Optimization of supply chain operation cost and gas usage quantity using non-dominated sorting genetic algorithm II (NSGA-II) Method

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Abstract. ABC plant is one of seven plants in XYZ industry which produce Cold Rolling Coil (CRC) and Cold Rolling Sheet (CRS). The problems faced by ABC plant in its supply chain network are the high overall costs of supply chain operations and the quantity of gas usage. The characteristics of this problem consist of more than one objective, the best method for solving this problem called multi-objective optimization. This research is aim to identify the decision variables that will be optimized and determine the optimal quantity of each decision variable using NSGA-II method. The parameters used in this research are the population size of 50, crossover probability with range 0.1-0.9, mutation probability 0.1 and 0.2 also the number of generation 50 and 100. The result shows that the selected parameters for this research are the crossover probability of 0.7, mutation probability of 0.1, number of generation 100. Four decision variables that are optimized, namely CRC produced (Lite, Medium, and Heavy) and CRC stored with the quantities simultaneously are 40,918, 112,479, 173,758, and 43,209 tons. This result will assist the ABC plant in minimizing the overall cost of supply chain (124,532,272 USD) and the quantity of gas usage (39,634,749,440 Kcal).

1. Introduction
The supply chain is a network consisting of companies that work together with the aim of making and distributing a product to end-user. In a supply chain network, it consists of three flow must be managed, namely information, finance, and material [1]. The method used in managing supply chain network is known as supply chain management [2]. ABC plant is one of seven plants in XYZ industry which produce CRC and CRS. This plant implements supply chain management under the supervision of the Supply Chain Improvement (SCI) division. As an actor in a supply chain network ABC plant must be able to see from a variety point of view, one of them is a business view (voice of business) [3]. In this view, the main priority that requires special attention is about the cost without compromising product quality and flexibility [4]. So, the ABC plant still able to fulfil the end user specification, it’s called process capability [5]. Some researchers conduct the research about the cost reduction such as Wiliamson [6]; Ridwan and Noche [5]; and Roeck et al. [7]. Wiliamson [6]
examining the transaction cost economics in outsourcing as an analysis of the basic unit and the procurement decision. Ridwan and Noche [5] decreasing the cost of poor quality of cargo handling in the port, consist of lost cargo, damaged cargo, equipment and transporter breakdown, and delay time. Roeck et al. [7] explaining there are six effects of distributed ledger technology (DLT) solutions to the supply chain transactions as a cost reduction. On the other side, an ABC plant must consider the impact resulting from the production process on the environment around the plant.

The problems faced by ABC plant in its supply chain network are the high overall costs of supply chain operations and the quantity of gas usage. Both problems are caused by the machine performance that is not optimal and sometimes ABC plant has to produce in quantities exceed the order. As a result of excessive production, the supply chain operation cost and the quantity of gas usage are high. The expenses include production, logistics, and savings. Production costs are divided into four variables, such as direct fixed cost, fixed allocations, raw materials, and conversions. Logistics cost is the cost of shipping CRC from ABC plant directly to end users while the storage cost is the cost for storing CRC in the ABC warehouse. Likewise, with the quantity of gas which consists of boiler natural gas, fuel, and process gas. Because of this problem, it is necessary to minimize both using the optimization model. The characteristics of this problem consist of more than one objective, so the best method for solving this problem called Multi Objective Optimization.

Multi-objective optimization is a completing method of optimization which consists of more than one objective function which is simultaneously optimized [8]. There are several methods in Multi-objective Optimization such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Simulated Annealing, etc. Genetic Algorithm (GA) is a metaheuristics search algorithm which is based on the mechanism of biological evolution with the nature of searching for the possibilities of prospective solution to get the optimal solution for the problem [9], GA can be implemented in various fields such as video game [8], maintenance scheduling [10], and also in supply chain [3]. In GA, there are several methods which often used, including Non-Dominated Sorting Genetic Algorithm (NSGA-II), Multi-objective Genetic Algorithm (MOGA), and Non-Dominated Ranking Genetic Algorithm (NRGA).

The focus of this research is to solve the optimization problem in the supply chain network of ABC plant not only from the voice of business but also by paying attention to the impact on the surrounding environment. In this research, we set two objective functions according to the problems that exist in the ABC plant, including minimizing the overall cost of supply chain operations and quantity of gas used as an innovation. We used the Non-Dominated Sorting Genetic Algorithm (NSGA-II) as completing method to solve this problem. NSGA-II is a genetic algorithm which uses fast non-dominated sorting procedure, an elitist-preserving approach, and a parameterless niching operator [11]. The consideration to use NSGA-II in this research is due to the advantages of this method compared to the other genetic algorithm and metaheuristics. Utama [3] compared NSGA-II with MOGA, and as a result, NSGA-II provides a better optimum value in achieving the objective function. Mousavi et al. [12] also compared three metaheuristics methods including NSGA-II, NRGA, and PSO, with the results NSGA-II having an average the completion time is shorter than the other two metaheuristics methods.

Some example from previous researches using NSGA-II to solve supply chain optimization problem like in Utama [3] setting two objective functions namely minimizing the total cost of supply chain operations and inaccurate of shipping goods to customers by calculating future and present value. Decision variables used in this research are the quantity of product delivery from producers to wholesalers and wholesalers to retailers. Bandyopadhyay and Bhattacharya [13] establishing three objective functions such as minimizing the total cost of the supply chain, the variance of the quantity of product order, and the total amount of products in inventory. In this research, the decision variables are the number of products stored, ordered, and sent. Another study, Chan et al. [14] setting objective function to minimize total cost which includes total production cost, transportation cost, storage cost, and penalty fee and the second objective is to reduce the percentage of the number of order by retailers
within a particular time. The decision variable used in this study is the type of truck and the quantity of product demand from retailers.

Same with some previous researches mentioned above using the quantity of production as the decision variable. So, this research also uses the quantity of CRC produced consist of three types of CRC (Lite, Medium, and Heavy) and CRC stored as decision variables which will be optimized then. To obtain the optimal configuration for the quantity of CRC produced and stored, several trials were carried out on parameters with different values. The parameter which produces the best average fitness value will be selected and used as a reference to assist XYZ industry in achieving its goal to minimize the overall cost of supply chain operation and quantity of gas usage in ABC plant in certain time horizon.

2. Research Method
This research used quantitative approaches which in the process of solving problems using numerical data as a tool to analyze information under predetermined research objectives. The data used in this research include production cost, logistics cost, storage cost, the quantity of gas usage, production capacity, storage capacity, and also the proportion of production for each CRC product. After data has been collected, data processing start with determining decision variables, objective functions, and constraints. Then, this data presented in a mathematical model and testing the model using NSGA-II method. The NSGA-II process consists of several steps [15]. Before we start the NSGA-II procedures, the parameters are determined. The number of the population used is 50 with crossover probability in range 0.1-0.9, mutation probability 0.1 and 0.2; also the number of generations are 50 and 100. First, based on its range and constraints, a random population was initializing. Then, we evaluate chromosomes in population according to the objective functions. Once the population is evaluated, it is then sorted according to non-domination using fast sort algorithm into each front. The individuals in each front are assigned with rank. The rank one is assigned to individuals in the 1st front and so on. In each front, we measure the distance of individual with its neighbours called crowding distance.

After sorting the individuals, we selected parents using tournament selection and crowded comparison operator. Selected individuals are individuals with smaller rank and greater crowding distance than the other one. To produce offspring, selected parents will undergo crossover and mutation. The method used is a one-point crossover and swap mutation. Chromosome evaluation will also be experienced by the offspring population. The next step is to merge the initial population with the offspring population, so the population size becomes 2N. This merge population is again sorted based on non-domination, and crowding distance and only N individuals are selected. The new generation population will be filled by elements from each front until it exceeds the population size (N) on adding the final front. In this case, the elements in the final front will be sorted in descending order based on their crowding distance and then filled in new generation population until the population size reaches N. This procedure will be repeated until the number of generations is reached. After all NSGA-II procedures are completed, the final step is to measure the attainment of NSGA-II method based on execution time and objective functions attainment in each period. This research follows the steps, as shown in Figure 1.
3. Input Data and The Mathematical Model
In this section, we will discuss the input data used in this research and mathematical model of the problems that exist in the ABC plant.

3.1. Input Data
The data used in this research include production cost consists of conversion cost, raw material cost, direct fixed cost, and fixed allocation cost. Then the logistics cost, storage cost, quantity of gas usage which includes boiler natural gas, fuel gas, and process gas, production and storage capacity as well as the proportion of production for each CRC product of the ABC plant in XYZ industry. Assume all of the data collected have been converted to the monthly average value.

3.2. The Mathematical Model
Mathematical model of the problem in ABC plant are presented in this section using the following notation include indexes, parameters, and decision variables and can be expressed in the numerical equations.
Sets
\(p\) types of finish product \(\{p = 1, 2, \ldots, P\}\)

Parameters
- \(B_{K_p}\) conversion cost of product type \(p\) in a period
- \(B_{BB_p}\) raw material cost of product type \(p\) in a period
- \(B_{TL}\) direct fixed cost in a period
- \(B_{TA}\) allocation fixed cost in a period
- \(B_{L_p}\) production cost of product type \(p\) in a period
- \(B_{S}\) storage cost in a period at ABC warehouse
- \(G_{AB_p}\) quantity of boiler natural gas used for producing product type \(p\) in a period
- \(G_{BB_p}\) quantity of fuel gas used for producing product type \(p\) in a period
- \(G_{P_p}\) quantity of process gas used for producing product type \(p\) in a period
- \(Q_p\) production capacity of ABC plant in a period
- \(Q_s\) storage capacity of ABC warehouse in a period

Decision variables
- \(CR_{CL}\) quantity of CRC type Lite in a period
- \(CR_{CM}\) quantity of CRC type Medium in a period
- \(CR_{CH}\) quantity of CRC type Heavy in a period
- \(CR_{C_f}\) quantity of CRC stored in ABC warehouse in a period

First of all, variables are converted into notation form. Next step is to make a mathematical model of the problem discussed in this research. The objective functions used in this research are minimized the overall cost of the supply chain and minimize the quantity of gas usage, which simultaneously expressed by \(Z_1\) and \(Z_2\). The first objective function (\(Z_1\)) can be seen, as shown below:

\[
\text{Min } Z_1 = B_{P_p} (CR_{CL} + CR_{CM} + CR_{CH}) + B_{L_p} (CR_{CL} + CR_{CM} + CR_{CH}) + B_{S} (CR_{C_f})
\]  

The objective function is shown in Eqs.(1) aim to minimize the overall cost of the supply chain in ABC plant that includes three components such as production cost, logistics cost, and storage cost. For production and logistics cost will be multiplied by the amount of production of three types of CRC while storage cost will be multiplied by the number of CRC stored in ABC warehouse. After knowing the value for each component, then the components are summed up to produce the overall cost of the supply chain in ABC plant. Since the production cost consists of four cost variables, it can be formulated, as shown in Eqs.(2):

\[
B_{P_p} = B_{K_p} + B_{BB_p} + B_{TA_p} + B_{TL_p}
\]

The second objective function (\(Z_2\)) can be formulated as:

\[
\text{Min } Z_2 = G_{AB_p} (CR_{CL} + CR_{CM} + CR_{CH}) + G_{BB_p} (CR_{CL} + CR_{CM} + CR_{CH}) + G_{P_p} (CR_{CL} + CR_{CM} + CR_{CH})
\]  

Eqs.(3) aims to minimize the quantity of gas usage, which include boiler natural gas, fuel gas, and process gas. The quantity of each type of gas will be multiplied by the amount of production of three types of CRC and summed up to produce a total quantity of gas usage. Also, there are constraints that indicate the capacity of ABC plant which formulated as:

Subject to:
\[ \text{CRC}_L + \text{CRC}_M + \text{CRC}_H \leq Q_p \]  
(4)

\[ \text{CRC}_L \leq Q_s \]  
(5)

\[ \text{CRC}_L, \text{CRC}_M, \text{CRC}_H \geq 50 \]  
(6)

\[ \text{CRC}_L \geq 0 \]  
(7)

Eqs.(4) is the constraint that shows the production capacity of ABC plant where the amount of CRC production must be smaller or equal to its production capacity. However, Qp is a composite constraint for three CRC products so to determine the production constraint of each type of CRC the production capacity will be multiplied by the proportion of production of each type of CRC. Eqs.(5) represented storage capacity of ABC warehouse while Eqs.(6) is the minimum quantity to produce each type of CRC (Lite, Medium, and Heavy) and Eqs.(7) and the lower bound for the number of CRC stored. In the next section, will be discussed regarding the results obtained using NSGA-II method.

4. Result and Discussion

In this research, the experimentation has been conducted in a PC with specification Pentium ®, Dual-Core CPU E5500 2.8 Ghz processor, 6 Gb memory, windows 10 Pro 64 bit, DirectX version 11.1. NSGA-II algorithm has been experimented using Matlab R2017a. The tuning parameters used in this research include population size of 50, crossover probability within range 0.1-0.9, mutation probability 0.1 and 0.2, and the number of generation 50 and 100. Metaheuristic algorithms are sensitive to their parameters, and a small change can affect the quality of the solution obtained [16]. After processing the data using NSGA-II method, the next step is to measure NSGA-II attainment based on objective function attainment and execution time. The execution time is the time required by the algorithm to obtain Pareto optimal solutions in one run [16]. In this research, we use several combination parameters which include nine values of crossover probability, two values of mutation probability, and two number of generations, so the total trials conducted in 36 trials. The result of trials, as shown in Table 1 below.

| Crossover Probability | Mutation Probability | Number of Generation | Cost of Supply Chain Operation (f1) | Quantity of Gas Usage (f2) | Execution Time (sec) |
|-----------------------|-----------------------|----------------------|-------------------------------------|---------------------------|----------------------|
| 0.9                   | 0.1                   | 50                   | 154,301,225                         | 151,133,861.120           | 9.459                |
| 0.8                   |                       |                      | 152,527,687                         | 48,574,970.880            | 6.486                |
| 0.7                   |                       |                      | 173,987,044                         | 55,442,391.040            | 5.44                 |
| 0.6                   |                       |                      | 145,055,808                         | 46,170,373.120            | 5.646                |
| 0.5                   | 0.1                   | 50                   | 165,718,566                         | 52,778,204.160            | 5.641                |
| 0.4                   |                       |                      | 160,576,278                         | 51,094,149.120            | 5.84                 |
| 0.3                   |                       |                      | 174,055,228                         | 55,406,725.120            | 5.492                |
| 0.2                   |                       |                      | 177,030,106                         | 56,359,546.880            | 5.538                |
| 0.1                   |                       |                      | 180,432,533                         | 57,475,594.240            | 5.571                |
| 0.9                   | 0.2                   | 50                   | 156,966,963                         | 49,965,056.000            | 6.003                |
| 0.8                   |                       |                      | 147,279,450                         | 46,873,482.240            | 5.773                |
| 0.7                   |                       |                      | 189,787,621                         | 60,449,315.840            | 5.803                |
| 0.6                   |                       |                      | 161,780,011                         | 51,498,449.920            | 5.481                |
| 0.5                   | 0.2                   | 50                   | 154,677,410                         | 49,251,517.440            | 6.83                 |
| 0.4                   |                       |                      | 190,500,385                         | 60,657,505.280            | 6.791                |
| 0.3                   |                       |                      | 170,167,129                         | 54,187,868.160            | 6.773                |
| 0.2                   |                       |                      | 182,786,957                         | 58,215,162.880            | 5.456                |
| 0.1                   |                       |                      | 150,799,915                         | 48,014,033.920            | 6.718                |
From Table 1 above, we can find out the average fitness and execution time for each different parameter value. For the probability of mutation 0.1 with the number of generation 50, the optimal fitness is at the crossover probability 0.6 with an average fitness value of 145,055,808 USD (f1) and 46,170,373,120 Kcal (f2) with an execution time of 5.646 seconds. With the same number of generation but different mutation probability (0.2), the optimal fitness is at the crossover probability 0.8 with average fitness value of 147.279.450 USD (f1) and 46,873,482,240 Kcal (f2) with an execution time of 5.773 seconds. While in generation 100 with a mutation probability of 0.1, it can be seen that the optimal fitness is at the probability of crossing 0.7 with an average fitness value is 124,532,272 USD (f1) and 39,634,749,440 Kcal (f2) with an execution time 15.727 seconds and for the mutation probability 0.2 the optimal fitness is at the crossover probability 0.8 with an average fitness value of 136,703,873 USD (f1) and 43,501,276,160 Kcal (f2) with an execution time 10.936 seconds.

Also, from Table 1, when using different parameter values will produce different output because NSGA-II is very sensitive to its parameters [8][16]. First, by comparing two value mutation probability 0.1 and 0.2 for the same number of generation, the comparison will look like in the graph, as shown in Figure 2 and Figure 3 below.
Based on the comparison graph for 50 generations, the mutation probability of 0.1 will produce more optimal fitness value than the mutation probability of 0.2. Likewise, for 100 generations, where the graph shows that the mutation probability 0.1 produces more optimal value than the mutation probability of 0.2. So the mutation probability of 0.1 will be chosen for this research. Another parameter that is compared is the number of generation. By using the chosen mutation probability for two different number of generation, namely in the 50th and 100th generations, the comparison is shown in Figure 4 below.
From Figure 4 above by using the chosen mutation probability, the average fitness value in 50\textsuperscript{th} generation is greater than the average fitness value in the 100\textsuperscript{th} generation. It means that the 100\textsuperscript{th} generation has more optimal fitness value than the 50\textsuperscript{th} generation according to the minimization function used in this research. After the probability of mutation and the number of generation is chosen, the next step is to find out the best crossover probability with mutation probability of 0.1 and the number of generation 100. From Table 1 above, shows that the crossover probability with the average fitness value is at the crossover probability of 0.7 with fitness value 124,532,272 USD (f1), and the quantity of gas usage is 39,634,749,440 Kcal (f2) with an execution time of 15.727 seconds. So, the chosen parameters for this research are the crossover probability of 0.7, mutation probability of 0.1 and the number of generation 100. And the output produced using these selected parameters, as shown in Table 2 below.

| Chromosome | Solution Population | Cost of Supply Chain Operation (f1) | Quantity of Gas Usage (f2) |
|------------|---------------------|-------------------------------------|---------------------------|
|            | Lite                | Medium                             | Heavy                     | Stored        |                           |                          |
| 1          | 4,067               | 73,038                             | 954                       | 39,423        | 62,997,548               | 19,983,104,000            |
| 2          | 426                 | 73,745                             | 39,923                    | 37,578        | 70,994,158               | 22,441,984,000            |
| 3          | 12,092              | 48,855                             | 66,175                    | 51,896        | 70,994,158               | 22,441,984,000            |
| 4          | 44,119              | 62,074                             | 67,753                    | 26,290        | 84,212,560               | 26,776,320,000            |
| 5          | 32,316              | 91,512                             | 87,467                    | 19,763        | 90,075,984               | 28,568,832,000            |
| 6          | 69,913              | 54,376                             | 14,789                    | 21,446        | 70,994,158               | 22,441,984,000            |
| 7          | 2,887               | 70,659                             | 75,160                    | 51,159        | 75,899,722               | 24,060,416,000            |
| 8          | 72,656              | 54,948                             | 52,582                    | 32,886        | 75,899,722               | 24,060,416,000            |
| 9          | 46,112              | 30,872                             | 130,138                   | 66,307        | 76,990,186               | 24,514,048,000            |
| 10         | 71,172              | 151,859                            | 10,406                    | 31,588        | 84,212,560               | 26,776,320,000            |
| 11         | 57,710              | 21,201                             | 155,364                   | 71,283        | 84,212,560               | 26,776,320,000            |
| 12         | 60,546              | 105,317                            | 134,441                   | 61,023        | 85,173,770               | 27,016,960,000            |
| 13         | 77,927              | 71,861                             | 192,123                   | 25,038        | 85,173,770               | 27,016,960,000            |
| 14         | 40,844              | 165,612                            | 227,858                   | 52,613        | 86,209,298               | 27,401,984,000            |
| 15         | 61,514              | 150,088                            | 276,799                   | 20,629        | 89,828,164               | 28,568,832,000            |
| 16         | 69,736              | 51,298                             | 65,502                    | 53,230        | 90,075,984               | 28,568,832,000            |
| Chromosome | Lite  | Medium | Heavy  | Stored | Cost of Supply Chain Operation (f1) | Quantity of Gas Usage (f2) |
|------------|-------|--------|--------|--------|-----------------------------------|---------------------------|
| 17         | 10,215| 89,326 | 98,920 | 16,367 | 96,253,546                        | 30,608,128,000            |
| 18         | 77,291| 49,633 | 102,378| 27,291 | 98,199,442                        | 31,161,856,000            |
| 19         | 37,761| 83,907 | 110,707| 31,350 | 100,374,378                       | 31,938,304,000            |
| 20         | 20,059| 118,277| 107,043| 51,027 | 107,100,158                       | 34,156,544,000            |
| 21         | 20,814| 72,126 | 171,767| 53,261 | 107,100,158                       | 34,156,544,000            |
| 22         | 74,623| 126,029| 85,426 | 38,969 | 113,613,516                       | 36,204,288,000            |
| 23         | 24,777| 147,011| 116,038| 44,805 | 113,613,516                       | 36,204,288,000            |
| 24         | 51,927| 195,659| 55,785 | 40,522 | 113,943,126                       | 36,204,288,000            |
| 25         | 49,634| 155,005| 114,352| 28,082 | 122,639,702                       | 38,981,376,000            |
| 26         | 22,246| 33,859 | 274,343| 22,212 | 123,920,428                       | 39,440,384,000            |
| 27         | 6,800 | 87,083 | 236,248| 61,434 | 123,920,428                       | 39,440,384,000            |
| 28         | 24,323| 103,469| 213,339| 64,298 | 133,670,138                       | 42,662,144,000            |
| 29         | 46,889| 119,520| 175,199| 46,121 | 144,634,832                       | 45,971,456,000            |
| 30         | 13,909| 111,150| 220,699| 31,294 | 145,251,176                       | 46,148,608,000            |
| 31         | 55,208| 33,124 | 323,516| 57,669 | 149,517,930                       | 47,560,960,000            |
| 32         | 47,478| 84,221 | 295,564| 48,947 | 149,517,930                       | 47,560,960,000            |
| 33         | 3,174 | 138,366| 290,748| 75,173 | 149,517,930                       | 47,560,960,000            |
| 34         | 16,813| 199,210| 261,633| 7,742  | 153,663,812                       | 48,884,736,000            |
| 35         | 48,972| 150,050| 282,736| 60,283 | 155,381,572                       | 49,510,656,000            |
| 36         | 7,368 | 149,267| 102,721| 13,878 | 155,381,572                       | 49,510,656,000            |
| 37         | 42,123| 149,864| 138,213| 6,772  | 155,638,212                       | 49,592,576,000            |
| 38         | 68,905| 146,186| 114,890| 78,410 | 161,797,352                       | 51,480,576,000            |
| 39         | 63,936| 190,684| 85,452 | 65,726 | 161,893,872                       | 51,480,576,000            |
| 40         | 14,723| 72,521 | 306,631| 62,681 | 161,893,872                       | 51,480,576,000            |
| 41         | 69    | 207,312| 190,270| 8,585  | 166,231,338                       | 53,055,744,000            |
| 42         | 68,823| 84,994 | 279,123| 13,948 | 168,463,280                       | 53,699,840,000            |
| 43         | 15,604| 107,551| 331,036| 26,577 | 168,759,806                       | 53,854,208,000            |
| 44         | 44,540| 187,570| 222,489| 79,935 | 170,484,106                       | 54,404,608,000            |
| 45         | 42,371| 81,766 | 354,559| 64,912 | 174,749,276                       | 55,778,048,000            |
| 46         | 38,353| 127,335| 315,297| 40,986 | 174,798,676                       | 55,778,048,000            |
| 47         | 68,268| 178,326| 267,037| 32,442 | 174,798,676                       | 55,778,048,000            |
| 48         | 61,419| 187,400| 280,240| 55,475 | 178,261,100                       | 56,887,040,000            |
| 49         | 77,347| 198,362| 187,043| 61,363 | 178,738,310                       | 56,887,040,000            |
| 50         | 55,120| 196,459| 288,248| 79,747 | 188,946,146                       | 60,297,728,000            |

Average 40,918 112,479 173,758 43,209 124,532,272 39,634,749,440

Based on Table 2, it can be seen the optimal quantity of each decision variable where the quantity used in this research is the average quantity. For CRC type Lite the optimal quantity is 40,918 tons, CRC type Medium 112,479 tons, CRC type Heavy 173,758 tons and quantity of CRC stored is 43,209 tons. Cost of supply chain operation is 124,532,272 USD, and the quantity of gas usage is 39,634,749,440 Kcal.
5. Conclusion
There are four decision variables used in this research including the quantity of CRC produced which consist of CRC type lite, medium, and heavy also the quantity of CRC stored in ABC warehouse with the quantity of each decision variables simultaneously is 40,918 tons, 112,479 tons, 173,758 tons, and 43,209 tons. Cost of supply chain operation is 124,532,272 USD, and the quantity of gas usage is 39,634,749,440 Kcal. By obtaining the quantity of each decision variable, it will assist the XYZ industry, especially ABC plant, in minimizing the overall cost of supply chain operation and the quantity of gas usage.

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