THE OPEN UNIVERSITY OF SRI LANKA

FACULTY OF ENGINEERING TECHNOLOGY

THE DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING

EEX5362 PERFORMANCE MODELLING

Mini Project

Optimizing an Automated Egg Collection System to Minimize Breakage and Energy Consumption

GitHub: https://github.com/ShahrulHaqPro/EEX5362-MP-322516498

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1. Introduction

I selected a mid-range egg production farm which runs on an automatic egg collection system. The farm has 10000+ layer hens across three cages. Each cage has three tiers with two sides, and a total of 18 conveyor belts that transport the eggs to a central collection point. The collection system operates at a fixed belt speed that has not been optimized since start.

The problem is, during the hot months, temperatures like 30-35°C and above, many eggs break during the collection. Because the laying pattern of the hens will change due to stress and less food consumption and other reasons. So, they need to use the ventilation and cooling systems more often which increases the electricity utilization more.

So, I decided to find a best schedule for egg collection that reduces the overall cost in egg collection unit.

Some cases that cause problems.

» Less frequent collection and low belt speed cause eggs to accumulate on the belt. This leads to egg-to-egg contact, collisions, and overcrowding, and increases breakage rates.
» High frequent and Fast belts operation cause low utilization because the belt is often empty, and belt motors operate at high energy costs, this wastes electricity.
» Excessively high speeds cause eggs to shake, spin, and collide with cage or other eggs, it increases breakage.

2. System Description and Performance Goals

2.1 System Overview

The farm has 3 cages. Each cage has 3 tiers, and each tier has 2 sides, left and right. Each side has a conveyor belt that connects to the central collection point. So, each cage has six conveyor belts and in total the system has 18 conveyor belts, each approximately 12 meters long.

Each belt is run by a approximately 0.5 kW of power motors. The belts operate from 6:00 AM to 6:00 PM daily, aligning with the natural laying patterns of hens. Eggs collected from all 18 belts converge at a central collection point where they are sorted, cleaned, and packaged.

I identified several operational patterns:

- » Hens don't lay eggs at a constant rate throughout the day. Their laying follows a distinct temporal pattern.
- » During cooler months (25-28°C), breakage averages 2-3%.
- » During hot months (30-35°C), this increases to 4-5%.
- » High temperatures make eggshells more brittle and hens more restless, contributing to increased breakage.
- » Egg laying normal days:
    - Morning peak (6–10 AM): Highest arrival rate.
    - Midday (11 AM–3 PM): Reduced rate.
    - Afternoon/evening (4–7 PM): Low rate.

Current Operating method:

- » The system currently operates at a fixed belt speed, without considering egg arrival rates or environmental conditions.
- » Belts continuously run during operating hours with three scheduled collection times at 9:00 AM, 1:00 PM, and 5:00 PM.

2.2 Performance Objectives

Performance Goals:

1. Minimize egg breakage to increase saleable yield.
2. Minimize energy consumption of conveyor motors to support reduce overall energy use and the cost.
3. Optimize the trade-off between breakage costs and energy costs to enhance overall farm profitability.

During Hot peak time:

Metric	Symbol	Formula	Current	Target
Breakage Rate	P_b	$\frac{\text{Broken Eggs}}{\text{Total Eggs}} \times 100\%$	6-7%	< 5%
Energy Consumption	E_e	$\frac{\text{Energy Consumed}}{\text{Intact Eggs}}$ (kWh/egg)	10 kWh	< 7 kWh
Throughput	λ_{out}	Intact eggs	6500-7000 eggs/day	Maximize
Queue Length	L_q	Average eggs waiting	45 eggs	< 30 eggs
Total Cost	C_{total}	(Energy×40)+(Broken×20) Rs	165,649 Rs/day	Minimize

3. Modelling Approach and Assumptions

- To model the system I used simulation method
  - Egg arrivals follow non-homogeneous Poisson process
  - System exhibits typical queuing behavior with time-varying arrivals
  - Need to test various operational strategies efficiently
  - Requires multiple replications for confidence intervals
  - Allows testing without physical experimentation

- I primarily used SimPy python library and some of other python libraries to make the simulation code

System Model Formulas:

» Arrival Process

Egg laying follows a Non-Homogeneous Poisson Process:

$$\lambda(t) = \begin{cases} 0.03 & 6{:}00 \le t < 10{:}00 \\ 0.02 & 10{:}00 \le t < 14{:}00 \\ 0.01 & 14{:}00 \le t < 18{:}00 \end{cases} \quad \text{eggs/hen/minute}$$

With temperature correction:

$$\lambda_{\text{eff}}(t, T) = \lambda(t) \times [1 - 0.04(T - 25)] \qquad \text{for } T > 25°C$$

» Service Process

Each belt modelled as M/M/1 queue with service rate μ

$$\mu = \text{Belt Speed(eggs/minute)}$$

» Total system

Using Kendall's notation:

$$\mathrm{M}_t/\mathrm{M}/18/\infty/\infty/\mathrm{FCFS}$$

- M_t: Time-dependent Poisson arrivals
- M: Exponential service times
- 18: Parallel servers
- ∞: Infinite queue capacity
- ∞: Infinite population
- FCFS: First-Come-First-Served discipline

Assumptions:

Mathematical Assumptions:

1. Egg arrivals are memoryless and independent => non-homogeneous Poisson process
2. Transport times follow exponential distribution
3. Stationary Processes: Arrival and service rates stable within time slots
4. Independent Belts
5. Physical belt length limitations ignored

Operational Assumptions:

1. 10,080 hens uniformly distributed
2. Linear Temperature Effects: 4% production reduction per °C above 25°C
3. Breakage rate increases with queue length, speed, and temperature
4. Energy Consumption is proportional to belt speed and runtime
5. The simulation only for egg collection unit

Economic Assumptions:

1. Rs 25 per intact egg
2. Rs 40 per kWh

4. Data Description and Methodology

The primary data for the model are taken by simulating the cases due to the practical difficulty in observing real farm data.

Simulation Parameters

PARAMETER	VALUE	JUSTIFICATION
Total hens	10,080	10,000+ hens
Number of belts	18	3 cages × 3 tiers × 2 sides
Belt length	12m	
Motor power	0.75 hp/belt	
Egg value	Rs 25	At the time
Energy cost	Rs 40/kwh	Approximately match with the unit prices while calculating for month
Operating hours	6:00-18:00	Most eggs arrival duration

Simulation Methodology

I used 5 test case by changing the parameters to run in simulation to find the best case for the modeling (see Table 3.1)

1. Baseline Scenario (B0)
    1. At 25°C: Breakage ~2.5%, energy ~9 kWh/day per belt.
    2. At 35°C: Breakage rises to ~4.8%, energy ~9 kWh/day per belt
    3. Total cost: Higher on hot days due to both breakage and energy.

2. Temperature-Based Scenarios => Different temperatures with speed variants.
    1. T1 (25°C),
    2. T2 (32°C),
    3. T3 (≥35°C)

3. Time-of-Day Load Scenarios
    1. D1 (Morning peak)
    2. D2 (Midday low)
    3. D3 (Full day)

4. Belt Speed Optimization with different temperatures
    1. S1 (Low speed)
    2. S2 (Medium speed)
    3. S3 (High speed)

5. Collection Frequency Optimization
    1. F1 (3 runs/day)
    2. F2 (5 runs/day)
    3. F3 (6 runs/day)

By running the simulation , I collected the following Performance Metrics data:

- Queue length per belt
- Eggs arrived/processed/broken
- Energy consumed
- Current speed and temperature

5. Detailed Analysis and Findings

We can see graph 1.1 and 1.2 , the base case of the farm at hot seasons its cost is so high. All other cases which are in 35-degree temperatures are showing less breakage rate than the base case. But even better cases for the farm we can see the few scenarios are at under threshold rate. But the best optimal case we can find for the hot season is T3_35C_LOW which is low speed, 6 frequent schedules. Which generates 3.89% of breakage rate. Which is far below from our target.

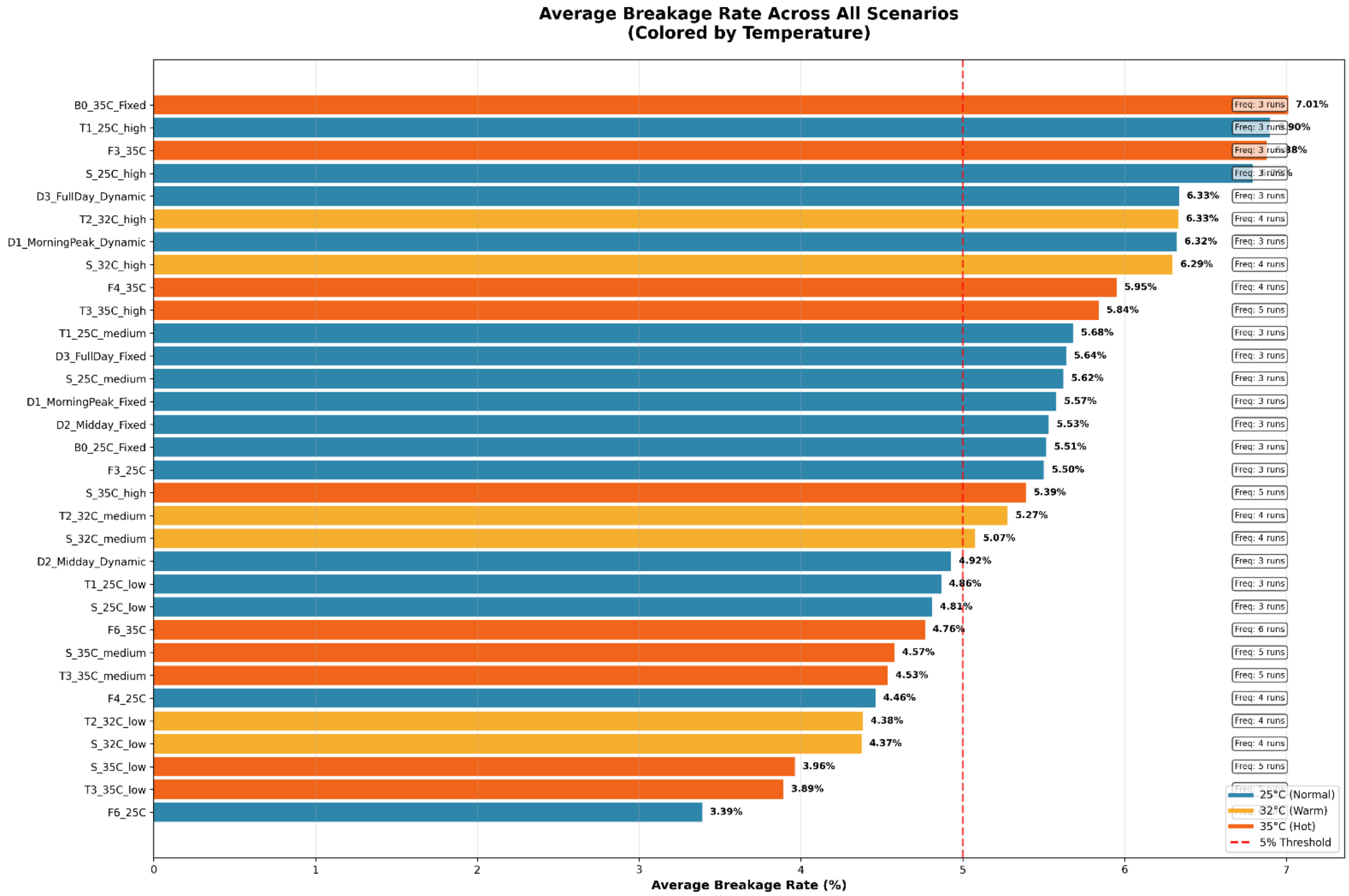
And we can see graph 2.1 the cost we can reduce from this schedule to Rs.275,910.00 from Rs.469,292.00. which means Rs.193,382.00 we can save a month.

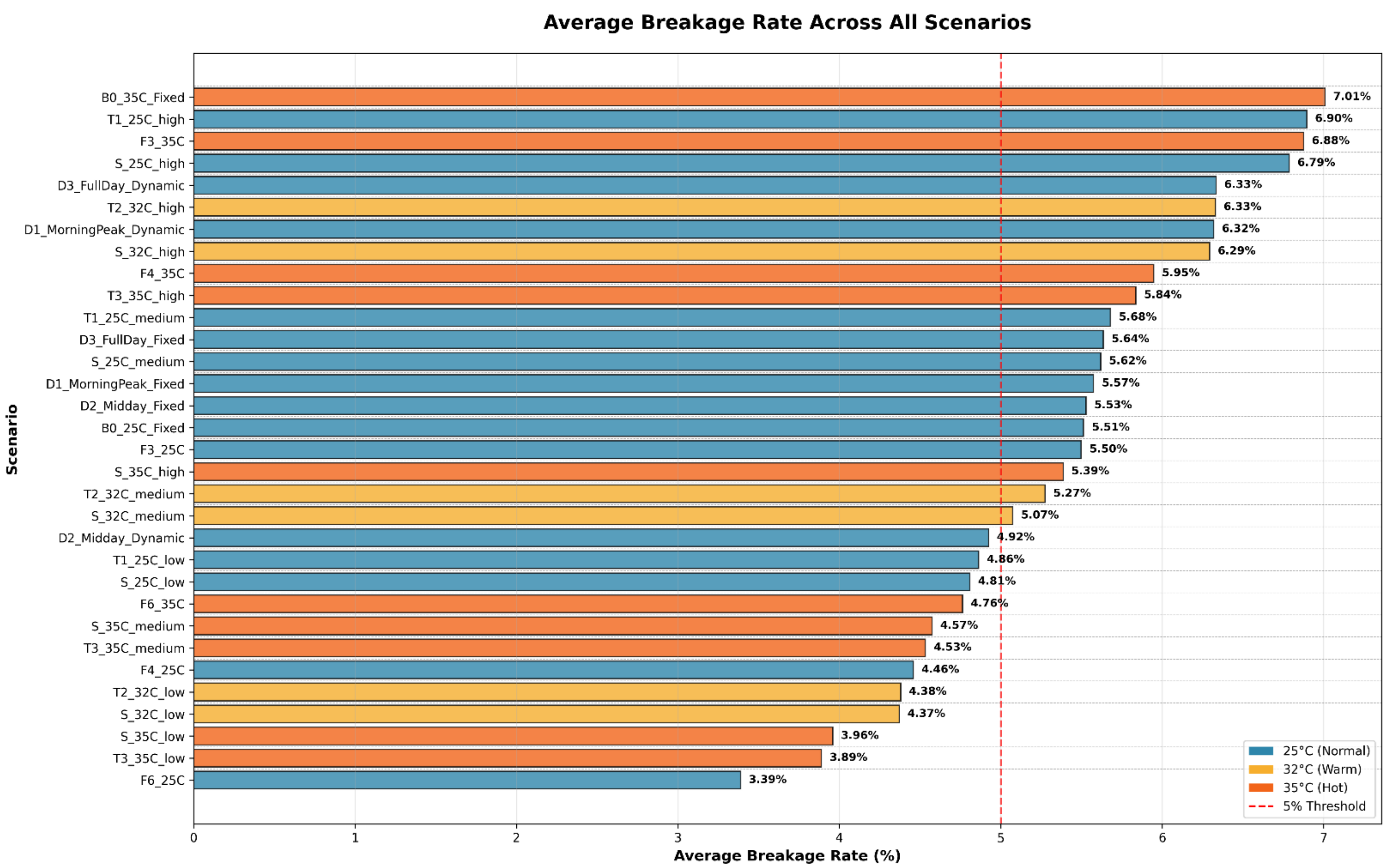
Graph 3.1 shows how far better the optimal case is than the base case. Even it is better in the normal season as well.

Finally, we can come to the conclusion of our performance modeling project that the optimal case we found is:

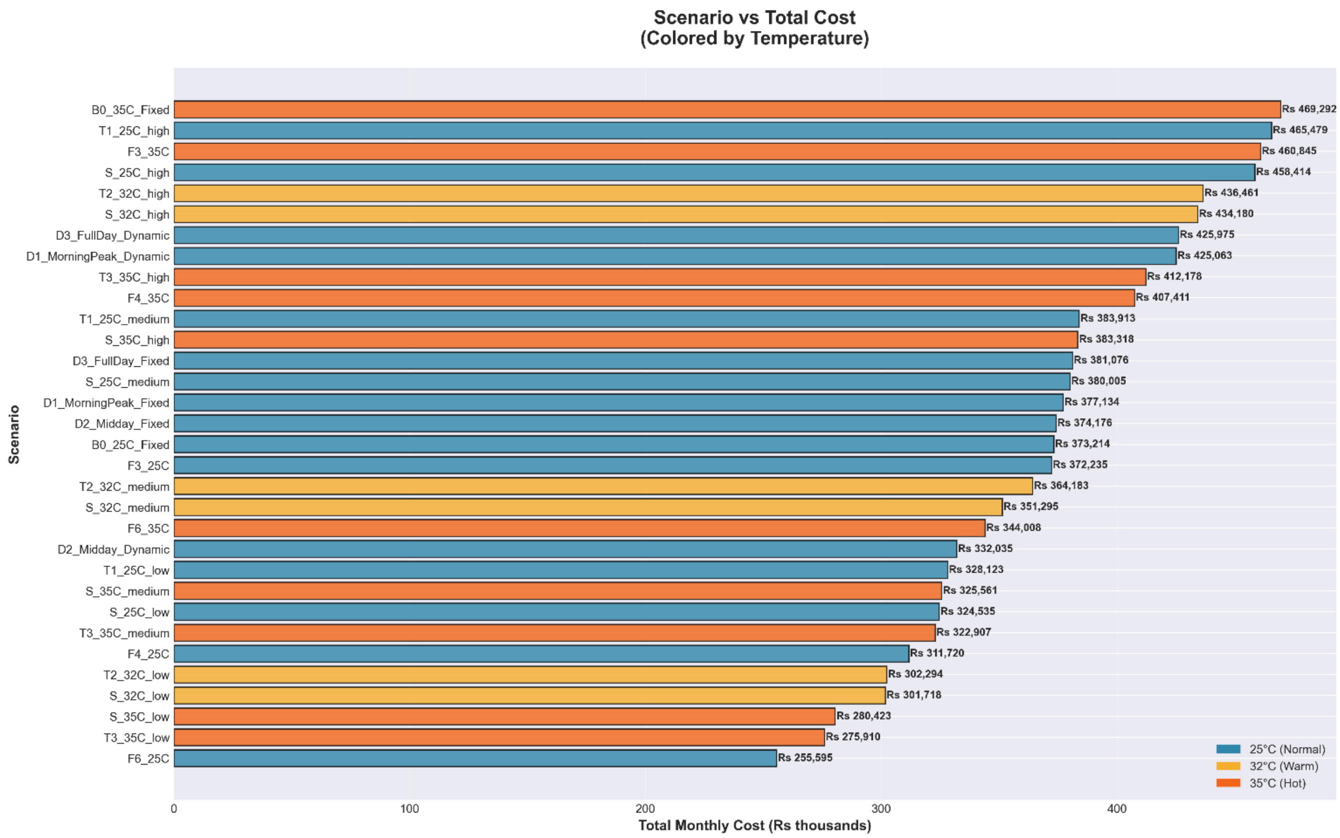
To run belts under Frequent 6/day at Low belt speed which is 80egg/min

6. Visualizations

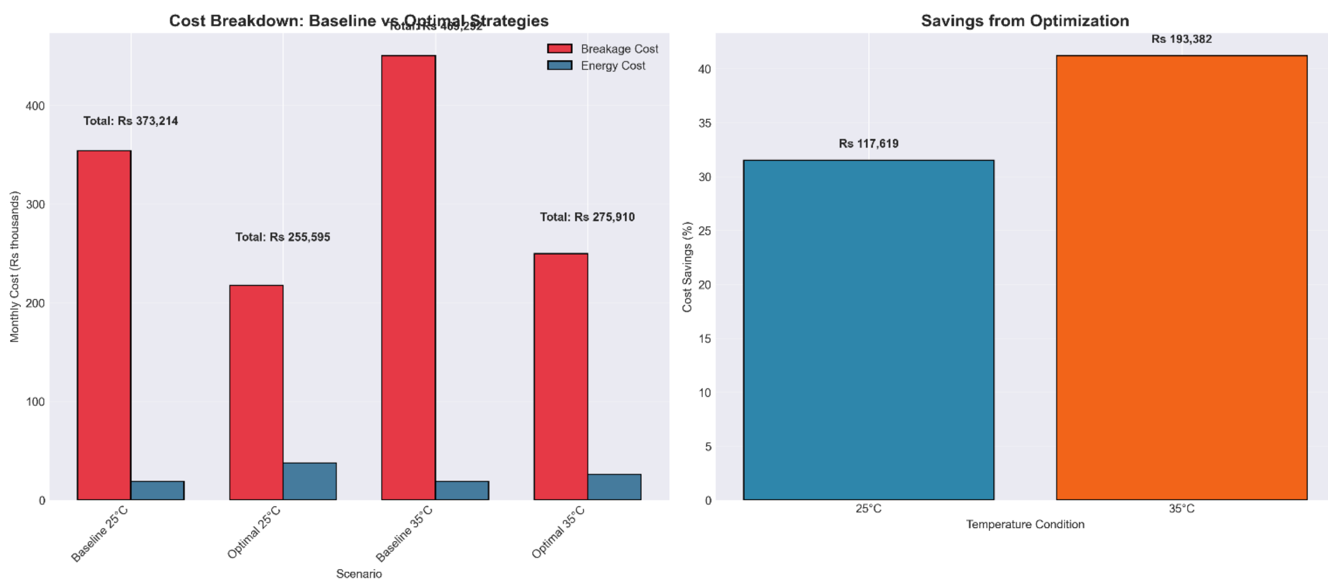




Graph 1.1 and Graph 1.2 : Breakage vs Test cases



Graph 2.1: Total cost vs Test cases



Graph 3.1 : Optimal case vs Base case(35^{o}C)

Complete Scenario and Definitions

SCENARIO CODE	DESCRIPTION	PARAMETERS	PURPOSE
B0	Baseline	120 eggs/min, 25°C, 3 runs	Reference case
T1	Normal Temp	25°C, speeds: 80,120,160	Temperature baseline
T2	Warm Temp	32°C, speeds: 80,120,160	Moderate heat effects
T3	Hot Temp	35°C, speeds: 80,120,160	Extreme heat effects
D1	Morning Peak	6:00-10:00, adaptive control	Peak load management
D2	Midday	10:00-14:00, adaptive control	Low load efficiency
D3	Full Day	6:00-18:00, adaptive control	Complete daily profile
S1	Low Speed	80 eggs/min, various temps	Lower bound analysis
S2	Medium Speed	120 eggs/min, various temps	Current operation
S3	High Speed	160 eggs/min, various temps	Upper bound analysis
F3	3 Runs	Fixed frequency	Low frequency baseline
F5	5 Runs	Increased frequency	Balanced approach
F6	6 Runs	High frequency	High responsiveness

Table 3.1: Scenario and Definitions

7. Limitations and Future Work

7.1 Limitations

- Does not account for mortality, replacement, or stress induced variations
- Actual temperature-breakage relationship may be nonlinear
- Ignores mechanical interactions
- Assumes immediate speed changes without acceleration delays
- lacks farm-specific calibration
- Some breakage factors estimated rather than measured
- Does not capture seasonal variations or equipment degradation
- Stress factors and behavioral adaptations not modelled
- Assumes the same temperature for whole farm.
- Ignores computational delays in real-time control
- Assumes stable power supply without fluctuations

7.2 Future Research Directions

- Use multi-agent simulation to model individual hen behavior and social interactions
- Use reinforcement learning for continuous parameter optimization
- Integrate weather forecasts for proactive speed adjustments
- Develop sensor network and control system
- Integrate blockchain traceability to quality tracking from collection to market

9. Conclusion

I successfully done the performance modeling simulation and found the best schedule for the farms profitability. The graphs show clear output of the best cases that the farm can apply in different scenarios. And I studied lot in this project, I studied how simulations help in the real world scenarios to find the solutions.

10. References

- Ceylon Electricity Board. (2024). *Electricity Tariff Structure*. Government of Sri Lanka.
- Performance Simulation : https://www.sciencedirect.com/topics/computer-science/performance-simulation

END