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INTEGRATED FORECASTING AND AGGREGATE PLANNING FOR PRODUCTION OPTIMIZATION: A COMPARATIVE ANALYSIS OF OVERTIME AND SUBCONTRACTING CONTROLS

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ABSTRACT

The current potential market demand with ever-changing situations and conditions must be managed properly to find out the potential market demand in the future. Rumah Warna Yogyakarta is one of the manufacturing industry players that has experienced fluctuations in market demand, even tending to decline from the end of 2021 to mid-2022. Data was obtained from the database and direct interviews with Rumah Warna in Yogyakarta from November 2021 to November 2022. This study aims to determine the prediction of product demand for Rumah Warna Yogyakarta in the next period, so that companies can carry out production planning strategies to minimize production cost. Product demand prediction is carried out using the Grey System method of the GM (1,1) model. Then proceed with the heuristic aggregate planning method that focuses on overtime control and subcontracting control. Based on the results of the analysis, the Grey System GM (1,1) method produces good prediction accuracy of 9.231%. The best aggregate planning method is the overtime control where Rumah Warna Yogyakarta can reduce costs by Rp 351,258,758 when compared to the subcontracting control method.

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1. INTRODUCTION

Industries that are in Indonesia remain confronted with a myriad of obstacles that hinder productivity as well as economic expansion [1]. One of the policies that have an impact significant on the industry is the rise in the regional minimum wage (RMW) within the Java-Bali area, which makes companies adjust their operating costs. This is most affecting the manufacturing industry, as an increase in the cost of labor could reduce profits and hamper growth [2].

The effects from this RMW policy is felt by companies that manufacture products such as Rumah Warna in Yogyakarta [3], [4], who manufactures bags and accessories for teens. Since its inception in 2002, Rumah Warna has been recognized by both the national and local marketplaces for the superiority of its goods. The increase in the cost of labor has forced the company to restructure its cost structure and operations which has led to a decrease in profit margins and productivity. As with many other businesses, Rumah Warna must seek innovative strategies to ensure productivity and be at the top of its game [5].

Based on data collected directly by the author, Rumah Warna experienced a downward trend in production data from the end of 2021 to mid-2022. The peak of the decline occurred in May 2022, which even required laying off some of its employees. The decision to lay off employees has almost occurred in several manufacturing industries in Indonesia. With the decline in production levels, it will reduce the level of sales as well because of the difficulty of the company to meet consumer demand. So as not to have a negative impact on the sustainability of the industry in the future, it is necessary to carry out a production planning strategy at Rumah Warna. Grey System GM (1,1) and Aggregate Planning are key in overcoming demand uncertainty and production heterogeneity [6].

The Grey System GM (1,1) method, well-known for its capability to cope with uncertain and incomplete data, recommends an effective prediction approach for situations with high inconsistency [7]. The main advantage of the Grey method is its capability of processing small data, making it ideal for situations where historical data may not reflect the actual market conditions. Aggregate Planning, on the other hand, allows companies to optimize production capacity and market demand to be more proportional through setting variables such as production quantity, labor, overtime hours, and subcontracting rates [8]. Past research shows the application of Aggregate Planning and Grey method in various industries to improve efficiency and reduce operational costs. For example, studies on Grey System were explored in demand forecasting in the automotive industry, while research on Aggregate Planning was once applied in optimizing manufacturing operations [9] [10].

The study differs from other studies by combining two methods within the context of industries manufacturing which are impacted by the hike in regional minimum wages (RMW) and provides fresh insights on how to address the challenges created by the policy. The value of this strategy is its capacity to adjust to major adjustments in cost structures for operations. Furthermore, it will provide fresh insights on the efficiency of strategies for subcontracting and overtime in a variety of economic situations.

2. RESEARCH METHODS

2.1 Aggregate Planning

Aggregate planning is a process of determining the level of production capacity planning, inventory, subcontracting, and even prices in the medium term by the company itself [11]. The purpose of aggregate planning is to create a plan that can meet consumer demand at minimal cost, to get maximum profit [12]. Aggregate planning solves production problems related to aggregate-level decisions by trial and error in several aggregate techniques. Among the aggregate techniques that companies can use are [13]:

1. Labor control techniques. A technique in aggregate planning that assumes the production level and demand in the first period are the same. If in the next period there is an increase or decrease in demand, then the production level is also increased or decreased according to demand.
2. Subcontracting control technique. The aggregate planning technique, which determines the production level, adjusts to the lowest level of demand during the planning period. Because if the

demand level is higher than the production level, the production process is allocated to a partner company (subcontracting).

Aggregate planning seeks to identify several important operational variables in the company's production process in the medium term. These variables include production rate (number of units per unit time), workforce (amount of labor required), overtime (amount of overtime production), subcontracting (subcontracting capacity required during the planning period), and inventory (planned demand each period during the planning period) [14].

To facilitate the process of identifying the operational variables above, several cost and information variables must be known, including: c_H (recruitment cost of one worker), c_F (lay off cost of one worker), c_I (cost to hold one unit of stock for one period), c_R (production cost of one unit at regular time), c_O (incremental production cost of one unit at overtime), c_U (idle cost per unit of production), c_S (subcontracting cost/unit), n_t (number of days in period t of production), I_0 (demand at the beginning of the planning period), K (number of units produced by one worker/day), W_0 (number of workers at the beginning of the planning period), and D_t (predicted demand in period t) [15].

Then the decision variables in aggregate planning include: W_t (number of workers in period t), P_t (number of production units in period t), I_t (total demand in period t), H_t (number of workers to be recruited in period t), F_t (number of workers to be laid off in period t), O_t (number of production units during overtime in period t), U_t (number of production units during regular time in period t), and S_t (number of production units subcontracted in period t). The equations for aggregate planning are as follows:

a. Workforce balance:

$$W_t = W_t - 1 + H_t - F_t, \text{for } 1 \le t \le T \quad (1)$$

b. Inventory balance:

$$I_t = I_t - 1 + P_t + S_t - D_t, \text{for } 1 \le t \le T \quad (2)$$

c. Production-workforce balance:

$$P_t = K\, n_t W_t + O_t - U_t, \text{for } 1 \le t \le T \quad (3)$$

Then the linear equation for aggregate planning that can be used is as follows.

$$\text{Min} \sum_{t=1}^{T} (c_H H_t + c_F F_t + c_I I_t + c_R P_t + c_O O_t + c_U U_t + c_S S_t) \quad (4)$$

However, the use of linear equations for aggregate planning must still consider the high uncertainty factor.

2.2 Grey System GM (1,1)

GM (1,1) is the main model in the Grey System, so that it can analyze time series that are essentially derived from uncertainty, scarce or incomplete data information, and limited data quantity [16]. The general modeling of GM (1,1) is $GM\ (n, m)$, where n is the number of orders of the differential equation and m is the number of variables in the equation [17]. The differentiation process in GM (1,1) only occurs once and the time series data used also has one variable [18].

Among the virtues of GM (1,1) is that it does not require the assumption that the data is normally distributed and can be applied to small data that tends to trend patterns [17]. The following are the steps for predicting data using the Gray System GM (1,1) model [19].

1. Transform the original data into an initial data sequence $x^{(0)}(k), k = 0,1,2, \dots, n$ with the following equation.

$$x^{(0)}(k) = \{x^{(0)}(1), x^{(0)}(2), x^{(0)}(3), \dots, x^{(0)}(n)\} \quad (5)$$

2. Generate a new data row $x^{(1)}(k)$ which is the aggregation of the k initial rows with the following 1-AGO (one-time Accumulated Generating Operation) method.

$$x^{(1)}(k) = \{x^{(1)}(1), x^{(1)}(2), x^{(1)}(3), \dots, x^{(1)}(n)\} \quad (6)$$

where,

$$x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), k = 1,2,3, \ldots, n$$

3. Creates a first-order differential equation, namely:

$$x^{(0)}(k) = \alpha x^{(1)}(k) = b, k = 2,3, \ldots, n \tag{7}$$

where α is the developing coefficient and b is the Grey.

4. Calculate the MGO (Mean Generating Operation) $z^{(1)}(k)$ to solve the following differentiation equation.

$$z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1) = b, k = 1,2, \ldots, n \tag{8}$$

5. Determine the values of α and b with the following equations.

$$\hat{c} = \begin{bmatrix} \alpha \\ b \end{bmatrix} = (B^T B)^{-1} B^T Y_N \tag{9}$$

6. Based on the values of α and b, the following equation solution is obtained.

$$\hat{x}^{(1)}(k+1) = \left(x^{(0)}(1) - \frac{b}{\alpha}\right) e^{-\alpha k} + \frac{b}{\alpha} \tag{10}$$

7. Generate a prediction model with the following equation based on the concept of IAGO (Inverse Accumulated Generating Operation) from the **Equation (10)**.

$$\hat{x}^{(0)}(k+1) = (1 - e^{\alpha}) \left(x^{(0)}(1) - \frac{b}{\alpha}\right) e^{-\alpha k} + \frac{b}{\alpha} \tag{11}$$

8. Calculating the Mean Absolute Percentage Error (MAPE) value as a measure of prediction goodness using the following formula.

$$\mathbf{MAPE} = \frac{1}{n} \sum_{t=1}^{n} \left| \frac{x_t - \hat{x}_t}{x_t} \right| \times 100\% \tag{12}$$

MAPE numbers are usually interpreted according to the following A value below 10% suggests an excellent accuracy for prediction. 10-20% is a good level of precision, 20-50% suggests decent accuracy, while at least 50% indicates low accuracy [20].

2.3 Data and Research Variable

This type of research is observational analytic based on time series data. The time series data in this study is data obtained from databases and direct interviews with Rumah Warna in Yogyakarta from November 2021 to November 2022. The variables used are the amount of production and the number of product requests from consumers each month. The data analysis method used in this research is aggregate planning by comparing labor control techniques and subcontracting control techniques. The goal is to choose the lowest production cost between the two techniques. Previously, time series analysis was carried out first using the Grey System GM (1,1) method. The goal is to predict the amount of demand in the next period. The results of demand prediction are then used in the aggregate planning calculation process.

3. RESULTS AND DISCUSSION

Writing the results and discussion can be separated into different subs or can also be combined into one sub. The summary of results can be presented in the form of graphs and figures. The results and discussion sections must be free from multiple interpretations. The discussion must answer research problems, support, and defend answers with results, compare with relevant research results, state the study’s limitations, and find novelty.

3.1 Descriptive Statistics

The following is an overview of the data on the amount of production and the amount of demand for Rumah Warna products from November 2021 to November 2022.

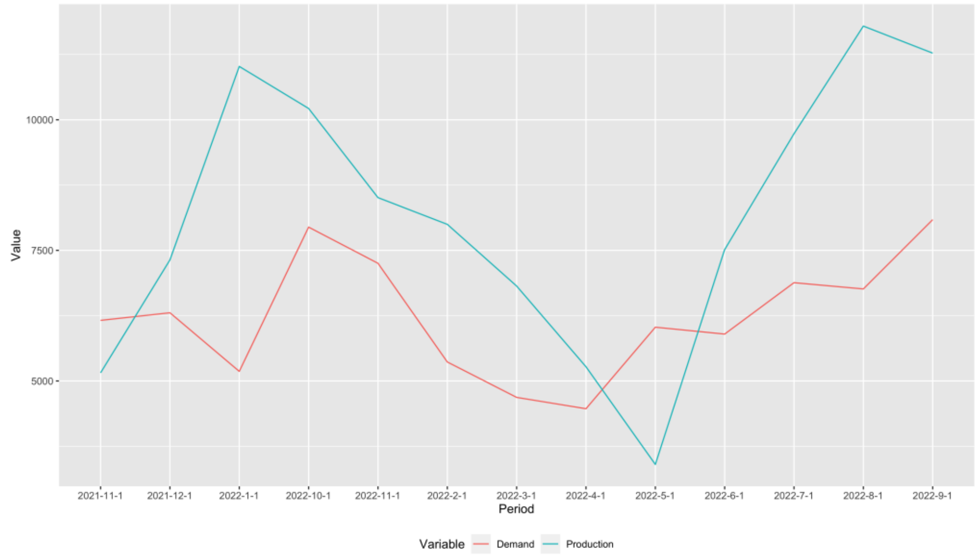

Figure 1. Movement of Production and Demand

Figure 1. Shows that there is an imbalance in the movement between the amount of production and the amount of demand for Rumah Warna products. This imbalance causes the company to experience losses because it cannot make savings or efficiency in production costs based on the amount of demand.

For example, in January 2022, Rumah Warna has incurred high costs due to producing large quantities of its products. But on the other hand, the number of product requests from consumers is very low.

Unlike what happened in May 2022, the number of product requests from consumers was higher than the amount of production by Rumah Warna. This is also very detrimental because the Rumah Warna is considered unable to meet consumer needs. There is a possibility of causing consumer purchasing power for Rumah Warna products to decrease in the future. So, it is necessary to carry out a production planning strategy using time series analysis followed by aggregate planning.

3.2 Product Demand Prediction with Grey System GM (1,1)

Grey System GM (1,1) is used because the research data used is small and the information obtained on the data is also limited. Using data on product demand for Rumah Warna from 2021 to 2022, the order of prediction results with Grey System GM (1,1) is obtained as follows.

Based on **Equations (5)** and **Equation (6)**, the initial and new data rows are obtained as shown in **Table 1**.

Table 1. Initial and New Data Rows

k	Period	Initial Data	New Data
1	Nov-21	6160	6160
2	Dec-21	6306	12466
3	Jan-22	5184	17650
4	Feb-22	5364	23014
5	Mar-22	4686	27700
6	Apr-22	4469	32169
7	May-22	6029	38198
8	Jun-22	5898	44096
9	Jul-22	6882	50978
10	Aug-22	6762	57740
11	Sep-22	8088	65828
12	Oct-22	7945	73773
13	Nov-22	7253	81026

Table 1 demonstrates exactly how Grey System GM (1,1) model transforms initial data into new data to create predictions on demand for products. Initial data shows fluctuations in the demand for Rumah Warna's products between November 2021 until November 2022. New data generated using the Grey System GM (1,1) model indicates a steady increase in time. The model forecasts an incredibly increase in Rumah Warna's demand for its products, regardless of whether the original data exhibits variations.

The values of α and b are then calculated by solving **Equation (7)**, **(8)**, and **(9)**. The results are shown in **Table 2**.

Table 2. Values of α and b in GM (1,1)

Variable	α	b
Demand	-0.0421	4526.076

The value of α indicates an upward trend within the demand data that is being studied. That means, in the absence of any other external influences it predicts that demand for products will fall at the speed that is indicated by this number. The value b is linked to the scale used for initial data that was used for the model, and is a contributing factor to the predicted result.

Then calculations are made to predict the demand for Rumah Warna products using **Equation (10)** and **(11)**. The results of predicting the demand for Rumah Warna products for the next 12 (twelve) periods are shown in **Table 3**.

Table 3. Product Demand Prediction

Period	Prediction
Dec-22	8110
Jan-23	8459
Feb-23	8824
Mar-23	9204
Apr-23	9601
May-23	10014
Jun-23	10446
Jul-23	10896
Aug-23	11365
Sep-23	11855
Oct-23	12366
Nov-23	12899

Each time, there is an increase in the demand for product that ranges with 8110 units during December 2022 and rising to 12899 units in the month of November 2023. This suggests that the forecast model is predicting steady increase in demand in Rumah Warna products over the timeframe. This steady growth in demand will allow the business to develop appropriate strategies for production to satisfy the constantly growing demand for the product.

Using **Equation (12)**, the value of the prediction goodness measure is obtained, namely MAPE of 9.23%. This means that the results of predicting the demand for Rumah Warna products with Grey System GM (1,1) have good accuracy and are feasible to use. Furthermore, aggregate planning is carried out based on the results of this demand prediction.

3.3 Aggregate Planning

Aggregate planning seeks to identify some of the important operational variables in the production process of Rumah Warna in the medium term. In this research, the period used is for the next 12 (twelve) months. The identification of operational variables that are the focus of this study are overtime (the amount of overtime production) and subcontracting (the subcontracting capacity required during the planning period). Since these two variables are crucial in the management of a company's production capacity effectively and with flexibility and flexibly, particularly in coping changes in demand. The initial information known before the calculation of aggregate planning because of the researcher's interview with the company is as follows.

Table 4. Operational Variable Information

Number	Variable	Value(s)
1	Demand (D_t)	8110; 8459; …; 12899
2	Number of workers (W_0)	36
3	Number of days (n_t)	25; 24; …; 27
4	Number of days of overtime work (no_t)	6; 4; …
5	Overtime cost (Rp.) per unit (C_O)	8,148
6	Subcontracting cost (Rp.) per unit (C_S)	20,000
7	Labor wage (Rp.) per month	1,846,000
8	Number of units produced per day (K)	340

In general, **Table 4** gives an overview of the main aspects that impact the capacity of production in Rumah Warna, including available resources (workers or working days) and production expenses (overtime and subcontracting) as well as the needed production capacity to satisfy the market demands. The data will be used to develop optimal production plans, including the best time to utilize overtime, or subcontracting to ensure that demand for the product is satisfied efficiently and cost-effective way.

3.3.1 Aggregate Planning with Overtime Control

The first step of aggregate planning with overtime control in this study is to calculate the number of production units during regular time in period $t(U_t)$ with the $U_t = K \times n$ formula. The calculation results are presented in **Table 5**.

Table 5. Initial Calculation of Overtime Control

Period (t)	D_t	n_t	no_t	K	U_t
Dec-22	8110	25	6	340	8496
Jan-23	8459	24	4	340	8156
Feb-23	8824	25	6	340	8496
Mar-23	9204	25	5	340	8496
Apr-23	9601	22	9	340	7476
May-23	10014	25	5	340	8496
Jun-23	10446	25	6	340	8496
Jul-23	10896	25	6	340	8496
Aug-23	11365	26	4	340	8836
Sep-23	11855	25	6	340	8496
Oct-23	12366	26	4	340	8836
Nov-23	12899	27	4	340	9175

Table 5 will assist the business in making choices regarding resources and overtime to ensure that the demand is fulfilled in the most efficient manner. In April, for instance 2023, production of the normal month decreased by 7,476 units because of the reduction of working hours by 22 days. But the demand for the month grew to 9,601 units. It's resulted in a deficit of 2,125 units. This implies that the business must make use of the overtime (9 days) to fill this gap and to satisfy the demands.

The next step calculates overtime costs, labor costs, and total costs. Total cost is the sum of overtime cost and labor cost. All costs are in Rupiah. The calculation results are presented in **Table 6**.

Table 6. Final Calculation of Overtime Control

W_0	Production capacity of overtime	O_t	Overtime Cost (Rp)	Labor Wage (Rp)	Labor Cost (Rp)	Total Cost (Rp)
36	73403	0	0	1,846,000	66,456,000	66,456,000
36	48935	303	2,472,435	1,846,000	66,456,000	68,928,435
36	73403	328	2,673,437	1,846,000	66,456,000	69,129,437
36	61169	708	5,771,408	1,846,000	66,456,000	72,227,408
36	110104	2124	17,309,863	1,846,000	66,456,000	83,765,863

W_0	Production capacity of overtime	O_t	Overtime Cost (Rp)	Labor Wage (Rp)	Labor Cost (Rp)	Total Cost (Rp)
36	61169	1519	12,373,556	1,846,000	66,456,000	78,829,556
36	73403	1950	15,889,492	1,846,000	66,456,000	82,345,492
36	73403	2400	19,556,920	1,846,000	66,456,000	86,012,920
36	48935	2530	20,613,376	1,846,000	66,456,000	87,069,376
36	73403	3359	27,372,655	1,846,000	66,456,000	93,828,655
36	48935	3530	28,765,871	1,846,000	66,456,000	95,221,871
36	48935	3723	30,338,429	1,846,000	66,456,000	96,794,429

Based on the Table 6, the total cost summation result for the aggregate planning method with overtime control from December 2022 to November 2023 is Rp 980,609,443.

3.3.2 Aggregate Planning with Subcontract Control

The first step of aggregate planning with subcontracting control is to determine the production level in period $t(U_t)$ with the $U_t = (\min(D_t))$ formula. The next step is to determine the number of subcontracted production units in period $t(S_t)$ with the $S_t = D_t - U_t$ formula. Calculation of subcontracting costs in period t using the subcontracting cost formula $S_t \times c_s$. Then the calculation results are presented in Table 7.

Table 7. Calculation of Subcontract Control

Period (t)	D_t	U_t	S_t	Subcontract Cost (Rp)	Labor Cost (Rp)	Total Cost (Rp)
Dec-22	8110	8110	0	0	66,456,000	66,456,000
Jan-23	8459	8110	349	6,988,760	66,456,000	73,444,760
Feb-23	8824	8110	714	14,278,660	66,456,000	80,734,660
Mar-23	9204	8110	1094	21,882,660	66,456,000	88,338,660
Apr-23	9601	8110	1491	29,814,300	66,456,000	96,270,300
May-23	10014	8110	1904	38,087,700	66,456,000	104,543,700
Jun-23	10446	8110	2336	46,717,600	66,456,000	113,173,600
Jul-23	10896	8110	2786	55,719,340	66,456,000	122,175,340
Aug-23	11365	8110	3255	65,108,960	66,456,000	131,564,960
Sep-23	11855	8110	3745	74,903,140	66,456,000	141,359,140
Oct-23	12366	8110	4256	85,119,340	66,456,000	151,575,340
Nov-23	12899	8110	4789	95,775,740	66,456,000	162,231,740

Based on the Table 7, the total cost summation result for the aggregate planning method with subcontracting control from December 2022 to November 2023 is Rp 1,331,868,200.

When compared between the aggregate planning method of overtime control and the aggregate planning method of total cost-based subcontracting control, the overtime control method is better used by the industry Rumah Warna Yogyakarta.

4. CONCLUSIONS

Based on the results and discussion on the research case study using data and information at Rumah Warna Yogyakarta, the researcher gets a conclusion. Consumer demand for Rumah Warna Yogyakarta from November 2021 to November 2022 tends to fluctuate so that future demand predictions are needed. The Grey System method GM (1,1) model is appropriate for predicting this demand data where the MAPE value of 9.23% represents good accuracy in predicting. The results of demand prediction for the next 12 months (December 2022 to November 2023) are followed by the calculation of the total production cost of Rumah Warna Yogyakarta using the Aggregate Planning method of overtime control and Aggregate Planning of subcontracting control. The best aggregate planning method used to minimize the total production cost of Rumah Warna Yogyakarta in this period is the overtime control method with a cost difference of around Rp 351.258.758 lower than the subcontracting control method.

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