Hybrid Metaheuristics for Solving Vehicle Routing Problem in Bulk Cement Distribution

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Abstract

Vehicle Routing Problem (VRP) is a famous tool in solving a logistic management problem. A lot of efforts are being made to research it so that VRP can be implemented effectively and efficiently. The goal is that the costs incurred on the VRP can be achieved as least as possible and the company has good competitiveness by using any methods to achieve optimum solution. In this research a new problem of VRP in bulk cement delivery is provided to be solved by a metaheuristic method. A hybrid metaheuristic is developed to solve the problem by combining two metaheuristic methods namely Nawaz-Enscore-Ham (NEH) and Particle Swarm Optimization (PSO), called NEH-PSO. By conducting several experiments, NEH-PSO provides better solution compared with its building methods. It gives 3.66% effectiveness of the average of total distance compared with NEH and PSO as well as 3.68% effectiveness if it is compared with Tabu Search (TS) and Genetic Algorithm (GA).

Keywords
Vehicle Routing Problem, Metaheuristics, Bulk Cement Distribution

1. Introduction

In the logistics system, transportation plays an important role to move one product or some products either raw materials, semifinished or finished products from one place to another place (Yu et al. 2017). Optimizing the transportation routes may significantly reduce the final price of products due to the facts that in the US, transportation itself accounts for 28% of total energy consumption (Farahani et al. 2011). Because of its wide range of applications, Vehicle Routing Problem (VRP) is considered one of the most frequently used in operational research society.

VRP was first proposed by Dantzig and Ramser (1959). They researched the delivery of fuel products from a depot to some fuel stations. Following their steps, many researchers continued to do research on VRP. The VRP problem mostly tries to have better solution by using any improvement methods or with different handling techniques (Zhang et al. 2017). The other variants of VRP that emerged were mostly related to the addition of new constraints from the original VRP case, such as palettes and time windows. The example of pallet constraints is that different sizes of products must be transported in standard size boxes and limited capacity. Another example of time window limit that is products must be delivered during a certain period (Zhang et al. 2017).

Bulk cement distribution is one of VRP case study. In an island country such as Indonesia, bulk cement will be distributed by ships from a port called depot to other ports. Depot is the port for a factory of the cement. A ship will be scheduled to deliver cement according to the demands of every port. Compartments of the ships are limited therefore a ship must return to the depot to bring cements to the next routes. This routine will be repeated until all demands are fulfilled. The long distance and cost of delivery by ships become a main consideration for the company. Large percentage of ships transportation cost component is one of the focuses for company to make an efficiency (Rusdianto and Siswanto 2020). Most of companies currently are still use operational research methods to determine the assignment route for bulk cement distribution ships (Rusdianto and Siswanto 2020). However, this bulk VRP problem become more complex compared with the original VRP since the number of ship compartments used to bring cements are limited and less than the number of product types. A new strategy and plan must be considered and researched to solve this kind of complex problem.

The problem of VRP is classified as NP-hard which means it cannot be solved within the reasonable computational time by the exact method (Yu et al. 2017). Thus, the exact method such as mathematical formulation method cannot be used to solve this problem. For the efficiency of the time calculation, the solution of VRP can be done by heuristics or metaheuristics methods (Yakici 2017). Some metaheuristics are combined to become a new hybrid metaheuristic. The hybrid metaheuristics used to solve VRP in bulk cement distribution can provide effective solution to solve VRP in bulk cement distribution.

The objective of this research is to solve VRP in bulk cement distribution. Therefore, a hybrid metaheuristic method as a combination of Nawaz-Enscore-Ham (NEH) and Particle Swarm Optimization (PSO) algorithms, called NEH-PSO is developed so that the problem can be solved efficiently and effectively. By combining these algorithms, VRP in bulk cement distribution is expected to be solved more effective than the origin algorithm. NEH-PSO will search the shortest distance of routes taken by the ships to deliver the cements.

2. Literature Review

Some researchers try to develop methods to solve VRP. Most of the methods are metaheuristics since these methods are the reliable method to solve combinatorial optimization problem such as VRP efficiently. Yu et al. (2017) used simulated annealing to solve the Hybrid Vehicle Routing Problem (HVRP), which is an extension of the Green Vehicle Routing Problem (G-VRP). Costa et al. (2018), Mohammed et al. (2017), and Baniamerian et al. (2019) used Genetic Algorithm (GA) to solve VRP. Costa et al. (2018) solved the case of Green VRP. Mohammed et al. (2017) used GA to schedule eight buses which are used for transporting students within campus. Then, Baniamerian et al. (2019) combined GA and variable neighborhood search to solve profitabel heterogeneous vehicle routing problem with cross-docking. Another researcher, Peng (2017) used PSO to solve capacitated location-routine problem as a combination of Facility Location Problem (FLP) and VRP. Ng et al. (2017) used Bee Colony to solve capacitated VRP and re-routing strategies under time-dependent traffic congestion. Silvestrin and Ritt (2017) used an iterated Tabu Search (TS) for the multi-compartment VRP. Yakici (2017) used Ant Colony Optimization (ACO) to solve a rich VRP with mixed fleet, mixed demand, and regional constraints. Albdulkader et al. (2015) developed hybridized ACO algorithm for solving multi compartment VRP. This hybridization improved the performance of ACO. Yu et al. (2017) in their research used Simulated Annealing to solve hybrid VRP and in other research used Symbiotic Organisms Search (2017) to solved capacitated VRP.

Over the years the NEH heuristic algorithm from Nawaz et al. (1983) published in journals are generally considered to be the best heuristics for solving flow-shop scheduling problems (Kalczynski and Kamburowski 2007). NEH is one of the most effective heuristics in solving permutation flow-shop problems (PFSPs) scheduling problems (Pagnozzi and Stützle 2019).

According to Marichelvam et al. (2020), NEH heuristic algorithm consists of three steps, which detail as follow:

1. All jobs are sorted by decreasing amount of processing time.
2. The first two sequence jobs are taken and compared to the two possible partial schedules. The result of this comparison is to assign the better sequence as the current sequence.
3. Job i, $i = 3, ..., n$ is taken and find the best schedule with placing it in all possible i-th positions in the order of work that has been scheduled. The best partial order is selected for the next iteration.

The NEH algorithm is quite simple by placing a new job in the best position for the job. Partially, some of the jobs that have been formed will calculate the fitness value of the desired goal. The best position will be added to the next job in the next partial. Thus, this step is repeated until the entire job is placed.

Research using this algorithm, or its modifications is still being carried out until now. Several researchers have modified the NEH algorithm (Kalczynski and Kamburowski 2007, Dong et al. 2008, Liu at al. 2017), others such as Rauf et al. (2020), Marichelvam et al. (2020), and Zhao et al. (2019) used it to solve scheduling problems, Zhang and Xing (2019), Rossi and Nagano (2019), and Miyata and Nagano (2019) used it as a comparison of calculations and results. Chen et al. (2012) combined NEH and ACO to solve VRP.

The PSO algorithm, which was introduced by Kennedy and Eberhart in 1995, is a parable scheme of a group of birds or fish (Eddaly et al. 2016). In the PSO algorithm, individuals called particles represent solutions to problems, and a swarm has several S particles. According to Eddaly et al. (2016), each particle i is represented by a vector with n dimensions. The position of particle i is denoted by $X^t_i = \{x^t_{i1}, x^t_{i2}, ..., x^t_{in}\}$ where $i = (1, 2, ..., S)$ which indicates the position of particle i in the search space in the t iteration. While the velocity of particle movement i is denoted by $V^t_i = \{v^t_{i1}, v^t_{i2}, ..., v^t_{in}\}$. The best position of particle i is denoted by $P^t_i = \{p^t_{i1}, p^t_{i2}, ..., p^t_{in}\}$, while the global or overall best position is denoted by $G^t = \{G^t_1, G^t_2, ..., G^t_n\}$.

Every t iteration, particle i will adjust its velocity and position by considering the best position in the previous iteration, both local P^{t-1}_i and global G^{t-1}_i. The speed calculation is as follows:

$$v^t_{ij} = v^{t-1}_{ij} + c_1 r_1 (p^{t-1}_{ij} - x^{t-1}_{ij}) + c_2 r_2 (G^{t-1} - x^{t-1}_{ij}) \quad (1)$$

while the change in the position of particle i is as follows:

$$x^t_{ij} = x^{t-1}_{ij} + v^t_{ij} \quad (2)$$

$c1$ and $c2$ are learning factors from self-awareness and learning factors from their social environment. $r1$ and $r2$ are random numbers between 0 and 1.

The PSO algorithm was further developed to improve its performance by adding a weight, so that it became a weighted particle swarm optimization (W-PSO) algorithm. This algorithm is an algorithm developed for continuous optimization. To be used for VRP, it is necessary to perform a special operation to change from continuous to discrete optimization.

NEH and PSO as other metaheuristics method can be used to solve VRP effectively. Combination of these methods will provide better solution (Adhi et al. 2021). NEH and PSO is different optimization algorithm type. NEH provide integer optimization while PSO provide continues optimization. Combination of these algorithms need special treatment.

3. Methods

A new metaheuristics algorithm is developed from the hybrid PSO metaheuristics algorithm to solve VRP in bulk cement distribution. This algorithm is improved and developed by utilizing the capabilities of the NEH heuristic algorithms. The combination of these algorithms is called NEH-PSO. The model of combining this algorithm can be seen as in Figure 1.

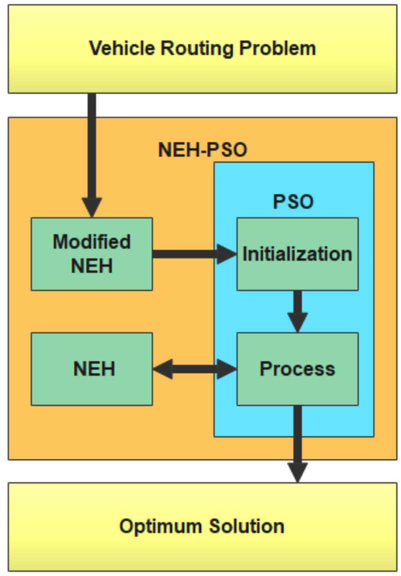

Figure 1. NEH-PSO

The basic step of finding the optimum point is to use the PSO algorithm. NEH has a good procedure in solving problems that are not too complex. For this reason, the NEH algorithm is used in the initialization process of one or some of the particles in the PSO. With PSO initialization from NEH, the value of particles is better than random initialization by origin PSO. NEH always provide one output to initial particles of PSO. It is modified to provide more than one output to initial particles of PSO. On the other hand, the results of the initialization by NEH will also be improved by PSO to run to a better point that NEH will not be able to do.

The PSO algorithm is also improved so that it does not get stuck at the local optimum. A jump or quantum is performed on the PSO algorithm if there is no change in the replacement of the *pBest* and *gBest* variables until a certain iteration. The quantum uses the NEH algorithm to produce the best series of *pBest* and *gBest* values. The trick is to process the *pBest* that has been obtained from PSO which will become the initialization data of NEH. The results of this NEH are returned to the PSO *pBest* value in the form of a sequence.

NEH-PSO is used to solve VRP by finding the best solution from the alternatives considered to solve the problem. The optimum series produced by NEH-PSO is an optimal or near optimal solution with optimization objectives is shortest routes. The algorithm of NEH-PSO is shown below:

For each particle
  Initialize particle
End
Replace initialized particles based on NEH results
Do
  For each particle
    Calculate fitness value
    If the fitness value is better than the best fitness value (pBest) in history
      set current value as the new pBest
  End
  Choose the best of pBest of every particle as the gBest
  If there are no change in pBest for certain iteration
    change pBest based on NEH
      choose the best of pBest of every particle as the gBest
  For each particle
    Calculate particle velocity according to equation (1)
    Update particle position according to equation (2)

End
While maximum iterations or minimum error criteria is not attained

NEH-PSO in the completion of the bulk cement VRP will provide a sequence of cities to be served by the depot. Bulk cements will be sent from the depot to these cities in the order of the sequence provided by NEH-PSO. If the number of products determined to be transported in advance based on a strategy has exceeded the carrying capacity of the ship's compartment, the ship will depart for transportation and return to the depot to pick up the product again after all the compartments are empty. The selection of products to be brought first according to the chosen strategy is based on the fitness value of the strategy which is better than other strategies. This process is repeated. The ship will transport and return to the depot to pick up the bulk cement again until all city demands are met.

The fitness value that determines the effectiveness of product delivery from the depot port to completion and back again to the depot port is the distance traveled by the ship. In subsequent calculations, the distance can be converted into the cost of the ship trip or travel time. In this research, fitness is calculated based on the distance traveled by the ship to serve port cities. A ship in its assignment can serve several port cities. This will make the calculation process to find the closest distance more complex. Calculations cannot be performed using exact methods. The NEH-PSO metaheuristic algorithm will solve this optimization problem.

In real conditions, the case of VRP is very complex. They are more complex than standard VRP cases with one product and one compartment. The complexity of the VRP will increase if there is more than one bulk cement product types demanded by the port cities. The limited number and capacity of the compartments also increase the complexity of the VRP. In this study, the number of compartments is less or equal than the type of product sent to the port.

The process of solving VRP with multiple products and compartments can be achieved by combining metaheuristics algorithms and strategy selection. Metaheuristics are used to find the best order and strategies are used to determine the best way to select product types and compartments. The NEH-PSO metaheuristic method will provide a sequence of port cities to be traversed. In the NEH-PSO calculation process, this sequence will adjust, therefore the fitness value will move towards the optimum point. With the existence of several types of products and compartments, there are several strategies for choosing the type of product and how many products will be carried by the ship. The strategy is calculated in the NEH-PSO fitness calculation process. Several strategies are selected and combined with NEH-PSO to find the best strategy. At least three strategies will be selected in the calculation. Each strategy will be calculated and thus the best strategy will be selected. Each strategy algorithm is divided into two processes. The first process is to take the city request and put it in the compartment. The second process is to move the product in each compartment to the cities that request it. These strategies are:

Strategy 1: Each compartment of the ship will carry a different type of product from the other compartments in one transportation route. The type of product specified in the compartment is selected sequentially from the port city route. This route sequence is obtained from the NEH-PSO process. The number of compartments is smaller or equal than the product type, therefore the ship will return to the city if some product types have not been served. This strategy will level the product type.

Strategy 2: Different compartments can be used to carry the same type of product. The first demand for a product type will be served first. If one compartment is full to carry that type of product, another compartment can be used for the same product. If there is a type of product that cannot be served, the ship will return to the city after returning to the depot. This second strategy can make frequently requested products more efficient

Strategy 3: This strategy is the same as in the second strategy, which is more than one compartment can carry the same type of product. In this third strategy, the most demanded products from all port cities will be served first. The ship will return to the city requesting another type of product that has not been served. This strategy has the advantage when a product that is requested more frequently to be served first.

4. Data Collection

NEH-PSO is used to calculate maritime shipping in transporting cement products (Rusdianto and Siswanto 2020). They used these data to calculate problem in Inventory Routing Problem (IRP) in a horizon of time. In this research these data is used to calculate VRP regardless of the inventory position of each city. Such products are produced in a city defined as a port depot and shipped to other port cities either on the same island or other islands by several ships. This data has two types of products, namely Portland Composite Cement (PCC) and Ordinary Portland Cement (OPC). Cities that are delivered cements product from depot city are port cities. Distances between cities are not Euclidean distance that are calculated from two points. These distances are calculated as a ship traveling from an island to the other island. Something the ship is moving around and stop by in another port city. The distances are measured in Nautical Mile. Demands of cities for every type of cements and the distances between cities are shown in Table 1.

Table 1. Cities demand and distance between cities.

City	Demand (Ton)		Distance (Nautical Mile)									
	PCC	OPC	1	2	3	4	5	6	7	8	9	10
1	0	0	0	744	432	163	274	361	301	634	768	882
2	719	279	744	0	369	616	617	928	606	382	150	449
3	811	0	432	369	0	573	680	728	711	336	417	558
4	527	0	163	616	573	0	153	376	170	774	713	1021
5	221	0	274	617	680	153	0	352	78	881	715	1023
6	1030	0	361	928	728	376	352	0	412	930	1025	1178
7	610	538	301	606	711	170	78	412	0	913	703	1011
8	204	0	634	382	336	774	881	930	913	0	321	361
9	302	0	768	150	417	713	715	1025	703	321	0	374
10	462	0	882	449	558	1021	1023	1178	1011	361	374	0

The cement company has four ships to send its products from the depot city to other cities, namely V1, V2, V3, and V4. Each ship has a different number and capacity of compartments. All compartments are undedicated compartments which means they can be used to carry different types of cement on other shipments. Some ships have one compartment and others have two compartments. The number of compartments and its capacity is shown in Table 2. NEH-PSO is used to solve this problem for every ship if they used to delivery and compare the results with its single metaheuristics (NEH, PSO, 3-Opt) and other metaheuristics, namely TS and GA.

Table 2. Compartment capacity of the ships

Ship	Compartment Capacity (Ton)	
	1	2
V1	1500	0
V2	5200	0
V3	4000	3500
V4	3400	2500

5. Results and Discussion

5.1 Numerical Results

Every ship is calculated for 30 times to obtain rate of total route distance of the ship. The result of calculation by NEH-PSO is shown in Table 3.

Table 3. Calculation result of NEH-PSO for solving bulk cement

Ships	Total Distance (Nautical Mile)
V1	6324.53
V2	4878.00
V3	3912.00
V4	3553.00

NEH-PSO gives schedule of delivery after its calculation. Table 4 shows schedule of ship V3. The sequence of optimum solution is 6, 3, 8, 10, 9, 2, 7, 5, 4 with total distance is 3912 mil.

Table 4. Schedule of ship V3 to deliver cement

No	City	Distance	Compartment		Product			
			1	2	PCC		OPC	
					dm	Ac	dm	ac
1	6	361	(A) 4000	(B) 817	1030	1030		
2	3	728	(A) 2970	(B) 817	811	811		
3	8	336	(A) 2159	(B) 817	204	204		
4	10	361	(A) 1955	(B) 817	462	462		
5	9	374	(A) 1493	(B) 817	302	302		
6	2	150	(A) 1191	(B) 817	719	719	279	279
7	7	606	(A) 472	(B) 538	610	472	538	538
8	Depot	301	(-)	(-)				
9	7	301	(A) 886	(-)	138	138		
10	5	78	(A) 748	(-)	221	221		
11	4	153	(A) 527	(-)	527	527		
12	Depot	163	(-)	(-)				
Total Distance:		3912						

dm = Demand, ac = Accepted

5.2 Graphical Results

Sample of the searching process of NEH-PSO to obtain optimum value is shown in Figure 2. This figure is capture from ship V3 that has two compartments with capacity 4000 and 3500 ton. Searching process shown that NEH-PSO can comply its duty to search better solution from iteration to iteration.

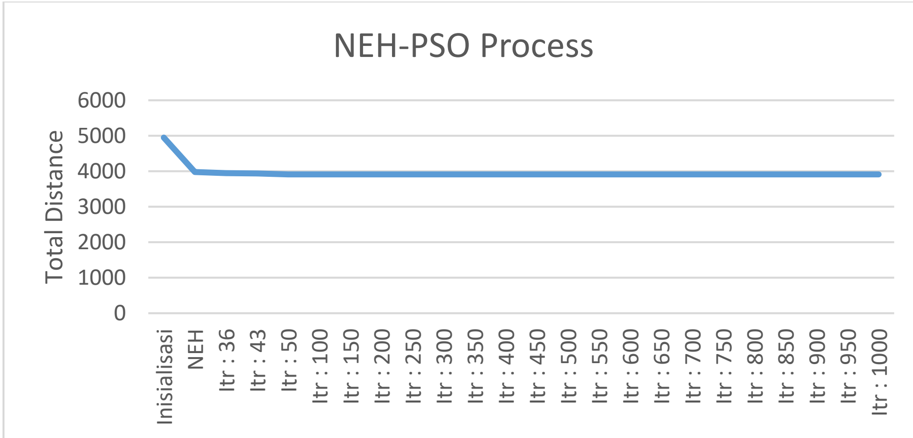

Figure 2. NEH-PSO searching process

Total distance is obtained first from *gBest* after all populations is initialized randomly. *gBest* value at this period is 4949 mil. Modified NEH improve *gBest* into 3981 mil. Better solution is achieved progressively into 3946 mil in iteration 36th, 3940 mil in iteration 43rd, 3912 mil in iteration 50th. The optimum distance is achieved after this iteration and never achieved better again until 1000 iteration. There is no quantum process give better solution after reach 3912 mil. It means NEH-PSO give global optimum fast.

5.3 Proposed Improvements

NEH-PSO as a hybrid metaheuristic provide performance improvement of the heuristic and metaheuristic that build the hybridization namely NEH and PSO algorithm. Table 5 show the comparison between NEH-PSO, NEH, and PSO.

Table 5. Performance improvement by hybrid metaheuristic NEH-PSO

Ship	Rate of routes distance (Nautical Mile)			Effectivity (%)
	NEH	PSO	NEH-PSO	
V1	6738	6324.57	6324.53	0.00
V2	5030	4888.13	4878.00	0.21
V3	4237	3953.13	3912.00	1.04
V4	3893	3688.53	3553.00	3.67
Total	19898	18854.36	18667.53	0.99

Effectiveness is used to compare the performance of the algorithm with its formulation as shown in Equation (3).

$$Ef = \frac{D_{2-}D_1}{D_2} \times 100\% \quad (3)$$

Ef denotes effectivity of the calculation result. Effectivity column in Table 4 shows the effectiveness of the NEH-PSO calculation results. *D*1 denotes the average route distance calculated by NEH-PSO while *D*2 denotes second-best metaheuristic. Effectiveness was calculated from the deviation between the second-best metaheuristic and NEH-PSO. Effectiveness shows how much reduction in route distance obtained by NEH-PSO compared to the second-best algorithm. PSO gives the second-best result on every ship. The effectiveness column shows that NEH-PSO provides increased effectiveness compared to PSO. This proves that the addition of the NEH process at initialization and quantum process of PSO will improve this metaheuristic performance for solving VRP.

Each metaheuristic experiment was carried out 30 times. The experimental results are the average of the final solutions. The results show that NEH-PSO has a better solution compared to other metaheuristics for each ship or the company's total vessels. It is shown by the route distance solution that NEH-PSO has 0.99% more effective than the second best and about 3.66% of the average of total distance of NEH and PSO.

5.4 Validation

Validation of the hybrid method, NEH-PSO, is also measure its improvement from other metaheuristics method namely GA and TS. The data also calculated by GA and TS and compare their result with the result of NEH-PSO as shown in Table 6.

Table 6. Improvement of NEH-PSO compare with GA and TS.

Ship	Rate of routes distance (Nautical Mile)		
	TS	GA	NEH-PSO
V1	6521.67	6423.17	6324.53
V2	4998.30	4934.80	4878.00
V3	4149.73	4001.57	3912.00
V4	3939.00	3791.27	3553.00
Total	19608.70	19150.81	18667.53

NEH-PSO also provides better solution for bulk cement VRP compared with TS and GA. The effectiveness that is achieved by NEH-PSO compared with those two metaheuristics is 3.68%. It shows that hybrid method NEH-PSO that is developed in this research provides better solution than the methods that build it and other metaheuristic methods.

6. Conclusion

In its operation, NEH-PSO was developed to provides sequence of cities that a ship must pass to fulfill the demands of these cities in bulk cement VRP. The fitness value in the NEH-PSO calculation is the distance of the route. NEH-PSO is combined with the strategies of cement type in the limited undedicated compartment of the ship. The strategies consider what products are selected and which compartments are filled with what products. NEH-PSO is quite effective to solve bulk cement VRP cases with multiple products and compartments. It gives better solution to solve real data of cement product transportation compared with other metaheuristics. It solves more effective by giving shortest route distances for every ship used to deliver the product.

In the next research, scheduling of bulk cement VRP can be developed by interacting four ships used to deliver product simultaneously. This new problem is more complex by considering using of two metaheuristics in one calculation. The first metaheuristic process will provide sequence of the cities will be served, and the second metaheuristic process will provide sequence of the ships will assign to deliver product.

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