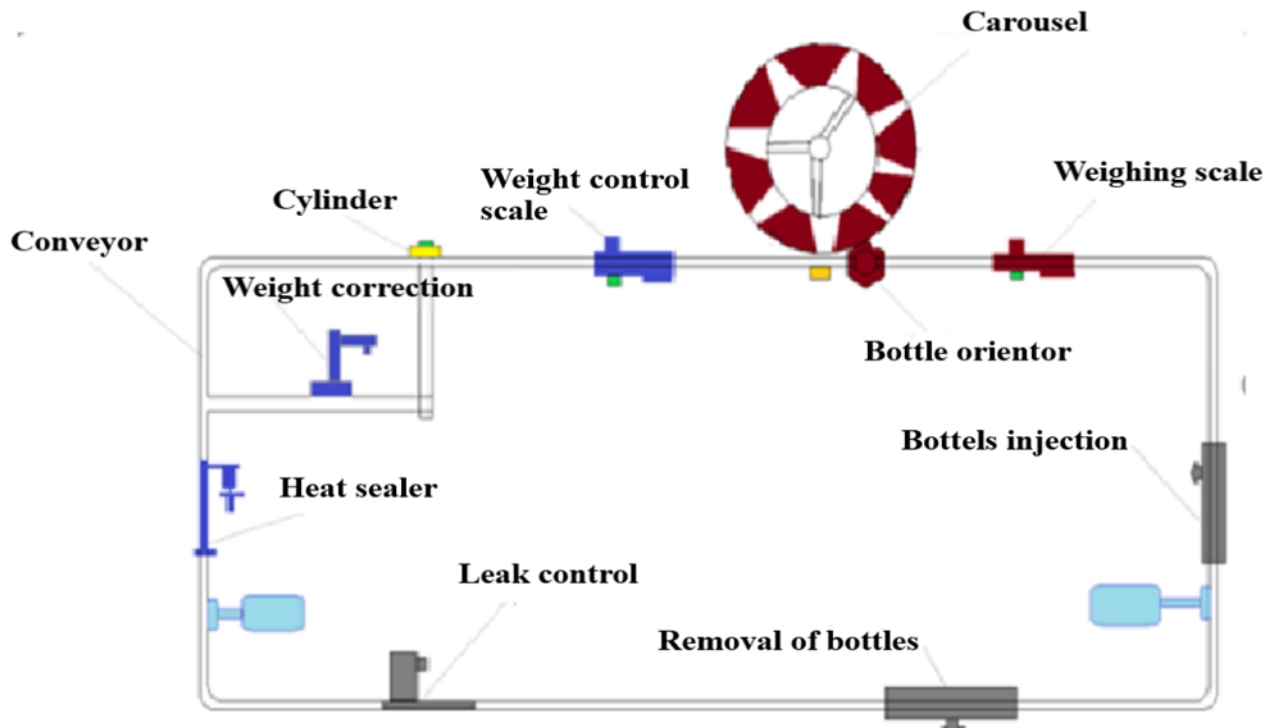
JOURS	TIME	PRODUCTION			TARGET			TOTALS			DIFFERENCE		
		6 kg	12,5 kg	35 kg	6kg	12.5kg	35kg	6kg	12.5kg	35kg	6kg	12.5kg	35kg
Feb. 01	6 a.m-2 p.m	0	0	0	800	5000	60	0	1934	0	-800	-3066	-60
	2p.m-10p.m	0	1934	0									
Feb. 02	6 a.m-2 p.m	0	903	0	800	5000	60	588	2651	0	-212	-2349	-60
	2p.m-10p.m	588	1748	0									
Feb. 05	6 a.m-2 p.m	0	2103	29	800	5000	60	0	3977	29	-800	-1023	-31
	2p.m-10p.m	0	1874	0									
Feb. 06	6 a.m-2 p.m	0	1872	32	800	5000	60	873	3627	32	73	-1373	-28
	2p.m-10p.m	873	1755	0									
Feb. 07	6 a.m-2 p.m	0	1735	0	800	5000	60	835	2413	0	35	-2587	-60
	2p.m-10p.m	835	678	0									

Feb. 08	6 a.m-2 p.m	0	1062	14	800	5000	60	0	3485	14	-800	-1515	-46
	2p.m-10p.m	0	2423	0									
Feb. 09	6 a.m-2 p.m	385	455	44	800	5000	60	385	2177	44	-415	-2823	-16
	2p.m-10p.m	0	1722	0									
Feb. 12	6 a.m-2 p.m	0	2388	0	800	5000	60	0	2388	0	-800	-2612	-60
	2p.m-10p.m												
Feb. 13	6 a.m-2 p.m	0	840	0	800	5000	60	970	957	0	170	-4043	-60
	2p.m-10p.m	970	117	0									
Feb. 14	6 a.m-2 p.m	0	2381	0	800	5000	60	0	4818	0	-800	-182	-60
	2p.m-10p.m	0	2437	0									
Feb. 15	6 a.m-2 p.m	251	1000	25	800	5000	60	251	3423	25	-549	-1577	-35
	2p.m-10p.m	0	2423	0									
Feb. 16	6 a.m-2 p.m	135	727	0	800	5000	60	767	2922	0	-33	-2078	-60
	2p.m-10p.m	632	2195	0									
Feb. 19	6 a.m-2 p.m	0	2016	25	800	5000	60	0	4054	25	-800	-946	-35
	2p.m-10p.m	0	2038	0									
Feb. 20	6 a.m-2 p.m	0	1026	0	800	5000	60	496	3226	0	-304	-1774	-60
	2p.m-10p.m	496	2200	0									
Feb. 21	6 a.m-2 p.m	0	2122	30	800	5000	60	607	3870	30	-193	-1130	-30
	2p.m-10p.m	607	1748	0									
Feb. 22	6 a.m-2 p.m	0	1898	5	800	5000	60	171	4272	5	-629	-728	-55
	2p.m-10p.m	171	2374	0									
Feb. 23	6 a.m-2 p.m	0	899	4	800	5000	60	0	1649	4	-800	-3351	-56
	2p.m-10p.m	0	750	0									
Feb. 26	6 a.m-2 p.m	0	1800	20	800	5000	60	568	3858	20	-232	-1142	-40
	2p.m-10p.m	568	2058	0									

Table (3) is a monthly production report from plant X. Repetitive breakdowns on the mechanical filling line are at the root of the deviations shown in the green columns. Let's consider only the case of production of 12.5 kg LPG cylinders, for which the daily target in the blue column is 5,000 cylinders per day. The orange column represents the quantity of cylinders produced daily by category, and we note that plant X is barely able to produce 4,000 12.5 kg cylinders, even though this is the format most sold by plant X. The loading price for 12.5 kg bottles is 6500 CFA. There was a loss of 214,077,500 CFA in the month of February.

## 2.2. Sizing Results and Presentation of the Proposed System

The proposed system has similar technical specifications to those of the semi-automatic system already in place on the filling site. In order to adapt the filling system to the realities of the filling center, the aim is to set up a system with operations that can be carried out in the space of the filling hall, while complying as far as possible with the quality and safety standards, as well as the ergonomic standards of an LPG filling center. As shown in Figure (6), the new filling line will comprise the following stations: Double-drive conveyor, vacuum weighing scale, bottle orientor, carousels with digital scales (12 scales), weight control scale, weight correction, leakage control, thermobonding and conveyor exit.



**Figure (3):** Proposed filling chain.

The system proposed in Figure (6) comprises the following main components: Bottle gripping and positioning system; filling and control system; control panels and displays; framework; weight correction machine; leak testing machine and heat-sealing machine.

### 2.2.1. Bottle Gripping and Positioning System

The cylinder gripping and positioning system contains various stations for filling LPG cylinders, including: A conveyor, an empty bottle weighing scale, a weight control scale, cylinders, bottle orienters and bottle presence and position detection sensors. The data in Tables (4 & 5) were used to calculate the dimensions of the conveyor parameters.

**Table (1):** Values measured on site and empirical data on conveyor.

Data	Values
Conveyor length (L)	30 m
Conveyor width (l)	7 m
Bottle diameter (d)	0.3 m
Chain thickness (e)	0.442 m
Chain pitch (y)	0.063 m

**Table (2):** Motor and drive unit parameters.

Parameters	Values
Motor power	200 kW
Reference	IEC60034
Power factor	80 %
Supply voltage	525V/3PH
Motor speed	1500 rpm
Torque	110- 100,000 Nm

Table (6) summarizes the results of the conveyor calculations based on the data in Tables (4 & 5).

**Table (3):** Conveyor design results.

Parameters	Values
Conveyor volume capacity	7500 m <sup>3</sup> /h
Filling rate	65 %
Total conveyor mass	653 kg
Total force to move loads	22 730 N
Friction resistance	2430 N
Conveyor speed	5.922 5.922 ms <sup>-1</sup>

The choice for the proposed filling chain is to use a chain conveyor due to its hardness and shock resistance. The characteristics of a chain conveyor are: Suitable for all bottle types; modular and flexible; lay-out as required and manual or fully automatic control of bottle circulation. The advantages of a chain conveyor are: Less load to be lifted by operators; long service life; minimum manpower requirements; high safety thanks to controlled bottle logistics; minimal wear and tear, low power consumption and low noise levels. The system is double-chained to ensure work continuity even when Ya stops on one side of our conveyor. The conveyor system has two drive units, one upstream and one downstream, to designate respectively the pre- and post-filling of the bottles. The chains chosen for the system will be CC600 type.

The weighing system is integrated before filling, to avoid any operator intervention when tabulating or recording the bottle tare. Using a sensor, the bridge records the bottle's tare weight. The empty cylinder weight value is transmitted to the human-machine interface (HMI) modules on the scale, so that the operator knows how much gas to fill into the next cylinder to be loaded, according to the stored program. The system enables the cylinders to pass quickly onto the conveyor, saving the process from obvious tabulation errors. After filling, the checkweigher verifies the cylinder weights according to the information provided by the vacuum scale and the modules placed on the cylinder filling scales. Table (7) shows the actual values used to size the cylinder.

**Table (4):** Cylinder design results.

Parameters	Values
Stem stroke	500 mm
Mass to be moved	15 kg
Accelertaion due to gravity	10 N/kg
Mounting	Square
Working pressure	8 Bars

Based on Table (7), the parameters for selecting the cylinders are determined and presented in Table (8).

**Table (8):** Cylinder design results.

Aspect	Values
Cylinder displacement force	150 N
Friction force	75 N
Acceleration force	11,5 N
Cylinder diameter	10.2 mm

Pneumatic cylinders were chosen for two purposes: blocking and selection. Blocking cylinders are used to regulate the order in which bottles pass over the weight control scale, while selection cylinders are used to remove non-conforming bottles from the production line, either because they are overweight or underweight. The right choice of cylinder is essential to ensure system performance and reliability. This choice is dictated by a number of parameters, including: Form factor and ISO standard; type of pneumatic cylinder; bore strength and size; course length, damping, mounting option and speed [17].

A bottle orientator is proposed to place the LPG bottle valve in a favorable position for automatic engagement of the filling gripper. This bottle orientator will be placed at the carousel entrance to facilitate bottle positioning on the scale. Orientation is counter-clockwise. Bottle presence and position detection sensors are used to detect the presence of bottles on the vacuum and checkweighing scales, on the filling scales, on the bottle filling cylinder, on the blocking cylinders, at the leak testing station and at the sealing station. They are therefore very important for automatic task completion.

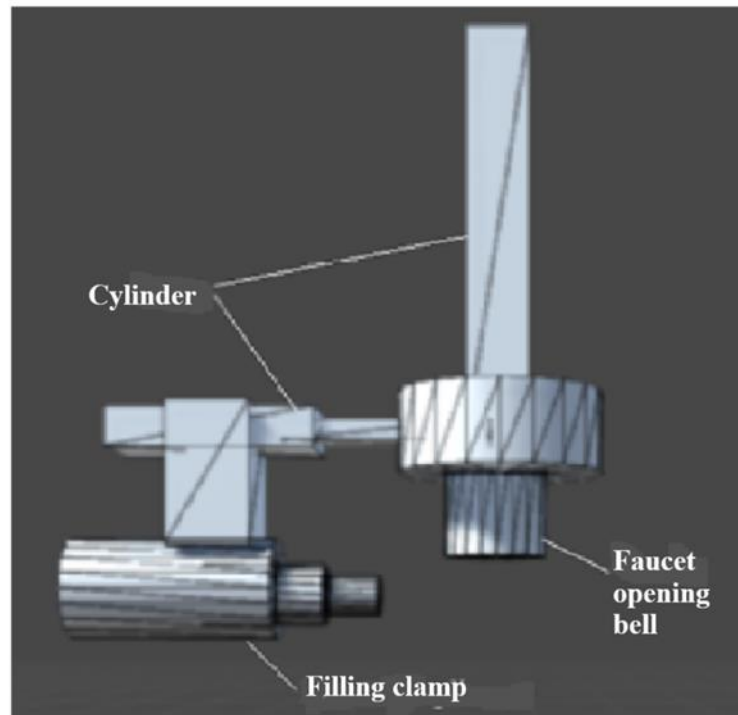
### 2.2.2. Filling and Inspection System

The filling and control system include specific equipment for bottle filling, including: Digital scales; automatic filling grippers; bottle opening and closing bells. A system of digital scales with automatic centering and opening of the bottles and automatic connection of the bottles is used to replace the mechanical system in place at the X plant. The characteristics of the scales are listed in Table (9).

**Table (9):** Characteristics of selected balances.

Aspect	Values
Format	12 to 18 kg
Scale accuracy	10 g
Max. loadable weight	18 kg
Scale weight	83 kg
Certified	ATEX

Once the bottle has been accepted on the scale, a sensor sends the signal to hook the bell to open the valve. The bell is carried by a pneumatic cylinder, which raises it to the top of the bottle's valve. At the same time, carried by the same cylinder, the filling gripper associated perpendicularly with the bell performs the same downward movement, but hooks the gas cylinder valve perpendicularly, without operator intervention. The system is fully pneumatic and electronic (automatic). At the end of bottle filling, the bell closes the bottle and, by a reverse movement, the filling clamp disconnects to allow the bottle to be ejected. The prototype connection system is shown in Figure (7).

**Figure (7):** Sketch of the proposed connection system.

To ensure transmission of the energy used to switch and control the circulation of pressurized fluids, 3/2 directional control valves are chosen for single-acting cylinders, and 5/2 directional control valves for double-acting cylinders. It is necessary to control pressure and temperature variations in a gas handling system. PCM160 series sensors are used for the proposed system. Being all-metal or stainless steel, this feature makes them even more resistant and compatible with most fluids. This sensor operates in the pressure range from 1 to 500 bar, and in the temperature range from -55°C to 175°C. The PCM160 range is available in 3 models, as shown in Table (10).

**Table (10):** Sensor parameters.

MODEL	SUPPLY VOLTAGE	OUTPUT SIGNAL	CONSUMPTION
PCM161	10 Vdc stabilized and filtered	mV/V	$\leq 10$ mA
PCM163	5 Vdc	0.5 - 4.5 Vdc with regulated power supply	$\leq 10$ mA
PCM167	8 to 16 Vdc	0.5-4.5 Vdc with regulated power supply	$\leq 10$ mA

### 2.2.3. Control Panels and Displays

Control panels and displays are necessary for the automation of the filling system. These instruments provide the commands for programming the system. The LDC filling parameter display provides real-time filling parameters for each gas cylinder, and outputs a digital report on a daily, weekly or monthly basis. This makes it possible to monitor filling rates and conditions, and make corrections if necessary. For this system we opted for a 12.1" diagonal LDC TFT a-Si panel. Table (11) shows some of the characteristics of the chosen screen.

**Table (11):** LDC display features [11].

Brand	BOE
model P/N	QV121WXB-N11
Resolution	1280 (RVB)*800, WXGA 124PPI
Refresh frequency	60 Hz
Supply voltage	3.3 V
Storage temperature	-30°C to 80°C
Operating temperature	-20°C to 70°C

Universal controllers are programmable logic controllers with intrinsic safety and HMI. They provide automatic control of systems in an LPG cylinder filling plant. Equipped with IP65 connectors, they are waterproof and resistant even in damp, dusty environments. They feature a 3.1" screen for close-up or remote monitoring of cylinder filling progress on filling scales [19].

Programmable Logic Controllers (PLCs) are devices for controlling industrial processes through sequential processing. They send control signals to the operating parts in response to data transmitted by sensors from set points or programs [20]. Despite the multitude of models and brands in the PLC sector, the SCHNEIDER range is essential for this system, including the CPU BMX P34 20302. The characteristics of the PLC chosen for this project are listed in Table (12).

**Table (12):** PLC properties.

Specifications	Values
RAM	4096 Kb
Speed	0.12/0.17/0.25/1.16
Ethernet port	10 BASE-T/ 100 BASE-TX

TOR I/O management	1024 1024 multi-rack; 704 single-rack
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Power supply modules require a power supply. The PLCs are supplied with power supply modules for the racks. The most suitable for our PLC is the BMX CPS 3500 module. The choice of this application module was influenced by its ease of installation and compact design, the type of power supply (electrical), its wide input voltage range and its long product life [18]. For an automatic system requiring recovery of huge amounts of information, a BMX DDI 6402K digital input module (64 channels), a BMX AMI 0801 analog input module (8 channels) and a BMX DDO 6402K digital output module (64 channels) are useful. All the modules are rack-mounted, and our choice is the Mondion X80 series for M340-6 bus X- IP20, reference BME XBP 0800.

#### 2.2.4. Results of Frame Sizing

The frame of the LPG filling carousels is circular, like a disc, and made of S235JR steel, the properties of which are shown in Table (13).

**Table (13):** Characteristics of selected steel.

Parameters	Values
Normal thickness	3 to 10 mm
Mechanical resistance	360 to 510 MPA
Elastic limit	235 MPA
Density	7800 kg/m <sup>3</sup>
Melting points	1370 to 1400 °C

From Table (13), a few framework parameters are found and presented in Table (14).

**Table (14):** Parameters during frame design.

Parameters	Values
Total mass of carousel	1257.3 kg
Rotation torque	3.45 N.m
Carousel angular speed	0.0384 m/s
Mechanical power of rotation	32.6 W
Inertia of rotating mass	4654.54 kg.m <sup>2</sup>

The properties of the selected carousel are shown in Table (15).

**Table (5):** Characteristics of selected balances.

Parameters	Values
Number of scales	12
Operating pressure	10-15 bar
Mass flow rates	0.3125 kg/s

Filling time	40 s maximum
Diameter	2,8 m

### 2.2.5. Weight Correction, Leak Testing and Thermobonding Machines

Being electronically controlled, the weight correction machine is an independent unit designed for in-line installation in a roller conveyor. Based on information transmitted by the universal controller and the weight sensors, the weight machine checks whether the fill level has been respected. If not, the bottle is directed to the weight correction station. The leak-testing machine chosen is a rotating platform for fixed installation on the floor, connected to a chain conveyor system via automatic infeed and outfeed units. This machine is equipped with numerous LPG cylinder leak test units all over the body [11]. The machine is fully automatic and each leak test is performed on the entire cylinder body using the unique CIR-T infrared test tube [19]. The heat-sealing machine is designed for safe and efficient shrinking of thermoplastic plugs or sleeves around LPG cylinder valves [19].

### 2.3. PLC Execution / Implementation

Table (16) shows the nomenclature of GRAFCET codes.

**Table (6):** GRAFCET nomenclatures.

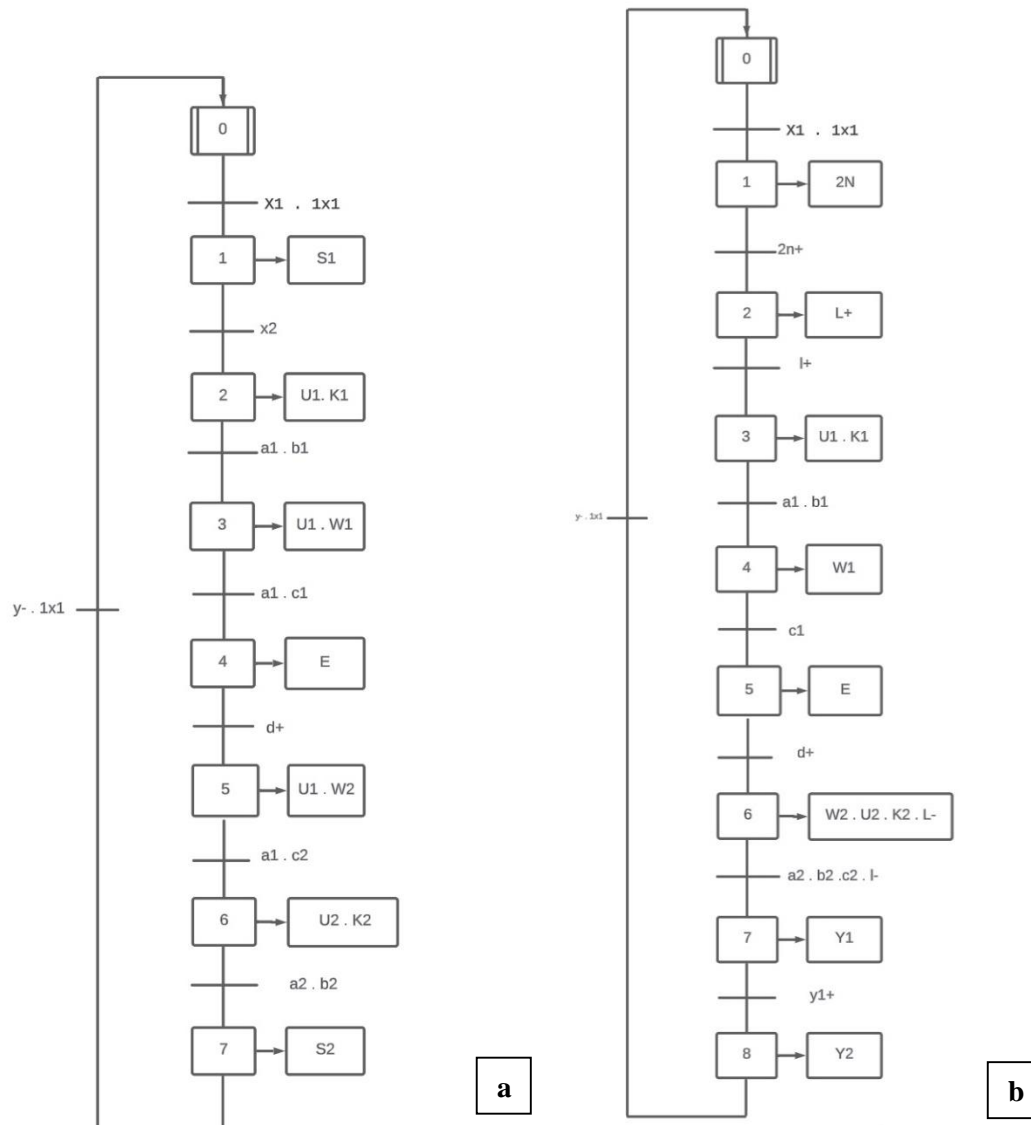
Codes	Meanings
1x1	Cylinder in initial position
x1	Bottle present
x2	Lowered hooking arm position
a1	Clamp connected
a2	Clamp disconnected
b1	Bell connected
b2	Bell disconnected
c1	Bottle open
c2	Bottle closed
d+	Bottle full
2n+	Weight sensor
l+	Bottle centered
y+	Bottle extracted
y-	No bottle
v1+	Cylinder out position block 1 leak control
v2+	Cylinder out position block 2 leak control
v1-	Cylinder retract position block 1 leak control
v2-	Cylinder retract position block 2 leak control
2k+	Cylinder outlet position leak control head

2k-	Cylinder retracted position leak control head
dz+	Scanner on
dz-	Scanner off
q1+	Cylinder outlet position block 1 heat seal
q2+	Cylinder outlet position block 2 heat seal
q1-	Cylinder retract position block 1 heat seal
q2-	Cylinder retraction position block 2 heat seal
r+	Thermosealing cylinder contact position
r-	Thermosealing bottle detached position
g	Bottle sealed
Ab1+	Extend cylinder block1 heat seal
Ab2+	Extend cylinder block 2 heat seal
R+	Extend fusing head cylinder
R-	Retract sealing head cylinder
Sq.	Contact bottle and heat seal
Ab1-	Retract block cylinder 1 heat seal
Ab2-	Retract cylinder block2 heat seal
V1+	Extend cylinder block1 leak test
V2+	Extend cylinder block2 leak control
2K+	Extend leak control head cylinder
D+	Scanner on
D-	Scanner off
2K-	Retract leak control head cylinder
V1-	Retract block1 leak control cylinder
V2-	Retract block2 leak control cylinder
cb1+	Weighing blocker1 output position
cb2+	Weighing blocker 2 output position
cb1-	Weighing blocker 1 retracted position
cb2-	Retract position of blocking cylinder 2 for weighing
cp1+	Position of slewing cylinder 1 output
cp2+	Orienter cylinder 2 output position

cp1-	Orienter cylinder 1 retracted position
cp2-	Orienter cylinder 2 retracted position
f+	Tilt cylinder output position
e+	Registered weight
f-	Tilt cylinder retracted position
m+	Tilt cylinder out position
m-	Tilt cylinder retracted position
b1+	Bottle oriented
U1	Filling cylinder out
U2	Fill gripper cylinder in
S1	Filling arm cylinder out
S2	Enter filling arm cylinder
K1	Take out bell cylinder
K2	Enter vernouche
E	Open distributor
L+	Remove centering cylinder
L-	Enter centering cylinder
E-	Close distributor
2N	Enter inlet cylinder
W1	Open cylinder
W2	Close bottle
E+	Save weight
F+	Remove weight cylinder
F-	Enter weight cylinder
Y1	Extract cylinder
Y2	Enter extraction cylinder
Pb1+	Extend locking cylinder 1 weight scale
Pb2+	Extend locking cylinder 2 weight scale
Pv1+	Extend locking cylinder 1 swivel
Pv2+	Extend lock cylinder 2 swivel
Pb1-	Enter lock cylinder 1 weight scale

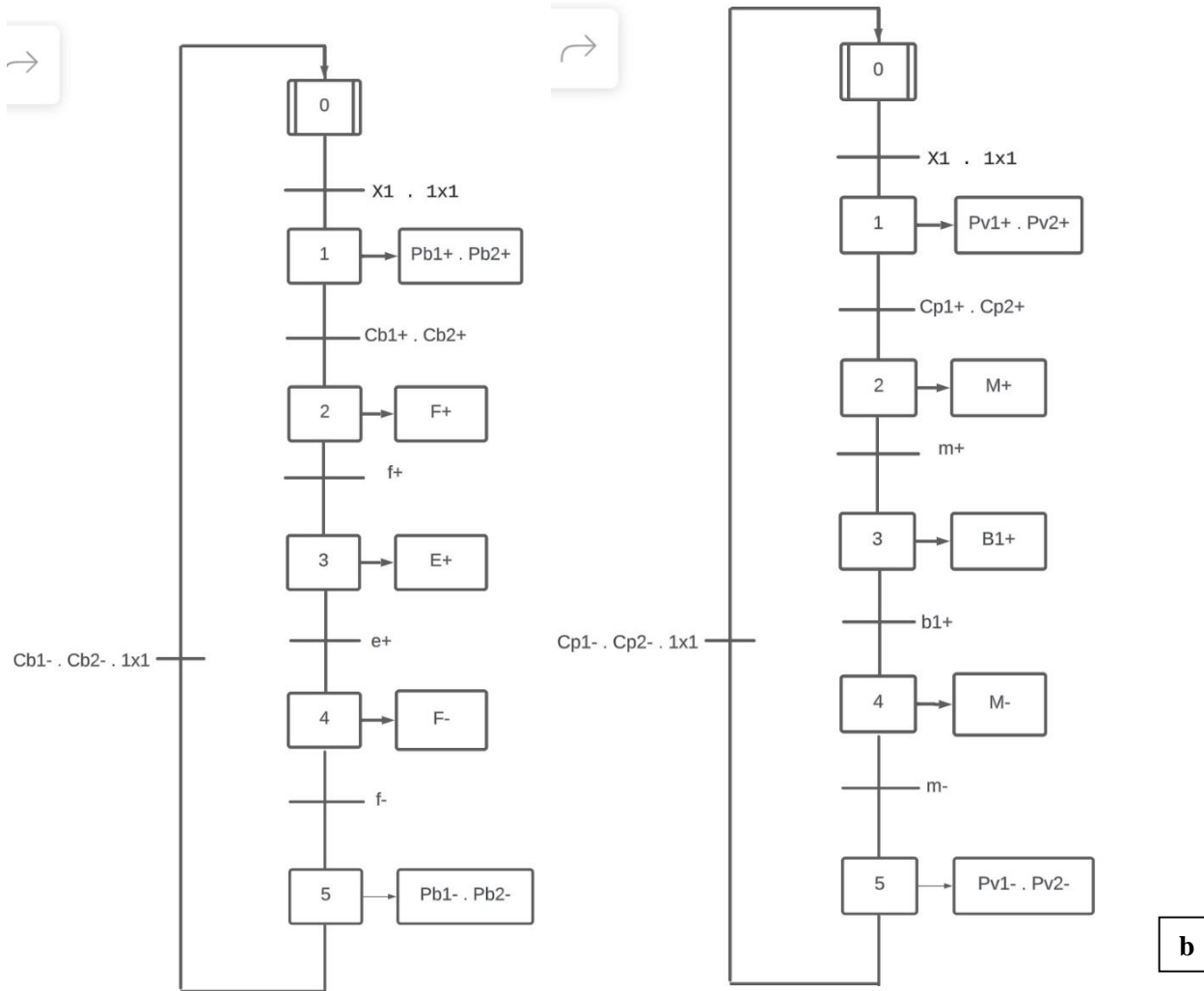
Pb2-	Enter lock cylinder 2 weight scale
Pv1-	Enter lock cylinder 1 swivel
Pv2-	Enter lock cylinder 2 swivel

The GRAFCETS for the branching system and the carousel are shown in Figure (8).



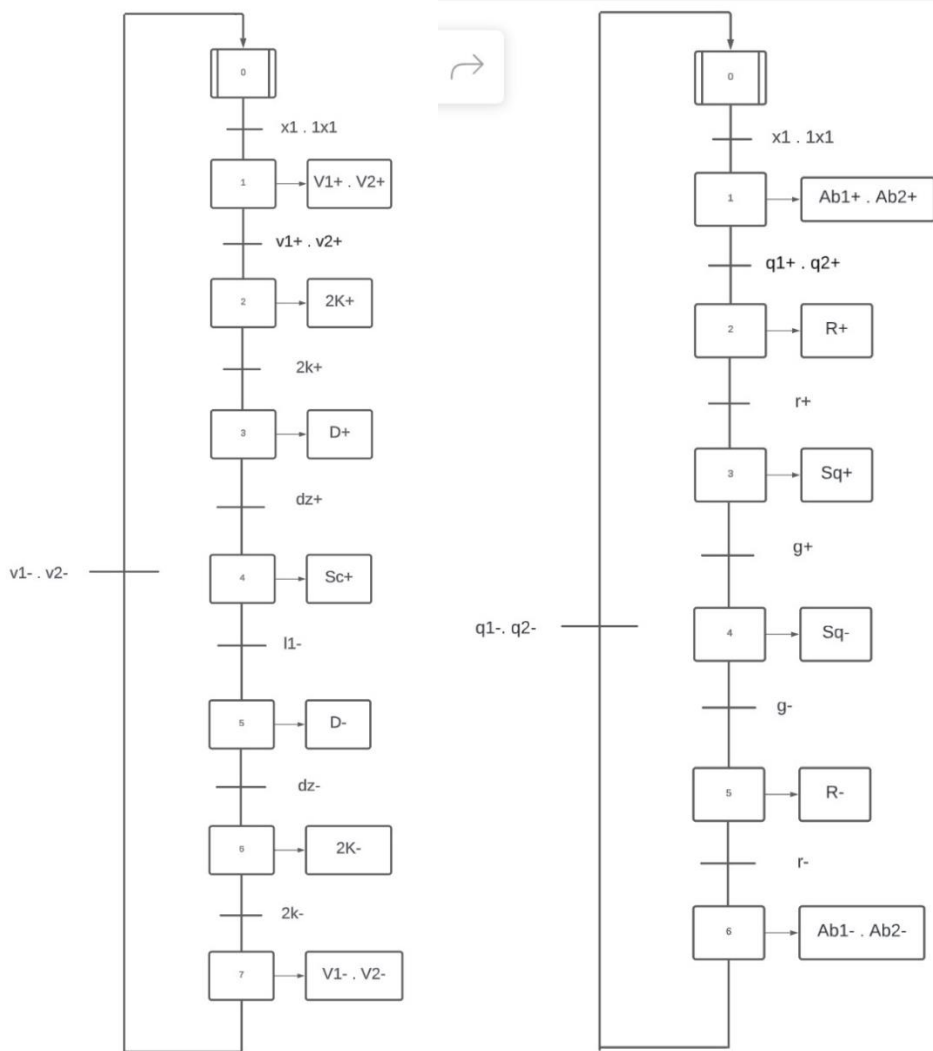
**Figure (8): (a) GRAFCET of the automatic cylinder connection, filling and opening system and (b) GRAFCET of the carousel.**

The GRAFCETS in Figure (8) help to understand the operation of the carousel and filling machine during LPG cylinder filling. Figure (9) shows the GRAFCETS for weight control and cylinder orientation.



**Figure (9):** (a) GRAFCET for upstream weight control and (b) GRAFCET for bottle orientation.

The two GRAFCETS in Figure (9) are used to set bottle weights and orient bottles. Figure (10) shows the GRAFCETS for the leak control and heat-sealing station, which help to understand and, where possible, adjust the leak control and heat-sealing station.



**Figure (10):** GRAFCET of the leak control station and heat sealer.

Table (17) shows the comparison between the proposed filling line and the one on site at plant X.

**Table (17):** A comparison of the two filling lines.

	Manual production line	Proposed automatic production line
Production	300 b/h	1500 b/h
Number of operators	16	5
Number of operations	08	11
Control system	Wired logic	Programmed logic
Installation cost	Lower cost	High cost

## 2.4. Economic Evaluation

Table (18) shows the estimated cost of implementing the project.

**Table (7):** Project cost estimate.

	Specification	Reference	Unit cost	Quantity	Total cost (CFA)
Carrusel	Power supply box	RADWAG ATEXP-M01	781 284	12	9375408
	Rotating electric collector	ATEX MT90	2 148 000	1	2148000
	Push button	LAY7 IP55	300 000	12	3600000
	Electronic scale		13 200 000	12	158400000
	Gear motors	CHM63-80-71B4	279 612,95	1	279612,95
	Magnetic Weight Sensors		43 183	14	604562
	Pressure gauges 0-300 BAR	INOX DN100	70 000	2	140000
	Carousel trainer		37 999 080	1	37999080,42
	Transformer T	SBK 16KVA	80 000	1	80000
	<b>TOTAL (CFA)</b>			<b>212626663,4</b>	
Conveyor	Pneumatic bottle orientator		1 200 000	1	1200000
	Single-acting pneumatic cylinder	C85N10-50S	27 638,78	4	110555,1328
	Double-acting pneumatic cylinder	DSNU-32-100-PPS-A	70 041,43	53	3712195,536
	AU push button	EN60947-5	1 122	2	2243,12
	Gear motor	R37 DRN90L4	1 200 000	2	2400000
	Weight sensors	TAL108	1 667	1	1667
	Chains	C600	8 088 500	4	32354000
	Weight control scale		496 000	2	992000
	AISI 304 tubes	X5CrNi18-10	18 000	17	306000
	AISI 321 steel bars	X6CrNiTi 18-10	42 000	19	798000
	2P+E power sockets	042 80	5000	2	10000
	Electrical cabinet		300 000	1	300000
	Presence sensor		85 000	4	340000
	M1 engine		20 270	2	40540,96
	Conveyor trainer		148 996	1	148996,09
	Insulating material	Polyethylene	5000	50	250000
<b>TOTAL (CFA)</b>			<b>42966197,84</b>		
Others	ATEX fans	95 inch MCC	70 000	2	140000
	Distributor 5/2		781 000	49	38269000
	3/2 distributor		60 000	5	300000
	Infrared leak test rod		447 850	1	447850
	Rack	BME XBP 0800	58 391,19	1	58391,19
	Converter adapter cord	990NAD21130	24 428	1	24428
	Weight corrector		7 000 000	1	7000000
	Smoke detector	ET-GD	543 000	2	1086000

AC/DC converter	ABL8RPS240	85 000	1	85000
Converter	TSXCUSB MBP	1 306	1	1305,6
Gas Detector	TIA090	485 000	2	970000
Analog input module	BMX AMI 0800	190 410	1	190410,24
Power module	CPS 3020	1 666 644	1	1666644
Digital input module	BMX DDI 6402K	214 704	1	214703,96
Digital output module	BMX DDI 6402K	262 635	1	262634,82
UNITY PRO XL	V17	90 000	1	90000
SOLIDWORKS	V22	350 000	1	350000
Cables	H07VU100m 1,5mm <sup>2</sup>	9 035	1	9035
Digital input module	BMX DDI 3202K	173 995,57	1	173995,57
SCHNEIDER ELECTRIC Automation Processor	CPU BMXP342030	900 250,80	1	900 250,80
<b>TOTAL (CFA)</b>				<b>52239649,18</b>
<b>TOTAL MATERIAL COST</b>				<b>307832510,4</b>

The total investment results are given in Table (19).

**Table (8):** Related costs and total investment.

Customs clearance fees	172 386 205,824 CFA
Transportation costs	76 958 127,6 CFA
Labor costs	92 349 753,12 CFA
<b>580 264 286,944 CFA</b>	

Based on the data in Table (3), average production for the month was 3,000 bottles for 16 working hours. Production performance at the filling plant was below the targets set by Factory X. The proposed new automatic electromechanical filling line aims to increase productivity by reducing costs and improving filling conditions to adapt to bottle safety styles. Such a 500-bph line could reach 5,000 bottles/day. The proposed new filling line produces 500 bottles/h in 8 working hours a day. Assuming 25 working days per month and 6500 CFA for the refill price of 12.5kg bottles. We obtain a monthly income. Revenue = [(500\*8) \*25] \*6500 is 650,000,000 CFA. SCDP delivers LPG to factory X at a rate of 300,249.63 CFA/tonne. By producing 500 12.5 kg cylinders per day, the BOCOM plant produces in 1 month a quantity corresponding to 500\*12.5\*8\*25 or 1,250,000 kg of gas. This gives us a monthly raw material purchase price of 375,312,037.5 CFA. Thus, depreciation A= 23,210,571.47776 CFA and monthly depreciation  $A_{mon}$  is  $A/12= 1,934,214.29$  CFA. The proposed filling line requires 5 operators. Considering the operator's unit salary, currently 300,000 CFA per month, and the salaries of the production managers and administrative staff. The estimated payroll is 30,250,000 CFA. Other expenses such as electricity and water are estimated at 6,000,000 CFA. The project's monthly revenue is 238,437,962.5 CFA. The company will recover its entire investment in 2 years 7 months.

### 3. Conclusions

This work presented the design of a fully automated filling line for LPG cylinders equipped with tap-type safety valves, a critical need in the regional market where existing solutions are inadequate. The conclusion is strengthened by explicitly summarizing the technical achievements, acknowledging design limitations, and outlining clear directions for future research and development.

### 3.1. Specific Technical Outcomes and Advancements

Our work advances current practice by moving from a manual, error-prone process to a deterministic, automated system. The specific technical contributions are:

**A Novel Integration for Tap-Type Valves:** We designed and specified a pneumatic bell-and-gripper system (Figure 7) integrated with a bottle orienter. This subsystem solves the specific incompatibility of existing automated fillers with the prevalent tap valve, enabling fully automatic connection, opening, filling, and closing without operator intervention, a key limitation of Plant X's current semi-automatic line.

**A Deterministic Control Architecture:** We developed a complete sequential control strategy using GRAFCETs (Figures 8-10) for a Schneider M340 PLC. This formalizes the entire process—from cylinder orientation and tare weighing to filling, leak testing, and sealing—into a verifiable, error-handling state machine. This replaces the ad-hoc, wired-logic control of the manual line, ensuring repeatable cycle times and enabling precise fault diagnosis (e.g., rejection via selection cylinders upon weight or leak test failure).

**A Validated High-Capacity Mechanical Design:** We provided detailed sizing calculations for core subsystems: A double-drive chain conveyor with a 7500 m<sup>3</sup>/h capacity and speed of 0.92 m/s (Table 6), designed for continuity and shock resistance.

A 12-station rotating carousel with a calculated rotational inertia of 4654.54 kg.m<sup>2</sup> and a mechanical power requirement of 32.6 W (Table 14), engineered to support a target cycle time of  $\leq 40$  seconds per station.

These calculations translate the performance target ( $\geq 500$  cylinders/hour) into engineered specifications, providing a blueprint for implementation.

**A Quantified Performance Leap:** The proposed system delivers a fivefold increase in baseline throughput (from  $\sim 300$  to  $\geq 500$  cylinders/hour) and reduces direct line operators from 16 to 5 (Table 17). The economic model, based on real production shortfalls (Table 3), demonstrates this design can meet Plant X's daily target of 5,000 cylinders in 8 hours, addressing the core business problem.

### 3.2. Limitations of the Proposed Design

While comprehensive, this design-phase study has inherent limitations that must be acknowledged:

**Prototype Validation Gap:** The performance metrics (500-1500 cylinders/hour, defect reduction) are theoretical projections based on component specifications and cycle time analysis. Physical validation through a functional prototype or digital twin simulation is required to confirm actual throughput, reliability (Mean Time Between Failures - MTBF), and the effectiveness of the automated leak test.

**Assumption of Idealized Conditions:** The sizing calculations and ROI assume consistent, high-quality input (cylinders within dimensional tolerances, stable gas supply pressure). The system's robustness to highly variable cylinder conditions (significant dents, rust, valve thread wear) common in returnable packaging cycles is not fully explored.

**Scalability and Flexibility:** The design is optimized for the dominant 12.5 kg cylinder format. Rapid changeover to other sizes (6 kg, 35 kg) would likely require manual adjustment of grippers, centering mechanisms, and PLC parameters, representing a limitation in flexibility compared to more advanced, self-adjusting systems.

### 3.3. Directions for Future Work

To transition this design into a validated, next-generation system, the following research and development steps are proposed:

**Digital Twin Development & Virtual Commissioning:** Future work should create a dynamic simulation model in Unity Pro XL or a dedicated platform (e.g., Siemens Process Simulate). This would allow for virtual testing of

the GRAFCET logic, optimization of the carousel index time, and stress-testing of the control strategy against failure scenarios before physical build, de-risking the commissioning phase.

**Integration of Machine Vision for Pre-Inspection:** A major advancement would be adding an in-line machine vision system prior to the orienter. Using a low-cost CMOS sensor and edge computing, it could reject cylinders with severe body damage, incorrect valve types, or illegible seals, preventing jams and protecting downstream automated equipment.

**Development of a Predictive Maintenance Framework:** Embedding vibration and current sensors on the conveyor drives and carousel motor, coupled with a simple PLC-based algorithm, could shift maintenance from reactive to predictive. Tracking motor current signatures over time could forecast bearing wear, minimizing unplanned downtime.

**Lifecycle and Sustainability Analysis:** A critical future study is a cradle-to-gate lifecycle assessment comparing the environmental impact of the automated line against the manual process. This would quantify reductions in LPG fugitive emissions during filling and the long-term resource efficiency gains from higher quality and reduced scrap.

**Conflict of Interest:** The authors declare that there are no conflicts of interest associated with this research project. We have no financial or personal relationships that could potentially bias our work or influence the interpretation of the results.

## References

- [1] D. A. Folatjar and K. Horn, "Polycarbonate PC," in *Traité Plastique et Composites*, Technique de l'Ingénieur, Paris, France, 1991.
- [2] B. Abdelhamid and H. Samir, "Role of LPG as an energy substitute in Algeria; Rôle des G.P.L. comme énergie de substitution en Algérie," World Energy Congress, Paper WEC-2010-279, 2010.
- [3] F. Amrouche, A. Benzaouib, F. Harouadic, B. Mahmaha, and M. Belhamel, "Compressed natural gas: The new alternative fuel for the Algerian transportation sector," *Procedia Engineering*, vol. 33, pp. 102–110, 2012.
- [4] G. T. Chala, A. R. Abd Aziz, and F. Y. Hagos, "Natural gas engine technologies: Challenges and energy sustainability issue," *Energies*, vol. 11, no. 11, p. 2934, 2018.
- [5] S. Semin, R. A. Bakar, and A. R. Ismail, "Green engines development using compressed natural gas as an alternative fuel: A review," *American Journal of Environmental Sciences*, vol. 5, no. 3, pp. 371–381, 2009.
- [6] X.-Y. Li, D.-L. Zhong, P. Englezos, Y.-Y. Lu, J. Yan, and S.-L. Qing, "Insights into the self-preservation effect of methane hydrate at atmospheric pressure using high-pressure DSC," *Journal of Natural Gas Science and Engineering*, vol. 86, p. 103738, 2021.
- [7] H. Al-Yafei, S. Aseel, M. Kucukvar, N. C. Onat, A. Al-Sulaiti, and A. Al-Hajri, "A systematic review for sustainability of the global liquefied natural gas industry: A 10-year update," *Energy Strategy Reviews*, vol. 38, p. 100768, 2021.
- [8] FAS North Africa, *Centre emplisseur des bouteilles GPL: Rapport technique sur les installations de remplissage de gaz*. Alger, Algeria, 2021.
- [9] S. C. Gülen, *Gas and Steam Turbine Power Plants: Applications in Sustainable Power*. Cambridge, U.K.: Cambridge University Press, 2023.
- [10] International Organization for Standardization, *Gas Cylinders—Specifications for the Design and Construction of Refillable Welded Steel LPG Cylinders*, ISO 22991:2020, Geneva, Switzerland, 2020.
- [11] Kosan Crisplant, *Carousel Filling Systems for LPG Cylinders – Technical Overview*. Aarhus, Denmark: Kosan Crisplant A/S, 2022.
- [12] RULMECA, *Motorized Pulleys and Components for Bulk Handling – Design Manual*, 5th ed. Almè, Italy: Rulli Rulmecca S.p.A., 2019.
- [13] S. Abauzit, "Réglementation des équipements sous pression: Stockage et remplissage de gaz de pétrole liquéfiés," *Techniques de l'Ingénieur*, Ref. BE8580, Paris, France, 2018.

- [14] N. Bruce, R. A. de Cuevas, J. Cooper, *et al.*, “The government-led initiative for LPG scale-up in Cameroon: Programme development and initial evaluation,” *Energy for Sustainable Development*, vol. 46, pp. 103–110, 2018.
- [15] R. E. Bee, “Executive summary of the LPG master plan for Cameroon,” presented at the LPG Ad Hoc Committee Meeting, Yaoundé, Cameroon, 2016.
- [16] R. Van Leeuwen, A. Evans, and B. Hyseni, “Increasing the use of liquefied petroleum gas in cooking in developing countries,” *World Bank Live Wire*, Washington, DC, USA, 2017.
- [17] J. A. Thangam, *Comment choisir un vérin pneumatique*. Paris, France, 2023.
- [18] MAKEEN Energy, *Instrumentation for LPG Filling Plants – Technical Specifications*. Randers, Denmark: MAKEEN Energy A/S, 2023.
- [19] Geaa, *Automates Programmables Industriels: Guide Technique*. Paris, France, 2021.
- [20] Schneider Electric, *Modicon M340 – Programming Guide*, Publication No. EIO0000001359. Rueil-Malmaison, France: Schneider Electric, 2020.