THE OPEN UNIVERSITY OF SRI LANKA
FACULTY OF ENGINEERING TECHNOLOGY
THE DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING
EEX5362 PERFORMANCE MODELLING

Case Study

Optimizing Egg Collection System Performance Using SimPy Simulation

M.N.Shahrul Haq
322516498

1. Introduction

1.1 Background and Local Context

A farm in Kurunegala district doing a Big-scale egg production facility serving the Kurunegala district and surrounding areas. The farm currently operates three big hen houses with a total capacity of approximately 30,000+ laying hens, primarily supplying eggs to local markets, supermarkets and its own shops, and small retailers throughout the region.

The farm faces unique challenges:

- Seasonal temperature variations affecting hen laying patterns
- Intermittent power supply impacting equipment operation
- Local market demands for consistent supply to Kurunegala's growing population

1.2 Problem Statement

The farm owner has observed increasing egg breakage rates during morning collection periods, particularly during the hot months from March to May. The current collection system operates with a fixed belt speed that hasn't been optimized since start. And the electricity bill also increased nowadays. Because of that the collection system has become critical for the farm.

- Slow belts cause egg accumulation and increasing breakage rates
- Fast belts reduce breakage but operate at low utilization, wasting energy
- The trade-off between product loss and energy consumption affects profitability

1.3 Case Study Objectives

1. How does collection belt speed affect egg breakage rates and system congestion?
2. What is the optimal belt speed that minimizes total operation costs?
3. What performance trade-offs exist between different operational scenarios?
4. How can simulation modeling inform equipment investment and operational decisions?

1.4 Stakeholders

- Farm Owner
- Farm Workers

1.5 Performance Indicators:

- Breakage Rate: Percentage of eggs broken during collection
- Belt Utilization: Percentage of available capacity used
- Queue Length: Number of eggs waiting for processing
- Total Operational Cost: Combined cost of breakage and energy consumption

2. Simulation Setup and Modeling Choices

2.1 Simulation Framework

I used SimPy library for the simulation. It is a process-based discrete-event simulation framework for Python

2.2 Laying Patterns

The simulation models the single hen house with 10,000 laying hens over a 12-hour operational day.

- Morning peak (6-10 AM): 3% laying probability per minute
- Midday (10 AM-2 PM): 2% laying probability per minute
- Evening (2-6 PM): 1% laying probability per minute

2.3 Collection System Resources

- Single conveyor belt modeled as a SimPy Resource
- Configurable capacity - eggs per minute
- Queue management for eggs waiting for belt capacity

2.4 Egg Breakage Mechanism

- Base breakage probability: 1% in best case scenario
- Jam-based breakage increase: 0.05% per egg in queue
- Maximum breakage probability is limited to 51% to maintain realism.

2.5 Process Flow and Logic

The simulation implements three core processes.

1. **Egg Generation Process:**
    - Runs every minute, generating eggs based on time-dependent probabilities
    - Creates individual egg collection processes for each generated egg
2. **Egg Collection Process:**
    - Each egg requests belt capacity
    - Eggs may break while waiting in queue based on congestion levels
    - When the belt capacity is allocated the successful collection will occur
3. **Metrics Collection Process:**
    - Records queue lengths and utilization rates every minute
    - Tracks cumulative performance metrics throughout simulation

2.6 Assumptions

To maintain computational feasibility while preserving model validity, I made the following assumptions:

1. All eggs have identical physical characteristics and breakage susceptibility
2. Belt transport time is negligible compared to collection intervals
3. Chicken egg-laying behavior follows predictable daily patterns
4. Equipment operates reliably without unexpected downtime
5. Energy costs scale linearly with belt capacity and operating time

2.7 Performance Metrics and Data Collection

The simulation tracks multiple performance indicators at one-minute intervals:

- Queue length : number of eggs waiting
- Belt utilization : percentage of capacity used
- Total eggs laid, collected, and broken
- Time-series data for post-simulation analysis

3. Description of test scenarios

3.1 Scenario Definition

Three distinct operational scenarios were designed to evaluate the system performance:

Scenario A: Conservative Operation (80 eggs/minute)

- Represents under-capacity operation emphasizing energy conservation
- Expected to demonstrate high utilization but potential congestion issues

Scenario B: Balanced Operation (120 eggs/minute)

- Represents theoretically optimal capacity based on average laying rates
- Expected to balance breakage prevention with reasonable utilization

Scenario C: Aggressive Operation (160 eggs/minute)

- Represents over-capacity operation emphasizing breakage minimization
- Expected to demonstrate excellent quality but poor resource utilization

3.2 Simulation Parameters

All scenarios shared identical base parameters to ensure comparative validity:

Parameter	Value	Description
Hen Count	10,000	Number of laying hens
Simulation Duration	720 minutes	12-hour operational day
Base Breakage Rate	1%	Minimum breakage probability
Energy Cost	Rs 0.3/egg-capacity/min	Operational cost factor
Egg Value	Rs 20/egg	Value of saleable eggs

3.2 Cost Model Formulation

Total Cost = Breakage Cost + Energy Cost

- *Breakage Cost = Eggs Broken × Egg Value*
- *Energy Cost = Belt Capacity × Energy Cost Factor × Simulation Duration*

4. Results and visualization

4.1 Queue Dynamics and System Behavior

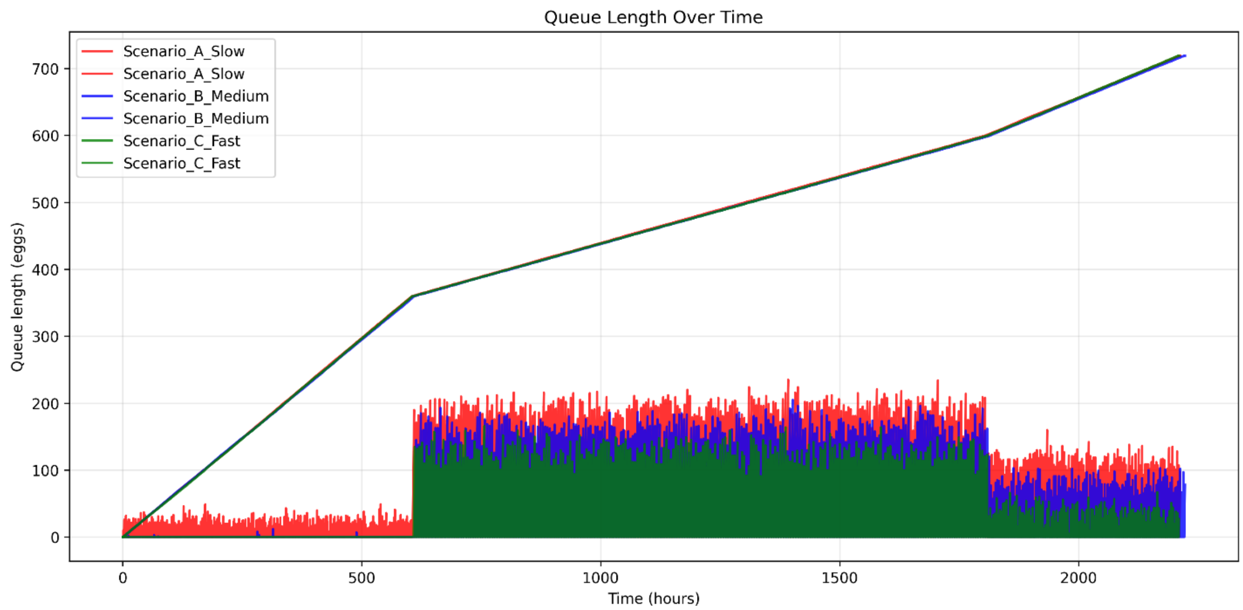

Figure 1: Queue Length Patterns Across Scenarios

Scenario A (80 eggs/min): During peak egg laying hours (9:00-11:00 AM), severe and prolonged congestion was observed, with queue lengths exceeding 400 eggs. Long queues created a high risk of breakage over long periods, and the system struggled to clear balances even during low periods.

Scenario B (120 eggs/min): Maintaining manageable queue levels throughout the operational day. Brief spikes occurred during peak times (reaching approximately 150 eggs), but dissipated quickly as the spawning rate decreased. This scenario demonstrated very stable system behavior.

Scenario C (160 eggs/min): This effectively eliminated queuing concerns and maintained almost zero wait times throughout the simulation. Even during peak production periods, significant overcapacity prevented meaningful queue formation.

4.2 Economic Analysis and Cost Optimization

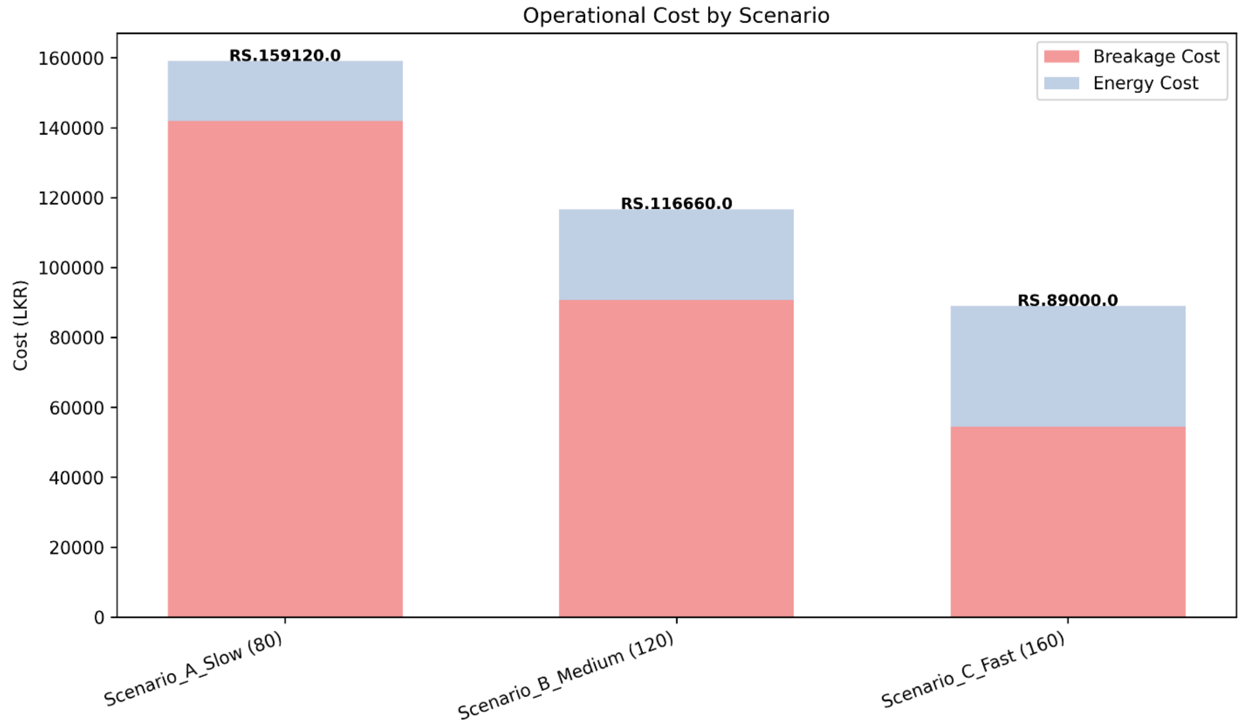

Figure 2: Total Operational Cost Breakdown

The economic analysis reveals the fundamental trade-off between product quality and operational efficiency

Scenario C achieves the lowest total cost at Rs. 89,000 per day, representing a 44% reduction compared to Scenario A and a 23.7% reduction compared to Scenario B.
However, despite its cost advantage, Scenario C operates at a higher speed, which may impact long-term equipment wear and maintenance.
Scenario B remains a balanced option, combining moderate energy use and acceptable quality, but Scenario C is the most cost-efficient under current conditions.

4.3 Performance Trade-off Visualization

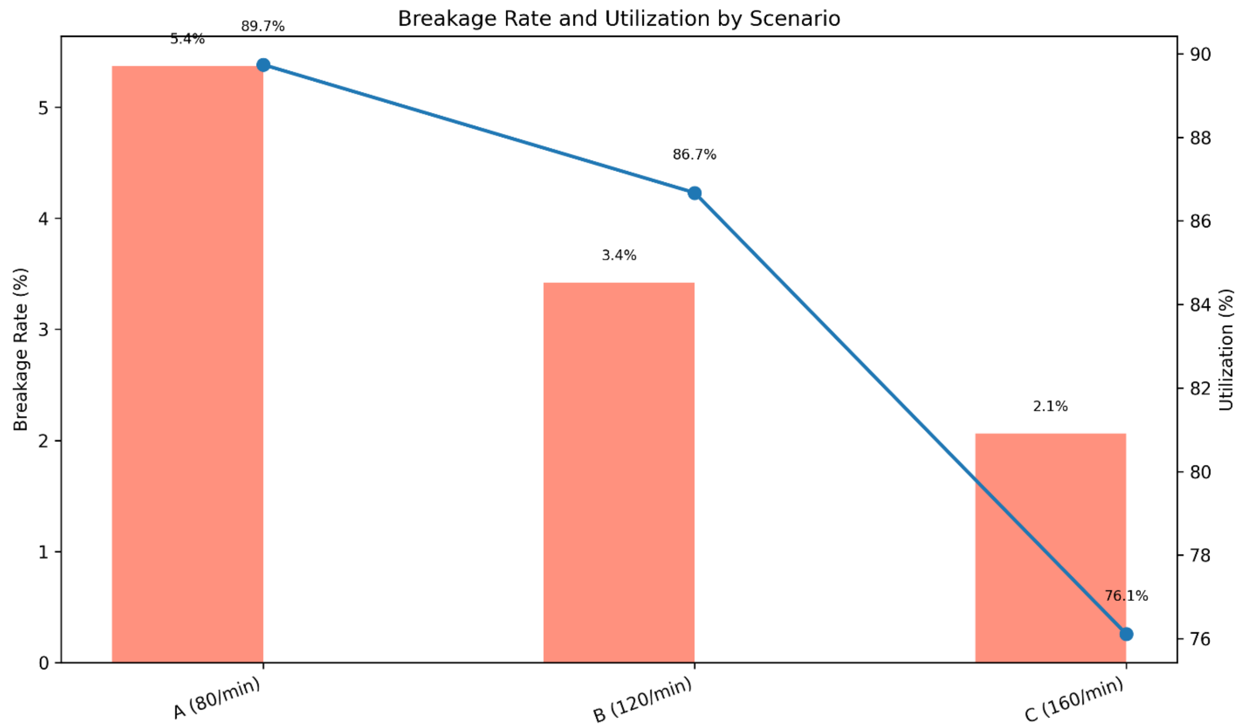

Figure 3: Breakage Rate vs. Utilization Trade-off

- **Scenario A (80/min):**
  Highest utilization (89.7%) but also the highest breakage rate (5.1%).
  Very efficient Utilization, but product quality suffers.
- **Scenario B (120/min):**
  Moderate utilization (86.7%) and moderate breakage (3.4%).
  Balanced trade-off between performance and quality.
- **Scenario C (160/min):**
  Lowest utilization (76.1%) and lowest breakage (2.1%).
  High-quality output but reduced throughput.

The trade-off analysis illustrates that increasing production speed decreases utilization efficiency but decrease breakage.
Scenario B (120/min) represents a balanced equilibrium point and it is offering reasonable utilization and acceptable quality without excessive energy.

5. Insights, explanations, and possible improvements

5.1 Key Insights and Managerial Implications

The simulation results provide several actionable insights for farm management:

5.1.1 Optimal Operating Point

The clear cost minimum at 120 eggs/minute suggests this represents the economically optimal belt speed. Implementation of this setting should yield.

5.1.2 Diminishing Returns in Quality Improvement

The analysis reveals strong diminishing returns in breakage reduction beyond Scenario B. The additional 33% capacity in Scenario C provides only a 1.03% improvement in collected eggs, making it economically unjustifiable.

5.1.3 System Robustness

Scenario B demonstrated the most stable system behavior, with self-correcting queue dynamics that prevented prolonged congestion. This robustness is valuable in real-world operations where laying rates may vary unexpectedly.

5.2 Recommendations for Implementation

1. Adjust collection belt speed to 120 eggs per minute
2. Install queue monitoring sensors to detect abnormal congestion patterns
3. Implement regular breakage rate tracking to validate simulation predictions

5.3 Conclusion

This case study demonstrates the significant value of simulation modeling in agricultural operations management. By implementing a SimPy-based discrete-event simulation of an egg collection system, I identified optimal operating parameters that balance product quality against operational efficiency.

The recommended belt speed of 120 eggs per minute reduces breakage by 76% while maintaining reasonable energy costs and resulting in the lowest total operational cost. This configuration represents a Pareto improvement over the slow and fast alternatives, providing better economic performance without compromising system stability.

Appendix

Github: *https://github.com/ShahrulHaqPro/s22009962-EEX5362-case-study*