

## ANALYSIS OF THE EFFECTIVENESS OF DEMAND DATA PATTERNS AND LOTTING TECHNIQUES BASED ON EXPERIMENTAL DESIGN



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### Abstract

Lot sizing technique is a method of determining the size of a lot in a procurement process. Lot sizing technique has been extensively analyzed by experts, as ordering costs, holding costs, and lot sizes have a significant impact on the total ordering cost. One of the many lot sizing techniques is the Groff algorithm, which is rarely used. Other lot sizing techniques include the Wagner-Whitin algorithm, Silver-Meal algorithm, Least Unit Cost, Least Total Cost, Part Period Balancing, Period Order Quantity, and Lot for Lot. Simulation data was collected from a real company, including ordering and holding costs, and demand data was generated with four different demand patterns: increasing, decreasing, random, and stationary. The initial analysis concludes that the Silver-Meal algorithm and Groff algorithm have relative biases that are close to the Wagner-Whitin algorithm. The second analysis concludes that for lot sizing techniques, the calculated F-value (84.3) is larger than the table F-value (2,1), indicating a significant influence of lot sizing techniques on the relative bias percentage. Furthermore, the analysis of demand patterns shows that the calculated F-value (80.0) is larger than the table F-value (2,6), indicating a significant influence of demand patterns on the relative bias percentage.

**Keywords:** ANOVA, Experimental Design, Groff Algorithm, Lotting Technique

## INTRODUCTION

The presence of Management Requirement Planning (MRP) in a company determines the stability of production or assets that will determine the success or failure of a company (Susanti, 2020; Putri & Rosydi, 2020; Haryani & Aldini, 2022). Therefore, it is necessary to create and manage an inventory system effectively to maximize profits for the company (Puspita et al., 2020; Najy, 2020; Rimawan et al., 2018). One of the techniques involved in MRP is lot sizing, which deals with balancing set-up costs/ordering costs or holding costs related to net requirements calculated from MRP planning processes (Badri et al., 2020; Budde et al., 2022; Florim et al., 2019).

Groff's algorithm is one of the many lot sizing techniques that can be used, but it is still less commonly used compared to techniques such as Silver and Meal (Walujo & Koesdijati, 2022; Poolcharuansin et al., 2018), Least Unit Cost (Al-najjar, 2022; Florim et al., 2019), Least Total Cost (Mahdi et al., 2018; Vania & Yolina, 2021), Part Period Balancing (Odedairo & Ladokun, 2018; Prakaiwichien & Rungreunganun, 2018), Period Order Quantity (Abdullah et al., 2020; Yıldız & Yaman, 2018), and Lot-for-Lot (Huda & Hartati, 2021; Kurniawan & Raphaeli, 2018).

Research on lot sizing techniques has been conducted extensively, with various techniques used in research, some of which are directly applied to a company and some in a research case. Therefore, the problem to be addressed in this study is to determine the effectiveness of lot sizing techniques with different demand patterns. The problem formulation for this research is as follows.

- (i) What is the effectiveness of the existing condition of heuristic lot sizing methods compared to deterministic lot sizing methods with the response variable of average relative bias percentage?
- (ii) What is the influence of demand pattern on lot sizing techniques with the response variable of relative bias percentage?

## RESEARCH METHOD

Inventory refers to materials or goods that are stored for a specific purpose, such as production or assembly processes, spare parts for equipment, or for sale. Based on their function, inventories are categorized into three types: lot-size inventory, which is held in larger quantities than needed at the time; fluctuation stock, which is held to address unpredictable demand; and anticipation stock, which is held to address predictable fluctuations in demand, such as seasonal demand. In terms of their physical form, inventories can be classified into five types: raw materials, parts/components, supplies, work in process, and finished goods. Costs associated with inventory can be categorized into four types (Gurtu, 2021; Onanaye & Oyebode, 2019); (Hamadneh et al., 2024).

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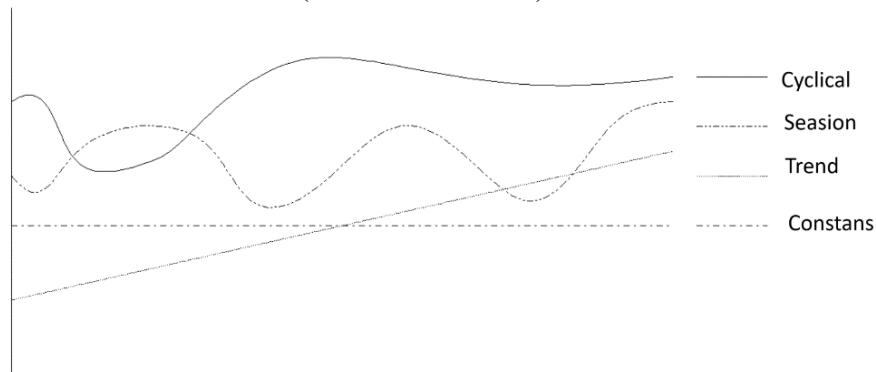
and finished goods. Costs associated with inventory can be categorized into four types (Gurtu, 2021; Onanaye & Oyeboode, 2019):

- (i) Holding cost, which include capital cost, handling, storage, obsolescence, depreciation, and costs that vary directly with inventory quantity;
- (ii) Ordering or procurement costs, which include administrative expenses associated with purchasing from suppliers;
- (iii) Manufacturing or set-up costs, which are incurred when materials are produced in-house rather than purchased; and
- (iv) Shortage costs, which are incurred when inventory levels are insufficient to meet demand.

### Various Types of Data Patterns

Typically, data patterns are not ideal and do not exhibit smooth lines, but instead always have a degree of randomness surrounding them. This randomness is caused by unpredictable data fluctuations. Various types of data are utilized, including historical purchasing data from company records and simulated data.

According to (Liu, 2020; Setyowati & Wahjuni, 2019), demand data patterns consist of four types: constant, trend, seasonal, and cyclical, as illustrated in Figure 1. Data patterns generally do not follow smooth lines, but rather always exhibit a level of randomness caused by unpredictable data fluctuations (Maier et al., 2019).



**Figure 1.**  
**Time Series Patterns.**  
Source: (Qu et al., 2020).

### Lotting

Lot sizing is a process used to determine the quantity of item components that should be provided to meet production process requirements. There are various techniques used in lot sizing to fulfill demand in a production system, including:

- (i) Wagner-Within algorithm: a dynamic programming approach that uses simple algorithms in its calculations. This technique considers all possible combinations to take the optimal lot size (Czajkowski et al., 2019; Hanafizadeh et al., 2019);
- (ii) Groff algorithm: developed by Groff (1979), based on determining the maximum lot size. It is a heuristic algorithm that selects the lot size covering the demand for a certain period, achieving the minimum total cost (Baciarello et al., 2013);
- (iii) Silver-Meal algorithm: developed by Edward Silver and Harlan Meal based on the period cost. It is a heuristic algorithm that selects the lot size covering the demand for

- a certain period, achieving the minimum total cost (Walujo & Koesdijati, 2022; Poolcharuansin et al., 2018);
- (iv) Part Period Balancing: similar to the least total cost technique, this method also evaluates the lot sizes by considering future or past periods. This technique utilizes all available information in the demand schedule and uses lot sizing to determine the order quantity based on a balance between ordering and holding costs to meet the demand. This method selects the number of periods required to meet additional orders based on accumulated holding and ordering costs (Odedairo & Ladokun, 2018; Prakaiwichien & Rungreunganun, 2018);
  - (v) Period Order Quantity: a calculation that focuses on demand at a fixed period based on modifications to the EOQ. This technique adjusts for the real situation where net requirements may not be uniform and continuous (Abdullah et al., 2020; Yıldız & Yaman, 2018);
  - (vi) Least Unit Cost: a method that uses the convexity property of per-unit costs (ordering and holding costs) against the order quantity to determine the optimal lot size. The optimal order quantity occurs at the lot size where the per-unit cost is the lowest (Al-najjar, 2022; Florim et al., 2019);
  - (vii) Lot-for-Lot Method: where the order quantity is equal to the demand for each period, meaning the planned order quantity is always the same as the total net requirements per period. This heuristic method is the simplest lot sizing method, minimizing inventory investment while allowing lead time reduction and manufacturing process flexibility. This is consistent with the goal of lot sizing in just-in-time production, where the setup cost is zero (Huda & Hartati, 2021; Kurniawan & Raphaeli, 2018).

### **Design and Analysis of Experiments**

Design in this context refers to three terms, namely designing: planning what needs to be done and arranging everything in advance. Design: what has been designed, prepared, planned or programmed. Designing: the effort, details, or intricacies of designing. Here, design is synonymous with designing. Analysis is an action or effort to draw conclusions from experimental data. An experiment is a series of trials or tests conducted by controlling several factors to produce measurable results (the characteristics being investigated) or it can also be said to be a planned investigation to obtain new facts, to strengthen or reject previous experimental results. Therefore, experimental design and analysis are the planning of experiments accompanied by a discussion of the statistical analysis to be used (Suherman et al., 2023); (Suherman et al., 2023); (Suherman et al., 2023); (Botha et al., 2021; Dangat et al., 2021); (Maier et al., 2019).

### **Statistics Analysis**

One of the statistical techniques used to test hypotheses of  $k$  correlated samples involves both parametric and non-parametric statistics. Parametric statistics, such as Analysis of Variance (ANOVA) (Riza et al., 2021), are used when the data are interval or ratio in nature (Botha et al., 2021; Dangat et al., 2021). ANOVA can be used to test  $k$  paired or independent samples. Two-way ANOVA is a type of variance analysis used to test the comparative means of  $k$  samples, where each sample consists of two or more categories (Riza et al., 2021). The response observations from a two-factor factorial experiment, with factor A having  $a$  levels and factor B having  $b$  levels, can be explained by the mean cell model as shown in the following table, Kritikos et al., 2019

**Table 1.**  
**Two-Factor Factorial Design**

		Factor B		
		1	2	.. b
Factor A	1	y <sub>111</sub> ,...,	y <sub>121</sub> ,...,	.. y <sub>111</sub> ,...,
	2	y <sub>11n</sub>	y <sub>12n</sub>	.. y <sub>11n</sub>
	...	y <sub>211</sub> ,...,	y <sub>221</sub> ,...,	.. y <sub>2b1</sub> ,...,
	a	y <sub>21n</sub>	y <sub>22n</sub>	.. y <sub>2bn</sub>
	...	...	...	...
		y <sub>a11</sub> ,...,	y <sub>a21</sub> ,...,	y <sub>ab1</sub> ,...,
		y <sub>a1n</sub>	y <sub>a2n</sub>	y <sub>abn</sub>

**Table 2.**  
**Research Methodology**

Criteria	Description
Statement of Problems	To examine the effectiveness of lot sizing techniques and demand pattern data on the response variable of relative percentage bias, we conducted an empirical study
Determining Factors and Levels	Factor: Lotting technique method and demand data patterns. Level 1: Eight lotting techniques Level 2: Demand data patterns of increase, decrease, random and stationary
The Determination of Response Variables	The response variable in this experiment is the relative percentage bias. $\% \text{ Relative Bias} = \sum_{i=1}^N (100(H_i - OPT_1) / OPT_1)$
Experimental Design Selection	The total cost value of each data set is denoted as H <sub>i</sub> , while the optimal solution value from the Wagner-Within algorithm is represented by OPT <sub>1</sub> . The relative bias is computed as the discrepancy between the total cost of each lotting technique and the total cost yielded by the Wagner-Within algorithm. The effectiveness of the heuristic lotting technique is determined by whether the relative bias value is zero or not. Using a two-factor factorial design method (ANOVA) to analyze the average relative bias percentage of lotting technique calculations (Riza et al., 2021).
Data Collection and Processing	<ul style="list-style-type: none"> <li>• Data collection of 12 months' demand, inventory holding costs, and ordering costs.</li> <li>• Data processing of demand using the Wagner-Within algorithm.</li> <li>• Data processing of demand using various lot-sizing techniques (resulting in ordering and holding costs).</li> <li>• Calculation of these costs with a percentage relative bias for each data pattern.</li> </ul>

	The data demand calculation is performed using all lot sizing methods to obtain the average relative bias percentage. The next step is to calculate the difference in relative bias among all the data processing results.
Qualitative Approach	The result of the experiment will be analyzed using ANOVA to determine the extent of the influence of demand pattern on lotting techniques with the response variable of relative bias percentage
Quantitative Approach	The decision based on the analysis of the experimental design using a factorial design will be made using ANOVA method.

**Table 3.**  
**Analysis of Experimental Design**

Variance Source	df	Sum of Squares	Root Squares	Mean	F <sub>0</sub>
Factor A	$a - 1$	$JKA = \frac{\sum_{i=1}^a Y_{i..}^2}{bn} - \frac{T_{...}^2}{abn}$	$KTA = \frac{JKA}{(a - 1)}$	$\frac{KTA}{KTE}$	$\frac{KTA}{KTE}$
Factor B	$b - 1$	$JKB = \frac{\sum_{i=1}^b Y_{i..}^2}{an} - \frac{T_{...}^2}{abn}$	$KTB = \frac{JKB}{(b - 1)}$	$\frac{KTB}{KTE}$	$\frac{KTB}{KTE}$
Error	$ab(n - 1)$	$JKE = JKT - JKA - JKB$	$\frac{JKE}{ab(n - 1)}$	$\frac{KTB}{KTE}$	$\frac{KTB}{KTE}$
Total	$abn - 1$	$JKT = \sum_{i=1}^a \sum_{j=1}^b \sum_{k=1}^n Y_{ijk}^2 - \frac{Y^2}{abn}$			

- Conclusion
- The effectiveness of heuristic lot-sizing method compared to deterministic lot-sizing method is examined using a qualitative approach
  - The impact of demand pattern on lot-sizing techniques is determined by analyzing the results of ANOVA and the relative bias percentage as the response variable using a quantitative approach

**Data Collection and Processing**

The first stage of the research involves using a qualitative method. Data on demand for the lot sizing technique is generated by performing random data generation on Microsoft Excel for a period of 12 months as a simulation of demand data. The generated data consists of four demand patterns, namely linearly increasing, linearly decreasing, random, and stationary demand patterns. The data processing method used includes the Groff algorithm, Silver and Meal method, Least Unit Cost, Least Total Cost, Part Period Balancing, Period Order Quantity, and Lot for Lot, and a comparison is made using the Wagner Within algorithm with an average total cost of IDR 5,050,000. An example of calculating the average relative bias percentage is as follows:

$$\% \text{ Relative Bias} = \sum_{i=1}^n \left( \frac{100(5.142.000 - 5.050.000)}{5.050.000} \right) = 2,01$$

The summary of the calculations can be seen in Table 4. Furthermore, in this research, a quantitative method was employed using analysis of variance to draw conclusions. A

factorial design with two factors was used to analyze the average relative bias percentage of lotting technique calculations. The results of each demand pattern group will determine which demand pattern produces the smallest relative bias, thus concluding that the demand pattern has an effect on the selection of lotting techniques. The research questions for the quantitative method are as follows:

- What is the effect of lotting techniques on the relative bias percentage?
- What is the effect of demand patterns on the relative bias percentage?

**RESULTS AND DISCUSSION**

**Selection of the Optimal Lotting Technique**

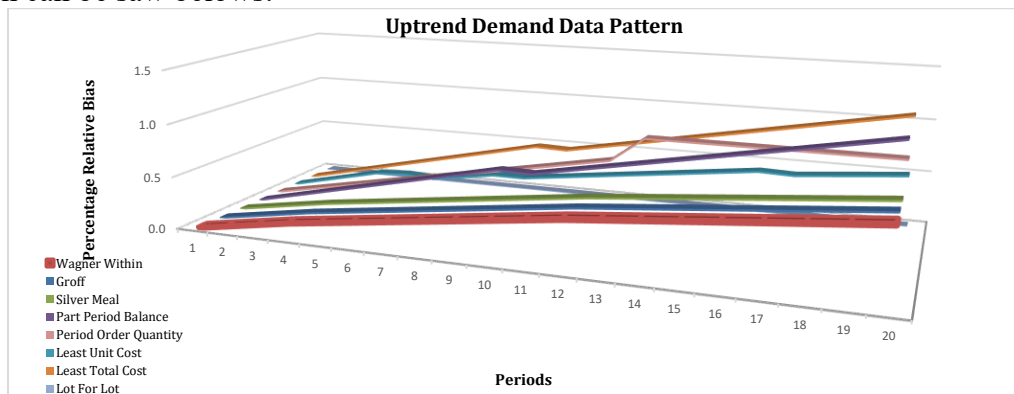
Based on the data processing results, a summary of the average relative bias percentages was obtained, as shown in the table below:

**Table 4.**  
**Summary of the Average Relative Bias Percentage**

No	Lotting Tech.	Data Demand Pattern				The Ave. % Relative Bias
		Up	Down	Rand.	Stat.	
1	GROFF	0	1	2	0	2
2	SM	0	1	3	0	3
3	LUC	1	1	10	0	10
4	LTC	4	1	9	0	9
5	PPB	4	1	8	0	8
6	POQ	4	1	8	1	8
7	LFL	11	1	18	9	18

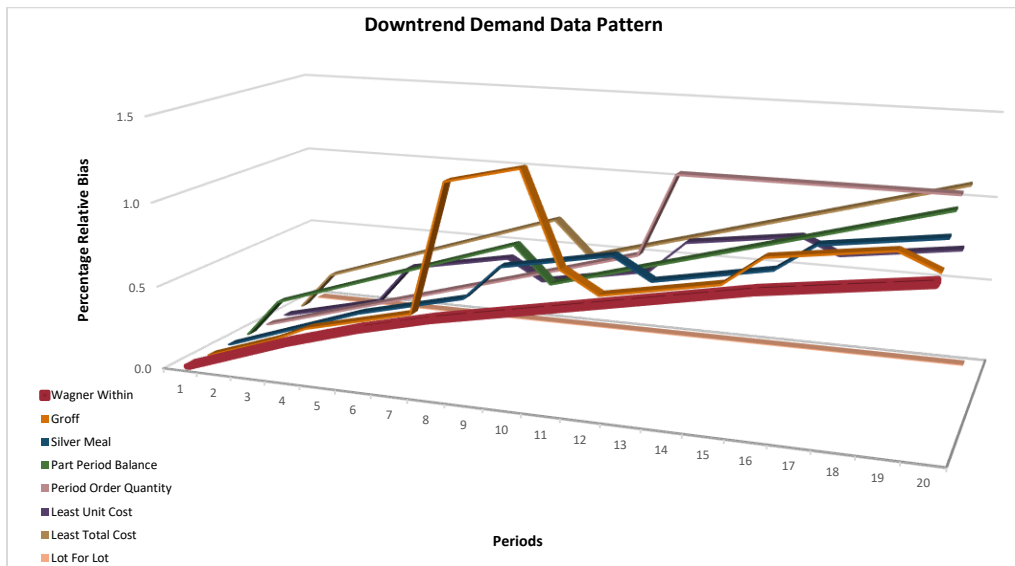
Source: Data Processing, 2023

The table displays that the Silver Meal method and the Groff algorithm exhibit superior performance when dealing with stationary and increasing demand patterns, and are also more suitable than other lot-sizing techniques when facing random demand patterns. However, the effectiveness of the Groff algorithm is not as strong when demand patterns are decreasing, and it is comparable to the Silver Meal method. Reference result graphic demand of data pattern can be saw belows:



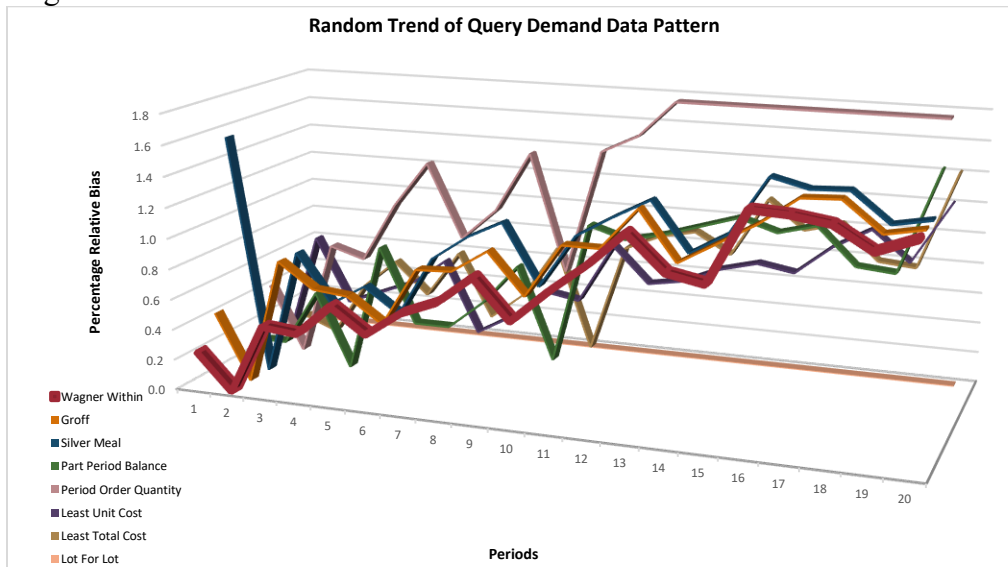
**Figure 2.**  
**Uptrend Demand Data Pattern**

From the graph above, it can be seen that the same approaches to the Wagner-Whitin algorithm method are the groff and silver feeding algorithm methods, apart from that there are significant differences.



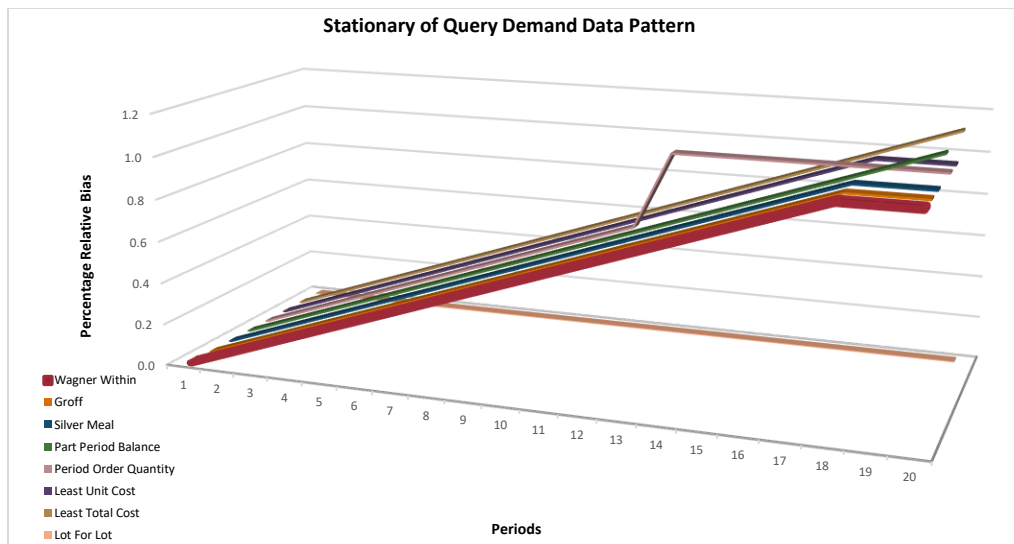
**Figure 3.**  
**Downtrend Demand Data Pattern**

From the graph above, it can be seen that there is nothing similar to the Wagner-Whitin algorithm method.



**Figure 4.**  
**Random Trend of Query Demand Data Pattern**

From the graph above, it can be seen that there is nothing similar to the Wagner-Whitin algorithm method.



**Figure 5.**  
**Stationer of Query Demand Data Pattern**

From the graph above, it can be seen that all methods are close to the Wagner-Whitin algorithm method except the period order quantity and lot for lot methods.

**Analysis of Variance**

After calculating the relative bias percentage of twenty sets of demand data, the next step is to determine the total response variable from the data table using the ANOVA method and the F-Table statistics. The purpose of the study is to determine whether there is an interaction between factor B (demand data pattern) and factor A (lotting technique). The hypothesis testing for factor A and factor B is as follows:

Hypothesis:

H<sub>0</sub>: There is no effect of demand data pattern on lotting technique with the relative bias percentage response variable.

H<sub>1</sub>: There is an effect of demand data pattern on lotting technique with the relative bias percentage response variable

The ANOVA calculation begins with calculating the Correction Factor, followed by the Total Sum of Squares, the Sum of Squares for Factor A, the Sum of Squares for Factor B, and the Sum of Squares for Error. The results are as follows.

**Table 5.**  
**Analysis of Variance**

Variance Source	df	Number of Quadrant	Mean Quadrant	Value of F	F-tab (0,05)
A	6	7587,5	1264,6	84,3	2,1
B	3	3603,0	1201,0	80,0	2,6
Error	532	7984,6	15,0		
Total	541	19175,2			

Source: Data Processing, 2023

The table indicates that hypothesis testing resulted in:

- a. The obtained value of F and the F Table concluded that the F value is greater than the critical value ( $84.3 > 2.1$ ), indicating that there is a significant effect of lotting technique on the relative bias percentage.
- b. The obtained value of F and the F Table concluded that the F value is greater than the critical value ( $80.0 > 2.6$ ), indicating that there is a significant effect of demand data pattern on the relative bias percentage. This suggests that both variables have a significant impact on the relative bias percentage.

## CONCLUSION

Based on the analysis results, several conclusions can be drawn as follows:

- a. Qualitative method conclusion can be seen in table 3 which shows that the silvermeal method obtained an average relative bias percentage of 3, and the groff algorithm obtained an average relative bias percentage of 2, which is closest to the results of the wagner within algorithm calculation that obtained a value of 0. This indicates that the heuristic lotting method is still effective to use, and the difference in relative bias values can be seen from a comparison with other lotting methods' relative bias values
- b. Quantitative method conclusion shows that the data processing using ANOVA method resulted in the conclusion that for the first hypothesis H1 is accepted, which means that there is an influence of lotting techniques on relative bias percentage. For the second hypothesis, H1 is also accepted, which means that there is an influence of demand data patterns on relative bias percentage.

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