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Optimization of Broiler Chicken Harvest Scheduling using Integer Linear Programming: A Case Study

Hilmi Akbar Wijaya[1], Danang Setiawan[1*]
[1]Industrial Engineering Department, Universitas Islam Indonesia, Jl. Kaliurang km 14.5, Sleman, Yogyakarta 55584
*Corresponding author: danang.setiawan@uii.ac.id

Abstract

An optimized scheduling system is essential for poultry farming to balance fluctuating market prices with fluctuating feed prices. In poultry farms, input costs account for over 90% of total expenses, with 66% allocated to feed and 25% to day-old chick purchases. This article presents an optimization model for chicken harvesting, using broiler chicken farming as a case study. A broiler chicken farm in Central Java is currently operating below optimal profitability because of a lack of a systematic harvest scheduling strategy. The Integer Linear Programming model was developed to obtain an optimal harvest schedule to maximize income with respect to operational constraints. The optimization indicates that the proposed schedule increases farm profit by 12.41% per production cycle, leading to an estimated additional yearly revenue of IDR 40,062,029. Furthermore, the sensitivity analysis indicates that market price and feed cost are the most significant factors that influence profitability, with market price fluctuations impacting profit by up to 100.17% and feeding cost changes affecting profitability by 66.10%. Minimizing the price of 5% feed can lead to an increase of 66% in profit and vice versa. This paper presents a framework of structured decision-making for poultry farms to obtain the highest possible profit and minimize loss occurrence by utilizing an optimal harvesting schedule.

Keywords : Integer Linear Programming, broiler chicken harvest, optimization, sensitivity analysis

INTRODUCTION

Broiler chicken farming is among the most important businesses in Indonesia's poultry industry since it plays a vital role in animal protein production. Chicken farming has grown dramatically in the last decade due to the increase in demand and technological advancement (BPS, 2022). In 2021, Indonesia's chicken meat consumption increased by 8.62% from 2020, and its production rose by 6.43% (BPS, 2022). Furthermore, in 2023, 135 million chickens valued at IDR 3.954 trillion were produced nationally, 64.65% of which originated from Java Island (BPS, 2024).

Despite the significant growth, small- and medium-sized chicken farms encounter enormous operational challenges. This challenge is particularly contributed to by the high proportion of input cost in total expense and the fluctuation of market price. Sehabudin et al. (2022) reveal that input costs account for over 90% of total farm expenses, with 66% spent on feed and 25% on day-old chick (DOC) purchases. Similar findings were made by the Central Bureau of Statistics (BPS), which reported that 68.81% of poultry expenditure in Indonesia is contributed by feed expenses (BPS, 2024). In addition, the fluctuation of feed costs and chicken prices substantially impacts profitability as it leads to reduced profit margins and increasing operational risks (Widiarta et al., 2024). Therefore, to minimize operational risk and unnecessary feeding expenses, poultry farmers aim to sell chickens at optimal maturity (You & Hsieh, 2018). In other words, poultry farms should determine the optimum harvesting schedule that considers various internal and external constraints and aims to minimize cost or maximize profit. Poor harvesting scheduling negatively affects farm profitability as it leads to excess feed consumption, suboptimal market timing, and increased mortality rates.

Numerous case studies have examined the application of optimization models in the agriculture and poultry sectors in great detail. Under specific operational constraints, prior research concentrated on maximizing profitability, minimizing expenses, and improving efficiency. Mixed Integer Linear Programming (MILP) has proven effective for scheduling problems in agricultural and livestock operations. Vincent & Sunarni (2022) utilized MILP to optimize rooftop garden planting schedules by minimizing costs, while Kello et al. (2017) applied the same method for tomato harvesting schedules, considering factors such as land availability, cost, demand, and quality control. Suharjito et al. (2010) demonstrated MILP's capability to address complex scheduling and resource allocation problems to improve corn planting schedules. In addition, to balance conflicting goals, Dwiratna et al. 2016) utilized GP in this research to address the conflicting goals of land use and regulatory requirements.

Linear programming (LP) is a common method in agricultural applications. Mallick et al. (Mallick et al., 2020) optimize poultry feed supply for cost minimization with consideration of demands and some specifications. In addition, Caixeta-Filho (Caixeta-Filho, 2006) uses LP to reduce orange harvesting schedules under resource and demand constraints. In addition, multi-objective optimization problems (MOAP) have been utilized to balance multiple operational goals. Asrol & Delfitriani (Asrol & Delfitriani, 2021) used MOAP to minimize transportation costs and maximize product quality in sugarcane harvesting with respect to capacity, time, and sugar content constraints. Furthermore, hybrid methodologies such as interacting Mixed Integer Programming (MIP) and heuristic models have been used for complex scheduling problems. Brevik et al. (Brevik et al., 2020) built an integrated MIP-based model of the chicken production supply chain from the acceptance of fertilized eggs to the delivery of mature chickens to slaughterhouses. You & Hsieh (You & Hsieh, 2018) employed hybrid heuristics to optimize multi-breed and multi-henhouse chicken harvesting for profit maximization subject to constraint management of demand, breeding time, and capacity.

Despite advancements in methodology, existing research highlights a gap in the use of optimization models for planning broiler chicken harvests in vertically integrated supply chains. From a supply chain perspective, broiler farming consists of breeders, hatcheries, feed mills, farms, slaughterhouses, wholesalers, and retailers, with this study focusing on the farm aspect (Solano-Blanco et al., 2023). Most studies sought to minimize costs or maximize profits without addressing the combined effects of volatility in operational uncertainty, market price, and mortality. This study attempts to bridge this gap by developing an integer linear programming (ILP) model that optimizes harvest planning, given consideration of critical operational factors such as feed prices, mortality rates, and price volatility in the marketplace. Sensitivity analysis is also conducted to establish the effect of market volatility and operational risks on farm profitability.

METHODS

This study follows the principal phase of implementing operation research (OR) consisting of 5 steps: (1) definition of the problem, (2) construction of the model, (3) solution of the model, (4) validation of the model, and (5) implementation of the solution (Taha, 2017). However, due to time limitation constraints, this study will cover steps 1-4.

Problem Definition

The definition of the problem aims to identify the problem's scope under study (Taha, 2017). This research used Arie Farm - a commercial broiler farm in Indonesia with a two-level poultry production system that can handle 40,000 chickens per cycle - as a case study. The farm employs a closed-house type of production system to guarantee optimal environmental growth conditions. Although it follows a systematic farming strategy, the farm does not have an optimal harvest scheduling system, leading to inefficient profitability as a result of excessive feeding expenses and poor market timing.

Model Construction

The model construction stage aims to translate the problem definition into a mathematical model (Taha, 2017). In order to support model construction, a combination of primary and secondary data sources was utilized to ensure the relevance and accuracy of the model. The primary data was obtained through historical farm data. It consisted of feed cost (feed types, consumption rate, feed cost), selling price in terms of chicken weight, chicken weight based on day, and production cost (DOC price, medicine price, operating cost). In addition, secondary data were collected from publications and government reports that were needed to support discussion and analysis.

An Integer Linear Programming (ILP) model was constructed to optimize the chicken harvest scheduling problem. ILP was selected due to its capability to handle discrete variables, such as the number of chickens harvested on specific days in this case. The modeling step is structured using a multi-stage flow framework, as depicted in Figure 1. The framework models the broiler harvesting system as a multi-stage decision process, where chickens from different batches move through sequential harvesting periods. The decision variables determine the number of chickens to harvest at each stage by ensuring an optimized schedule that minimizes costs and maximizes profitability while adhering to operational constraints.

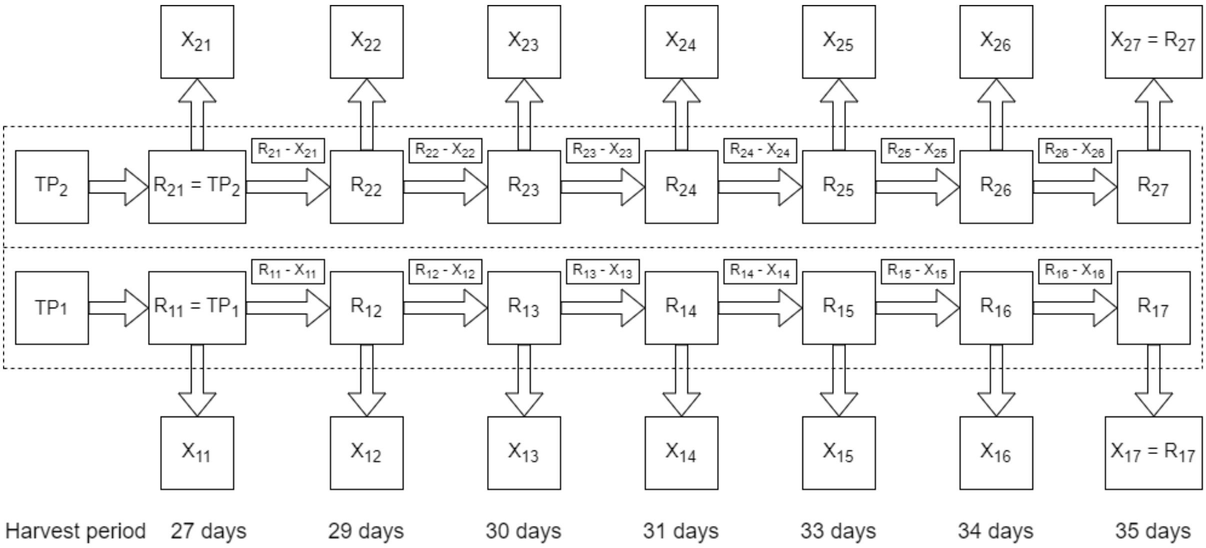

Figure 1. Conceptual Model (Wijaya, 2024)

Referring to the conceptual model, an ILP model was developed to optimize the harvest scheduling process.

Indices:

n = chicken coop (Coop no. 1, 2)
t = harvest period (Day no. 1, 2, 3, 4, 5, 6, 7 days)

Decision Variable:

X_{nt} = Number of chickens harvested from batch n at time t.
R_{nt} = Remaining chickens in batch n after harvest at t

Parameter

K_t = Harvest capacity at time t (kg)
W_{nt} = Weight of chicken batch n at harvest time t (kg/chicken)
HW_{nt} = Total harvested weight of chicken's batch n at time t (kg)
THW_t = Total harvested weight at time t (kg), where $THW_t = THW_{1t} + THW_{2t}$
F_{nt} = Cumulative feed cost for batch n until time t (Rp/bird)
FR = Remaining feed cost (Rp)
P_{nt} = Selling price of batch n at time t (Rp/chicken)
R_{nt} = Revenue from selling chickens of batch n at time t (Rp/chicken)
D_{nt} = Stock density of batch n at harvest time t (bird/m2)
A = Farm area per floor (m2)
C = day-old chick (DOC) price (Rp/chicken)
M = Medication cost per bird (Rp/chicken)
O = Operational cost (Rp)
TP = Initial total population (chicken)

Maximize:

$$Z = \sum_{n=1}^{2}\sum_{t=1}^{7}(P_{nt}X_{nt} - F_{nt}X_{nt} - CX_{nt} - MX_{nt}) - O \quad (1)$$

Subject to:

$$\sum_{n=1}^{2}\sum_{t=1}^{3} X_{nt} = 10{,}000 \quad (2)$$

$$\sum_{n=1}^{2}\sum_{t=4}^{7} X_{nt} = TP - 10{,}000 \quad (3)$$

$$\sum_{n=1}^{2}\sum_{t=1}^{7} D_{nt} \leq 14\,, where\ D_{nt} = \frac{R_{nt}}{A} \quad (4)$$

$$\sum_{n=1}^{2} THW_{nt} \leq 12000 \quad (5)$$

$$X_{nt} \in \text{integer}, \ \forall n, t \quad (6)$$

The objective function of this study is to maximize the total profit from broiler chicken harvesting while considering operational costs (1). Constraints (2) and (3) represent that the number of chickens harvested in the initial harvesting phase must equal 50% of the initial total population. In this study, the total initial population for planning purposes is assumed to be 20,000 chickens; therefore, the first phase harvesting constraint is set at 10,000 chickens. Constraint (4) ensures that stock density in cages must not exceed the maximum allowable limit. In this study, the cage density limit is 14 chickens/m2. Constraint (5) ensures that the number of chickens harvested per day must not exceed the chicken harvesting capacity per day. Constraint (6) ensure the integer value of each decision variable.

Model Solution and Validity

Subsequently, the harvesting model was solved using Excel Solver, an Excel add-in capable of efficiently solving linear programming problems. The following are the model solution and validity steps:

1. Data Structuring
   Relevant historical data were identified and structured into a spreadsheet. The harvesting model used minimizing cost as the objective function and demand, cage density, and harvesting capacity as constraints.
2. Model Formulation
   The ILP was formulated into an Excel spreadsheet by referring to the mathematical mode developed in the previous stage. Decision variables were entered into cells that represented the number of chickens harvested in each cage and time period. Constraints such as cage density, harvesting capacity, and demand levels were applied using Excel formulas. In addition, the objective function, which is to maximize profit, was determined through sum-product calculations.
3. Solver Setup
   Model mathematics was then added to Excel Solver. The objective function cell was selected and defined as maximizing profit. The decision variables were added to the changing variable cells to represent the harvesting schedule. Furthermore, constraints were added to ensure that all operational constraints were met, and Simplex LP was selected as the solving method. The solver was run after ensuring all components in the mathematical model were captured in Excel Solver.
4. Validation and Sensitivity Analysis
   The optimization result was validated by comparing the results with the farm's historical data. Subsequently, a sensitivity analysis was performed to analyze the effect of parameter changes on the objective function.

RESULTS AND DISCUSSION

Optimized Harvest Scheduling

The ILP model successfully optimized the harvest scheduling for optimal profitability under operating constraints. By staggering the harvest dates based on chicken growth patterns, market price fluctuations, and feed efficiency, the model allowed better cost management and revenue realization. The optimized schedule distributed the harvest over a number of days, preventing overfeeding costs and mortality loss due to overcrowding.

The optimized harvest plan produced more revenue by IDR 8,012,505 per cycle of production, which translates to an annual amount of IDR 40,062,029 for Arie Farm. Slaughtering the chickens at the peak of their efficiency growth, the model did not waste any feed, and they saved a lot of money. The model optimized harvesting during the highest market price to ensure maximum profitability. Through optimal density levels in the poultry house and optimizing the number of chickens that overgrow, mortality was reduced, and farm sustainability was enhanced. This finding is relevant to research conducted by You & Hsieh (2018), which suggests that farmers should harvest and sell chicken at optimal maturity. The optimized harvest schedule is depicted in Table 1, while the comparison of the current and proposed methodology is stated in Figure 2. The proposed harvesting schedule focuses on harvesting day, which has the highest difference between chicken price per kg and feed cost.

Tabel 1. Optimized harvest schedule

Partial harvests	
Day No	Number of chickens harvested
Day 27	5,948 chickens
Day 29	7,272 chickens
Day 30	6,780 chickens

Final harvests	
Day 31	6,269 chickens
Day 33	5,383 chickens
Day 34	5,059 chickens
Day 35	3,281 chickens

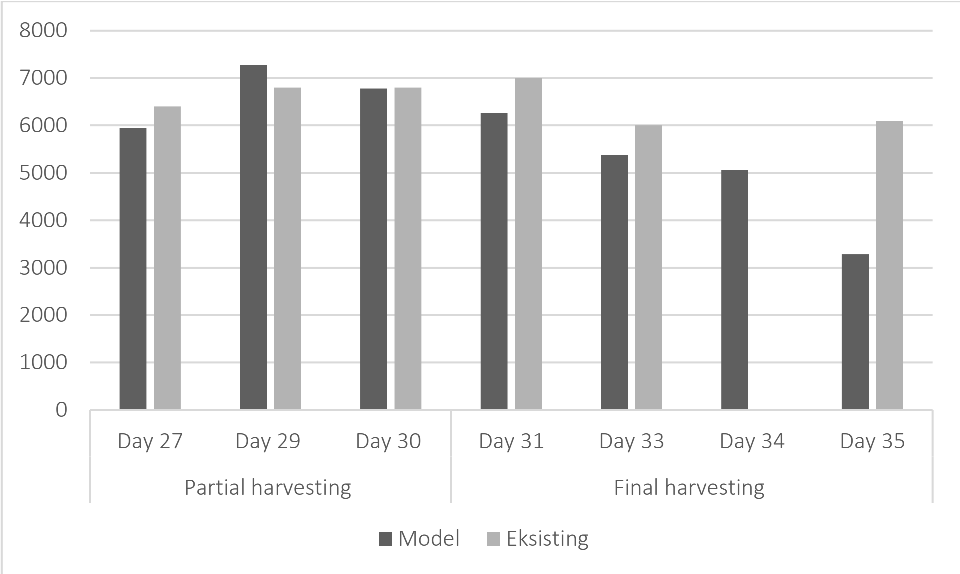

Figure 1. Comparison of Optimized Scheduling and Existing Scheduling

The results demonstrate a notable improvement in profitability when using the optimized scheduling model. The ILP model achieved an optimal profit of Rp72,556,160.59, significantly higher than the average profit of Rp64,543,655.60 obtained from the farm's existing scheduling method. This represents an increase of approximately 12.42% in overall profits, indicating the model's ability to enhance operational efficiency and financial performance. Table 1 depicts a comparative analysis of profits between the farm's current scheduling approach and the optimized scheduling model developed in this research. The existing scheduling method, implemented over five different periods, resulted in profits ranging from Rp64,315,388.80 to Rp64,761,240.80. Despite the consistency in results across these periods, none approached the profitability levels achieved by the ILP-optimized schedule.

Table 1. Comparison of Optimized Scheduling and Historical Data

Scheduling Method	Farming Period	Profit (Rp)
Historical Data (Farm)	Period 1	64,315,388.80
	Period 2	64,440,203.80
	Period 3	64,761,240.80
	Period 4	64,761,240.80
	Period 5	64,440,203.80
	Average	64,543,655.60
Optimized Scheduling (ILP)		72,556,160.59

4.2 Sensitivity Analysis

A sensitivity analysis was conducted to evaluate the robustness of the ILP model developed for broiler harvest scheduling optimization. Sensitivity analysis investigates how variations in key operating parameters—market price, feed cost, demand, and harvesting capacity—affect overall profitability. The sensitivity analysis indicates that some factors affect financial performance much more significantly than others, as depicted in Figure 3.

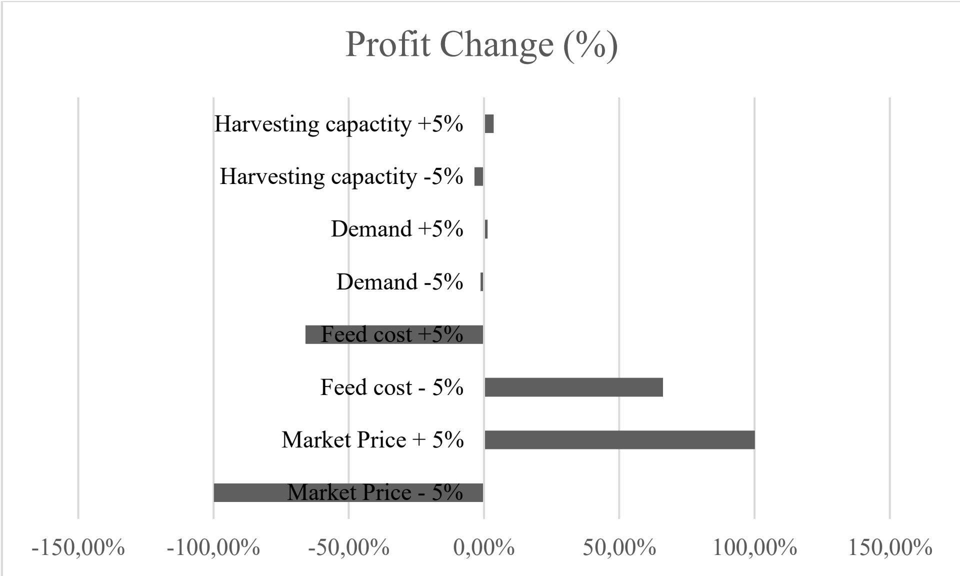

Figure 2. Sensitivity Analysis

The most notable parameter in sensitivity analysis is the market price, which indicates extreme sensitivity in influencing profitability. A 5% rise in market price caused a profit growth of 100.17%; conversely, a 5% fall in market price led to a decrease in profit of 99.79%. Sensitivity analysis reveals that market price uncertainty is the biggest risk in the poultry farm industry. Therefore, conducting poultry farming under a partnership scheme could be a potential strategy to minimize the impact of market price volatility. Sehabudin et al., 2022) highlight two possible partnership strategies in poultry farming in Indonesia: Perusahaan Inti Rakyat (PIR) and Maklon. Farmers engaged in partnership schemes tend to have higher incomes compared to those operating without a partnership (Effendi et al., 2023). Furthermore, a study by (Sutanto et al., 2024) found that farmers currently face a condition of powerlessness in determining prices and dealing with unpredictable market conditions, where partnerships can serve as an alternative solution to maintain stable prices.

On the other hand, feed price is also a significant factor in profitability, even though it is to a smaller degree than market price variability. Cutting feed costs by 5% provided a rise in profits of 66.10%, while a 5% increase provided a decline of 66.03%. Feed costs constitute a very high proportion of the overall costs of production. Sehabudin et al. (2022) and BPS (2022) stated that feed costs contribute to more than 66% of farming expenses. Therefore, effective consumption of feed and long-term purchase agreements potentially offers financial security and improved margins.

On the other hand, demand and variation in harvesting capacity influenced profitability fairly less. On the increase of demand by 5%, profit increased by 1.26%, but a reduction in demand by 5% reduced profit by 1.34%, which illustrates that variability in demand leads to no significant effect on the objective function. In addition, an increase in harvesting capacity by 5% added only 3.57% in profit, while its reduction by 5% lost 3.49%. This sensitivity analysis suggests that under current conditions, increasing demand and investing to obtain an increase in harvesting capacity should not be prioritized. To conclude, the sensitivity analysis suggests that market price and feed cost are the most sensitive parameters on profitability in broiler chicken farms. At the same time, demand and harvesting capacity have small impacts. These findings indicate that the harvesting optimization model can be a potential solution to address market price and feed cost by ensuring chickens are harvested at the optimum profitability. This study strengthens the findings of research (Salim et al., 2020), mentioning that supportive strategies should be provided by the government to ensure the availability of feed and stability of feed prices.

This study can be extended by incorporating the company's perspective. From the standpoint of a company that partners with multiple farmers, a multi-level scheduling approach can be applied to allocate Day-Old Chicks (DOCs) to farmers and coordinate scheduling among them, as explored by Praseeratasang et al. (Praseeratasang et al., 2019). The current mathematical model developed in this study can be used with modification in the number of farmers instead of chicken cope.

CONCLUSION

This study optimized the scheduling of broiler chicken harvesting using an integer linear programming (ILP) model for maximum profitability under operating limitation constraints. The optimal model earned a profit of Rp72,556,161, 12.42% higher than the average profits from implementing the current scheduling technique at Arie Farm. Sensitivity analysis indicated that market price and feed price are the most influential variables affecting profitability, with demand and harvesting capacity having little effect. The research findings highlight the necessity of strategic planning for considering price volatility and managing feed costs in order to achieve financial success in the long run. The ILP model is also an effective decision-support tool for harvest planning and obtaining profitability optimization in broiler chicken production. Future research can be conducted by evaluating different approaches, such as multi-objective optimization or heuristic, and considering additional constraints, such as labor costs, seasonal variations in demand, and governmental policies, to make the model more applicable.

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