Facility Location and Multi Capacity Vehicles Model for Minimizing Emissions for Environmentally Friendly Logistics

A Lathifah1, S R Sulistyos2 and I W Murti3

1Department of Logistics Engineering, Universitas Internasional Semen Indonesia, Gresik, East Java, Indonesia
2Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia
3Department of Engineering Management, Universitas Internasional Semen Indonesia, Gresik, East Java, Indonesia

E-mail: artya.lathifah@uisi.ac.id

Abstract. Transportation and distribution are two things that are closely related to logistics problems. On the one hand, these two things are at the heart of an organization or company in terms of delivering goods sold to consumers. However, on the other hand this activity can sometimes damage the environment. Emissions from fuels used in transportation and distribution activities accounted for 29.4% of the total costs incurred by the organization in logistics activities. So that, many organizations finally make environmentally friendly logistics a priority in their activities, where the goal of minimizing distribution costs and maintaining sustainability of both environments can be fulfilled. Some factors that can be improved are the determination of the location of the warehouse or depot, the combination of vehicle composition and the optimum route. Therefore, this study aims to develop a mathematical model that will optimize these three factors in an integrated manner to minimize the fuel carried out by the organization in its distribution activities with the aim of realizing environmentally friendly logistics. The expected results from the study of this research is the contribution of theoretical studies namely mathematical models of the problems raised applied to the problem of determining the location, route and combination of vehicle capacity.

1. Introduction

In the last 10 years, research discussing Green Logistics or environmentally friendly logistics has become an interesting topic for researchers. This issue arises because of environmental damage caused by transportation and distribution of goods. The goal is in addition to realizing the economic benefits of certain subjects, it is also needed to maintain resources and protect the environment, so that this has become the highest priority in several organizations [1].

Transportation has the highest cost, which occupies 29.4% of total logistics costs. Followed by inventory of warehousing costs, packing costs, management costs, movement costs, and finally, ordering costs [2]. One mode of transportation commonly used is road freight transportation. This sector is a significant emitter of carbon dioxide (CO2). Green freight transportation considers other factors such as Green House Gas (GHG) and fuel costs [3]. The percentage of total Green House Gas (GHG) emissions from transportation increased from 24.9% to 27.3% in only 15 years 1990-2005 and road transportation contributed 78% of emissions produced by all modes of transportation [4]. This volume of emissions is
the same as fuel consumption [5] and fuel consumption depends on various factors such as vehicle speed, acceleration, distance, and load [6].

From the description above, the company can improve its distribution activities to be environmentally friendly by optimizing fuel use. This optimization can be done with several factors that can be improved, as follows:

- Determining the location of the warehouse or depot, so that the location is indeed placed in a strategic location and can reach all distributors or consumers.
- Assignment of vehicles used to distribute finished goods with different capacities according to the demand.
- Determination of the route of each vehicle that is assigned so that there is no sequence distribution error that can cause waste of fuel use.

The research object used in this study is data on the distribution of cement demand in the form of zak. This data was chosen because of the increasing demand for cement and the widening spread of demand and an increasingly diverse fleet. So that the company needs to consider these three factors to support environmentally friendly business activities.

Based on the above three reasons, organizations need tools to facilitate the design of their fleet assignments with the aim of minimizing fuel that can produce decisions for all three factors. But before implementing the algorithm used, it is necessary to have a valid model to be optimized. Therefore, researchers found a gap that the selection of facility locations and the combination of vehicle capacity by considering emissions for environmentally friendly logistics had never been conducted in a research because of the current conditions as follows:

- From a theoretical point of view there is no mathematical model that addresses the optimization of these three logistical components. this research will produce a contribution of thought in the form of a mathematical model with the objective function is to minimize the fuel that will be achieved by decision variables namely, determining the location of facilities, determining what types of vehicles are assigned to do the distribution, and as well as the route of each vehicle is assigned.
- From a practical perspective, the location of warehouse or depot facilities, fleet composition and routes can all generate an environmentally friendly transportation mission. some interactions between these factors have not been well integrated. the results of this research can be used as a reference for an organization in opening or closing a warehouse or depot facility and in assigning a fleet or vehicle to distribute. so it is expected that at the managerial level will get a solution to realize green logistics which not only saves costs but is also environmentally friendly.

Researchers suspect that it is necessary to optimize the three factors in an integrated manner. However, from a review of the literature that has been carried out, so far it has not been found, or very little research is related to the topic. The model developed will provide a managerial insight illustrated in Figure 1., where fuel optimization is generated by assigning large and small capacity vehicles at facility A or depot and different decisions for facility / depot B. This decision is very valuable for an organization that has an impact on fuel savings. Thus, the organization not only saves its transportation costs but is also able to contribute meaningfully to the environment. Therefore, researchers have contributed novelty to the development of models and their optimization with appropriate methods.

![Figure 1. Problem Illustration](image-url)
2. Literature Review
Research on environmentally friendly logistics (Green Logistics) has been carried out by several other researchers. Table 1. shows the results of a summary of several studies on Green Logistics in recent years.

| Researcher, Year | Summary | Relation to Research | Research Gap |
|------------------|---------|----------------------|--------------|
| Bektas and Laporte, 2011[7] | Introduction of a mathematical model that considers emission minimization on the first route formation made (Pollution Routing Problem). | As the initial foundation for developing a model that considers the environment. | The model is only applicable to one type of vehicle. |
| Demir et al, 2012[8] | Application of previously created models (Bektas and Laporte, 2011) in cities in the UK using the Adaptive Learn Neighborhood Search algorithm. | Basic calculation of fuel consumption and emissions generated. | |
| Kwon et al, 2013[9] | Development of emission minimization calculation model with its application in a simple dataset. The test is using Tabu Search and the combination of vehicle capacity. | As a basis for developing mathematical models for several types of vehicles. | Application problems have not considered fuel costs by means of detailed calculations such as calculations carried out by Demir et al, 2012. |
| Koç et al, 2014[10] | Model development from Kwon et al, 2013 by minimizing detailed fuel cost calculations as done by Demir et al, 2012. | | Application problems have not considered the opening of warehouse / depot facilities, only routing and determining the composition of vehicle capacity. |
| Toro et al, 2017[11] | The model made considers fuel minimization and depot location determination, as well as determining the routes served by each depot. | Determination of the location of the warehouse / depot facility that becomes and the route of each vehicle. | The problem has not been based on how to use a combination of vehicle capacity. |

This proposed research will fill the research gap that is used as a reference as shown in Table 1. Researchers will develop a model with the object of research is transportation and distribution of cement. This model will have an objective function to minimize emissions from some point of view, namely: opening warehouse facilities, determining fleet management with a combination of vehicle capacity.
composition, and determining an integrated route so that the decision can save fuel consumption when compared to current conditions. This fuel saving will reduce emissions, so that the distribution activities carried out will be environmentally friendly.

3. Research Method
The research method consists of the stages of data collection, development of model and validation.

| Table 2. Research Stage                                                                 |
|---------------------------------|---------------------------------|--------------------------------|-----------------|
| **Stages**                      | **Description**                 | **Expected Output**           |
| Data collection                 | Data collection is related to the development of the model that will be optimized to be able to minimize emissions produced by vehicles and the routes generated | Warehouse Location Data, customer or distributor data, data on the effect of each type of vehicle on the emissions produced |
| Development of Mathematical Models | Development of Mathematical Models for Site Selection, Determination of Routes with Selection of Combination Types of Vehicles used | Mathematical model that will be validated |
| Model validation and testing    | The initial model developed will be validated with the help of data obtained previously | Mathematical models that have been validated by exact methods for five consumers |

4. Result and Discussion

4.1. Problem Definition
This problem is defined in a complete graph with the indexes as shown below

**Decision Variable:**

**Sets**
- \( F \) Set of facilities (depots)
- \( S \) Set of customers
- \( N \) Set of nodes \( N = F \cup S \)
- \( V \) Set of vehicles

**Parameters**
- \( \text{Cap}_f \) Capacity of facilities \( f \) for \( f \in F \)
- \( \text{FC}_f \) Fixed cost opening facilities \( f \) for \( f \in F \)
- \( q_s \) Demand from customer \( s \) for \( s \in S \)
- \( \text{Cap}_v \) Capacity of vehicle \( v \) for \( v \in V \)
- \( \text{FC}_v \) Fixed dispatch cost vehicle \( v \) for \( v \in V \)
- \( C(i,j,v,t_{ijv}) \) Fuel and CO\(_2\) emissions cost of traveling from node \( i \) to node \( j \) using vehicle \( v \) for \( i,j \in N \) having a load equal to \( t_{ijv} \) upon leaving node \( i \)

**Variables**
- \( x_{ijv} \) Binary variable indicating the vehicle \( v \) uses of the path between nodes \( i, \in N \)
- \( y_f \) Binary variable for the use of a facility \( f \in F \)
- \( z_{if} \) Binary variable that determines if the customer at node \( i \in S \) is assigned to facilities \( f \in F \)
\( t_{ijv} \) Continuous variable indicating the amount of commodity transported from node \( i \) to node \( j \) using vehicle \( v \) for \( i, j \in N \)

Objective Function

\[
\min = \sum_{f \in F} FC_f y_f + \sum_{v \in V} \sum_{i \in F} \sum_{j \in N} FC_v x_{ijv} + \sum_{v \in V} \sum_{(i,j) \in E} C(i,j, t_{ijv}) x_{ijv}
\]

(1)

Constraints:

\[
\sum_{v \in V} \sum_{j \in N} x_{ijv} = 1, \quad \forall i \in S
\]

(2)

\[
\sum_{v \in V} \sum_{j \in N} x_{ijv} - \sum_{v \in V} \sum_{j \in N} x_{ij'} = 0, \quad \forall i \in N
\]

(3)

\[
\sum_{v \in V} \sum_{j \in N} t_{ijv} - \sum_{v \in V} \sum_{j \in N} t_{ij'} = q_{iv}, \quad \forall i \in S
\]

(4)

\[
t_{ijv} \leq \text{Cap}_v x_{ijv}, \quad \forall i \in F, j \in N, i \neq j, v \in V
\]

(5)

\[
\sum_{v \in V} \sum_{j \in S} t_{ijv} - \sum_{v \in V} \sum_{j \in S} z_{kj} = 0, \quad \forall k \in F
\]

(6)

\[
\sum_{v \in V} \sum_{j \in S} t_{ijv} = 0, \quad \forall k \in F
\]

(7)

\[
t_{ijv} \leq (\text{Cap}_v - q_i) t_{ijv} \quad \forall i \in S, j \in N, v \in V
\]

(8)

\[
t_{ijv} \geq q_i x_{ijv} \quad \forall i \in N, j \in S, v \in V
\]

(9)

\[
\sum_{i \in S} q_i z_{ik} \leq \text{Cap}_f y_f \quad \forall k \in F
\]

(10)

\[
\sum_{k \in F} z_{ik} = 1, \quad \forall i \in E
\]

(11)

\[
x_{ijv} + \sum_{q \in V, q \neq v} \sum_{k \in N, j \neq k} x_{jkv} \leq 1, \quad \forall i \in N, j \in S, i \neq j, v \in V
\]

(12)

\[
\sum_{v \in V} x_{ikv} \leq z_{ik}, \quad \forall k \in F, i \in S
\]

(13)

\[
\sum_{v \in V} x_{kiv} \leq z_{ik}, \quad \forall k \in F, i \in S
\]

(14)

\[
\sum_{v \in V} x_{ijv} + z_{ik} + \sum_{m \in F, m \neq k} z_{jm} \leq 2, \quad \forall k \in F, (i,j) \in S, i \neq j
\]

(15)

The objective function (1) it to minimize the total cost including fixed facility location, vehicle costs, fuel and \( \text{CO}_2 \) emissions cost. Constraints (2) and (3) guarantee that each customer is visited exactly once. Constraints (4) imply that the demand of each customer must be full served. Constraints (5) mean that the total load on any arch cannot exceed the capacity of the vehicle that transverse into it. Constraints (6) ensure that the total load of the vehicles departing from a facility location is equal to the total demand of the customers assigned to it. Constraints (7) state that the load on all vehicles returning to each facility location must be equal to zero. Constraints (8) and (9) are the bounds on the load variables. Constraints (10) guarantee that total demand associated with a facility location cannot exceed its capacity. Constraints (11) and (12) ensure that each customer is assigned to only one facility location and one vehicle, respectively. Constraints (13)–(15) forbid the formation of routes that do not start and
end at the same facility location. Finally, constraints about the integrality and non-negativity restrict on the variables.

4.2. Model Validation
Scenarios for validation: two facilities location, three customers, and two vehicles with different capacities. Facility F (Capacity: 70, Fixed Cost 70) and Facility G (Capacity: 50, Fixed Cost 50). The demand of the customers (A, B, C) are A 30, B 40 and C 50, respectively. Here is the data of the truck used: (Vehicle, Capacity, Vehicle Fixed Cost, Fuel and Emission Cost) X (Big, 70, 7, 0.07) and Y (Medium, 50, 5, 0.05). Combination of customer configuration with depot. Each customer can only be supplied by one facility (constraint 10). Configuration that does not violate the constraint is a configuration that ensures that each customer has a supplier and each customer can only be supplied by a facility.

The next constraint, the total demand of the customer supplied by a depot does not exceed the production capacity of the depot (Constraint 9). Of the eight configurations, there is one configuration that does not violate the 9th constraint, namely Customer A and Customer B supplied by Depot F, and Customer C is supplied by Depot G. Vehicle configuration at each customer. Every customer is sure to have a vehicle that will deliver demand. The route for each vehicle is made based on the configuration of the vehicle and by looking at the existing constraints. There are 24 routes that do not violate restrictions. Of these 30 routes, the 6 routes generated from configuration 8 give the lowest cost value of 141.

Table. 3 Total Cost Each Route

| Configuration | Route- | Big Vehicle | Medium vehicle | Total Cost |
|---------------|--------|-------------|----------------|------------|
| 1             | 1      | F-A-F-B-F-G-C-G-F | -              | 149.4      |
|               | 2      | F-A-F-G-C-G-F-B-F | -              | 143.2      |
|               | 7      | F-A-B-F-G-C-G-F | -              |            |
|               | 8      | F-B-A-F-G-C-G-F | -              |            |
|               | 9      | G-C-G-F-A-B-F | -              |            |
|               | 10     | G-C-G-F-B-A-F | -              |            |
| 2             | 11     | F-A-F-B-F | G-C-G | 146.4      |
|               | 12     | F-B-F-A-F | G-C-G |            |
|               | 13     | F-A-B-F | G-C-G |            |
|               | 14     | F-B-A-F | G-C-G | 142.2      |
|               | 24     | G-C-G | F-B-F-A-F |            |
|               | 25     | - | F-A-F-B-F-G-C-G-F |            |
| 8             | 26     | - | F-A-F-G-C-G-F-B-F |            |
|               | 27     | - | F-B-F-A-F-G-C-G-F |            |
|               | 28     | - | G-C-G-F-A-G-B-F-G |            |
|               | 29     | - | G-C-G-F-B-F-A-F-G |            |
|               | 30     | - | F-B-F-G-C-G-F-A-F |            |

5. Conclusion
The proposed model for minimizing emission cost has been developed. The model shows that it can integrate three decision variables: determining facility location, vehicle type and each route, respectively. The further research is using real data that can be used as a reference for an organization in opening or closing a warehouse or depot facility and in assigning a fleet or vehicle their distribution activity.
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