Application Genetic Algorithm In solving three-level supply chain distribution problems.

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Abstract. Every company cannot be separated from transportation problems, both for the procurement of raw materials or in allocating finished goods. One method that can be used to minimize transportation costs is to optimize the distribution of goods as possible, using transportation methods. Given the complexity of supply chain problems, the use of meta-heuristic methods such as genetic algorithms is expected to be able to quickly resolve supply chain problems, where time is a mandatory requirement to satisfy the market. The problem in the application of genetic algorithms in this study is the distribution of three levels. This study uses 3 producers, 3 agents, 5 distributors and 7 retails. Optimal solutions were obtained from population sizes of 10, 20, and 30 with a combination of mutation probabilities, 0.1 and 0.2, crossover probabilities of 0.1 and 0.2, amounting to 100.454, by conducting experiments 20 times for each genetic parameter. The lowest cost distribution is obtained at population size 20, mutation probability 0.1 and crossover probability 0.2. Based on these results obtained goods distribution channels from each producer, agent and distributor.

Keywords: genetic algorithm, supply chain, three-level supply chain distribution.

1. Introduction
Supply chain is a network of companies that jointly work to create and deliver a product to the end user. These companies usually include suppliers, factories, distributors, stores or retail, as well as supporting companies such as logistics service companies [1].

Supply chain management has become an important concept in the business world today. The main core of supply chain management is the distribution process. One of the problems of distribution is the decision strategy in determining the allocation of the number of products that must be moved from the supplier level to the customer level. Supply chains are focused on the upstream and downstream sides. The focus of the supply chain on the upstream and downstream sides is shown in Figure 1.

Figure 1. Supply chain structure (Source: [2]).
According to (Sunil, in [3]), that the process of distribution and storage of goods from the supplier level to the hands of consumers is at the core of supply chain management. This is a concept that is needed in the business world. The main basis for the company’s success in business distribution activities is how the distribution runs with maximum results with minimal distribution costs. Transportation problems that often occur is a decision strategy process to create a shipping distribution channel and the number of products to be allocated from suppliers to consumers. In determining the best decision, it can be modeled various processes and distribution problems. In this study, the type of costs that affect distribution costs is used, namely variable costs which are the distribution costs of each amount of goods distributed to each level of distribution. The supply chain distribution studied is a three-level distribution.

Genetic algorithms are part of the evolution algorithm. Genetic algorithm in its application is able to solve complex problems in various problem areas. The basic thing about genetic algorithms is that individuals in the population race to obtain resources and their partners by doing reproduction to obtain new individuals who have better genes than their parents. Furthermore, it will go through a genetic process in the form of individual natural selection, where individuals with the best genes will survive to get the next best generation [4]. The main strength of a genetic algorithm is its ability to solve complex problems in a relatively fast time. [5]

Some researches that have been done related to supply chain completion by using the genetic algorithm approach are the basis for researchers to conduct this research. The research that has been conducted is as follows: According to [6] in his book that discusses various methods both deterministic and stochastic methods for supply chain, searching with genetic algorithms is more reliable for various common supply chain problems (less-problem dependent). The advantage of searching with GA is that there is a recombination between individuals to get better results in the next iteration. Furthermore [6], states that one way to improve the performance of GA is by installing mutation rates that change throughout the iteration (adaptive).

Research conducted [7], in his research on solving multi-stage supply chain problems that are multi-period, multi-product with a genetic algorithm approach to obtain results in the form of minimization of the total supply chain costs compared to production and distribution costs. In contrast to [8], his research uses a comparison between genetic algorithms and particle swarm optimization in solving three-level supply chain problems.

In the study [9], explained that the advantages of genetic algorithms are, get a fast optimal solution, and are flexible with various input data factors in the algorithm. The model is focused on achieving the target inventory and transportation quantity by minimizing the total cost of the system by combining random local search methods with genetic algorithms.

Research in 2017 was conducted by [10], in which his research solved a case of solving the distribution of fuel routes to the islands using the concept of a traveling salesman problem which was solved by the Genetic Algorithm method, by determining the best distribution path that can be traversed by the ship so that the costs become optimal.

2. Research Methods

2.1 Sample data

Data used in this study include:

a) Number of producers, agents, distributors and retails.

b) Variable costs for distribution from each producer to each agent, from each agent to each distributor, from each distributor to each retail. The amount of capacity that can be provided by each producer, agent and distributor.

c) The maximum number of products that can be produced by each producer in one production period.

d) The maximum number of products that can be accommodated by the warehouse of each agent and distributor.

e) Number of product requests for each retail.
f) Data entered in the distribution process, in the form of the number of producers, agents, distributors and retailers, as well as the distribution costs between each level are simulation data. Data characteristics are adjusted to real problems.

g) The final outcome expected from this research is to produce the lowest distribution costs and determine the amount of distribution of goods for distribution channels from each producer to agent, from each agent to distributor and from each distributor to each retail.

2.2 Genetic Algorithms
The genetic algorithm starts with the formation of a number of alternative solutions called populations. The initial population formation in the genetic algorithm was carried out randomly. In this population there are members of the population called chromosomes.

2.3 Chromosome Representation
Chromosome representation is a process for solving problems, where a problem can be coded into chromosomes [11].

Chromosome is a representation of a desired solution. Chromosomes will be divided into 3 sub, the length of each sub can be different, thus, then a chromosome is represented in 3 sub, where the first sub represents the amount of goods distributed from each producer to the every agent. The length of the first sub is the number of producers multiplied by the number of agents. The second sub represents the number of goods distributed from each agent to each distributor with the length of the number of agents multiplied by the number of distributors, while the third sub represents the number of goods distributed from each distributor to each retail, with the length of the number of distributors multiplied by the number of retails. Figure 2 shows the chromosome representation.

| Sub 1 | P1A1 | P2A1 | ... | PiA1 | P1A2 | P2A2 | ... | PiAj |
|-------|------|------|-----|------|------|------|-----|------|
| Sub 2 | A1D1 | A2D1 | ... | AjD1 | A1D2 | A2D2 | ... | AjDk |
| Sub 3 | D1R1 | D2R1 | ... | DkR1 | D1R2 | D2R2 | ... | DkRl |

Figure 2. Representation of chromosomes [3].

2.4 Selection Process
The selection method used is the roulette wheel method, where the greater the value of the chromosome fitness, the greater the chance to be chosen. Chromosomes that have good objective values will have a higher probability of being chosen.

2.5 Crossover Process
The crossover method used is the one point crossover method. The crossover process requires two parent chromosomes. This process is carried out by exchanging some information about the first parent chromosome with information from the second parent chromosome.

2.6 Mutation Process
The process of mutation is one genetic operator to produce random changes on one chromosome. The easiest way to do mutations is to change one or more parts in a chromosome by selecting a chromosome to be randomly mutated, and then determining the mutation point on that chromosome randomly.

2.7 Fitness function
Each chromosome that has been raised will be evaluated by a function called the fitness function. The higher the value of fitness, the stronger an individual is. Calculation of fitness value in this case is based on distribution costs. The cost of distribution of goods is determined by the mathematical model in equation (1).
\[
Z = \sum_{i=1}^{p} \sum_{j=1}^{p} (X_{ij}B_{ij}) + \sum_{j=1}^{p} \sum_{k=1}^{q} (X_{jk}B_{jk}) + \sum_{k=1}^{q} \sum_{l=1}^{r} (X_{kl}B_{kl})
\]  
(1)

with:
- \(X_{ij}\): the amount of distribution of goods from producers \(i\) to agents \(j\)
- \(B_{ij}\): distribution cost of goods from producer \(i\) to agent \(j\)
- \(X_{jk}\): the amount of distribution of goods from agent \(j\) to distributor \(k\)
- \(B_{jk}\): cost of goods distribution from agent \(j\) to distributor \(k\)
- \(X_{kl}\): amount of distribution of goods from distributor \(k\) to retail \(l\)
- \(B_{kl}\): cost of goods distribution from distributor \(k\) to retail \(l\)

The problem in this study is to minimize distribution costs, so the value of fitness can be determined by Equation (2).

\[
Fitness = \frac{1}{Z}
\]  
(2)

3. Results and Discussion

The experiments were carried out with various genetic parameter values. It aims to determine the effect of genetic parameters on the results of genetic algorithms. The observed population size values are 10, 20 and 30, the value of the probability of mutation in experiments is 0.1 and 0.2, and the value of the probability of crossover in experiments is 0.1 and 0.2. The maximum number of chromosomes in each population is 200. Each experiment carried out for each combination is 20 times to get an average value of transportation costs.

3.1 Test Data

The experiments in this study involved 3 producers, 3 agents, 5 distributors and 7 retailers. Then Table 1. shows the capacity of goods that can be provided by each producer, agent and distributor. Table 2. shows the number of requests from each retail. Table 3. shows the transportation costs for the distribution of goods. Genetic parameters are determined as follows:

- Total initial population: 10, 20 and 30
- Maximum generation: 200
- Mutation Probability: 0.1 and 0.2
- Crossover Probability: 0.1 and 0.2

The experiment was carried out 20 times for each genetic parameter..

Table 3. shows the distribution costs from each producer to each agent. Rows indicate producers, columns show agents. Table 4. shows the distribution costs from each agent to each distributor. Rows indicate agents, columns show distributors. Table 5. shows the distribution costs from each distributor to each retail. Rows indicate distributors, columns show retail.

| Name     | Capacity |
|----------|----------|
| Producer 1 | 450      |
| Producer 2 | 220      |
| Producer 3 | 410      |
| Agent 1   | 330      |
| Agent 2   | 400      |
| Agent 3   | 350      |
| Distributor 1 | 180   |
| Distributor 2 | 175   |
| Distributor 3 | 300   |
| Distributor 4 | 225   |
| Distributor 5 | 200   |
Table 2. Demand from every retail.

| Retail | Demand |
|--------|--------|
| Retail 1 | 160 |
| Retail 2 | 100 |
| Retail 3 | 130 |
| Retail 4 | 80 |
| Retail 5 | 230 |
| Retail 6 | 270 |
| Retail 7 | 110 |

Table 3. Distribution cost table from producers to agents.

| from | to | Agent 1 | Agent 2 | Agent 3 |
|------|----|---------|---------|---------|
| Producer 1 | 54 | 27 | 16 |
| Producer 2 | 33 | 40 | 38 |
| Producer 3 | 28 | 32 | 29 |

Table 4. Distribution costs from agents to distributors.

| from | Distributor 1 | Distributor 2 | Distributor 3 | Distributor 4 | Distributor 5 |
|------|---------------|---------------|---------------|---------------|---------------|
| Agent 1 | 17 | 23 | 33 | 40 | 68 |
| Agent 2 | 38 | 16 | 61 | 26 | 45 |
| Agent 3 | 55 | 67 | 45 | 32 | 30 |

3.2. Experiment Results

Observations were made with various genetic parameter values, for the purpose of knowing the effect of each parameter values that can be achieved by genetic algorithms. Observation 1 was made of population size 10, with a mutation probability value of 0.1, a crossover probability of 0.1. Each observation was carried out 20 times each experiment to get the average distribution cost for each genetic parameter combination.

Observation 2, the experiment was carried out with a population size of 20, a mutation probability value of 0.1, a crossover probability of 0.1. Each observation was carried out each experiment 20 times for each genetic parameter combination. Observation 3, conducted an experiment with a population size of 30, the value of the probability of mutation of 0.1, the probability of a crossover of 0.1. Each observation was carried out each experiment 20 times for each genetic parameter combination.

Table 5. Distribution costs from distributors to retails.

| from | Retail 1 | Retail 2 | Retail 3 | Retail 4 | Retail 5 | Retail 6 | Retail 7 |
|------|---------|---------|---------|---------|---------|---------|---------|
| Distributor 1 | 20 | 23 | 14 | 32 | 68 | 16 | 21 |
| Distributor 2 | 62 | 66 | 61 | 26 | 55 | 67 | 50 |
| Distributor 3 | 31 | 21 | 54 | 25 | 22 | 20 | 23 |
| Distributor 4 | 67 | 57 | 24 | 18 | 62 | 66 | |
| Distributor 5 | 28 | 50 | 37 | 22 | 30 | 41 | 38 |

Table 6. shows a summary of Observation 1, 2 and 3 results, namely by conducting experiments with mutation probability values of 0.1, crossover probabilities of 0.1 and population sizes of 10, 20 and 30. The lowest transportation cost of each trial is 20 times. Table 6 shows that the lowest cost obtained
was 102,820 from each trial, the largest Z value of the best individual was 129,023, while the average best cost obtained by the best individuals was 115,160 with a population size of 10. The worst cost of the whole the trial obtained was 130,489.

Table 6. Summary of observations 1, 2 and 3

| Pop Size | Best Z  | Worst Z  | Average Z | Best Fitness | Worst Fitness | Avg Fitness |
|----------|---------|----------|-----------|--------------|---------------|-------------|
| 10       | 102.820 | 129.023  | 115.160   | 9.73E-06     | 7.75E-06      | 8.71E-06    |
| 20       | 104.707 | 130.489  | 118.047   | 9.55E-06     | 7.66E-06      | 8.48E-06    |
| 30       | 105.477 | 129.552  | 118.529   | 9.48E-06     | 7.72E-06      | 8.28E-06    |

Observations 4, 5, and 6, experiments carried out with a population size consisting of 10, 20 and 30, respectively, with a mutation probability value of 0.1, a crossover probability of 0.2. Table 7. shows the results of the experiment with these parameters. Table 7. shows that the lowest cost obtained was 100,454 from each best individual in every 20 trials, with a population size of 20. The largest Z value for the best individual was 125,572. While the average best cost obtained by the best individuals is 115,359,077 with a population size of 10. The worst cost of the whole trial obtained is 130,441 with a population size of 10.

Table 7. Summary of observations 4, 5 and 6

| Pop Size | Best Z  | Worst Z  | Average Z | Best Fitness | Worst Fitness | Avg Fitness |
|----------|---------|----------|-----------|--------------|---------------|-------------|
| 10       | 102.822 | 130.441  | 116.916   | 9.95E-06     | 7.96E-06      | 8.57E-06    |
| 20       | 100.454 | 125.572  | 119.746   | 9.79E-06     | 7.87E-06      | 8.55E-06    |
| 30       | 102.102 | 127.080  | 117.051   | 9.79E-06     | 7.87E-06      | 8.55E-06    |

Observations 7, 8, and 9, experiments carried out with a population size each consisting of 10, 20 and 30, with a mutation probability value of 0.2, a crossover probability of 0.1. Table 8. shows the results of the experiment with these parameters. Table 8. shows that the lowest cost obtained was 101,989 of each best individual in every 20 trials, with a population size of 30. The largest Z value of the best individual was 133,959. While the average best cost obtained by the best individuals is 115,269,375 with a population size of 10. The worst cost of the whole trial obtained is 133,959 with a population size of 30.

Table 8. Summary of observations 7, 8 and 9

| Pop Size | Best Z  | Worst Z  | Average Z | Best Fitness | Worst Fitness | Avg Fitness |
|----------|---------|----------|-----------|--------------|---------------|-------------|
| 10       | 102.885 | 128.665  | 115.269   | 9.72E-06     | 7.77E-06      | 8.70E-06    |
| 20       | 103.292 | 126.606  | 115.545   | 9.68E-06     | 7.90E-06      | 8.67E-06    |
| 30       | 101.989 | 133.959  | 116.957   | 9.80E-06     | 7.46E-06      | 8.57E-06    |

Observations 10, 11, and 12, experiments carried out with a population size consisting of 10, 20 and 30, respectively, with a mutation probability value of 0.2, a crossover probability of 0.2. Table 9. shows the results of the experiment with these parameters. Table 9. shows that the lowest cost obtained was 102,669 of each best individual in every 20 trials, with a population size of 10. The largest Z value of the best individual was 131,255. While the average best cost obtained by the best individuals is 115,217,812 with a population size of 10. The worst cost of the whole trial obtained is 134,692 with a population size of 20.

Table 9. Summary of observations 10, 11 and 12

| Pop Size | Best Z  | Worst Z  | Average Z | Best Fitness | Worst Fitness | Avg Fitness |
|----------|---------|----------|-----------|--------------|---------------|-------------|
| 10       | 102.669 | 131.255  | 115.217   | 9.74E-06     | 8.01E-06      | 8.90E-06    |
3.3 Analysis of Results

Based on the results of experiments conducted with various combinations of genetic parameters, it is obtained a comparison chart of the value of transportation costs for each population size on various mutational probabilities, and crossover probabilities. Figure 3. shows a graph of the lowest transportation costs resulting from the experiments for each combination of genetic parameters. P1 shows a probability of mutation of 0.1, and a probability of a crossover of 0.1. P2 shows a mutation probability of 0.1, and a crossover probability of 0.2. P3 shows a mutation probability of 0.2, and a crossover probability of 0.1. P4 shows the probability of mutation of 0.2, and the probability of a crossover of 0.2. Every P1, P2, P3 and P4 were observed for population size values of 10, 20 and 30. Each experiment was carried out 20 times each for each combination of genetic parameters. Based on the experimental results obtained the best transportation costs on P2 with a population size of 20, amounting to 100,454. The worst transportation costs were obtained in P1 with a population size of 30, amounting to 105,477.

The table that shows a summary of the best cost values for each combination of genetic parameters, is shown in Table 10. Table 10. lists the best transportation costs obtained in 20 trials. Rows for population size popsize = 20 and column P2 in the table are the lowest transportation costs, while rows for popsize = 30 and column P1 are the highest transportation costs.

The graph in Figure 4. shows a comparison of the average costs of all experiments for each genetic parameter. P1 shows the probability of mutation of 0.1, the probability of a crossover of 0.1. P2 shows the mutation probability of 0.1, the crossover probability of 0.2. P3 shows a mutation probability of 0.2, crossover probability of 0.1. P4 shows the probability of mutation of 0.2, the probability of a crossover of 0.2. Every P1, P2, P3 and P4 were observed for population sizes of 10, 20 and 30. Each experiment was carried out 20 times each to get the average transportation cost for each genetic parameter combination.

Based on the experimental results obtained the lowest average transportation cost in P1 with a population size of 10 is 115,160,000. The worst average transportation costs were obtained in P1 with a population size of 30, amounting to 118,529,334. Based on the graph shows that the average between each parameter does not differ much. Average transportation costs look stable for each mutation probability, and crossover probability in population size 10.

![Figure 3. Lowest distribution cost](image.png)

**Table 10.** The lowest distribution cost for each genetic parameter.

| Pop Size | P1     | P2     | P3     | P4     |
|----------|--------|--------|--------|--------|
| 10       | 102.820| 102.822| 102.885| 102.669|
| 20       | 104.707| 100.454| 103.292| 103.178|
| 30       | 105.477| 102.102| 101.989| 103.631|
The table that summarizes the average cost for each genetic parameter is shown in Table 11. Table 11 contains the average transportation costs from observations in 20 trials. Rows for population size popsize = 10 and column P1 in the Table are the lowest average distribution costs, while rows for popsize = 30 and column P1 are the highest average distribution costs.

Based on the graph in Figure 3, shows that the lowest distribution cost is obtained at 100,454 in population size 20, mutation probability 0.1, crossover probability 0.2.

**Table 11.** The lowest average cost of distribution on each genetic parameter.

| Pop Size | P1      | P2      | P3      | P4      |
|----------|---------|---------|---------|---------|
| 10       | 115,160,000 | 115,359,077 | 115,269,375 | 115,217,812 |
| 20       | 118,047,555 | 116,916,580 | 115,545,164 | 116,480,156 |
| 30       | 118,529,334 | 117,051,313 | 116,957,039 | 116,484,930 |

Distribution channels that produce the lowest distribution costs in the results of this study are shown in table 12, Table 13, and Table 14.

**Table 12.** Table of the distribution of goods from producers to agents.

| from      | to Agent 1 | to Agent 2 | to Agent 3 |
|-----------|------------|------------|------------|
| Producer 1| 17         | 120        | 313        |
| Producer 2| 180        | 3          | 37         |
| Producer 3| 133        | 277        | 0          |

Table 12 shows the amount of distribution of goods that produces the lowest distribution costs, from each producer to each agent. Rows represent producers, while columns represent agents. There are 3 producers and 3 agents. Goods from producer 1 are sent as many as 17 units to agent 1, 120 units to agent 2 and 313 units to agent 3. Producer Goods 2 are sent as many as 180 units to agent 1, 3 units to agent 2 and 37 units to agent 3. Goods from Producer 3 sent 133 units to agent 1, 277 units to agent 2 and 0 units to agent 3.

**Table 13.** shows the amount of distribution of goods which results in the lowest distribution cost, from each agent to each distributor. Rows represent agents, while columns represent distributors. There are 3 agents and 5 distributors. Goods from Agent 1 are sent as many as 89 units to distributor 1, 37 units to distributor 2, 180 units to distributor 3, 4 units to distributor 4 and 20 units to distributor 5. Goods from Agent 2 are sent as many as 37 units to distributor 1, 113 units to distributor 2, 34 units to distributor 3, 116 units to distributor 4 and 100 units to distributor 5. Goods from Agent 3 are sent as many as 54 units to distributor 1, 25 units to distributor 2, 86 units to distributor 3, 105 units to distributor 4 and 80 units to distributors 5.
Table 13. Table of the distribution of goods from agents to distributors.

| from | Distributor 1 | Distributor 2 | Distributor 3 | Distributor 4 | Distributor 5 |
|------|---------------|---------------|---------------|---------------|---------------|
| Agent 1 | 89            | 37            | 180           | 4             | 20            |
| Agent 2 | 37            | 113           | 34            | 116           | 100           |
| Agent 3 | 54            | 25            | 86            | 105           | 80            |

Table 14. shows the amount of distribution of goods that produces the lowest distribution costs, from each distributor to each retail. Rows represent distributors, while columns represent retail. There are 5 distributors and 7 retails. Goods from distributor 1 were sent 97 units to retail 1, 39 units to retail 2, 44 units to retail 3, 0 units to retail 4, 0 units to retail 5, 0 units to retail 6, 0 units to retail 7. Goods from distributor 2 sent 45 units to retail 1, 25 units to retail 2, 69 units to retail 3, 3 units to retail 4, 8 units to retail 5, 25 units to retail 6, 0 units to retail 7. Goods from distributor 3 sent to retail 1, 1 unit to retail 2, 6 units to retail 3, 4 units to retail 4, 42 units to retail 5, 138 units to retail 6, 107 units to retail 7. Goods from distributor 4 were sent as many as 2 units to retail 1, 4 units to retail 2, 6 units to retail 3, 65 units to retail 4, 145 units to retail 5, 0 units to retail 6, 3 units to retail 7. Goods from distributor 5 are sent as many as 14 units to retail 1, 31 units to retail 2, 5 units to retail 3, 8 units to retail 4, 35 units to retail 5, 107 units to retail 6, 0 units to retail 7.

Table 14. Table of the distribution of goods from distributors to retailers.

| from | To | Retail 1 | Retail 2 | Retail 3 | Retail 4 | Retail 5 | Retail 6 | Retail 7 |
|------|----|---------|---------|---------|---------|---------|---------|---------|
| Distributor 1 | 97 | 39 | 44 | 0 | 0 | 0 | 0 |
| Distributor 2 | 45 | 25 | 69 | 3 | 8 | 25 | 0 |
| Distributor 3 | 2 | 1 | 6 | 4 | 42 | 138 | 107 |
| Distributor 4 | 2 | 4 | 6 | 65 | 145 | 0 | 3 |
| Distributor 5 | 14 | 31 | 5 | 8 | 35 | 107 | 0 |

4. Conclusions
The application of genetic algorithm in this study uses a three-level supply chain distribution channel. Various genetic parameters are used in this study to see the lowest distribution results of each genetic parameter. Based on observations made about the supply chain distribution with the application of genetic algorithms, several conclusions can be drawn as follows:

1. Application of genetic algorithms can provide solutions to solve the problem of distribution of goods in determining distribution channels so that the lowest distribution costs can be obtained.

2. Based on observations in this study, the lowest distribution cost was 100,454 in population size 20, mutation probability 0.1, crossover probability 0.2. The worst distribution cost is obtained at 0.1 mutation probability, 0.1 crossover probability, with a population size of 30 that is 105,477.

3. Based on observations in the experiment obtained the lowest average transportation cost of population size 10, mutation probability 0.1, crossover probability 0.2 that is 115,160,000. The worst average transportation cost is obtained at a mutation probability of 0.1, crossover probability of 0.2 with a population size of 30 that is equal to 118,529,334.

4. Based on the results of the study it was found that the average between each parameter did not differ greatly. Average transportation costs look stable for each mutation probability, and crossover probability in population size 10.
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