The fuzzy goal programming approach to production planning of intermediate gear spare parts: a case study

Aulia Ishak[*], Poltak Nababan

Department of Industrial Engineering, Universitas Sumatera Utara, Jalan Dr. T. Mansur No.9, Medan, Sumatera Utara 20222, Indonesia

ARTICLE INFORMATION

ABSTRACT

Production planning has an important role in the company's business processes. A company engaged in the manufacture of intermediate gear parts has a problem in optimizing its production system. The production planning system that occurs is still based on predictions from decision-makers. This study aims to optimize the production planning system to maximize the 15T intermediate gear spare parts' production capacity and the 30T intermediate gear spare parts. Optimization of production planning uses the fuzzy goal programming method to optimize objectives based on existing constraints such as working hours, profit tolerance values, and demand tolerance values. The results showed that the use of fuzzy goal programming was able to increase the production level by 2.765, with an increase in profit of 2.57%. Fuzzy goal programming implementation provides an optimal solution in increasing profits in accordance with company goals based on the constraints that occur.

*Corresponding Author

Aulia Ishak
E-mail: aulia.ishak@usu.ac.id

1. INTRODUCTION

Production planning is an important process in manufacturing to plan production activities that are efficient in achieving company goals [1]. Production planning requires coordination from management in organizing its resources related to a defined product and directing or regulating the movement of materials (materials, parts/components/sub-assemblies, and products) through the entire production cycle [2]. This process has challenges in facing uncertain future demand in determining optimal production [3]. The uncertainty factor makes production planning require a proper analysis based on existing resources and its ability to distribute its products. Production planning also requires cooperation between functions to achieve maximum profit [4] and minimize inventory levels.

Fuzzy goal programming is a tool that can be used to plan production planning. The goal programming concept is to minimize deviations from the actual results achieved based on the priority scale [5]. The goal programming model functions as a decision-making tool in setting multiple goals simultaneously [6] by including uncertainty and imprecision [7], [8]. Goal programming is effective in production planning because it can solve conflicting obstacles such as manufacturing, product, and consumer aspects.

The fuzzy goal programming model was

developed to optimize decision-making by minimizing the lower deviation variable [9]. This model combines inaccuracies in data input and the level of target objectives with a hierarchy of objectives based on the analysis of fuzzy relationships between paired interests between objectives [10]. This method effectively helps decisions about production planning related to minimizing raw material costs [11], production costs [12], [13], and profit optimization [14], [15].

XYZ Company deals with the manufacture of machinery/spare parts for palm oil mills, which one of the products of this company is medium gear spare parts. There are two types of intermediate gear spare parts on the Digester engine: the 15T intermediate gear spare parts and the 30T intermediate gear spare parts. The production planning system in use today is based solely on the predictions of decision-makers. This system is considered unable to optimize production capacity based on cycle time and the benefits of each product. This study aims to optimize production capacity with the fuzzy goal programming approach. The fuzzy goal programming results are expected to be able to optimize the level of profit from intermediate gear spare parts products.

2. RESEARCH METHODS

This research is a descriptive study to assist in operational decision making. This study uses primary data, including processing time and product production (May 2018-April 2019), and secondary data, namely sales and demand data, costs and selling prices, available working hours, and product benefits. Data collection is done by making direct observations of real conditions on the production floor with a stopwatch and interviews or company records. Data processing using LINGO 17.1 software.

The fuzzy goal programming method is also useful when used to determine the optimal combination of products and, at the same time, achieve the desired goals of the company. In the Fuzzy goal, programming presented a pair of variables called "variable deviational" and serves to accommodate deviations or deviations in the segment's value if we have an equation constraint to the value of the right segment. Functional constraints become a limitation for the maximization or minimization of the objective function. In the fuzzy goal programming model, these constraints realize the goals to be achieved [16]. This study uses two variables: the dependent variable is the

15T intermediate gear spare parts, and the 30T intermediate gear spare parts, and the independent variables are the number of demands, the number of production, production cost, selling price, and work time. In production planning, demand forecasting is used as an initial stage of production planning to determine future demand.
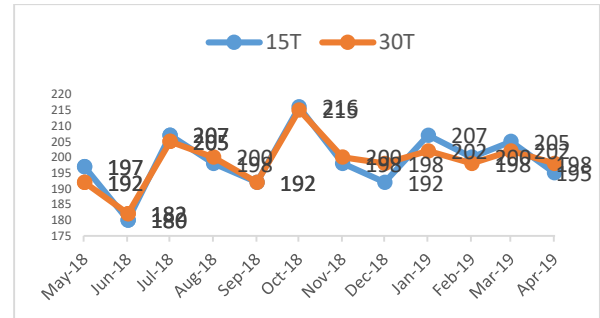

Fig. 1. Historical data patterns

The initial step in fuzzy goal programming projects the amount of production based on the smallest error rate. This study uses the time series method because historical data shows a cyclical pattern (Fig. 1). The time series method is using to analyze data series, which is a function of time [17].

$$Y' = a + b\,sin\left(\frac{2\pi x}{n}\right) + c\,cos\left(\frac{2\pi x}{n}\right) \qquad (1)$$

Where Y'= number of product forecasts, n= number of period, x= period of forecasting, and a,b,c= variable of forecasting.

The formation of a fuzzy goal programming model requires decision variables, objective functions to be achieved, constraint functions, and tolerance values. This study's decision variables are X1= Number of 15T intermediate gear spare parts products and X2= Number of 30T intermediate gear spare part products. The objective function to be achieved (max T) with T= fuzzy membership function value, Pi= Goals to be achieved, d1+= positive deviation, and i-= negative deviation.

$$Max\ T = P1(d1+ \ldots + d1-) + P2\ (d2+ \ldots + d2-) + \ldots + Pi\ (di+ + di) \qquad (2)$$

Constraint functions relate to the availability of working hours in the intermediate gear spare parts production process; the company has set working hours.

$$a1\ X1 + di+ + di- <= Yi \qquad (3)$$

Where, di+= positive deviation, di-= negative

deviation, X_i= number of variables X, and Y_i = number of variables Y

Tolerance values relate to profit and the rate of decrease/increase in the projected demand.

$$Z(x) - (Z^* - \bar{Z})T \geq \bar{Z} \qquad (4)$$

Where, Z^*= maximum income tolerance limit, T= fuzzy membership function value and $\bar{Z}$= minimum income tolerance limit.

Based on several predetermined variables, a fuzzy goal programming model can be formed (Max T) with d_1^+= positive deviation, d_i^-= negative deviation, and T = Fuzzy membership function value.

$$Max\ T = d_1^+ + d_2^+ + d_3^+ + d_4^+ + d_5^+ + d_6^+ + d_7^+ + d_8^+ \qquad (5)$$

3. RESULTS AND DISCUSSION

This research focuses on two intermediate gear spare parts on the Digester engine: the 15T intermediate gear spare parts and the 30T intermediate gear spare parts. Production planning forecasting is based on historical data for the May 2018-April 2019. Based on the calculations using the times series method, the demand forecasting for the May 2019-April 2020 intermediate gear type is obtained (Table 1).

Table 1. Forecasting result for demand intermediate gear spare parts

Period	Forecasting results (unit)	
	15T	30T
May-19	166	160
Jun-19	168	153
Jul-19	170	155
Aug-19	169	164
Sep-19	167	175
Oct-19	165	159
Nov-19	166	160
Dec-19	168	153
Jan-20	170	155
Feb-20	169	164
Mar-20	167	170
Apr-20	165	169

Forecasting results are then optimized using fuzzy goal programming. The formulation of the fuzzy goal programming model functions. The initial steps are to determine decision variables, goal functions, constraint functions for working hours, profit tolerance values, and demand tolerance values. Decision variables are variables

that want to optimize their output by meeting several constraint criteria. Decision variables on optimal production planning are X1 = Number of 15T intermediate gear spare part products, and X2 = Number of 30T intermediate gear spare part products.

The objective function to be achieved using the fuzzy goal programming method is to maximize profits and meet customer demand. The company has set working hours for the availability of working hours in the intermediate gear spare parts production process (Table 2).

Table 2. Cycle time of sparepart intermediate gear

Cycle time of spare parts intermediate gear (minutes)		Total work hours applicable (minutes)
Type 15T	Type 30T	
4.54	4.34	2880
13.35	13.05	5760
2.25	2.41	7200
49.45	48.94	20160
22.69	21.39	11520
3.03	2.98	14400
11.30	11.32	11520
0.74	0.91	18720

Based on Table 2, the formula for constraint functions for working hours is as follows:

$$4.54X1 + 4.34X2 + d1- - d1+ \leq 2880$$
$$13.35X1 + 13.05X2 + d2- - d2+ \leq 5760$$
$$2.25X1 + 2.41X2 + d3- - d3+ \leq 7200$$
$$49.45X1 + 48.94X2 + d4- - d4+ \leq 20160$$
$$22.69X1 + 21.39X2 + d5- - d5+ \leq 11520$$
$$3.03X1 + 2.98X2 + d6- - d6+ \leq 14400$$
$$11.30X1 + 11.32X2 + d7- - d7+ \leq 11520$$
$$0.74X1 + 0.91X2 + d8- - d8+ \leq 18720 \qquad (6)$$

Determination of profit tolerance values based on interviews with the company, each intermediate gear spare part unit's profit is Rp. 48,000 for intermediate gear spare parts type 15T and Rp. 49,000 for intermediate gear spare parts type 30T, and the company wants a profit of at least Rp. 16,000,000. The largest production capacity is 170 unit for intermediate gear spare parts type 30T and 175 unit intermediate gear spare parts type 30T

$$Maximum\ profit = 48,000 \times 170) + (49,000 \times 175)$$
$$= Rp16,735,000$$

The company does not expect a decline in profit, so the fuzzy linear up function is used, which can be seen in Fig. 2.

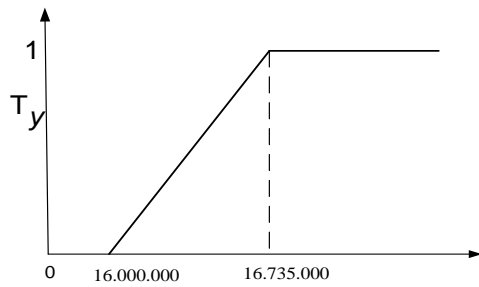**Fig. 2.** Fuzzy membership function for profit

So the formulation is:

$Z(x) - (Z* - \overline{Z})T \geq \overline{Z}$
$48000X1 + 49000X2 - (16735000 - 16000000)T \geq 16000000$
$48000X1 + 49000X2 - 735000T \geq 16000000$
$48X1 + 49X2 - 735T \geq 16000$ (7)

Determination of demand tolerance values a decrease and increase in demand, so the fuzzy triangular function describes the increase and decrease in demand (Fig. 3 and Fig. 4). Tolerance values of spare parts intermediate gear type 15T for May 2019, are:

Lower tolerance value = forecasting result - (8%
x forecasting result)
= 166 - 13
= 153
Top tolerance value = forecasting results + (6%
x forecasting results)
= 166 + 10
= 176

Tolerance values of spare parts intermediate gear type 30T for May 2019, are:

Lower tolerance value = forecasting result - (8%
x forecasting result)
= 160 - 10
= 150
Top tolerance value = forecasting results + (6%
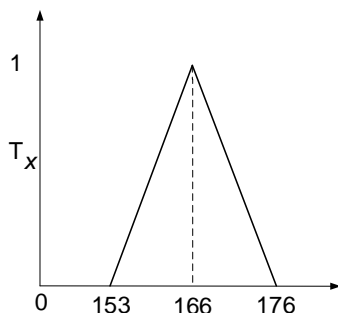*x forecasting results)*
= 160 + 8
= 168

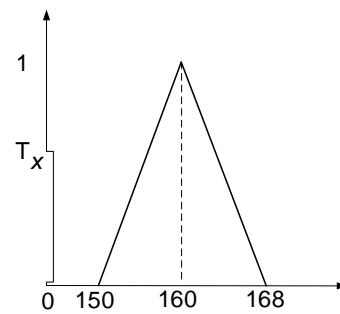**Fig. 3.** Fuzzy membership function 15T

Fig. 4. Fuzzy membership function 30T

Based on the lower tolerance value and top tolerance value, the formula for demand tolerance values in May 2019 is:

$D(x) - (D* - \overline{D})T \geq \overline{D}$, and
$D(x) + (\overline{D} - D*)T \leq \overline{D}$
$X1 - 13T \geq 153$
$X1 + 10T \leq 176$
$X2 - 10T \geq 150$
$X2 + 8T \leq 168$ (8)

Based on the stipulated conditions, the formulation of the achievement function for the May 2019 fuzzy goal programming method is as follows:

$Max\ T = d_1^+ + d_2^+ + d_3^+ + d_4^+ + d_5^+ + d_6^+ + d_7^+ + d_8^+$
Subject to
$48\ X1 + 49X2 - 735T >= 16000$
$X1 - 13T >= 153$
$X1 + 10T <= 176$
$X2 - 10T >= 150$
$X2 + 8T <= 168$
$4.54X1 + 4.34X2 + d_1^- - d_1^+ \leq 2880$
$13.35X1 + 13.05X2 + d_2^- - d_2^+ \leq 5760$
$2.25X1 + 2.41X2 + d_3^- - d_3^+ \leq 7200$
$49.45X1 + 48.94X2 + d_4^- - d_4^+ \leq 20160$
$22.69X1 + 21.39X2 + d_5^- - d_5^+ \leq 11520$
$3.03X1 + 2.98X2 + d_6^- - d_6^+ \leq 14400$
$11.30X1 + 11.32X2 + d_7^- - d_7^+ \leq 11520$
$0.74X1 + 0.91X2 + d_8^- - d_8^+ \leq 187200$
$0 \leq T \leq 1$ (9)

The achievement function that has been formulated can be calculated using LINGO 17.1 software to obtain the optimum production amount for each product type. The results will appear in the report window showing the calculation results for May 2019 (Fig. 5). Recapitulation of the optimal production planning calculation results of intermediate gear spare parts using
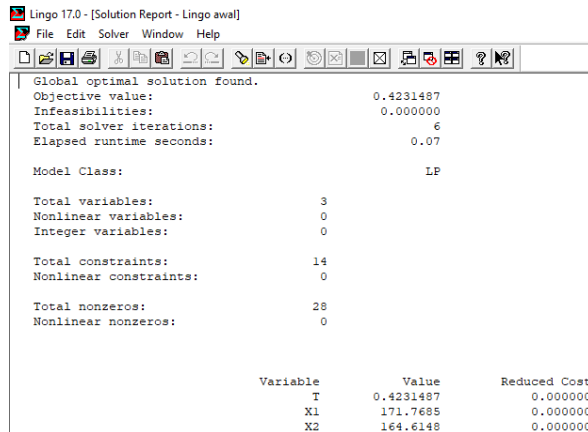
LINGO 17.1 software is shown in Table 3.

Fig. 5. Display calculation results with LINGO 17.1. software

Using LINGO software, calculation results show that production planning in May 2019 is 172 units for the 15T intermediate gear spare parts and 165 units for 30T intermediate gear spare parts (Table 3). These results indicate an increase in production capacity from the previous plan, namely 166 units for the 15T intermediate gear spare parts and 160 units for 30T intermediate gear spare parts. From May 2019 to April 2020, there was an increase in production by 112 units or 2.76% from the planning time series method. Optimizing production capacity by streamlining each product's cycle time can increase worker productivity at a fixed cost. This shows that the implementation of fuzzy goal programming can minimize production costs [18], [19] because it can increase production results at the same cost.

Table 3. Production planning results with fuzzy goal programming

Period	Forecasting planning (unit)	
	15T	30T
May-19	172	165
Jun-19	175	159
Jul-19	176	160
Aug-19	172	168
Sep-19	168	177
Oct-19	169	171
Nov-19	172	164
Dec-19	175	159
Jan-20	176	160
Feb-20	172	168
Mar-20	169	172
Apr-20	168	172

Table 4. Achievement of profit (thousand)

Period	Fuzzy goal programming		Times series method	
	15T	30T	15T	30T
May-19	8,256	8,085	7,968	7,848
Jun-19	8,400	7,791	8,064	7,513
Jul-19	8,448	7,840	8,160	7,615
Aug-19	8,256	8,232	8,112	8,052
Sep-19	8,064	8,673	8,016	8,575
Oct-19	8,112	8,379	7,920	8,232
Nov-19	8,256	8,036	7,968	7,791
Dec-19	8,400	7,791	8,064	7,513
Jan-20	8,448	7,840	8,160	7,615
Feb-20	8,256	8,232	8,112	8,052
Mar-20	8,112	8,428	8,016	8,330
Apr-20	8,064	8,428	7,920	8,285
Total	99,072	97,755	96,480	95,421
	196,827		191,901	

An increase in the amount of production indirectly has an impact on increasing company profits. Based on May 2019 - April 2020, it shows an increase in profits of 2.57% or Rp. 4,926 (Table 4). The results achieved correspond to an increase in revenue in the cement industry by 2.02 [20] and a maximum profit increase of $ 666825.5 in the production of vehicle spare parts [21] from the implementation of fuzzy goal programming. This shows that the implementation of fuzzy goal programming can increase the level of company profits in accordance with the objectives set. The use of actual data in the formation of fuzzy programming models is useful in obtaining rational benefits and costs [22]. The fuzzy Goal Programming method is able to optimize a problem with various objectives based on existing constraints.

4. CONCLUSION

The results of forecasting the demand for intermediate gear spare parts in May 2019 - April 2020 show a demand trend based on the cycle pattern for each type of intermediate gear spare parts 15T and 30T. The fuzzy function to the number of requests is triangular fuzzy because of the increase and decrease in demand, and the fuzzy function to profit is the fuzzy linear increase. Based on the results of processing with the fuzzy goal programming method, optimization of the production planning for intermediate gear

spare parts can increase the production capacity by 2.76% and increase profits by 2.57%. Research is still based on internal factors of production, such as the level of working hours, profit, and demand tolerance values. Future research could be used for short-term and intermediate production planning in other continuous process industries. The number of fuzzy goals can be increased based on the decision maker's desirability.

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