

PLC-Based Automatic Control of a Poultry Feed Mill in Lualaba, DR Congo

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Abstract: Poultry farming in Lualaba Province (DR Congo) relies heavily on feed imported mainly from Zambia, which raises input costs and exposes farmers to supply disruptions. This paper presents the design of an automatic control system, based on a programmable logic controller (PLC) and modelled with GRAFCET, for a poultry feed unit producing 1.2 t batches. The method combines four mathematical models: least-cost formulation by linear programming, cumulative batch weighing with in-flight cut-off compensation, an exponential mixing model based on the coefficient of variation (CV), and electromechanical sizing of the drives. The reference broiler grower diet was corrected to meet calcium requirements: 20.2% crude protein, about 2,990 kcal ME/kg and 0.99% calcium. Sizing yields 45.2 kW installed power and an operating current of about 64 A. MATLAB/Simulink simulation validates the dosing sequence, and preliminary tests report 1.08 t/h, 28.5 kWh/t and a CV below 8%. The recalculated investment is USD 37,906; it must still include the technical corrections, notably a 60 kVA standby generator instead of 6 kVA.

Keywords: Programmable Logic Controller; GRAFCET; Poultry Feed; Linear Programming; Batch Weighing; Coefficient of Variation; Electrical Sizing; Lualaba.

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I. INTRODUCTION

Feed accounts for the largest share of production cost in poultry farming, up to 70% depending on the production system (Thobe, 2025). In Lualaba Province, in the south-east of the Democratic Republic of the Congo, the economy is dominated by mining, but urban demand for animal protein, particularly in Kolwezi, supports a growing poultry sector. The sector nevertheless remains fragile, because a large share of compound feed is imported from Zambia.

This dependence has three effects. It raises input costs through transport and taxes. It imposes formulations that are not always suited to the species raised locally (broiler chicken, turkey, duck, pigeon). Finally, it exposes farmers to supply disruptions. Local feed production remains largely artisanal: approximate weighing, shovel mixing and no control of batch-to-batch reproducibility.

➤ Research Problem

The research question is: how can an automatic control system be designed for a poultry feed unit that ensures accurate dosing and homogeneous mixing from local raw materials, while remaining compatible with the technical

constraints of Lualaba (dust, humidity, unstable grid, limited maintenance capacity)?

➤ Objectives

The general objective is to design and validate, through modelling and simulation, a PLC-based control system for a unit producing 1.2 t per batch. The specific objectives are:

- Establish a balanced reference formulation from locally available ingredients;
- Model the process (dosing, grinding, transfer, mixing, pelleting) in GRAFCET and derive the control equations;
- Formalise dosing and mixing mathematically in order to set the PLC setpoints;
- Size the motors, protection devices, cables and standby power supply;
- Estimate the investment cost and assess performance through simulation and preliminary tests.

➤ Contributions

Compared with the thesis on which it is based (Minda Mwilambwe, 2026), this paper makes three contributions. It corrects the formulation, whose calcium content far exceeded broiler requirements. It adds an explicit mathematical

framework (linear programming, dosing with cut-off compensation, mixing kinetics, voltage drop). Finally, it harmonises the sizing and the budget, which contained conflicting values from one chapter to another. Appendix A summarises these corrections.

The rest of the paper is organised as follows: Section 2 reviews the literature; Section 3 presents materials and models; Section 4 describes the control system; Section 5 covers sizing; Section 6 presents results and discussion; Section 7 concludes.

Table 1 Indicative Nutritional Requirements by Species (After NRC, 1994; Larbier & Leclercq, 1992)

Species	Crude protein (%)	Metabolisable energy (kcal/kg)	Calcium (%)	Available phosphorus (%)
Broiler chicken	20–24 (starter), 18–20 (grower)	2,900–3,200	0.9–1.1	0.35–0.50
Turkey	18–22	2,800–3,100	1.0	0.40–0.50
Duck	16–20	2,800–3,100	0.8–1.0	0.35–0.45
Pigeon	14–18	2,600–2,900	0.8–1.0	0.30–0.40

Excess calcium is as harmful as a deficiency: in broilers, it reduces absorption of phosphorus, zinc and manganese and impairs growth (NRC, 1994). Levels around 3–4% are suitable only for laying hens.

➤ Locally Available Ingredients

Maize is the main energy source; it is low in lysine and tryptophan and must therefore be combined with an oilseed meal. Soybean meal supplies most of the protein. Rice bran, rich in oxidisable fat, can be included up to 10–15%. Groundnut meal is limited to 4–5% because of the aflatoxin risk, and cottonseed meal contains gossypol (Larbier & Leclercq, 1992). Chalk (calcium carbonate) and dicalcium phosphate (DCP) cover calcium and phosphorus needs; palm oil supplies energy and carotenoids that are precursors of vitamin A.

➤ Feed Manufacturing Technology

A feed mill chains together receiving, storage, cleaning (magnet and screening), dosing, grinding, mixing, optional pelleting and packaging (McElhiney, 1994). Two layouts exist: dosing before grinding (the weighed premix is ground together) and grinding before dosing. The first, adopted here, needs only one grinder and suits small units.

Mix homogeneity is measured by the coefficient of variation (CV) of a tracer across a series of samples. Industry practice considers a CV below 10% as good and below 5% as excellent (McElhiney, 1994; Clark et al., 2007).

➤ Automation with PLCs and GRAFCET

Programmable logic controllers are programmed according to IEC 61131-3 (International Electrotechnical Commission [IEC], 2013b). GRAFCET, standardised by IEC 60848 (IEC, 2013a), describes sequential behaviour through steps, transitions and actions; it translates directly into Boolean equations or into the SFC language (David & Alla, 1992). Machine safety is governed by IEC 60204-1 (IEC, 2016).

II. LITERATURE REVIEW

➤ Nutritional Requirements of Poultry

Requirements for energy, protein, amino acids, minerals and vitamins vary with species and physiological stage (National Research Council [NRC], 1994; Larbier & Leclercq, 1992). Table 1 summarises the ranges adopted for the four species studied.

Several studies have automated feed distribution or manufacturing in low-resource settings (African Development Bank, 2024). Few, however, address formulation, sequential control and electrical sizing together for a mining province in Central Africa. This paper aims to fill that gap.

III. MATERIALS AND METHODS

The approach has four steps: diet formulation, dosing model, mixing model, then control modelling (Section 4) and sizing (Section 5). Ingredient composition data are standard tabulated values (NRC, 1994; Larbier & Leclercq, 1992); they must be confirmed by analysis of local batches.

➤ Least-Cost Formulation by Linear Programming

Let n be the number of ingredients, with unit prices c_j (USD/kg) and inclusion rates x_j in the diet. The least-cost formula is the solution of the following linear program (Pesti & Miller, 1993):

$$\min_x Z = \sum_{j=1}^n c_j x_j$$

$$\text{s.t.} \quad \sum_{j=1}^n x_j = 1, \quad b_i^{\min} \leq \sum_{j=1}^n a_{ij} x_j \leq b_i^{\max} \quad (i = 1, \dots, m), \quad l_j \leq x_j \leq u_j$$

Here a_{ij} is the content of nutrient i in ingredient j (protein, energy, calcium, phosphorus, lysine, methionine), b_i are the bounds from Table 1, and l_j, u_j are inclusion limits (for example $u \leq 0.15$ for rice bran, $u \leq 0.05$ for groundnut meal). The model is solved offline with Kolwezi market prices using a simplex-type solver; each resulting formula is then stored as a recipe in the PLC.

➤ Corrected Reference Formulation

The thesis formulation contained 102 kg of chalk per 1,200 kg, i.e. 8.5%. With chalk at about 38% calcium, this gives about 3.6% calcium in the diet (including DCP and

other ingredients), more than three times the broiler requirement (Table 1). Chalk was therefore reduced to 16 kg, DCP raised to 20 kg to cover phosphorus, and the freed mass

was reallocated to soybean meal and maize to raise protein (Table 2).

Table 2 Corrected Reference Formulation — Broiler Grower Phase, 1,200 kg Batch

Ingredient	Mass (kg)	Share (%)	Thesis formulation (kg)
Maize	638.0	53.17	600.0
Soybean meal	380.0	31.67	320.0
Rice bran	100.0	8.33	115.0
Palm oil	40.0	3.33	40.0
Dicalcium phosphate (DCP)	20.0	1.67	17.0
Chalk (CaCO ₃)	16.0	1.33	102.0
Salt (NaCl)	3.0	0.25	3.0
Vitamin premix	1.2	0.10	1.2
Trace minerals	1.2	0.10	1.2
DL-methionine	0.6	0.05	0.6
Total	1,200.0	100.00	1,200.0

The content of nutrient i in the diet is the weighted mean of ingredient contents:

$$N_i = \frac{\sum_j m_j a_{ij}}{\sum_j m_j}$$

With standard contents (maize: 8.5% CP, 3,350 kcal/kg; soybean meal: 46% CP, 2,250 kcal/kg; rice bran: 13% CP, 2,400 kcal/kg; oil: 8,800 kcal/kg; DCP: 22% Ca, 18% P; chalk: 38% Ca), the values in Table 3 are obtained.

Table 3 Nutritional Check of the Corrected Formulation

Criterion	Calculated value	Requirement (Table 1)	Thesis formulation
Crude protein (%)	20.2	18–20 (grower)	17.8
Metabolisable energy (kcal/kg)	≈ 2,990	2,900–3,200	≈ 2,800
Calcium (%)	0.99	0.9–1.1	≈ 3.6
Total phosphorus (%)	0.78	—	0.71
Available phosphorus (%)	≈ 0.44	0.35–0.50	≈ 0.40

For example, crude protein equals $(638 \times 0.085 + 380 \times 0.46 + 100 \times 0.13) / 1,200 = 242.0 / 1,200 = 20.2\%$. Lysine and sulphur amino acid levels still need to be checked by analysis, since synthetic methionine is included at only 0.05%.

Four major ingredients dosed automatically total $638 + 380 + 100 + 16 = 1,134$ kg. The cumulative scale thresholds therefore become 638, 1,018, 1,118 and 1,134 kg, instead of 600, 920, 1,035 and 1,137 kg in the thesis. The micro-ingredients (66 kg) are added at the mixer.

➤ Cumulative Dosing Model with Cut-Off Compensation

Dosing is sequential on a single scale. For ingredient k , the cumulative target mass is:

$$M_k^* = \sum_{j=1}^k m_j^*$$

While the gate is open, the mass on the scale increases at flow rate q_k (kg/s):

$$M(t) = M_{k-1} + \int_{t_0}^t q_k(u) du \approx M_{k-1} + q_k(t - t_0)$$

Between the closing command and the actual stop of the flow there is a response time τ_k (gate closure plus the falling column of material in flight). To avoid overdosing, the PLC issues the closing command at the compensated threshold:

$$M_k^c = M_k^* - q_k \tau_k$$

The relative dosing error must stay within tolerance:

$$\varepsilon_k = \frac{|m_k - m_k^*|}{m_k^*} \leq \varepsilon_{\max}, \quad \varepsilon_{\max} = 1\% \text{ (macro-ingredients)}$$

As an illustration, for $q = 2$ kg/s and $\tau = 0.6$ s, the compensation is 1.2 kg. Without it, overdosing would reach 7.5% for chalk (1.2 kg on 16 kg). For small masses such as chalk, two-speed dosing is therefore recommended: coarse flow up to 90% of the setpoint, then a fine flow q_f . The correction term $q_f \tau$ then becomes negligible. The compensation τ_k is readjusted automatically after each batch from the measured error.

The dosing time for one batch is:

$$T_{dos} = \sum_{k=1}^4 \left(\frac{m_k^*}{q_k} + t_{o,k} + t_{c,k} \right)$$

Where t_o and t_c are the gate opening and closing times.

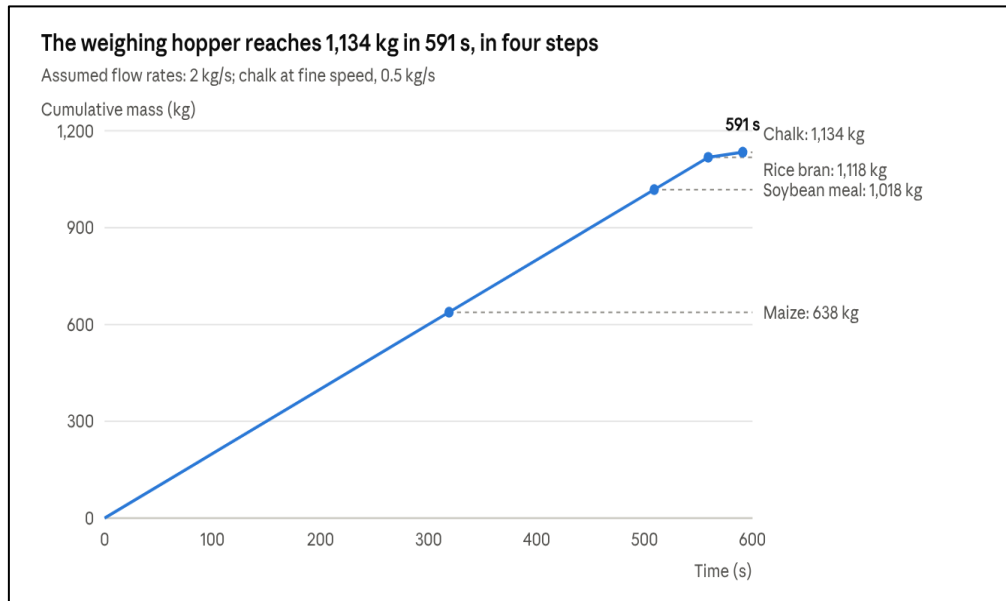


Fig 1 Dosing Model (Section 3.3), Table 2 Formulation · Illustrative Flow Rates

Each step corresponds to one gate opening; the slope is the flow rate q_k and the final plateau is the threshold $M_4^* = 1,134$ kg.

➤ Mixing Model

Homogeneity is measured on N samples taken at the mixer outlet. A tracer (salt or methionine) is assayed in each sample, with content y_i :

$$CV = \frac{s}{\bar{y}} \times 100, \quad s = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (y_i - \bar{y})^2}$$

As a first approximation, the CV decreases with mixing time t according to a first-order exponential law:

$$CV(t) = CV_{\infty} + (CV_0 - CV_{\infty}) e^{-t/\tau_m}$$

CV_0 is the initial CV, CV_{∞} the limiting CV of the mixer and τ_m its time constant. The minimum mixing time to reach a target CV_c is:

$$t_m = \tau_m \ln \left(\frac{CV_0 - CV_{\infty}}{CV_c - CV_{\infty}} \right)$$

The parameters τ_m and CV_{∞} are identified by a mixing test (samples at 1, 2, 3, 5 and 8 min). With plausible values for a ribbon mixer ($CV_0 = 100\%$, $CV_{\infty} = 4\%$, $\tau_m = 1.2$ min), a CV of 10% is reached after 3.3 min. The thesis gave mixing times from 3 to 20 min depending on the chapter. A single timer setting $T_{mix} = 10$ min is adopted: 5 min dry, then 5 min after oil addition. It remains adjustable from the HMI and will be validated by the CV test.

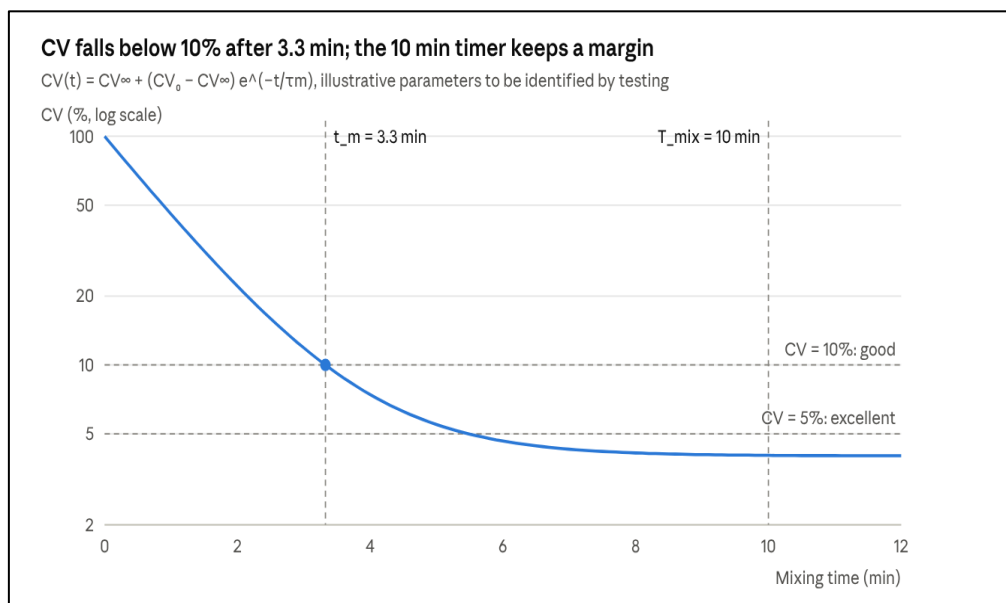


Fig 2 Mixing Model (Section 3.4) · $CV_0 = 100\%$, $CV_{\infty} = 4\%$, $\tau_m = 1.2$ min (Illustrative)

The CV falls quickly during the first three minutes, then levels off towards CV_{∞} ; beyond 6 min, longer mixing gains almost nothing.

➤ Plant Throughput

The average throughput of a batch plant is:

$$Q = \frac{m_{batch}}{T_{cycle}}$$

If the steps run in series, T_{cycle} is the sum of the step durations. If they overlap (dosing batch $n + 1$ while batch n is mixing), T_{cycle} tends towards the duration of the slowest step, the bottleneck. For $Q = 1.2$ t/h and $m_{batch} = 1.2$ t, $T_{cycle} \leq 60$ min is required.

IV. CONTROL SYSTEM DESIGN

➤ Process and Architecture

The process uses dosing before grinding. Four silos (maize, soybean meal, rice bran, chalk) feed a single weighing hopper through a magnet and a centrifugal sifter. The weighed premix is ground in a hammer mill, then transferred through a buffer hopper and a belt conveyor to a holding bin above the mixer. Micro-ingredients and palm oil are added at the mixer. A diverter valve then sends the product either to the mash bin (meal feed) or to the pelleting line (conditioner, pellet press, screw), which feeds the pellet bin. Bagging remains manual.

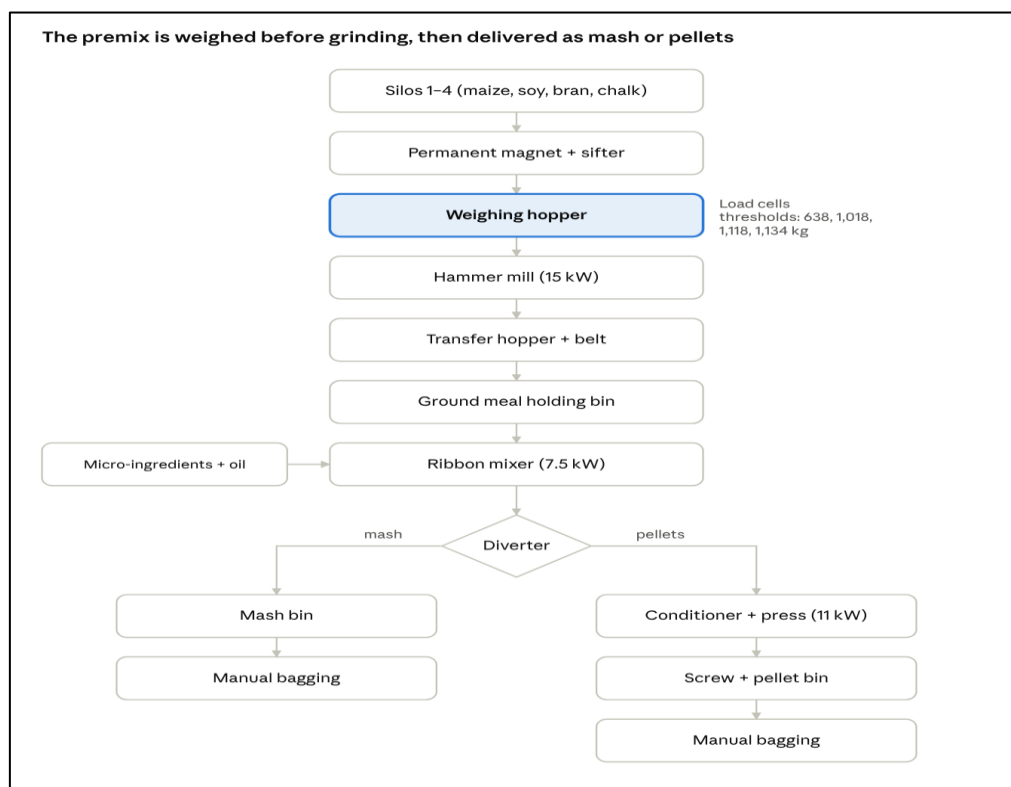


Fig 3 Automated Production Line · Dosing Before Grinding, Two Outputs

Weighing takes place before grinding; the diverter downstream of the mixer sends each batch to mash or to pelleting.

The control architecture has four levels: acquisition (level detectors, load cells, gate limit switches), control (PLC), execution (contactors, pneumatic cylinders, solenoid valves) and supervision (touch HMI and traceability database).

One consistency correction is needed here. The thesis used a mechanical dial scale whose thresholds are fixed pointers on the dial. Such a device cannot change recipe from the HMI, which contradicts the objective of multiple formulations. Load cells (class C3) under the weighing hopper are therefore adopted, connected to a 4–20 mA weighing transmitter read by a PLC analogue input. The

thresholds M_k^c from Section 3.3 then become recipe parameters.

➤ PLC and Actuator Selection

The selected PLC is a compact industrial controller (Siemens S7-1200 or Schneider M221 type), programmed in SFC/GRAFCET according to IEC 61131-3. The I/O count is about 40 digital inputs, 1–2 analogue inputs and 35 digital outputs, which requires an expansion module.

The eleven gates are driven by single-acting pneumatic cylinders with spring return. On loss of air or power they therefore close by themselves, which is a safe state. Each gate has two limit switches (open, closed).

The mercury level switches proposed in the thesis are replaced by rotary paddle or capacitive switches. Mercury is

banned in food environments and its contacts are sensitive to vibration. Optical through-beam detectors are kept for low levels, but their lenses must be protected from dust.

➤ GRAFCET Model

The GRAFCET comprises a main dosing sequence (steps 1–8), a grinding, transfer and mixing sequence (steps 21–26) and two mutually exclusive delivery branches: mash (27–28) and pellets (29–33). Table 4 gives the main transition conditions with the corrected thresholds.

Table 4 Main GRAFCET Steps and Transition Conditions (Corrected Thresholds)

Step	Action	Exit condition
1	Idle, plant stopped	start · dn1 · dn2 · dn3 · dn4 · tf1 · tf2 · tf3 · tf4 · tf5
3	Magnet and sifter running	start-up delay elapsed (5 s)
4	Open gate 1 (maize)	$M \geq M_1^c$ (638 kg – compensation)
5	Open gate 2 (soybean meal)	$M \geq M_2^c$ (1,018 kg) · tf1
6	Open gate 3 (rice bran)	$M \geq M_3^c$ (1,118 kg) · tf2
7	Open gate 4 (chalk)	$M \geq M_4^c$ (1,134 kg) · tf3
8	Stop sifter and magnet	tf4 (AND divergence to 9 and 21)
21	Start hammer mill	speed reached · tf10 · not dn6
22	Open gate 5, grinding	dn6 (transfer hopper full) or $M = 0$
23	Belt conveyor, open gate 10	dn7 (holding bin full) · tf6 · tf11
24	Add micro-ingredients (operator)	HMI acknowledgement
25	Open gate 6, mixing, oil	$T_{mix} = 10$ min elapsed
26	Diverter selection (mash or pellets)	pcf · tf7 or pcg · tf8 · tf9
27–28	Fill then empty the mash bin	dn8 then not dn8 (low level)
29–33	Pelleting, pellet bin, emptying	dn10, then not dn11 (pellet bin low)

➤ Activation Equations

Each step X_n is represented by a latched Boolean variable. With a single upstream and a single downstream step, its equation is (David & Alla, 1992):

$$X_n = X_{n-1} \cdot r_{n-1} + X_n \cdot \overline{X_{n+1}}$$

$R_{\{n-1\}}$ is the receptivity (transition condition) of the upstream transition. The first term activates the step, the second holds it until the next step is activated. The initial step must be forced at power-up by the initialisation bit Init. The thesis equation " $X_1 = 0$ " is therefore wrong: it would leave the initial step permanently inactive. The correct equation is:

$$X_1 = \text{Init} + X_9 \cdot X_{end} \cdot r_{end} + X_1 \cdot \overline{X_3}$$

X_{end} denotes the final step of the active delivery branch (28 or 33). The transition after step 7 is an AND divergence: it activates steps 8 and 21 simultaneously.

$$X_8 = X_7 \cdot r_7 + X_8 \cdot \overline{X_9}, \quad X_{21} = X_7 \cdot r_7 + X_{21} \cdot \overline{X_{22}}$$

In the thesis, step 8 returned directly to step 1 while branch 21 continued. The GRAFCET could then start a new dosing cycle before grinding had finished, which violates the convergence rule. A waiting step 9 and an AND convergence are added: return to step 1 is possible only when the dosing branch has finished (X_9) and the batch delivery is complete (X_{end}). The mash branch ends at step 28 and the pellet branch at step 33, with no path from one to the other.

Outputs are combinations of active steps. For example, gate 1 is driven by $Y_{T1} = X_4$, and the sifter by $Y_{SIFT} = X_3 + X_4 + X_5 + X_6 + X_7$.

➤ Safety and Risk Analysis

The control system includes a category 0 emergency stop, hard-wired outside the PLC, in accordance with IEC 60204-1 (IEC, 2016). An Auto/Manual selector allows maintenance, with manual commands interlocked by the PLC. Table 5 summarises the main risks.

Table 5 Risk Analysis and Adopted Measures

Risk	Cause	Measure
Motor overload or stall	Choking of the hammer mill or pellet press	Motor circuit breaker, thermal relay, HMI alarm
Belt blockage	Obstruction, belt failure	Speed monitor, automatic stop of upstream equipment
Silo or bin overflow	Failed detector	Redundant high level, maximum fill-time watchdog
Grid failure	Load shedding	Spring-closed gates, UPS for PLC and HMI, standby generator
Dust explosion	Airborne feed dust	Dust extraction and filtration, equipment earthing, IP55 equipment
Maintenance accident	Work on moving parts	Lockout/tagout, fixed guards, emergency stop

➤ Human–Machine Interface

The touch HMI (7–10 inch, IP65 front) shows the plant mimic, the state of gates and motors, the current mass on the scale and alarms. It allows the operator to select a recipe by species and stage, adjust T_{mix} and the compensations τ_k , and archive each batch (recipe, actual masses, errors ε_k , date, operator) for traceability. Labels are in French, with pictograms for less-trained operators.

➤ Electromechanical Sizing

The corrected sizing gives 45.2 kW installed power, 86 A total current and an operating current of about 64 A at 400 V three-phase. The thesis values were inconsistent from one chapter to another; those adopted here are harmonised and justified by the relations below.

• Mechanical Characteristics of the Loads

The load torque of a mechanism driven at angular speed ω is:

$$M_{st}(\omega) = M_0 + (M_{stn} - M_0) \left(\frac{\omega}{\omega_n} \right)^x$$

M_0 is the friction torque, M_{stn} the load torque at rated speed ω_n , and x the load exponent. The belt conveyor and the screw are constant-torque loads ($x = 0$). The hammer mill, dominated at no load by internal fan action, approaches a quadratic load ($x = 2$). The ribbon mixer and the pellet press require a high breakaway torque at low speed. Steady state is reached when motor torque equals load torque ($M = M_{st}$).

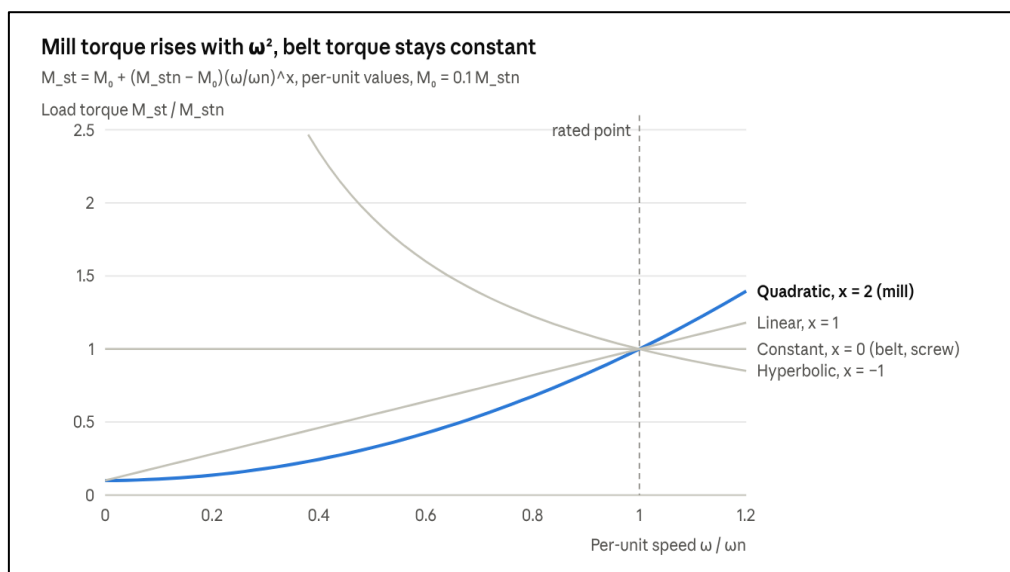


Fig 4 Load Torque–Speed Characteristics, Equation of Section 5.1 · Per-Unit Values

All curves pass through the rated point; they diverge at start-up and at overspeed, which guides the choice of starting method for each motor.

• Sizing Relations

Mechanical power, rated torque and line current of a three-phase induction motor are related by:

$$P = C \omega = \frac{C N}{9550}, \quad C_n = \frac{9550 P_n}{N_n}, \quad I_n = \frac{P_n}{\sqrt{3} U \cos \varphi \eta}$$

Where P is in kW, C in N·m and N in rpm.

• Hammer Mill Correction

The thesis computed $P = (120 \times 2,900) / 9,550 = 36.5$ kW, then selected 15 kW "by safety factor", although such a

factor can only increase power. The error lies in the torque: 120 N·m is a starting torque, which must not be multiplied by rated speed. The mill is instead sized from the specific grinding energy e_s (kWh/t):

$$P_{mill} = \frac{e_s Q_{mill}}{\eta_{tr}}$$

With an order of magnitude $e_s \approx 10$ kWh/t for maize ground through a 3 mm screen, a throughput $Q_{mill} = 1.2$ t/h and a transmission efficiency of 0.9, this gives 13.3 kW. The standard 15 kW, 2,900 rpm motor is selected. Its rated torque is $9,550 \times 15 / 2,900 = 49.4$ N·m, and its direct-on-line starting torque $2.5 \times 49.4 = 123.5$ N·m, which covers the 120 N·m required. The value of e_s must be confirmed by testing.

➤ Motor Summary

Table 6 Selected Motors (400 V, 50 Hz, $\cos \varphi = 0.85$, IE3, IP55, Insulation Class F)

Equipment	Power (kW)	Speed (rpm)	η	Rated current (A)	Starting
Hammer mill	15	2,900	0.92	27.7	Soft starter
Pellet press	11	1,480	0.90	20.8	Soft starter
Ribbon mixer (gearbox, output ≈ 45 rpm)	7.5	1,450	0.90	14.2	Direct on line

Air compressor (gates)	5.5	1,450	0.89	10.5	Direct on line
Conditioner / feeder	4	1,450	0.88	7.7	Direct on line
Centrifugal sifter	1.1	1,400	0.80	2.3	Direct on line
Belt conveyor	0.55	1,400	0.75	1.2	Direct on line
Screw conveyor	0.55	1,400	0.75	1.2	Direct on line
Total	45.2			85.6	

For example, for the hammer mill: $I = 15,000 / (1.732 \times 400 \times 0.85 \times 0.92) = 27.7$ A.

Three thesis values were corrected. The 0.31 W sifter was unrealistic; a 1.1 kW motor is adopted, to be confirmed by the supplier. The 9.16 kW magnetic separator is replaced by a permanent grate magnet, with no power consumption, a standard solution in feed milling. The 9 kW press, a non-standard rating, is raised to 11 kW. Even so, a press of this size produces only a fraction of 1.2 t/h as pellets; the 1.2 t/h throughput therefore applies to mash feed only.

- *Operating Current, Cables and Protection*

Not all motors run at the same time: the mill and the belt run during transfer, the press only during pelleting. The operating current I_B is obtained with a diversity factor $k_s = 0.75$:

$$I_B = k_s \sum_j I_{n,j} = 0.75 \times 85.6 \approx 64 \text{ A}$$

For safety, the main supply cable is sized on the total current of 86 A. A $4 \times 25 \text{ mm}^2$ copper cable is suitable; the $4 \times 16 \text{ mm}^2$ cable in the thesis budget is undersized. The voltage drop, neglecting reactance, is:

$$\Delta U = \sqrt{3} I \frac{\rho L}{S} \cos \varphi, \quad \Delta U \% = \frac{\Delta U}{U} \times 100$$

For $I = 86$ A, $L = 30$ m (assumed length from the main board to the control panel), $\rho = 0.0225 \Omega \cdot \text{mm}^2/\text{m}$ and $S = 25 \text{ mm}^2$, $\Delta U = 3.4$ V, i.e. 0.85%. This is below the usual 5% limit for power circuits.

Main protection is provided by a 100 A switch-disconnector and a 100 A main circuit breaker; the 63 A disconnector of the original budget must be replaced. Each motor feeder has a motor circuit breaker (or fuse plus thermal relay) and an AC-3 contactor, chosen one rating above the rated current for electrical endurance. The control circuit is supplied at 24 V through a transformer, with 1.5 mm^2 wiring.

- *Standby Power Supply*

The thesis specified a 25 kVA generator in the sizing chapter and a 6 kVA unit in the budget. The apparent power in steady operation, however, is:

$$S = \sqrt{3} U I_B = 1.732 \times 400 \times 64 \approx 44 \text{ kVA}$$

With a 30% margin for starting the mill through a soft starter, the required rating reaches 57 kVA. A standard 60 kVA generator is selected. A 6 kVA unit can supply only the PLC, HMI and lighting; it would be suitable as a backup for the control system alone, alongside a UPS.

- *Storage Volumes*

The volume of a cylindrical silo and the mass it holds are:

$$V = \frac{\pi D^2}{4} H, \quad m = \rho_b V$$

ρ_b is the bulk density. The thesis silos ($D = 0.85$ m, $H = 1.5$ m) have a volume of 0.85 m^3 , not 0.6 m^3 . With $\rho_b \approx 0.72 \text{ t/m}^3$ for maize, they hold 613 kg, less than one batch of maize (638 kg). For ground meal ($\rho_b \approx 0.55 \text{ t/m}^3$), 0.85 m^3 holds only 470 kg, not 1,200 kg. Table 7 gives the corrected volumes, with a 15% margin.

Table 7 Corrected storage Volumes (Typical Bulk Densities)

Vessel	Mass to hold (kg)	ρ_b (t/m ³)	Selected volume (m ³)	Example dimensions
Ingredient silo (×4)	2 batches of maize = 1,276	0.72	2.0	D = 1.2 m, H = 1.8 m
Weighing hopper	1,134	0.65	2.0	1.2 × 1.0 × 1.7 m
Ground meal holding bin	1,134	0.55	2.4	D = 1.2 m, H = 2.1 m
Mash and pellet bins	1,200	0.55	2.5	D = 1.2 m, H = 2.2 m

Hopper cone angles must exceed the angle of repose of the materials (about 60° from horizontal for oilseed meals) to prevent bridging, especially with moist materials.

V. RESULTS AND DISCUSSIONS

➤ *Sequence Validation by Simulation*

The dosing logic was simulated in MATLAB/Simulink. The model includes four weight sensors, an analogue-to-digital converter, a control logic block and the digital outputs

of the gates. The simulation, run with the thesis formulation (600, 320, 115 and 102 kg), confirms three properties:

- The gates open in the order maize, soybean meal, rice bran, chalk, and only one is open at a time;
- Each gate closes when the cumulative mass reaches its threshold, then the scale discharge gate opens towards the mill;
- Oil is added only after the dry ingredients have been dosed, as specified by the GRAFCET.

Since the thresholds are recipe parameters, the same logic applies unchanged to the corrected formulation (638, 1,018, 1,118 and 1,134 kg).

The simulation also flagged two overloads: the sifter receives 20% more material than its rated capacity, and the weighing hopper 50% more. These deviations confirm the

undersized volumes identified in Section 5.6; they disappear with the volumes of Table 7 and a sifter sized for the actual throughput.

➤ Preliminary Tests

The preliminary tests reported in the thesis give the performance shown in Table 8, compared with the objectives.

Table 8 Preliminary Performance Versus Objectives

Indicator	Objective	Preliminary result	Assessment
Throughput (mash feed)	1.2 t/h	1.08 t/h	90% of objective
Specific energy consumption	≤ 30 kWh/t	28.5 kWh/t	Achieved
Homogeneity (CV)	≤ 10%	< 8%	Good (excellent if < 5%)
Continuous operation	8 h	8 h without incident	Achieved
Dosing accuracy	± 1%	To be measured	Not yet demonstrated

These values are mutually consistent. A throughput of 1.08 t/h corresponds, from $Q = m_{\text{batch}} / T_{\text{cycle}}$, to a cycle time of $1.2 / 1.08 = 1.11$ h, i.e. about 67 min. The thesis also gave a 45 min cycle, which would yield 1.6 t/h and contradict the 90% figure; the 67 min value is retained. Average power drawn is $28.5 \times 1.08 \approx 30.8$ kW, i.e. 68% of installed power, which agrees with the diversity factor of 0.75.

Cycle time can be brought below 60 min by overlapping steps: dosing of batch $n + 1$ starts while batch n is mixing.

This requires an AND convergence conditioned on the weighing hopper low level, rather than on completion of the whole batch.

➤ Corrected Economic Assessment

The mechanical equipment subtotal in the thesis (USD 11,159.88) does not match the sum of its line items, which is USD 10,098.88. The USD 1,061 discrepancy carried over into every total. Table 9 gives the recalculated budget with the same mark-up structure.

Table 9 Corrected Investment Cost Estimate (USD)

Item	Thesis	Corrected
Mechanical equipment	11,159.88	10,098.88
Electrical and automation equipment	3,107.52	3,107.52
Cabling and connections	2,602.60	2,602.60
Auxiliary equipment (6 kVA generator, computer)	5,250.00	5,250.00
Equipment subtotal	22,120.00	21,058.64
Transport and labour (50%)	11,060.00	10,529.32
Cumulative cost	33,180.00	31,587.96
Contingency (20%)	6,636.00	6,317.59
Total estimated cost	39,816.00	37,905.55

This budget remains provisional. The technical corrections of Section 5 must be re-priced: 60 kVA generator instead of 6 kVA, 4×25 mm² cable, 100 A disconnector, load cells, soft starters and enlarged silos. The 60 kVA generator alone is the largest item to add. Some unit prices (hammer mill at USD 247.66, electromagnet at USD 17.59) also seem very low for industrial equipment and must be confirmed by quotations.

The simple payback period of the investment I_0 is:

$$PBP = \frac{I_0}{Q_{yr} \Delta c}, \quad Q_{yr} = Q \times h_d \times d_{yr}$$

Δc is the saving per tonne relative to imported feed. With $Q = 1.08$ t/h, 8 h per day and 250 days per year, $Q_{yr} = 2,160$ t. This gives $PBP = 37,906 / (2,160 \times \Delta c) \approx 17.5 / \Delta c$ years, with Δc in USD/t. A saving of USD 10/t would give a payback of 1.75 years, and USD 20/t less than one year. A price survey in the Kolwezi market is still needed to determine Δc .

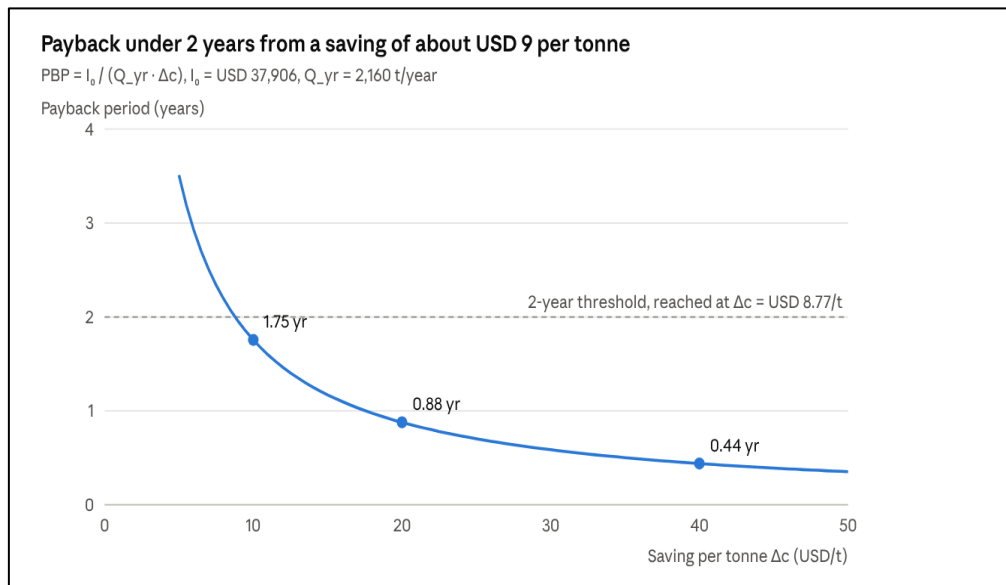


Fig 5 Simple Payback Period, Equation of Section 6.3 · 1.08 t/h, 8 h/day, 250 days/year

The curve is a hyperbola: the first dollars of saving per tonne shorten the payback sharply, then the effect fades beyond USD 20/t.

➤ Discussions

The results show that PLC-based sequential control is technically feasible with components available in the region. They also confirm that consistency between formulation, control and sizing is decisive: an error in the formula (calcium) or in volume (silos) propagates all the way to the simulation and the budget.

The thesis stated quantified hypotheses: production up 45%, costs down 35%, import dependence down 65%, 15 jobs created. These hypotheses are not tested by the present work, which covers design and simulation. They require a pilot plant in operation and an economic survey of farmers. Likewise, the $\pm 1\%$ dosing accuracy must be measured over a series of at least 30 batches.

VI. CONCLUSION

This paper has presented the design of a PLC-based automatic control system for a poultry feed unit suited to Lualaba Province. The approach links four models: linear-programming formulation, cumulative dosing with cut-off compensation, mixing kinetics and electromechanical sizing. The corrected GRAFCET, with a properly forced initial step and an AND convergence, yields control equations that can be programmed directly under IEC 61131-3.

Reviewing the thesis made it possible to correct several significant inconsistencies. The reference formula now meets the broiler calcium requirement (0.99% instead of about 3.6%) while reaching 20.2% crude protein. Sizing is harmonised: 45.2 kW installed, 64 A operating current, $4 \times 25 \text{ mm}^2$ cable and a 60 kVA generator. The recalculated equipment cost is USD 37,906 before re-pricing of the technical corrections.

The preliminary results (1.08 t/h, 28.5 kWh/t, CV < 8%) are encouraging and mutually consistent.

➤ Limitations

Performance figures come from simulation and preliminary tests, without a statistical series. Ingredient compositions are tabulated values, not analyses of local batches. The budget does not yet reflect the sizing corrections. The economic and social hypotheses of the thesis remain to be tested.

➤ Future Work

The following steps are planned: (1) measure dosing accuracy and identify τ_m and CV_∞ on the plant; (2) solve the linear program with Kolwezi prices for the four species and their stages; (3) overlap steps to bring the cycle below 60 min; (4) study a partial photovoltaic supply to reduce reliance on the generator; (5) conduct a techno-economic survey of farmers to assess the actual impact on the sector.

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Note: the references taken from the thesis (African Development Bank, 2024; Thobe, 2025) must be checked against the original source before submission, and URLs or DOIs added where available.

APPENDIX**APPENDIX A. CORRECTIONS MADE TO THE THESIS**

Item	Thesis value	Corrected value	Justification
Chalk in the diet	102 kg (8.5%), Ca $\approx$ 3.6%	16 kg (1.33%), Ca = 0.99%	Broiler requirement: 0.9–1.1% (Section 3.2)
Diet crude protein	17.8%	20.2%	Soybean meal raised to 380 kg
Scale thresholds	600 / 920 / 1,035 / 1,137 kg	638 / 1,018 / 1,118 / 1,134 kg	New formulation
Table 4.1 (broiler dosing)	Soybean meal 20%, chalk 10%	Replaced by Table 2	Contradicted Table 1.3
Weighing	Dial scale with fixed pointers	4–20 mA load cells	Recipes editable from the HMI
Equation X_1	$X_1 = 0$	$\text{Init} + X_0 \cdot X_{\text{end}} \cdot r_{\text{end}} + X_1 \cdot \text{not } X_3$	Initial step otherwise never active
Divergence 8 / 21	Step 8 $\rightarrow$ step 1	Waiting step 9 and AND convergence	Restart before batch completion
Mixing time	3–6, 5–10, 15 and 20 min	$T_{\text{mix}} = 10$ min, adjustable	Single value, validated by CV
Hammer mill	36.5 kW $\rightarrow$ 15 kW, or 5 kW	15 kW, 27.7 A	Sized by specific energy
Mixer	5.5 / 7.5 / 7.7 kW, 45 or 750 rpm	7.5 kW, gearbox output $\approx$ 45 rpm	Ribbon mixer
Sifter	0.31 W	1.1 kW	Unrealistic value
Magnetic separator	9.16 kW	Permanent magnet, 0 kW	Standard solution
Pellet press	9 kW	11 kW (standard rating)	Pelleting < 1.2 t/h
Main cable	$4 \times 16 \text{ mm}^2$	$4 \times 25 \text{ mm}^2$	Total current 86 A
Disconnecter	63 A	100 A	Total current 86 A
Standby generator	25 kVA or 6 kVA	60 kVA	$S = 44$ kVA steady state + margin
Silo volume	0.6 m ³	0.85 m ³ (calculated); 2.0 m ³ selected	$V = \pi D^2 H / 4$
Meal and product bins	0.85 m ³ for 1,200 kg	2.4 to 2.5 m ³	Meal bulk density $\approx$ 0.55 t/m ³
Mechanical subtotal	USD 11,159.88	USD 10,098.88	Sum of line items
Total cost	USD 39,816	USD 37,905.55	Error carried over
Cycle time	45 min	$\approx$ 67 min	Consistent with 1.08 t/h
Level detectors	Mercury switches	Rotary paddle or capacitive	Food safety, vibration
Quantified hypotheses	+45%, –35%, 15 jobs	Presented as to be tested	Not demonstrated by simulation
Bibliography	Bataus (2020), Wu (2025) cited off-topic	Removed	Unrelated to HMI or formulation
Section 5.9	Sentences addressed to the reader ("your image"), guinea fowl, laying hens	Rewritten (Section 6.1)	Outside the scope of the study