A Goal Programming Optimization Model for The Allocation of Liquid Steel Production

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Abstract. This research was conducted in one of the largest steel companies in Indonesia which has several production units and produces a wide range of steel products. One of the important products in the company is billet steel. The company has four Electric Arc Furnace (EAF) which produces liquid steel which must be processed further to be billet steel. The billet steel plant needs to make their production process more efficient to increase the productivity. The management has four goals to be achieved and hence the optimal allocation of the liquid steel production is needed to achieve those goals. In this paper, a goal programming optimization model is developed to determine optimal allocation of liquid steel production in each EAF, to satisfy demand in 3 periods and the company goals, namely maximizing the volume of production, minimizing the cost of raw materials, minimizing maintenance costs, maximizing sales revenues, and maximizing production capacity. From the results of optimization, only maximizing production capacity goal can not achieve the target. However, the model developed in this paper can optimally allocate liquid steel so the allocation of production does not exceed the maximum capacity of the machine work hours and maximum production capacity.

1. Introduction
The steel industry which is often seen as one of the cornerstone for economic growth, has encountered big challenges in recent years [1]. Hence, the steel company company has to maintain and continuously improve their service level to satisfy their customers. The company has several factories that produce steel products such as billet steel, slab steel, wire rod, and iron sponge. Along with the increasing competition of national and international steel industry, the company is required to improve its production efficiency so they can improve the productivity and make better profit. Billet steel production process consists of several stages. The first stage of the process is in the form of melting scrap and other raw materials such as iron sponge and limestone in an Electric Arc Furnace (EAF). In the second stage process, the chemical composition of the steel in Ladle Furnace (LF) is determined, and the last stage is the casting process which performed in a Continuous Casting Machine (CCM). This paper concerns with the first stage process. The company faced a problem about how to determine the optimal allocation of liquid steel production in each of four EAF so that the company can satisfy the demand efficiently. The company set several objectives namely maximize production volume, minimize the raw material cost, minimize the maintenance costs, maximize sales revenues, and maximize production capacity. Based on those objectives, the purpose of this paper is to develop an optimization model using goal programming approach to determine the amount of Ton Liquid Steel (TLS) to be produced by four EAF owned by the company. Goal programming is a special type of linear programming which is capable of handling decision situations involving single or multiple goals [2]. The basic approach of goal programming is to
establish a specific numeric goal for each of the objectives, formulate an objective function, and then find a solution that minimize the sum of deviations of the objective functions from their respective goals [3].

Recently, many researchers and practitioners have studied iron and steel production management issues. Solving production operational management problems in Steelmaking-continuous casting (SCC) production through mathematical models and computers is an important research topic and has recently been widely explored [4]. For example, a mathematical programming model has been developed by [5] for a steel production scheduling problem to optimally schedule the slab production through the reheating furnace and the rolling mill. In another study by [6], an optimization model based on EAF production was developed to determine the optimal allocation of semi-finished products to satisfy the final product demand. In research [1], multiple objectives and uncertainties are considered as a part of Integrated Programming (IP) problem. A multi-objective optimization model was developed in the paper with interval-valued objective functions to optimize the throughput of each process. Research [7] used an interactive evolutionary algorithm with decision-maker’s preferences to solve the interval multi-objective optimization problems.

2. Methodology

In the first stage of this study several data was collected including liquid steel demand, raw material cost per heat, the sales revenue per TLS, maintenance cost, and production capacity for each EAF. In the second stage. A goal programming model is developed and solved using LINGO 15.0 software.

2.1 Data Collection

Solving the optimization model requires data input which are used as parameters of the model. Table 1-4 shows the data needed to solve the model. Table 1 shows the actual liquid steel demand in 2014. Raw material prices and their corresponding standard usage and cost per heat are listed in Table 2. Table 3 shows standard maintenance cost for each EAF.

Table 1. Actual Liquid Steel Demand in 2014

| Period  | Demand (TLS) | Period  | Demand (TLS) |
|---------|--------------|---------|--------------|
| January | 16220.7      | July    | 15092.887    |
| February| 15793.6      | August  | 14479.642    |
| March   | 15377.7      | September| 7958.37     |
| April   | 10780.151    | October | 16757.425    |
| May     | 16454.189    | November| 15741.045    |
| June    | 16900.171    | December| 9829.759     |

Table 2. Raw Material Costs for Liquid Steel Production

| Raw Materials | Price per Ton | Standard Usage of Raw Material per Heat (%) | Material Cost per Heat |
|---------------|---------------|--------------------------------------------|------------------------|
| Scrap         | IDR 2,300,313.00 | 83                                       | IDR 133,648,194.00    |
| MJIS Sponge   | IDR 4,024,364.00 | 13                                       | IDR 36,621,712.00     |
| DRI Sponge    | IDR 4,164,000.00 | 4                                        | IDR 11,659,200.00     |
| Total material cost/heat | IDR 181,929,106.00 |  |  |
| Total material cost/TLS | IDR 3,032,152.00 |  |  |
| Electric Arc Furnace (EAF) | Maintenance costs (in thousand of IDR) |
|---------------------------|---------------------------------------|
| EAF 1                     | 1210                                  |
| EAF 2                     | 2300                                  |
| EAF 3                     | 3090                                  |
| EAF 4                     | 4309                                  |

### 2.2 The Development of Goal Programming Model

In goal programming model, it is necessary to consider the structural or technological constraints and objectives. For each constraint, possible deviations are stated, and for each objective, a target level is set [8]. In this paper, we use a goal programming without priority weight. The notations of index and variables used in this paper are as follows:

- $X_{ik}$: the volume of liquid steel generated in furnace $i$ at period $k$
- $i$: the type of liquid steel produced in the furnace, $i = 1, 2, 3, 4$
- $k$: period of production, $k = 1, 2, 3$
- $D_k$: the volume of demand for liquid steel in period $k$
- $D_i$: the volume of demand for liquid steel in the furnace $i$
- $B$: raw material cost per TLS
- $TB_k$: material cost target for period $k$
- $P$: the price of liquid steel per ton
- $TP_k$: total revenue target for the period $k$
- $W_i$: average maintenance costs per TLS in furnace $i$
- $TO_k$: total maintenance cost in period $k$
- $KP_{ik}$: total maximum capacity of liquid steel production for furnace $i$ in period $k$

#### 2.2.1 The Objectives Function

There are five goals considered in this paper:

1. Maximize the volume of production. To achieve this goal, we have to minimize the positive and negative deviations as shown in Equation (1).

   $\min Z_1 = \sum_{n=1}^{7} d_n^- + d_n^+$

2. Minimize the cost of raw materials at each period. To achieve this goal, we have to minimize the positive deviations as shown in Equation (2).

   $\min Z_2 = \sum_{q=8}^{10} d_q^+$

3. Maximize the revenue each period. To achieve this goal, the negative deviation must be minimized as in Equation (3).

   $\min Z_3 = \sum_{p=11}^{13} d_p^-$

4. Minimizes the maintenance cost. To achieve this goal, we have to minimize the positive deviations as expressed in Equation (4)

   $\min Z_4 = \sum_{r=14}^{16} d_r^+$
Maximize the use of production capacity per furnace. To achieve this goal, we have to minimize the positive and negative deviations.

\[
Min \, Z_5 = \sum_{i=1}^{n} d_i^- + d_i^+ \tag{5}
\]

2.2.2 The Model Constraints

1. Constraints of product demand. The product demand constraint for each period can be expressed as in equation (6), while the product demand for each furnace can be expressed as in equation (7).

\[
\sum_{i=1}^{n} X_{ik} = D_k \tag{6}
\]

\[
\sum_{k=1}^{n} X_{ik} = D_i \tag{7}
\]

2. Constraint of raw material cost. Equation (8) states the constraint for each period.

\[
\sum_{i=1}^{n} B_i X_{ik} \leq TB_k \tag{8}
\]

3. The revenue constraint from sales for each period can be expressed in equation (9).

\[
\sum_{i=1}^{n} X_{ik} P_i \geq TP_k \tag{9}
\]

4. The maintenance cost constraint for each furnace can be expressed in Equation (10).

\[
\sum_{i=1}^{n} W_i X_{ik} \leq TO_k \tag{10}
\]

5. The maximum capacity of liquid steel production for each furnace can be expressed in Equation (11).

\[
\sum_{i=1}^{n} X_{ik} = KP_k \tag{11}
\]

3. Results and Discussion

3.1 The Optimization Results

The results of the optimization can be seen in Table 4. The model was solved using LINGO 15.0 software.

| Period | Type of Furnace | Total Production (TLS) |
|--------|----------------|------------------------|
|        | EAF 1 | EAF 2 | EAF 3 | EAF 4 |                  |
| 1      | 328   | 11520 | 4372.7 | 0     | 16220.7           |
| 2      | 0     | 328   | 7475.3 | 7990.3 | 15793.6           |
| 3      | 11520 | 0     | 0     | 3857.7 | 15377.7           |

From table 4, we can see that the total of liquid steel production based on the optimal solution in each period is 16220.7 TLS, 15793.6 TLS, and 15377.7 TLS. The allocation of liquid steel production in EAF 1 for period 1 is 328 TLS, EAF 2 for the period 1 is 11520 TLS, EAF 3 for the period 1 is 4372.7 TLS, EAF 4 did not use to produce the demand in period 1. The allocation of liquid steel production in EAF 1 did not use to produce the demand in period 2, EAF 2 for period 2 is 328 TLS, EAF 3 for period 2 is 7475.3 TLS, EAF 4 for a period 2 is 7990.3 TLS. The allocation of liquid steel production in EAF 1 for period 3 is 11520 TLS, EAF 2 did not use to produce the demand in period 3, EAF 3 did not use to produce the demand in period 3, EAF 4 for period 3 is 3857.7 TLS.
The target achievement is shown in Table 5. From the table we can see whether the optimal outcome of the model satisfies the goals of the company or not. The summary of the multi goals achievement is shown in Table 5.

### Table 5. Summary of Multi Goal Achievement

| Constraint | Goal | Optimal Solutions | Information |
|------------|------|-------------------|-------------|
| Maximize the volume of production | P1: Min $\sum d_n^r + d_n^p$ | 0.00 | Achieved, with TB 1 = IDR 49,183,600,000.00 TB 2 = IDR 47,888,560,000.00 TB 3 = IDR 46,627,490,000.00 |
| Minimize the cost of raw materials each period | P2: Min $\sum d_q^r$ | 0.00 | Achieved, with TP 1 = IDR 111,217,200,000.00 TP 2 = IDR 108,288,800,000.00 TP 3 = IDR 105,437,200,000.00 |
| Maximize revenue every period | P3: Min $\sum d_p^r$ | 0.00 | Achieved, with TO 1 = IDR 40,404,520.00 TO 2 = IDR 58,283,280.00 TO 3 = IDR 30,562,030.00 |
| Minimize costs of maintenance | P4: Min $\sum d_r^r + d_r^p$ | 0.00 | Achieved, with TO 1 = IDR 40,404,520.00 TO 2 = IDR 58,283,280.00 TO 3 = IDR 30,562,030.00 |
| Maximize the use of production capacity per furnace | P5: Min $\sum d_s^r + d_s^p$ | > 0.00 | Not achieved |

From the table 5, we can see that the first goal of the model can be achieved. The factory is capable of producing the optimal solution which is indicated by the zero value. It means there is no negative deviation or achievement is less than the production target of liquid steel in each period. Since the results of the model suggested to produce 16220.7 TLS in period 1, 15793.6 TLS in period 2, and 15377.7 TLS in period 2.

The second goal of the model is to minimize the positive deviation. The factory is capable of producing the optimal solution which is indicated by the zero value. In other words, the second goal can be achieved. It shows that the solution does not have deviations which can increase the cost of raw materials in each period. The results of raw material cost from the optimal solution is IDR 49,183,600,000.00 in period 1, IDR 47,888,560,000.00 in period 2, and IDR 46,627,490,000.00 in period 3.

The third goal of the model is to minimize the negative deviation. The factory is capable of producing the optimal solution which is indicated by the zero value, this indicates that the solution does not have any deviations that can reduce the revenue in each period. The sales revenue from the optimal solution amounted to IDR 111,217,200,000.00 in period 1, IDR 108,288,800,000.00 in period 2, and IDR 105,437,200,000.00 in period 3.

The fourth goal of the model is to minimize the positive and negative deviation. The factory is capable of producing the optimal solution which is indicated by the zero value. Based on the optimal results from Lingo’s solution report, the value of a positive deviation on this goal is 0, which indicates that the results of the model already optimal yield maintenance cost is IDR 40,404,520.00 in period 1, IDR 58,283,280.00 in period 2 and IDR 30,562,030.00 in period 3.

The fifth goal of the model is to minimize the positive and negative deviation. The optimal result shows that the optimal solution is more than the zero value. It indicates that optimal allocation of liquid steel production exceeds the maximum capacity of liquid steel production in each EAF. The optimal results show some conditions like EAF 1 in period 1 has remaining production capacity 11,192 TLS, EAF 1 in
period 2 has remaining production capacity 11,520 TLS, EAF 2 in period 2 has remaining production capacity 11,192 TLS, EAF 2 in period 3 has remaining production capacity 11,520 TLS, EAF 3 in period 1 has production capacity remaining 71,473 TLS, EAF 3 in period 2 has remaining production capacity 4,044 TLS, EAF 3 in period 3 has remaining production capacity 11,520 TLS, EAF 4 in period 1 has remaining production capacity 11,520 TLS, EAF 4 in period 2 has remaining production capacity still left 3,529 TLS, EAF 4 in period 3 has remaining production capacity 7,662 TLS. According to the results of optimal production planning above we can see that there are some electric arc furnace with remaining production capacity. It indicates that the electric arc furnace can still be used to produce liquid steel exceeded the demand in this period. The remaining production capacity that is not 0 can occur due to product demand that are less than the production capacity of each electric arc furnace. Not achieving the 5th goal is influenced by some things such as utility engine that is not maximized, the demand is slightly in the period 1 - 3, so it is not proportional to the number of machine capacity. However, based on the achievement of goal to 5, it turns out the production in this plant does not exceed the capacity of the machine. Can be interpreted that the company was able to meet the demand for billet steel.

4. Conclusion
In this paper, a goal programming model was developed to determine the optimal allocation of steel production in EAF of a large steel company in Indonesia. The model was capable to find the optimal solution, so the company can allocate steel production optimally to fulfill the demand. According to the optimal solution, each EAF can achieve four goals for each period except the fifth goal which shows that the electric arc furnace can still be used to produce liquid steel exceeded the demand in this period. The rest of the production capacity with value other than zero can occur due to product demand that are less than the maximum production capacity of each electric arc furnace. This research can be further developed by considering not only the first stage but also second and third stages as an integrated model to give better solutions.

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