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Design of Corrugated Cardboard Product Delivery Allocation Model by Considering Heterogeneous Fleet and Multi Product

Novika Zuya[1], Meilita Tryana Sembiring [*1], Nazaruddin [1]
[1]*Industrial Engineering Study Program, Faculty of Engineering, Universitas Sumatera Utara, Medan, 20155, Indonesia*
[*]*Corresponding Author:* meilita@usu.ac.id

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ABSTRACT

Manually planning truck usage by estimating the right fleet selection, as well as considering capacity, delivery zones, and variations in demand, often results in inaccuracies. This inaccuracy has an impact on fleet utilization that is not yet optimal, characterized by low capacity used for each trip and the presence of fleets that are idle at certain times. Apart from that, inappropriate delivery allocation planning and less than optimal fleet utilization also affect delivery timeliness. This research proposes a delivery allocation model to solve the Capacitated Vehicle Routing Problem (CVRP) problem using a Genetic Algorithm (GA) implemented within the Multi-Objective Evolutionary Algorithm (MOEA) Framework. The model is designed to address CVRP by considering heterogeneous vehicle fleets, product variability, and diverse delivery destinations. The chromosome representation in the model describes the sequence of customer visits by the available fleet, while the fitness function is focused on minimizing the total traveled distance in order to maximize the efficiency of vehicle capacity utilization. Based on test results at PT In addition, this model succeeded in reducing the number of fleets used by up to 50%.

Keyword: Capacitated Vehicle Routing Problem, Delivery Allocation, Freight Utilization, Genetic Algorithm, Heterogenous Fleet

ABSTRAK

Perencanaan penggunaan truk secara manual dengan memperkirakan pemilihan armada yang tepat, serta mempertimbangkan kapasitas, zona pengantaran, dan variasi jumlah permintaan, sering kali menghasilkan ketidakakuratan. Ketidakakuratan ini berdampak pada pemanfaatan armada yang belum optimal, ditandai oleh rendahnya kapasitas terpakai dalam setiap perjalanan dan adanya armada yang menganggur pada waktu tertentu. Selain itu, perencanaan alokasi pengiriman yang tidak tepat dan pemanfaatan armada yang kurang optimal turut memengaruhi ketepatan waktu pengiriman. Penelitian ini mengusulkan model alokasi pengiriman untuk menyelesaikan masalah *Capacitated Vehicle Routing Problem* (CVRP) menggunakan *Genetic Algorithm* (GA) yang diimplementasikan dalam kerangka *Multi-Objective Evolutionary Algorithm* (MOEA) *Framework*. Model ini dirancang untuk mengatasi CVRP dengan mempertimbangkan armada kendaraan yang heterogen, variabilitas produk, dan tujuan pengantaran yang beragam. Representasi kromosom dalam model menggambarkan urutan kunjungan pelanggan oleh armada yang tersedia, sedangkan fungsi fitness difokuskan pada minimisasi jarak tempuh total guna memaksimalkan efisiensi pemanfaatan kapasitas kendaraan. Berdasarkan hasil pengujian di PT XYZ, bahwa model ini mampu meningkatkan efisiensi pengiriman melalui penggabungan pengiriman untuk beberapa pelanggan, dengan tingkat pemanfaatan armada mencapai 99%. Selain itu, model ini berhasil mereduksi jumlah armada yang digunakan hingga 50%.

Keyword: Capacitated Vehicle Routing Problem, Alokasi Pengiriman, Heterogenoeus Fleet, Freight Utilization, Genetic Algorithm

1. Introduction

Transportation plays an important role in the survival of companies, especially in the manufacturing industry, including the activity of shipping goods that ensures the smooth running of the company's business processes. Real-world transportation networks can consist of millions of nodes connected by a series of complicated edges, making it a complex NP-Hard problem [1]. PT XYZ is a manufacturing company engaged in the production of corrugated cardboard packaging that fulfills consumer orders using a make-to-order production system with product specifications that vary in terms of paper thickness and dimensions that are adjusted to customer demand. PT XYZ manages its logistics business processes with the help of external parties through the establishment of subsidiaries. The subsidiaries formed by PT IPI are specifically designed to manage logistics functions so that they have an important role in ensuring the smooth delivery of goods. To simplify logistics activities and meet customer demand, PT XYZ divides deliveries into four zones, namely outside the city, Medan City, surrounding Binjai, and surrounding Tanjung Morawa. The results of the interview explained that PT IPI's logistics team manually scheduled deliveries per day by looking at data on goods ready to be sent to the finished goods warehouse, then combining adjacent customers. PT IPI logistics then considers the fleet capacity by calculating the total weight requested by each customer, and then selects trucks. Regarding truck selection, this is adjusted to the types that the subsidiary has prepared per day, namely 20 trucks with different fleet specifications per day. From the company's historical data, the highest use of trucks in April 2024 reached 50 fleets and the fewest deliveries were only 3 fleets per day. The data also shows that fleet utilization has not reached the maximum level, which can be seen from the low capacity used in each trip and the presence of fleets that are idle at certain times. This indicates that there is an opportunity to optimize fleet utilization to be more efficient in supporting the distribution and delivery process. This phenomenon of unequal distribution of goods transport has resulted in several trucks that are not yet in operation having to wait in line and not even being used. In the end, manual planning caused communication between the company and subsidiaries to be disrupted regarding the number of trucks to be used. This causes delays in delivery to customers because they have to order and wait for another truck to be ready for the next delivery. Delivery delays will occur in 2023 with an average percentage of delays of 16.04%.

From the description above, there are several transportation problems at PT XYZ, namely the use of trucks that is not optimal, resulting in high operational costs, waste of resources and even causing delays due to limited availability of trucks, thus affecting customer satisfaction. [2]. In addition, the results of observations also show that the use of trucks affects the use of warehouses, because the large number of goods that are delivered late causes the accumulation of goods in the warehouse, thus disrupting the procurement process [3]. To overcome this problem, it is necessary to allocate shipments by determining the optimal route so as to maximize truck capacity by combining shipments from various destinations into one route [4]. The problem of determining the number of trucks used is closely related to vehicle capacity, which is often referred to as the Capacitated Vehicle Routing Problem (CVRP). CVRP considerations help in better utilization of resources, such as vehicles and manpower by ensuring that each vehicle is used optimally according to its capacity [5]. Optimizing vehicle routes by considering their capacity can also reduce operational costs such as fuel and travel time. Many studies have been proposed in solving the CVRP problem including [6], [7], [8] and [9]. However, each depot has different conditions related to the products shipped, the vehicles used and different delivery points. Therefore, not all transportation models can be used in every depot condition.

Based on previous research and the facts that have been presented, this study will provide an idea, namely designing a mathematical model that is adjusted to the problem as a mathematical representation of the logistics transportation system at PT XYZ. The model design is designed by claiming a contribution to minimizing distance and considering the varying fleet capacity, different delivery destinations and varying product specifications using the Genetic Algorithm approach in determining the best route, so that it is expected to overcome the problem of delays and increase the efficiency of fleet use. The stages of completion in mathematical modeling are defining the distribution problem at PT XYZ that has been going on so far, then the mathematical model is formulated using Integer Linear Programming (ILP) and designing a model solution using the Genetic Algorithm with implementation using the help of the Multi Objective Evolutionary Algorithm (MOEA) framework to improve the company's ability to meet product demand effectively and efficiently so that it can increase customer satisfaction and trust.

2. Method

This study utilizes the Operation Research (OR) Framework [10] to model distribution problems in the manufacturing industry with a metaheuristic approach. Model solving is done using a genetic algorithm as a solution method. This OR framework includes several stages, namely problem definition, problem formulation, solution model with genetic algorithm (GA), and implementation and validation of the model using case studies.

2.1. Transportation Problems in the Corrugated Cardboard Manufacturing Industry

This Figure.1 illustrates the product delivery process at PT XYZ, a company that produces corrugated cardboard with various specifications based on the make-to-order system. This system allows products to be produced according to specific customer requests. Each day, the number of requests that must be fulfilled can vary greatly, from shipping to 215 customers to only 3 customers at a given time. This figure reflects the importance of integrated planning in managing variations in customer demand, including in terms of fleet selection and optimal route determination, in order to improve operational efficiency and maintain on-time delivery.

Figure 1. The illustration of PT XYZ transportation system [11]

The main objective of the transportation system in this study is to minimize the distance traveled by maximizing the utilization of different fleets, products with different specifications and different delivery destinations. To achieve this, logistics operational managers must carefully consider various important aspects such as ensuring that each customer is visited once by a vehicle, maximizing the utilization of truck capacity, ensuring that vehicles do not carry loads exceeding their carrying capacity, and considering combining customer requests in one route to minimize the distance while still considering the capacity of the load being transported. This problem is known as the capacitated vehicle routing problem (CVRP) which integrates aspects of vehicle capacity with route optimization. This problem is categorized as NP-hard, which requires soft computing-based solutions such as genetic algorithms in its solution. This approach has the ability to handle uncertainty and solutions close to optimal in a relatively short time. Based on the description, this paper develops an optimization formulation by referring to specific assumptions in the transportation system at PT XYZ to present an effective and efficient solution.

- The types of transportation for delivery operations used in the system are 4 types of trucks (1000 kg, 1500 kg, 2500 kg and 4000 kg)
- Trucks with a load capacity of 4000 kg are not allowed to deliver customer requests in urban areas.
- Different product dimensions are converted to weight in kg.
- Distribution optimization takes into account the consolidation of several adjacent customers.

The notations used are defined in table 1.

Table 1. The notation used in this paper

Notation	Description
d_{ij}	Distance from node *i* to node *j*
x_{ijk}	Binary variables for route selection in the process of traveling from node *i* to node *j* using transportation *k*.
x_{jik}	Binary variables for route selection in the process of traveling from node *j* to node i using transportation *k*.
y_{ik}	Truck capacity *k* after leaving customer *i*
y_{jk}	Truck capacity *k* after leaving customer *j*
q_k	Transport capacity *k*

Notation	Description
p_j	Customer demand j
M	Cumulative capacity
i	Index for point of origin ($i = 1,2,3, \dots, n$)
j	Index for destination point ($j = 1,2,3, \dots, n$)
k	Index for vehicles ($k = 1,2,3, \dots, p$)

2.2. Problem Formulation of Corrugated Cardboard Manufacturing Industry Transportation

The CVRP model can be formulated in the form of an integer linear programming model [12]. The goal is to minimize the total distance traveled by various vehicles by considering the fulfillment of demand from each consumer point to be visited. The decision variables are in binary form expressed in the form x_{ijk} which has a value of 1 if the *arc* from node *i* to node *j* is the optimal route and is carried out by the *k* vehicle.

$$x_{ijk} \in \{0,1\}, \forall k \in \{1, \dots\dots, p\}, i, j \in \{1, \dots\dots, n\}$$

Where no journey occurs from a node to the node itself.

There is a parameter d_{ij} which describes the distance from node *i* to node *j*. There are *n* nodes (depot=0) and *p* vehicles. The objective function is formulated as follows.

$$\sum_{k=1}^{p} \sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij} x_{ijk} \tag{1}$$

With limitations:

1. A vehicle that is visited by a node will depart from the node it visited.

$$\sum_{i=1}^{n} x_{ijk} = \sum_{i=1}^{n} x_{jik} \quad , \quad \forall j \in \{1, \dots\dots, n\},\ k \in \{1, \dots\dots, p\} \tag{2}$$

2. Ensure that each node is visited once.

$$\sum_{k=1}^{p} \sum_{i=1}^{n} x_{ijk} = 1,\ \forall j \in \{2, \dots\dots\dots, n\} \tag{3}$$

3. Each vehicle must start its journey from the depot, so it is necessary to design constraints that ensure that depot 1 has a value of 1 as follows.

$$\sum_{j=2}^{n} x_{1jk} = 1, \quad \forall k \in \{1, \dots\dots, p\} \tag{4}$$

4. Vehicle capacity limitations that must meet the demand of each node to be visited.

$$\sum_{i=1}^{n} \sum_{j=2}^{n} y_{ik} + p_j\, x_{ijk} \le Q_k,\ \ \forall k \in \{1, \dots\dots, p\} \tag{5}$$

5. This constraint ensures that the cumulative load if vehicle *k* serves route *i* to *j*.

$$y_{jk} \ge y_{ik} + p_j - M(1 - x_{ijk}),\ \ \forall k \in \{1, \dots\dots, p\} \tag{6}$$

2.3. Model Solution: Metaheuristic Algorithm for Corrugated Cardboard Manufacturing Industry Transportation Problem

Metaheuristic algorithm based on Genetic Algorithm is applied as a solution approach to transportation problems in the distribution of corrugated cardboard products at PT XYZ. Genetic Algorithm (GA), is a metaheuristic method inspired by the principle of natural selection, which is included in the category of evolutionary algorithms (Evolutionary Algorithm). GA is widely used to handle various complex optimization problems, including those that are NP-Hard, using biological mechanisms such as mutation, crossover, and selection as their main operators [13].

The components referred to as genes in this problem are binary numbers that represent customer notation, while 0 is referred to as the starting point (depot). Genes are likened to nodes on a graph, while the initial population is formed by randomly creating a number of chromosomes. Each chromosome represents a potential solution, and the formation of the population is accompanied by a capacity division that groups routes based on truck carrying capacity. Therefore, $x_{011}, x_{021}, x_{031}, \ldots, x_{ijk}$ are the genes of problem solutions with illustrations such as Figure 2 below.

1	0	1	1	0	...	0
X011	X021	X031	X041	X051	...	XIJK

Figure 2. Chromosome initialization

The basis for forming chromosome initialization as an initial step in finding an optimum solution using the Traveling Salesperson Problem (TSP) [14] approach is to get a route that minimizes the distance from n-customers, where each customer is visited exactly once before returning to the starting point. Data processing is done by entering the distance matrix and the number of requests for each customer. The initial algorithm processing starts from the depot to the customer and/or other customers who are closest in distance and meet the available truck capacity. The search for the solution is carried out until it meets the constraints formed in equations (2), (3), (4), (5) and (6).

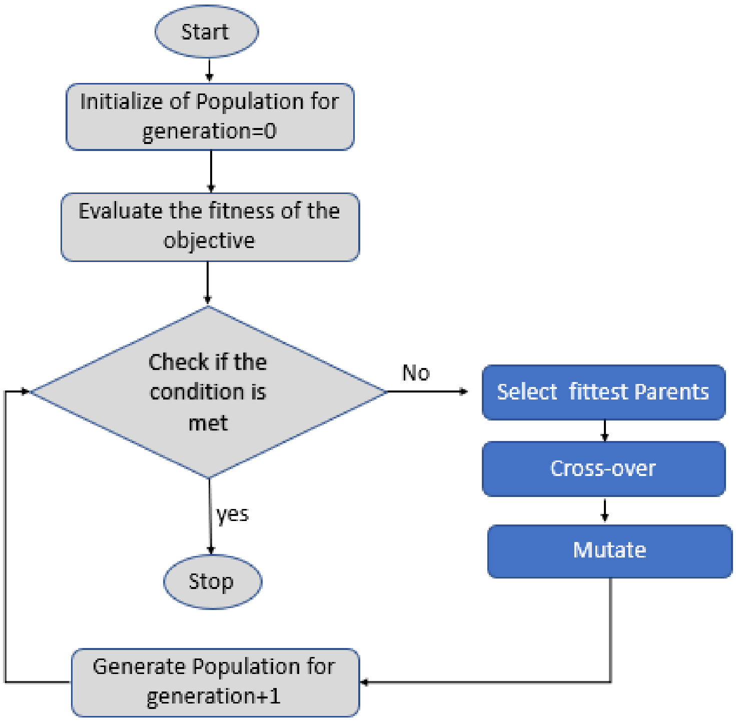

Figure 3. Genetic Algorithm

The process begins with an evaluation using a fitness function that aims to assess the quality of each chromosome [15]. Chromosomes with lower fitness values have a greater chance of surviving and evolving into the next generation. The selection process plays an important role in ensuring that the best solutions are retained and used to generate the next generation. In the context of the goods distribution problem, effective selection ensures that a given solution with high efficiency in terms of routes is maintained in the population. This process allows the algorithm to direct the search towards more optimal solutions from generation to generation, while still opening up the opportunity to discover new variations that can improve overall performance. After selection, crossovers are performed to create new genetic combinations. Crossovers use a sequence scheme approach, where a pair of parents produces two offspring. The probability of a crossover is determined by the Probability Crossover (Pc) value [16]. If the random number generated is smaller than Pc, crossovers are performed; otherwise, the offspring will be identical to their parents. This step aims to create diversity in the population. The next stage is mutation, which uses the swapping mutation method. In this stage, two genes in a chromosome are swapped if the random number generated is smaller than a certain mutation probability value. Mutation serves to increase the variety of solutions, allowing the creation of new individuals that have the potential to have better fitness values and approach the optimal solution. The process of selection, crossing, and mutation continues to repeat until the population reaches the desired optimal solution. Thus, proper selection becomes the foundation for achieving a balance between exploitation of existing solutions and exploration of a wider solution space, thus supporting the achievement of optimal and efficient distribution.

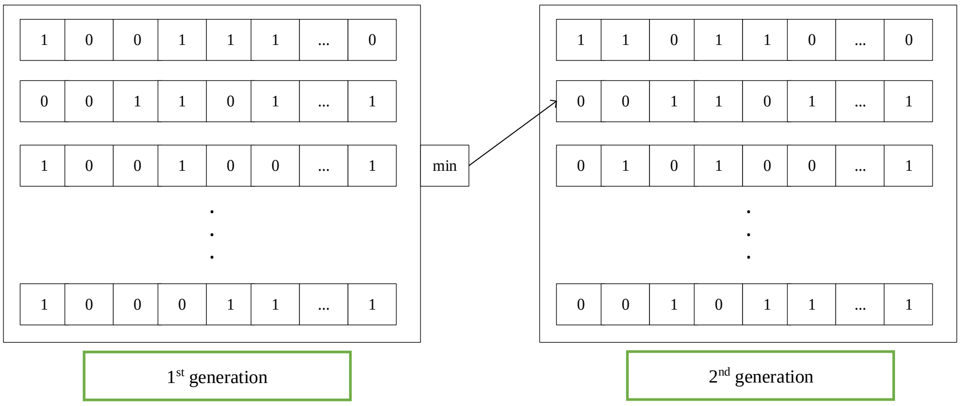

Figure 4. Population in Generations

2.4. Implementation and model testing: A real case industrial transportation problem in PT XYZ

In this stage, the proposed model is implemented and tested using real-world data from PT XYZ, with a number of requests from 35 customers to be allocated. The testing focuses on optimizing the allocation and routing of the company's fleet to address current logistics challenges. A specific scenario is selected where the company needs to ship goods to multiple distribution centers in minimizing transportation distance and ensuring timely delivery. Through this scenario, the effectiveness of the model in generating optimal routes and improving fleet utilization is thoroughly evaluated, demonstrating its practical application in solving complex transportation problems.

3. Result and discussion

This model will be tested with a real case of corrugated cardboard distribution at PT XYZ. This paper uses the help of the Multi Objective Evolutionary Algorithm (MOEA) framework based on Genetic Algorithm to determine the best route with various constraints. The first-generation population generated with the MOEA framework is shown in Figure 4. Each row represents a chromosome and the value represents a gene.

1	x000	x001	x002	x003	x004	x005
2	0	0	1	1	0	1
3	0	1	0	1	1	0
4	0	1	0	1	1	0
5	0	0	0	0	1	0
6	1	0	1	0	1	0
7	0	1	0	0	0	0
8	0	1	0	0	0	1
9	0	1	1	1	0	0

Figure 5. First generation generated by MOEA framework

Next, the fitness value of each chromosome is obtained, where the individual with the best fitness value from the first-generation population will be retained and carried over to the next generation. The next step is to conduct a selection to determine the individual as a parent. Iteration is carried out to obtain the optimum fitness value and produce a certain convergent value. MOEA (Multi-Objective Evolutionary Algorithm) works by generating solutions randomly, so that each time the selection process is carried out, the resulting solution will always be different. Therefore, several trials are needed in its application using MOEA to find the optimum solution. The experiment was carried out by trying various values of population size and number of generations. After several iterations, a convergence curve will be obtained, as shown in Figure 6. The convergence value reflects the optimal solution to the transportation problem.

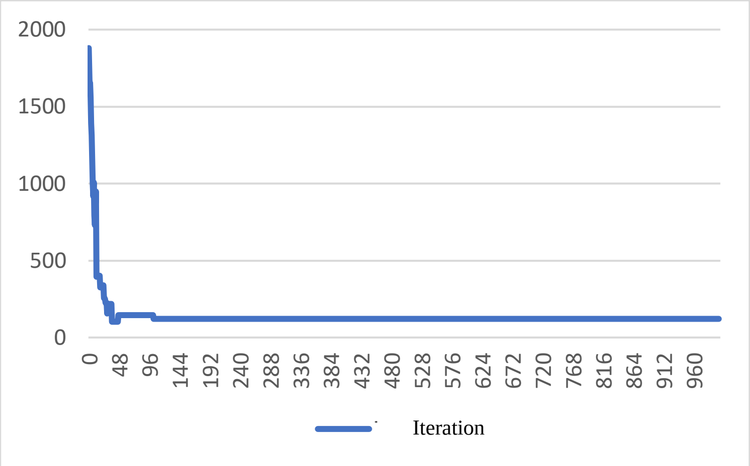

Figure 6. Convergence Curve of GA Process

The model design focuses on optimizing vehicle usage by considering the maximum capacity of each vehicle and the delivery needs at each location with the best route using a metaheuristic approach, namely a genetic algorithm. Programming is made by following the model design that has been formulated by considering distance, demand volume and heterogeneous vehicle capacity. Consolidation of one vehicle to several routes is a strategy in logistics that aims to combine deliveries from several locations or destinations into one vehicle trip [4]. In this context, vehicles are optimally utilized to serve several delivery points at once, as seen in Figure 7, where the vehicle loads requests from location A0 and visits other points, namely A28, A22, A35, A19, and A24 in one route and returns to A0. The request is transported by a vehicle with a capacity of 2500 kg with a breakdown of each request of 315 kg, 873 kg, 520 kg, 389 kg and 403 kg with a total of 2500 kg.

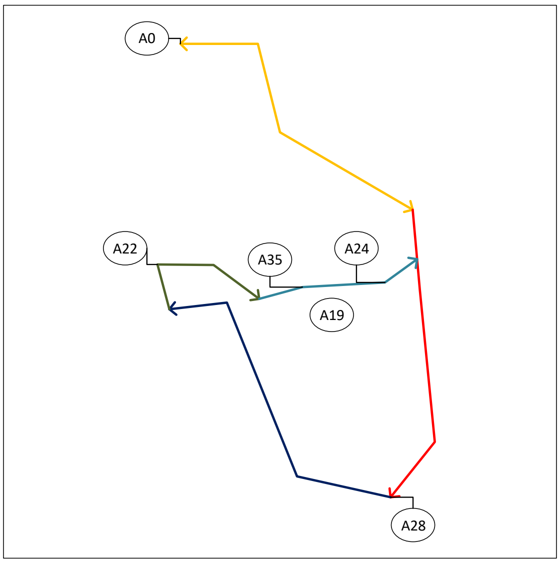

Figure 7. Freight Utilization

Table 2 below compares the values of the proposed approach with the performance before using the dispatch allocation model.

Table 2. Comparison between proposed approach and company approach.

Decision	Performance before using the delivery allocation approach	The value of the proposed approach
Freight Utilization	75%	100%
Demand Fulfilled	40%	100%
Total distance traveled	The total distance traveled for 41 delivery routes is 950.70km	Total distance traveled for 20 delivery routes is 1089km

It is proven that fleet utilization has been successfully increased to 100% with an increase of 25%. This implies that the model design can maximize fleet utilization by considering capacity and distance using a metaheuristic approach, namely the genetic algorithm. The number of demands fulfilled increased from 40% to 100%, which means that the proposed model is able to meet delivery deadlines and increase customer satisfaction.

3.1. Managerial Implementation

Optimization using algorithms can improve logistics performance and help logistics management manage their operations more efficiently than conventional or intuitive methods. The shipping allocation model developed in this study requires integrated technology support in its implementation [17]. This technology will help logistics management in mapping customers and tracking the whereabouts of the fleet when used. Customer mapping using the Internet of Things (IoT) helps find the best route in real-time because it is directly connected to Google Maps. This integration will also reduce the level of delays and accumulation of goods in the finished goods warehouse. Thus, software development with IoT or other real-time supporting technologies can be developed in further research.

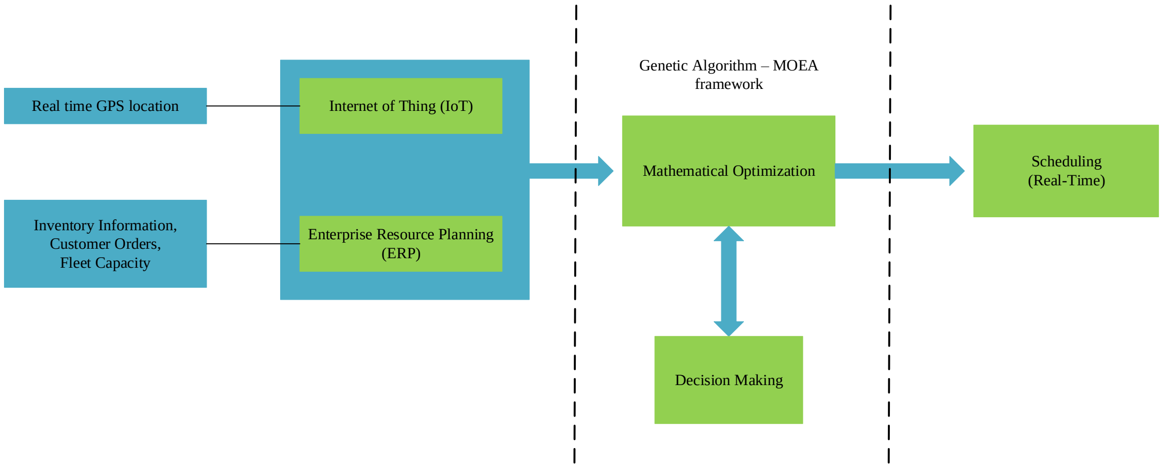

Figure 8. Managerial Implementation

From the Figure 8., IoT and ERP integration in logistics systems collect real-time data such as GPS location, inventory, delivery schedules, fleet capacity, and customer orders. This data is processed through mathematical models to generate optimal solutions, such as vehicle routes, fleet allocations, and delivery schedules. The results are forwarded to the IoT system for direct instructions to fleet selection and real-time tracking, and to the ERP to manage delivery sequences and update order statuses. The system is continuously monitored using real-time data, allowing dynamic adjustments in case of deviations, thereby increasing operational efficiency and responsiveness.

4. Conclusion

The results of designing a corrugated cardboard product delivery allocation model using the genetic algorithm metaheuristic method implemented in the Multi Objective Evolutionary Algorithm (MOEA) have succeeded in helping logistics management in determining the shortest distribution path. It is proven that fleet utilization has been increased by 25% by considering heterogeneous and multi-product fleets, the total distance traveled is 1089km in traveling 20 travel routes. The delivery allocation model developed in this study requires integrated technology support in its implementation. The goal is to improve operational efficiency, the ability to dynamically adjust plans based on real-time data, and the creation of a well-integrated system. The delivery allocation model developed in this study requires integrated technology support in its implementation. The goal is to improve operational efficiency, the ability to dynamically adjust plans based on real-time data, and the creation of a well-integrated system.

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