DEVELOPMENT OF AN ENVIRONMENTALLY-FRIENDLY LOGISTICS MODEL BY INTEGRATING DECISIONS OF LOCATION, MULTI-CAPACITY VEHICLE, AND ROUTING PROBLEM

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Abstract *Transportation and distribution are closely related to logistics. However, these activities sometimes damage the environment. Emissions from the fuels caused by transportation and distribution activities accounted for 29.4% of the total transportation costs. As a result, many organizations include environmentally planning as priority in their activities, where the goal are minimizing distribution costs and maintaining sustainability of environment simultaneously. To improve this, some factors that can be improved are: determination of the depot location, combination of vehicle and the route. Therefore, this study aims to develop mathematical model that optimize these integrated factors to minimize the emission cost. The results of this research are the mathematical model and optimization of the model using Simulated Annealing (SA) method. This method can obtain a reduction of the total emissions costs up to 18.8%.*

Keywords: environmentally logistics; determination offacility location; emissions cost; optimization; multi-capacity vehicles and routes

1. Introduction

In recent years, Green Logistics researches or environmentally friendly logistics has become an interesting topic for many 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 (CO_2). 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.

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The research object used in this study is data on the distribution of packaged goods. This data was chosen because of the increasing demand for cement and the widening spread of demand and an increasingly diverse fleet. Therefore, 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 **Fig 1.** 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.
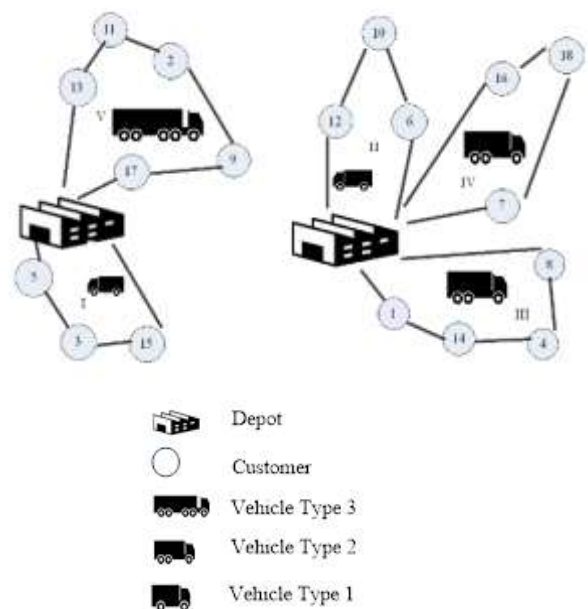

Fig 1. Problem Illustration

Research on environmentally friendly logistics (Green Logistics) has been carried out by several other researchers. Bektas and Laporte [7] has done research in Introduction of a mathematical model that considers emission minimization on the first route formation made (Pollution Routing Problem).Demir et al [8] has done an application of previously created models [7]

in cities in the UK using the Adaptive Learn Neighborhood Search algorithm. Their model is only applicable to one type of vehicle however, basic calculation of fuel consumption and emissions is generated. These two researches are as the initial foundation for developing a model that considers the environment.

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 is done by Kwon et al [9]. The next development is done by Koç et al, 2014 [10], he used the model development from [9] by minimizing detailed fuel cost calculations as done by [8]. The relation between these two and this research are as a basic for developing mathematical models for several types of vehicles, although the problems have not considered fuel costs by means of detailed calculations such as calculations shown by [8].

Toro et al[11]made model that considers fuel minimization and depot location determination, as well as determining the routes served by each depot. The relation of [11] to this research is the determination of the location of the warehouse / depot facility that becomes and the route of each vehicle. However, [11] have not considered the opening of warehouse / depot facilities, only routing and determining the composition of vehicle capacity.The problem has not been based on how to use a combination of vehicle capacity.

This proposed research will fill the research gap. Researchers will develop a model with the object of research is transportation and distribution of packaged goods. 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
3.1 Research Stages

The research method consists of the stages of data collection, development of model and validation as shown in Table 1.

Table 1. 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

3.2 Simulated Annealing Algorithm

The metaheuristic Simulated Annealing (SA) algorithm used is an adjustment of the algorithm in the metaheuristics handbook by [12] The algorithm consists of two parts, namely the initial phase and the repair phase. The initial phase will be used the Nearest Neighbor algorithm to find the initial solution. After getting the initial solution, the algorithm continues to the repair phase. In this phase, a new route will be selected by changing the neighborhood solution now

randomly, such as swap, insertion, reverse move, change vehicle, change facility, and change speed. The flow of this algorithm is presented in Fig 2.

The algorithm starts with setting the current temperature, which is *T0* and randomly raises the initial solution *X*. The best solution is now denoted by *Xbest* and the objective function of *X* denoted by *Fbest*. The new solution is denoted by *Y*, is the solution that results from the improvement of the previous solution *(X)*, each value of the objective function will be evaluated and compared. Suppose $\Delta = $ obj *(Y)* - obj *(X)*. If Δ is less than or equal to zero, then the objective value *Y* is better than *X*, therefore X is replaced by *Y*. Otherwise, the possibility of replacing *X* with *Y* is exp (Δ / KT). Xbest and Fbest will record the best current solution and the best objective function value. The current temperature *T0* will decrease after titration using the formula $T = \alpha T$. The algorithm ends when the current temperature T0 is lower than *Tfinal* or the best current solution *Xbest* is not repaired further as much as *Non-improving* in successive temperature reductions.

4. Problem Definition

In practice, many types of vehicles can be used for shipping. Different types of vehicles produce different emission levels. In this study used heterogeneous vehicle fleets and depot choices that can be used. The purpose of this study was to find the minimum total pollution costs caused by the fleet deployed. Illustration of this problem is shown in **Fig 1**. This problem can be applied by companies or organizations that have a fleet with different types of vehicles and different depot locations / facilities to service customers or other entities located in a wide geographical area. In this study, the location of the facility to be opened will be determined, the type of vehicle to be used along with the routing that must be passed, the third integration to minimize pollution costs. The tour must start and end at the same depot. Each customer must be visited exactly once and several other restrictions. The total number of requests cannot exceed the capacity of each type of vehicle. The following are the parameters of the type of vehicle used.
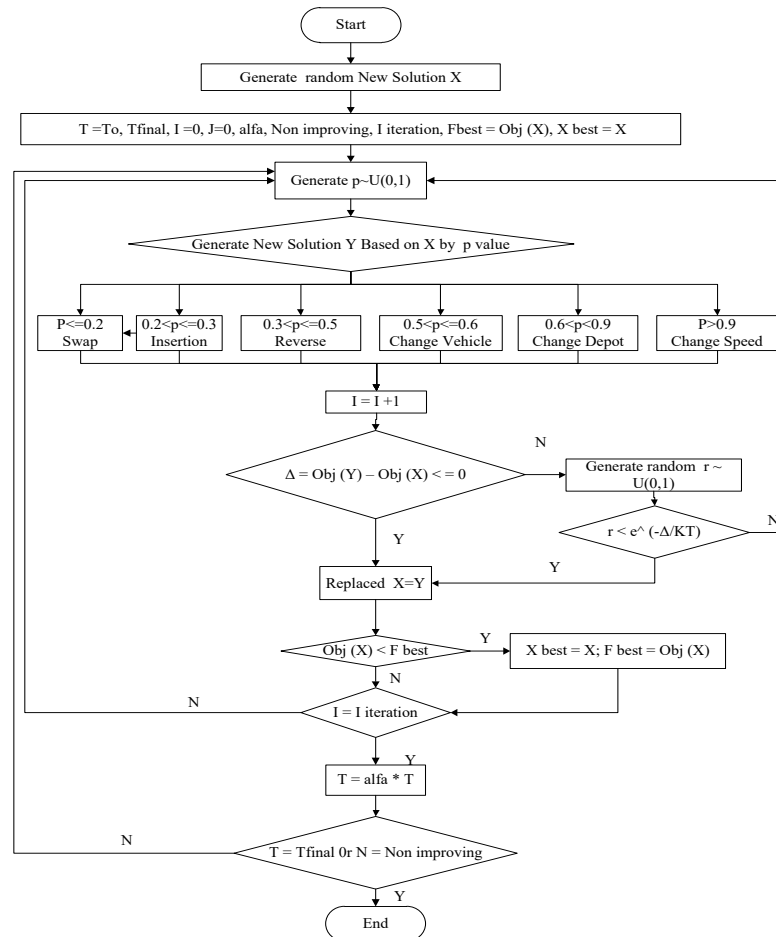
Fig 2 Simulated Annealing Algorithm in this Research

Table 2 Parameter Each Vehicle Type

Notation	Description	Parameter		
		Vehicle Type 1	Vehicle Type 1	Vehicle Type 1
Qv	Curb-weight (kilogram) of a type of m vehicle	2700	4500	6350
Cap	Capacity each type v vehicle	1000	2000	3650
ξ	Fuel-to-air-mass ratio	1	1	1
K	Engine friction factor (kilojoule/rev/liter)	0.4	0.3	0.2
N	Engine speed (rev/second)	33	33	33
V	Engine displacement (liters)	4	4.5	5
G	Gravitational constant (meter/second^2)	9.81	9.81	9.81
Cdv	Coefficient of aerodynamic drag of a type of v vehicle	0.25	0.35	0.7
R	Air density (kilogram/meter^3)	1.2041	1.2041	1.2041
A	Frontal surface area (meter^2)	2.1	3	3.912
Cr	Coefficient of rolling resistance	0.0062	0.009	0.01

η_{tf}	Vehicle drive train efficiency	0.6	0.5	0.4
η	Efficiency parameter for diesel engines	0.9	0.9	0.9
C	Fuel and CO_2 emission cost per liter (£)	1.4	1.4	1.4
κ	Heating value of a typical diesel fuel (kilojoule/gram)	44	44	44
ψ	Conversion factor (gram/second to liter/second)	737	737	737
v^r	Speed level, $r = 1,2,3,\ldots R$	$v = \{15.33,\ 16.44,\ 17.48,\ \ldots,\ 25\}\,\mathrm{m/s}$
Λ	$\lambda = \xi/\kappa\psi$	3.08E-05	3.08E-05	3.08E-05
γ_v	$g = 1/1000\ h_{tf}h$ of a type of v vehicle	0.001852	0.002222	0.002777
$\alpha_{v\|}$	$\alpha = \tau + g\sin\theta + gC_r\cos\theta$	0.060822	0.088291	0.098100
β_v	$\beta = 0.5C_d rA$ of a type of v vehicle	0.316076	0.632153	1.648653
FZ_v	Variable cost each vehicle v(£/m)	0.0001	0.00015	0.0002
FC_f	Fixed cost opening facilities f for $f \in F$ (£/f)	Depend on each depot opening cost
FCv	Fixed dispatch cost vehicle v for $v \in V$(£/v)	50	70	90

5. Result and Discussion

In this section the mathematical model and numerical experiments will be discussed.

5.1 Mathematical Model

In the graph, this problem is defined as a complete graph of G = (N, S) where S = {0, ..., n} is a set of vertices, 0, 1,...f is depot and A = {(i, j): i, j N and i ≠ j} is the set of arc. The distance from node i to j is denoted as dij. Vv is a set of vehicles with type v. Every vehicle in the fleet has a Qv capacity. The customer is set by $S0 = S$ {0}, each member with a request qs that cannot be negative. The time window is denoted as [ai, bi] is the limit for each node. Set ai is the temporary opening time set bi is closing time. The service time for customers is symbolized by ti. Early arrivals are permitted but services must always begin in the customer's time window. The vehicle speed and level are denoted as v and r, respectively. The following discussion is the mathematical model that developed:

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

Cap_f Capacity of facilities f for $f \in F$

FC_f Fixed cost opening facilities f for $f \in F$

FZ_v Fixed cost usage vehicle v for $v \in V$

q_s Demand from customer s for $s \in S$

Cap_v Capacity of vehicle v for $v \in V$

FC_v Fixed dispatch cost vehicle v for $v \in V$

$C(i, j, t_{ijv})$

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, that include: curb weight, engine module, speed

Variables

x_{ijv} Binary variable indicating the vehicle v uses of the path between nodes $i, j \in N$

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 $i, j \in N$

$\overline{v^r}$ speed

w_v Curb weight v vehicle

Objective Function:

$$\min = \sum_{f \in F} FC_f y_f$$

$$+ \sum_{v \in V} \sum_{i \in F} \sum_{j \in S} FC_v x_{ijv} + \sum_{v \in V} \sum_{(i,j) \in N} \lambda f_c k^v N^v V^v d_{ij} \sum_{r=1}^{R} x_{ij}^{rv} / \overline{v^r}$$

$$+ \sum_{v \in V} \sum_{(i,j) \in N} \lambda f_c \gamma^v \alpha_{ij} d_{ij} w_v x_{ijv} + \sum_{v \in V} \sum_{(i,j) \in N} \lambda f_c \gamma^v \alpha_{ij} d_{ij} t_{ijv}$$

$$+ \sum_{v \in V} \sum_{(i,j) \in N} \lambda f_c \beta^v \gamma^v d_{ij} \sum_{r=1}^{R} (\overline{v^r})^2 x_{ij}^{rv} + \sum_{v \in V} \sum_{(i,j) \in N} FZ_v d_{ij} x_{ijv}$$

Constraints:

$$\sum_{v \in V} \sum_{j \in N} x_{ijv} = 1, \qquad \forall i \in S \tag{1}$$

$$\sum_{v \in V} \sum_{j \in N} x_{jiv} - \sum_{v \in V} \sum_{j \in N} x_{ijv} = 0, \qquad \forall i \in N \tag{2}$$

$$\sum_{v \in V} \sum_{j \in N} t_{jiv} - \sum_{v \in V} \sum_{j \in N} t_{ijv} = q_i, \qquad \forall i \in S \tag{3}$$

$$t_{ijv} \leq Cap_v x_{ijv}, \qquad \forall i \in F, j \in N, i \neq j, v \in V \tag{4}$$

$$\sum_{v \in V} \sum_{j \in S} t_{kjv} - \sum_{j \in S} z_{jk} q_j = 0, \qquad \forall k \in F \tag{5}$$

$$\sum_{v \in V} \sum_{j \in S} t_{jkv} = 0 \qquad \forall k \in F \tag{6}$$

$$t_{ijv} \leq (Cap_v - q_i) x_{ijv} \qquad \forall i \in S, j \in N, v \in V \tag{7}$$

$$t_{ijv} \geq q_j x_{ijv} \qquad \forall i \in N, j \in S, v \in V \tag{8}$$

$$\sum_{i \in S} q_i z_{ik} \leq Cap_f y_f \qquad \forall k \in F \tag{9}$$

$$\sum_{k \in F} z_{ik} = 1 \qquad \forall i \in S \tag{10}$$

$$x_{ijv} + \sum_{q \in V, q \neq v} \sum_{k \in N, j \neq k} x_{jkq} \leq 1, \qquad \forall i \in N, j \in S, i \neq j, v \in V \tag{11}$$

$$\sum_{v \in V} x_{ikv} \leq z_{ik}, \qquad \forall k \in F, i \in S \tag{12}$$

$$\sum_{v \in V} x_{kiv} \leq z_{ik}, \qquad \forall k \in F, i \in S \tag{13}$$

$$\sum_{v \in V} x_{ijv} + z_{ik} + \sum_{m \in F, m \neq k} z_{jm} \leq 2, \qquad \forall k \in F, (i,j) \in S, i \neq j \tag{14}$$

$$x_{ijv} \in \{0, 1\} \qquad \forall i, j \in N, v \in V \tag{15}$$

$$y_f \in \{0, 1\} \qquad \forall f \in F \tag{16}$$

$$z_{fs} \in \{0, 1\} \qquad \forall f \in F, s \in S \tag{17}$$

$$t_{ijv} \in \mathbb{R} \qquad \forall i, j \in N, v \in V \tag{18}$$

The objective function minimizes the total cost including fixed facility cost and vehicle cost (curb weight, engine module, speed). Constraints (1) and (2) ensure that each customer is visited exactly once. Constraints (3) imply that the demand of each customer is fully served. Constraints (4) ensure that the total load on any path cannot exceed the capacity of the vehicle traversing it. Constraints (5) ensure that the total load of the vehicles departing from a depot is equal to the total demand of the customers assigned to it. Constraints (6) state that the load on all vehicles returning to each depot must be equal to zero. Constraints (7) dan (8) are the bounds on the load variables. Constraints (9) guarantee that total demand associated with a depot cannot exceed its capacity. Constraints (10) and (11) ensure that each customer is assigned to only one depot and one vehicle, respectively. Constraints (12) and (14) forbid the formation of routes that do not start and end at the same depot. Finally, constraints (15)-(18) enforce the integrality and non-negativity restrictions on the variables.

5.2 Model Validation

Scenarios for validation: two facilities location, three customers, and two vehicles with different capacities. Facility F (Capacity: 70, Fixed Cost 70) andFacility G (Capacity: 50, Fixed Cost 50). The demand of the customer A is 30, B is 40 and C is 50, respectively. 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.

5.3 Calculation of Total Emission Costs

Emission costs in this study consist of 7 types of costs as shown in the objective function in the mathematical model section, namely:
   a. Cost 1: Total Fixed Cost Depot(£)
   b. Cost 2:Total Fixed Cost Vehicle(£)
   c. Cost 3: Total Pollution Cost Low Speed (£)
   d. Cost 4: Total Vehicle Curb Weight (£)
   e. Cost 5: Total Pay Load (£)
   f. Cost 6:Total Pollution Cost High Speed(£)
   g. Cost 7: TotalVehicle Variable Cost(£)

By using dummy data to test algorithms, the following are examples of calculations for two depot choices, two customers, three types of vehicles we can see at Table 4.

Table 3. Total *Cost* Each Route

Configuration	Route-	Heavy 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	-	
	3	F-B-F-A-F-G-C-G-F	-	
	4	G-C-G-F-A-G-B-F-G	-	
	5	G-C-G-F-B-F-A-F-G	-	
	6	F-B-F-G-C-G-F-A-F	-	

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	7	F-A-B-F-G-C-G-F	-	143,2
	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	142,2
	14	F-B-A-F	G-C-G	
3	15	F-A-F-G-C-G-F	F-B-F	146,6
	16	G-C-G-F-A-F	F-B-F	
4	17	F-B-F-G-C-G-F	F-A-F	146,8
	18	G-C-G-F-B-F-G	F-A-F	
5	19	F-A-F	F-B-F-G-C-G-F	143,6
	20	F-A-F	G-C-G-F-B-F-G	
6	21	F-B-F	F-A-F-G-C-G-F	143,8
	22	F-B-F	G-C-G-F-A-F	
7	23	G-C-G	F-A-F-B-F	144
	24	G-C-G	F-B-F-A-F	
8	25	-	F-A-F-B-F-G-C-G-F	141
	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	

Table 4 Numerical Experiment Example

Depot	Cust	Demand	Vehicle	Fixed Cost Vehicle (£)	Depot	Fixed Cost Depot (£)
1	A	500	I	30	Depot 1	150
2	B	500	II	70	Depot 2	155
			III	90		

Table 5 Distance Matrix

	Depot 1	Depot 2	A	B
Depot 1	0	10	25	35
Depot 2	10	0	38	20
A	25	38	0	28
B	35	20	28	0

Validation will be done by enumerating or calculating all possibilities that arise, as follows:

Table 6 Enumeration

No Route	ROUTE				
Route 1	Depot 1	A	B	Depot 1	Vehicle III
Route 2	Depot 1	B	A	Depot 1	Vehicle III
Route 3	Depot 1	A	B	Depot 1	Vehicle II

Route 4	Depot 1	B	A	Depot 1	Vehicle II
Route 5	Depot 1	A	B	Depot 1	Vehicle I
Route 6	Depot 1	B	A	Depot 1	Vehicle I
Route 7	Depot 2	A	B	Depot 2	Vehicle III
Route 8	Depot 2	B	A	Depot 2	Vehicle III
Route 9	Depot 2	A	B	Depot 2	Vehicle II
Route 10	Depot 2	B	A	Depot 2	Vehicle II
Route 11	Depot 2	A	B	Depot 2	Vehicle I
Route 12	Depot 2	B	A	Depot 2	Vehicle I

Calculation of cost is based on the parameters in Table 3 and the data in Table 5. From the enumeration calculation for the data above, the results show that to minimize the total emissions costs is to open depot 1, using type one vehicles by route: Depot 1-AB-Depot 1, with the total cost of emissions is 200,02963(£). The details results are shown in Table 8 and Table 9.

5.4 Simulated Annealing Algorithm Validation

The parameters used in this study are non-improving = 200,000,000, To = 20, Tf = 0.001, Iiter = 150 and α = 0.999. This parameter was obtained from experiments conducted with 2k factorial combination. Validation The algorithm that is formed using Visual Studio will validate the results by comparing it with the enumeration results. Here are the results of the recapitulation of results is shown in table 9. From the results that shown in table 9, the formed algorithm can provide good performance and the same as the enumeration results, so that the SA that is formed can be used to run larger data.

5.5 Numerical Experiments

The following calculations are the results of the recapitulation running for data of 10 customers with two candidates for open depots and 50 customers with 3 candidates for depots that can be opened. Data is taken from http://www.apollo.management.soton.ac.uk/prp lib.htm. and some additional data for the location of prospective depots, including inter-distance distance and distance of the depot with all customers.

The running results will be compared with [13] which discusses the Heterogeneous Fleet Pollution Routing Problem (HFPRP) in which results are running with CPLEX for exact solutions and computational results for HFPRP, so that there will be differences in the total emissions costs if there are potential depots others to choose from. For small instances (10 Nodes) [13] done by two methods which are CPLEX and Heuristics using Simulated Annealing, on the other hand due to the computational time, the larger instances (50) nodes, they used only heuristics method (Simulated Annealing).

5.6 Result Discussion

Average emission costs have been generated by each scenario. By comparing the results of previous solutions with this research, the difference in the cost for each instance will be calculated. For example in UK10_01 Table 10 the results of 149.03 (£)were obtained in the previous study which only used one depot, and 139.9403 which used two prospective depots, the GAP result was 6.12% with the following calculation

$$GAP = \left(\frac{(149.03 - 139.9403)}{149.03} \right) x100\%$$

Therefore, the GAP shows that there was a decrease in the total cost of emissions of 6.12%. The computational results in the small sample shown in Table 10 show a difference in the total cost of emissions when there are other potential depots that can be opened. The average total cost of emissions is reduced by

4.15% for all instances.The reduction in total costs is due to the opening of new depots. As shown in the small example, a decrease in the total cost of emissions occurs when a new depot isopened. In a small example, there is no difference in the route and use of the type of vehicle that is formed, so that it can be analyzed that the reduction in the total cost of emissions produced is due to the difference in the depot being opened. Where as the computational results in the larger examples (50 nodes) which are also shown in Table**11** indicate a significant difference in the total cost of emissions when there are other potential depots that can be opened. The average total cost of emissions was reduced by 18.88% for all instances.The reduction in total costs on larger data is caused by several things including differences in the types of different vehicles used, the routes formed and the depots that are opened. This is shown in the table that there are differences in the use of vehicle types when compared with the[13].

In general, decisions that can integrate three things, namely: the location of the depot that can be opened, the type of vehicle chosen and also the order of the tour / route wil laffect the total cost of emissions.This model can be applied by organizations that consider the environment to be a priority, because with the optimization of the three, it can minimize fuel use which also save semissions costs and can be aligned with route optimization. So that both the environmentally friendly and the distribution cost savings can be achieved.

6. Conclusion

In this study a mathematical model has been developed to determine the location of facilities and the combination of the composition of vehicle capacity along with routes to minimize fuel use for the realization of environmentally friendly logistics. The applied algorithm is able to minimize the total fuel cost which is also an emission cost of 4.15% on small size data and 18.88% on larger data. This model together with the algorithm developed can be used by the organization that concern with logistics-environmentally issues.

To further enrich this type of problem, it will be a relevant extension to consider several additional rich constraints such as separate shipments. Each vehicle can twice or more in sending demand. As for the solution approach, it would be more comprehensive to use additional environmental movements such as 2-opt and CROSS-exchange. Hopefully it can provide more comprehensive exploration for better results because this study only uses the SA algorithm with basic environmental movements.We also recommend using metaheuristics that is suitable for combinatorial cases such as routing problems in this study, such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Ant Colony Optimization (ACO).

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Table7 Enumeration Result of Cost 1-7 Depot 1

DEPOT 1

Vehicle	Arc	fc	Knv	λ	dij	vr	zij/vr	Cost 3	w	γ	α	Cost 4	tijv	Cost 5	β	(vr)^2	Cost 6	Cost 7	Cost 1	Cost 2	TOTAL (£)
Vehicle III	0 to A	1.4	33	3E-05	25	21.132	0.047	0.0017	6350	0.003	0.098	0.002	1000	0.0003	1.65	446.6	0.00221	0.005	150	90	240.0383353
	A to B	1.4	33	3E-05	28	21.132	0.047	0.0019	6350	0.003	0.098	0.002	500	0.0002	1.65	446.6	0.00247	0.006			
	B to 0	1.4	33	3E-05	35	21.132	0.047	0.0024	6350	0.003	0.098	0.003	0	0	1.65	446.6	0.00309	0.007			
Vehicle III	0 to B	1.4	33	3E-05	35	21.132	0.047	0.0024	6350	0.003	0.098	0.003	1000	0.0004	1.65	446.6	0.00309	0.007	150	90	240.0384529
	B to A	1.4	33	3E-05	28	21.132	0.047	0.0019	6350	0.003	0.098	0.002	500	0.0002	1.65	446.6	0.00247	0.006			
	A to 0	1.4	33	3E-05	25	21.132	0.047	0.0017	6350	0.003	0.098	0.002	0	0	1.65	446.6	0.00221	0.005			
Vehicle II	0 to A	1.4	44.55	3E-05	25	21.132	0.047	0.0023	4500	0.002	0.088	1E-03	1000	0.0002	0.63	446.6	0.00068	0.005	150	70	220.0316773
	A to B	1.4	44.55	3E-05	28	21.132	0.047	0.0025	4500	0.002	0.088	0.001	500	0.0001	0.63	446.6	0.00076	0.006			
	B to 0	1.4	44.55	3E-05	35	21.132	0.047	0.0032	4500	0.002	0.088	0.001	0	0	0.63	446.6	0.00095	0.007			
Vehicle II	0 to B	1.4	44.55	3E-05	35	21.132	0.047	0.0032	4500	0.002	0.088	0.001	1000	0.0003	0.63	446.6	0.00095	0.007	150	70	220.031762
	B to A	1.4	44.55	3E-05	28	21.132	0.047	0.0025	4500	0.002	0.088	0.001	500	0.0001	0.63	446.6	0.00076	0.006			
	A to 0	1.4	44.55	3E-05	25	21.132	0.047	0.0023	4500	0.002	0.088	1E-03	0	0	0.63	446.6	0.00068	0.005			
Vehicle I	0 to A	1.4	52.8	3E-05	25	21.132	0.047	0.0027	2700	0.002	0.061	3E-04	1000	0.0001	0.38	446.6	0.00034	0.005	150	50	200.0296292
	A to B	1.4	52.8	3E-05	28	21.132	0.047	0.003	2700	0.002	0.061	4E-04	500	7E-05	0.38	446.6	0.00038	0.006			
	B to 0	1.4	52.8	3E-05	35	21.132	0.047	0.0038	2700	0.002	0.061	5E-04	0	0	0.38	446.6	0.00047	0.007			
Vehicle I	0 to B	1.4	52.8	3E-05	35	21.132	0.047	0.0038	2700	0.002	0.061	5E-04	1000	0.0002	0.38	446.6	0.00047	0.007	150	50	200.0296779
	B to A	1.4	52.8	3E-05	28	21.132	0.047	0.003	2700	0.002	0.061	4E-04	500	7E-05	0.38	446.6	0.00038	0.006			
	A to 0	1.4	52.8	3E-05	25	21.132	0.047	0.0027	2700	0.002	0.061	3E-04	0	0	0.38	446.6	0.00034	0.005			

Table 8 Enumeration Result of Cost 1-7 Depot 2

DEPOT 2

Kendaraan	Arc	fc	Knv	λ	dij	vr	zij/vr	Cost 3	w	γ	α	Cost 4	tijv	Cost 5	β	$(vr)^2$	Cost 6	Cost 7	Cost 1	Cost 2	TOTAL (£)
Vehicle III	1 to A	1.4	33	3E-05	38	21.132	0.047	0.0026	6350	0.003	0.098	0.003	1000	0.0004	1.65	446.6	0.00336	0.008	155	90	245.037627
	A to B	1.4	33	3E-05	28	21.132	0.047	0.0019	6350	0.003	0.098	0.002	500	0.0002	1.65	446.6	0.00247	0.006			
	B to 1	1.4	33	3E-05	20	21.132	0.047	0.0013	6350	0.003	0.098	0.001	0	0	1.65	446.6	0.00177	0.004			
Vehicle III	1 to B	1.4	33	3E-05	20	21.132	0.047	0.0013	6350	0.003	0.098	0.001	1000	0.0002	1.65	446.6	0.00177	0.004	155	90	245.03182
	B to A	1.4	33	3E-05	28	21.132	0.047	0.0019	6350	0.003	0.098	0.002	500	0.0002	1.65	446.6	0.00247	0.006			
	A to 1	1.4	33	3E-05	25	21.132	0.047	0.0017	6350	0.003	0.098	0.002	0	0	1.65	446.6	0.00221	0.005			
Vehicle II	1 to A	1.4	44.55	3E-05	38	21.132	0.047	0.0035	4500	0.002	0.088	0.001	1000	0.0003	0.63	446.6	0.00103	0.008	155	70	225.031075
	A to B	1.4	44.55	3E-05	28	21.132	0.047	0.0025	4500	0.002	0.088	0.001	500	0.0001	0.63	446.6	0.00076	0.006			
	B to 1	1.4	44.55	3E-05	20	21.132	0.047	0.0018	4500	0.002	0.088	8E-04	0	0	0.63	446.6	0.00054	0.004			
Vehicle II	1 to B	1.4	44.55	3E-05	20	21.132	0.047	0.0018	4500	0.002	0.088	8E-04	1000	0.0002	0.63	446.6	0.00054	0.004	155	70	225.026292
	B to A	1.4	44.55	3E-05	28	21.132	0.047	0.0025	4500	0.002	0.088	0.001	500	0.0001	0.63	446.6	0.00076	0.006			
	A to 1	1.4	44.55	3E-05	25	21.132	0.047	0.0023	4500	0.002	0.088	1E-03	0	0	0.63	446.6	0.00068	0.005			
Vehicle I	1 to A	1.4	52.8	3E-05	38	21.132	0.047	0.0041	2700	0.002	0.061	5E-04	1000	0.0002	0.38	446.6	0.00051	0.008	155	50	205.029023
	A to B	1.4	52.8	3E-05	28	21.132	0.047	0.003	2700	0.002	0.061	4E-04	500	7E-05	0.38	446.6	0.00038	0.006			
	B to 1	1.4	52.8	3E-05	20	21.132	0.047	0.0022	2700	0.002	0.061	3E-04	0	0	0.38	446.6	0.00027	0.004			
Vehicle I	1 to B	1.4	52.8	3E-05	20	21.132	0.047	0.0022	2700	0.002	0.061	3E-04	1000	1E-04	0.38	446.6	0.00027	0.004	155	50	205.024587
	B to A	1.4	52.8	3E-05	28	21.132	0.047	0.003	2700	0.002	0.061	4E-04	500	7E-05	0.38	446.6	0.00038	0.006			
	A to 1	1.4	52.8	3E-05	25	21.132	0.047	0.0027	2700	0.002	0.061	3E-04	0	0	0.38	446.6	0.00034	0.005			

Table 9 Comparison Result between Enumeration and SA

Dataset	Total Cost Enumeration(£)	Total Cost using SA(£)	GAP	Vehicle Used			Number of depots opened
				Type 1	Type 2	Type 3	
Data 1	200.02963	200.0296292	0.0000%	1	0	0	1
Data 2	235.24846	235.2484634	0.0000%	1	0	0	2
Data 3	220.05822	220.058223	0.0000%	0	1	0	1
Data 4	239.64957	239.649573	0.0000%	0	1	0	2
Data 5	263.09407	263.094072	0.0000%	0	0	1	2
	Average		0.0000%				

Table 10 Recapitulation of Computational Results for 10 Nodes

| | | | Previous Reseach [13] | | | | | | | This Research (different location of depot is allowed) | | | | | |
| | | | Total Cost (£) | | | | | | | Computational result | | | number vehicle needed | | |
No	Instances	Comp Time (s)	CPLEX	SA	Computational Time (s)	GAP between CPLEX and SA	Number of Opened Depot	No	Instances	Total Cost (£)	Number of Opened Depot	GAP with SA in [13]	type 1	type 2	type 3
1	UK10_01	14400*	160.251	149.063	5.156	6.98%	1	1	UK10_01	139.9403444	2	6.12%	2	2	0
2	UK10_02	14400*	179.604	178.661	5.067	0.53%	1	2	UK10_02	167.5661519	2	6.21%	1	2	0
3	UK10_03	14400*	171.036	156.365	5.949	8.58%	1	3	UK10_03	156.365	1	0.00%	0	3	0
4	UK10_04	14400*	156.898	154.507	5.094	1.52%	1	4	UK10_04	154.507	1	0.00%	1	2	0
5	UK10_05	14400*	150.608	146.323	5.057	2.85%	1	5	UK10_05	146.323	1	0.00%	1	2	0
6	UK10_06	14400*	180.701	172.857	5.075	4.34%	1	6	UK10_06	156.3664422	2	9.54%	3	1	0
7	UK10_07	14400*	165.548	161.991	5.054	2.15%	1	7	UK10_07	145.9700901	2	9.89%	3	1	0
8	UK10_08	14400*	217.988	217.618	4.982	0.17%	1	8	UK10_08	197.2924788	2	9.34%	0	3	0
9	UK10_09	14400*	153.384	144.718	4.871	5.65%	1	9	UK10_09	135.2534428	2	6.54%	0	2	0
10	UK10_10	14400*	189.165	188.881	4.998	0.15%	1	10	UK10_10	170.6539835	2	9.65%	2	2	0
11	UK10_11	14400*	242.619	239.13	5.348	1.44%	1	11	UK10_11	239.13	1	0.00%	3	1	0
12	UK10_12	14400*	154.64	144.833	5.328	6.34%	1	12	UK10_12	144.833	1	0.00%	4	1	0
13	UK10_13	14400*	172.265	161.699	4.906	6.13%	1	13	UK10_13	161.699	1	0.00%	0	2	0
14	UK10_14	14400*	172.154	164.517	5.066	4.44%	1	14	UK10_14	151.2404781	2	8.07%	1	2	0
15	UK10_15	14400*	129.349	124.63	4.675	3.65%	1	15	UK10_15	117.837665	2	5.45%	0	2	0
16	UK10_16	14400*	187.963	187.963	5.077	0.00%	1	16	UK10_16	187.963	1	0.00%	0	1	1
17	UK10_17	14400*	169.921	165.177	4.941	2.79%	1	17	UK10_17	165.177	2	0.00%	3	1	0
18	UK10_18	14400*	151.628	137.21	3.62	9.51%	1	18	UK10_18	129.430193	2	5.67%	2	2	0
19	UK10_19	14400*	164.39	149.237	5.22	9.22%	1	19	UK10_19	149.237	1	0.00%	3	1	0
20	UK10_20	14400*	142.237	134.999	5.036	5.09%	1	20	UK10_20	126.3185643	2	6.43%	0	3	0
Average			170.6175	164.01895	5.026	4.08%				157.1551917		4.15%			

Table 11 Recapitulation of Computational Results for 50 Nodes

Previous Research [13]				This Research (different location of depot is allowed)							
						Computational result			vehicle needed		
No	Instances	Total Cost using SA	Comp Time (s)	No	Instances	Total Cost	Number of Opened Depot	GAP with SA in [13]	type 1	type 2	type 3
1	UK50_01	644.77	38.061	1	UK50_01	542.2516	2	15.90%	1	5	5
2	UK50_02	647.87	36.829	2	UK50_02	508.578	2	21.50%	1	2	6
3	UK50_03	675.89	37.412	3	UK50_03	531.2495	2	21.40%	3	7	3
4	UK50_04	824.96	34.723	4	UK50_04	592.3213	3	28.20%	3	3	5
5	UK50_05	677.48	35.995	5	UK50_05	467.4612	3	31.00%	4	5	3
6	UK50_06	588.24	36.627	6	UK50_06	445.2977	2	24.30%	2	8	3
7	UK50_07	560.71	35.064	7	UK50_07	415.4861	2	25.90%	0	5	4
8	UK50_08	567.92	36.57	8	UK50_08	481.0282	3	15.30%	5	4	3
9	UK50_09	745.43	35.478	9	UK50_09	603.0529	2	19.10%	4	3	4
10	UK50_10	737.93	36.119	10	UK50_10	629.4543	2	14.70%	4	1	6
11	UK50_11	664.67	36.715	11	UK50_11	556.9935	1	16.20%	6	0	5
12	UK50_12	571.98	35.841	12	UK50_12	483.8951	2	15.40%	1	4	5
13	UK50_13	563.25	37.455	13	UK50_13	471.4403	1	16.30%	4	6	3
14	UK50_14	722.68	35.054	14	UK50_14	562.245	2	22.20%	0	7	3
15	UK50_15	621.74	35.866	15	UK50_15	502.9877	2	19.10%	2	3	4
16	UK50_16	626.77	33.465	16	UK50_16	544.0364	3	13.20%	1	4	4
17	UK50_17	424.4	34.649	17	UK50_17	365.4084	2	13.90%	1	13	0
18	UK50_18	741.24	35.158	18	UK50_18	651.55	1	12.10%	2	6	4
19	UK50_19	641.69	37.14	19	UK50_19	551.2117	1	14.10%	8	2	4
20	UK50_20	720.27	34.875	20	UK50_20	592.0619	1	17.80%	0	5	5
	Average	648.5	35.9548		Average	524.9005		18.88%			