The improvement of sea highway route by using parallel insertion and exhaustive search

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Abstract. Indonesia contains of island and ocean which perform some problems in logistics delivery such as create a gap between west side and east side of Indonesia. A sea highway program were made by president to send logistics to be more effective and efficient. This program has been implemented for four years recently but still has many adjustment such as creating the best route of sea highway. This research try to create a better route of sea highway by using tour construction to create an initial route in two steps, clark and wright saving matriks and parallel insertion. The second method is tour improvement aims to generate a new route after initial route by using exhaustive search. Five route of sea highway are generated in tour construction and two route has been adjusted in the tour improvement because of a better score came up. The improvement of fourth route from Depot-Malahayati-Batam-Telukbayur-Depot becomes Depot-Malahayati-Telukbayur-Batam-Depot and second route still being the same but there also another option of route which has 18 score different from the best route score , those are Depot-Sampit-Samarinda-Balikpapan-Pontianak-Depot.

1. Introduction

As technology becomes more sophisticated and human mobility needs keep growing, the logistics demand also increasing. The consumer want to get goods as soon as possible so that the lead time requirement should be shorter. By this condition, Indonesia has a main problem to increase the shipment of logistic from one city to another because Indonesia contains of thousands island.

The region of Indonesia mostly contains of ocean as much as 63% with the coastline 80.791 km². Meanwhile, the 37% contains of mainland with 17.499 islands. This condition of Indonesia that own lots of island which is surrounded by the ocean, the sea highway is one of the solution to support logistics transportation to be spreaded all over Indonesia and also able to reduce the logistics cost in the society [1]. In 2019 there are 18 route of sea highway with the frequency target and different day service on each route. However, the more sea highway route the more fuel that will be consumed, the more cost on loading unloading material, and also the amount of labour that will be taken. All of those variabel will increase the logistics cost so that a method such as Vehicle Routing Problem (VRP) should be implemented in this case to create a new route to be more efficient. Vehicle Routing Problem is a problem in the distribution to define vehicle route with certain capacity from one or two port to fullfill the consumer needs [2][3].
The improvement of sea highway route have not been implemented because this program has just running for four years and everything still on adjustment. However some research about sea highway have been created such as using AHP method to analyse the effectiveness and efficiency factor in the third year of sea highway implementation [4], analysing the consistency of route and capacity of the shipment [5] and giving a recommendation about improving the efficiency about route, frequency, and capacity.

Tools that will be used in this research is implementation of Vehicle Routing Problem which has been proven the effectiveness of creating a better route. Parallel insertion and Exhaustive Search will be implemented in this case to find out a better route of sea highway. The parallel insertion has been proven to get a better route compare with sequential version and also exhaustive search has better route to improve the previous option as long as there are enough time to calculate [6].

1.1. Theory

1.1.1. Vehicle Routing Problem. Vehicle Routing Problem (VRP) is a problem in distribution which has the objective to create an optimal route especially for vehicle that has been known the capacity to fulfil the consumer expectation in the certain location and certain demand [7]. VRP also can be defined as a problem to design optimal delivery route from several depots to several supplier by fulfilling certain constraints [8]. Both definition empezhised by [6] that VRP is a problem which focus on distribution of logistics from depot to the consumer. The solution of VRP is some routes to deliver the logistics by certain vehicle. Each route travelled by one vehicle and the vehicle should be back to the early port. There are some general objective VRP such as minimize the transportation cost, minimize the vehicle, balance the route and minimize the penalty due to unpleasant service of consumer.

The characteristic of VRP can be seen as follows [9][8]:
1. The travel route of vehicle should be started and finished in the early depot
2. There are some place that the demand should fulfill once
3. If the capacity of vehicle has been used and unable to serve the next consumen, the vehicle should turn back to the main depot and fulfill the capacity to serve the next consumen
4. The main objective of this problem is to minimize the total distance of vehicle by arrange the sequence of consumen and when the vehicle turn back to the main depot to fulfill the capacity

1.1.2. Tour Construction. In this step the early solution of sea highway route will be created. The method which used to create early route is construction method especially Clarke and Wright Saving Algorithm. This algorithm categorize as construction method because it works by gradually insert the consumen into a route. The saving means some distance can be reduced by combine two consumen into one [3]. The two route that having the greatest saving which has chance to create as the early route[6][10][11].

The algorithm of saving matriks categorized as heuristik algoritm which is not given the optimal solution in the certain problem. The illustration concept of saving matrix can be draw in the diagram below [7]:
Figure 1. Saving Matriks Illustration

I, j = consumer i, consumer j
O = depot

\[ D_a = C_{oi} + C_{io} + C_{oj} + C_{ja} \]  
\[ D_b = C_{oi} + C_{ij} + C_{jo} \]  
\[ S_{ij} = D_a - D_b = (C_{oi} + C_{io} + C_{oj} + C_{ja}) - C_{oi} + C_{ij} = C_{io} + C_{oj} - C_{ij} \]

There are two version to create the route after doing saving matriks. Sequential version which create route gradually by looking at every consumer saving list to try to put in to the route. The priority of this method is creating the first route by the greatest saving list. Meanwhile parallel version can be created more than one every choice on the saving list. Priority of parallel version are focus on the greatest saving list[12][6].

1.1.3. Tour Improvement. After getting the earlier route from tour construction, the next step is to optimize the route by tour improvement. The improvement were done by switch the node which stay on the solution (single route improvement). The location of sequential node moving by certain rules. During the movement if there is the best solution so that the earlier solution will be replaced by the new solution.

Exhaustive search is an approaches to problem solving with brute-force enumeration [13]. This method is simple based on the mathematical argument. An exhaustive search examines every search point inside the search region and gives the possible match. The basic principal of this methode is divide the search process into sequential steps and choosing the next step search direction based on the current step result[14]. However, this method considered inelegant, boring, error prone, and exhausting. When the option is too much then this method is unrecemended to be applied [6].

2. Materials and Method

Method that has been used in this research are divided into two step, tour construction and tour improvement. Tour construction used for defining the early route of sea highway which choosen Clark and Wright Saving Matriks as a tools to create the route. The Clark and Wright Saving Matriks done by parallel insertion due to it has better solution rather than sequential version. The next step is tour improvement which aims to optimize the earlier solution. Exhaustive search were choosen to solve this problem because it still feasible to get the best solution by looking at each sequential step to create the optimal solution.

2.1. Study Design and Overview

The data were got from ministry of maritime database that has been share into documents. There are 22 port which became consume and there is a port that became the main depot. The main depot located in Belawan the westenmost Indonesia. Distance Matrix that has been collected can be seen as follows:
| DESTINATION (Nm – Nautical Mile) | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|----------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| ORIGIN                          |     |     |     |     |     |     |     |     |     |     |
| Belawan                         | 0   | 1021| 1119| 1427| 2243| 372 | 251 | 630 | 784 | 673 |
| Tj. Priok                       | 1   | 0   | 358 | 750 | 1492| 468 | 977 | 334 | 495 | 225 |
| Tj. Perak                       | 2   | 1119| 358 | 0   | 431 | 725 | 1325| 640 | 1005| 540 |
| Makassar                        | 3   | 1427| 750 | 431 | 0   | 999 | 1569| 967 | 1167| 887 |
| Sorong                          | 4   | 2243| 1492| 1226| 754 | 0   | 1644| 2176| 1656| 849 |
| Batam                           | 5   | 372 | 725 | 999 | 1644| 0   | 573 | 155 | 245 | 246 |
| Malahayati                      | 6   | 251 | 977 | 1325| 1569| 573 | 155 | 649 | 490 | 756 |
| Jambi                           | 7   | 630 | 334 | 670 | 1316| 573 | 155 | 649 | 200 | 108 |
| Palembang                       | 8   | 784 | 495 | 1005| 1167| 490 | 200 | 0   | 289 | 400 |
| Panjang                         | 9   | 673 | 225 | 540 | 887 | 200 | 108 | 289 | 0   | 153 |
| Tj. Emas                        | 11  | 1102| 1055| 455 | 842 | 1578| 398 | 886 | 400 | 153 |
| Pontianak                       | 12  | 696 | 393 | 503 | 670 | 1101| 583 | 154 | 561 | 491 |
| Banjarmasin                     | 13  | 1104| 228 | 416 | 1101| 583 | 154 | 561 | 491 | 406 |
| Balikpapan                      | 14  | 1151| 257 | 309 | 1011| 689 | 1260| 662 | 862 | 586 |
| Samarinda                       | 16  | 1481| 700 | 510 | 308 | 846 | 792 | 1347 | 812 | 757 |
| Pantoloan                       | 17  | 1555| 841 | 578 | 266 | 683 | 955 | 1507 | 973 | 915 |
| Kendari                         | 18  | 1793| 949 | 636 | 202 | 552 | 1152| 1143 | 1343 | 1068 |
| Temau Kupang                    | 19  | 1806| 1018| 665 | 390 | 724 | 1347| 1924 | 1488 | 1198 |
| Ternate                         | 20  | 2048| 1295| 1107| 595 | 252 | 1400| 1931 | 1431 | 1376 |
| Ambon                           | 21  | 1994| 1281| 960 | 531 | 250 | 1476| 2035 | 1475 | 1403 |
| Jayapura                        | 22  | 2819| 2036| 1696| 1282| 555 | 2190| 2732 | 2422 | 2134 |

| DESTINATION (Nm – Nautical Mile) | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|----------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| ORIGIN                          |     |     |     |     |     |     |     |     |     |     |
| Belawan                         | 0   | 1033| 696 | 1104| 1151| 1421| 1481| 1555| 1793| 1806|
| Tj. Priok                       | 1   | 217 | 393 | 422 | 488 | 660 | 700 | 841 | 949 | 1018|
| Tj. Perak                       | 2   | 195 | 503 | 281 | 257 | 461 | 510 | 578 | 636 | 665 |
| Makassar                        | 3   | 547 | 670 | 416 | 309 | 279 | 308 | 266 | 202 | 390 |
| Sorong                          | 4   | 1298| 1316| 1101| 1011| 867 | 846 | 683 | 552 | 724 |
| Batam                           | 5   | 617 | 330 | 583 | 689 | 779 | 792 | 955 | 1152| 1347|
| Malahayati                      | 6   | 1168| 893 | 1154| 1260| 1340| 1347| 1507| 1720| 1924|
| Jambi                           | 7   | 518 | 352 | 561 | 662 | 789 | 812 | 973 | 1143| 1293|

Table 2. Destination Matriks location 11 – 22

| DESTINATION (Nm – Nautical Mile) | 11  | 12  | 13  | 14  | 15  | 16  | 17  | 18  | 19  | 20  | 21  | 22  |
|----------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| ORIGIN                          |     |     |     |     |     |     |     |     |     |     |     |     |
| Belawan                         | 0   | 1033| 696 | 1104| 1151| 1421| 1481| 1555| 1793| 1806| 2048| 1994|
| Tj. Priok                       | 1   | 217 | 393 | 422 | 488 | 660 | 700 | 841 | 949 | 1018| 1295| 1281|
| Tj. Perak                       | 2   | 195 | 503 | 281 | 257 | 461 | 510 | 578 | 636 | 665 | 1107| 960 |
| Makassar                        | 3   | 547 | 670 | 416 | 309 | 279 | 308 | 266 | 202 | 390 | 595 | 531 |
| Sorong                          | 4   | 1298| 1316| 1101| 1011| 867 | 846 | 683 | 552 | 724 | 252 | 250 |
| Batam                           | 5   | 617 | 330 | 583 | 689 | 779 | 792 | 955 | 1152| 1347| 1400| 1476|
| Malahayati                      | 6   | 1168| 893 | 1154| 1260| 1340| 1347| 1507| 1720| 1924| 1931| 2035|
| Jambi                           | 7   | 518 | 352 | 561 | 662 | 789 | 812 | 973 | 1143| 1293| 1431| 1475|
DESTINATION (Nm – Nautical Mile)

| ORIGIN          | Tj. Emas | Pontianak | Sampit | Banjarmasin | Balikpapan | Samarinda | Pantoloan | Kendari | Tenau Kupang | Ternate | Ambon | Jayapura |
|-----------------|----------|-----------|--------|-------------|------------|-----------|-----------|---------|--------------|---------|-------|----------|
| Telukbayur      | 8        | 700       | 541    | 761         | 862        | 986       | 1008      | 1169    | 1343         | 1488    | 1625  | 1675     | 2422   |
| Palembang       | 9        | 32        | 326    | 491         | 586        | 728       | 757       | 915     | 1068         | 1198    | 1376  | 1403     | 2134   |
| Panjang         | 10       | 317       | 406    | 490         | 567        | 732       | 769       | 916     | 1036         | 1119    | 1376  | 1371     | 2106   |
| Tj. Emas        | 11       | 0         | 421    | 265         | 371        | 454       | 470       | 633     | 829          | 1044    | 1085  | 1151     | 1887   |
| Pontianak       | 12       | 421       | 0      | 265         | 371        | 454       | 470       | 633     | 829          | 1044    | 1085  | 1151     | 1887   |
| Sampit          | 13       | 305       | 265    | 0           | 106        | 242       | 279       | 427     | 582          | 779     | 888   | 914      | 1643   |
| Banjarmasin     | 14       | 329       | 371    | 106         | 0          | 182       | 230       | 354     | 482          | 674     | 809   | 816      | 1548   |
| Balikpapan      | 15       | 511       | 454    | 242         | 182        | 0         | 50        | 186     | 382          | 669     | 647   | 697      | 1415   |
| Samarinda       | 16       | 558       | 470    | 279         | 230        | 50        | 0         | 162     | 386          | 695     | 619   | 688      | 1398   |
| Pantoloan       | 17       | 677       | 633    | 427         | 354        | 186       | 162       | 0       | 255          | 610     | 461   | 530      | 1235   |
| Kendari         | 18       | 748       | 829    | 582         | 482        | 382       | 386       | 255     | 0            | 377     | 407   | 335      | 1070   |
| Tenau Kupang    | 19       | 801       | 1044   | 779         | 674        | 609       | 695       | 610     | 377          | 0       | 699   | 478      | 1106   |
| Ternate         | 20       | 1118      | 1085   | 888         | 809        | 647       | 619       | 461     | 407          | 699     | 0     | 274      | 803    |
| Ambon           | 21       | 1078      | 1151   | 914         | 816        | 697       | 688       | 530     | 335          | 478     | 274   | 0        | 734    |
| Jayapura        | 22       | 1811      | 1887   | 1643        | 1548       | 1415      | 1398      | 1235    | 1070         | 1106    | 803   | 734      | 0      |

Demand of each location or consumer also need to be outlined as one of constrain in this research. The demand will be illustrated in TEUS (Twenty-foot Equivalent UnitS) which usually used for container or logistics metrices. The demand data has been collected and can be seen bellow :

**Table 3. Demand of each location/consumer**

| Location/ Consumer | Demand (TEUS) | Location/ Consumer | Demand (TEUS) |
|--------------------|---------------|--------------------|---------------|
| Tj. Priok          | 132510        | Pontianak          | 159303        |
| Tj. Perak          | 225514        | Sampit             | 159303        |
| Makassar           | 67547         | Banjarmasin        | 229438        |
| Sorong             | 47850         | Balikpapan         | 159303        |
| Batam              | 253369        | Samarinda          | 159303        |
| Malahayati         | 159303        | Pantoloan          | 159303        |
| Jambi              | 159303        | Kendari            | 159303        |
| Telukbayur         | 159303        | Tenau Kupang       | 159303        |
| Palembang          | 159303        | Ternate            | 159303        |
| Panjang            | 159303        | Ambon              | 159303        |
| Tj. Emas           | 159303        | Jayapura           | 159303        |
2.2. Software
The main software that used in this research is Ms. Excel 2013 especially on Excel Solver to calculate the saving matrices and create an optimal route. Netpas Distance also been used to define the distance between depot to consumer and consumer to consumer. Distance metrics illustrated in Nautical mile (Nm).

3. Result and Discussion

3.1. Saving List
Saving list can be found by calculating the destination and formula below:

\[ S_{ij} = C_{i0} + C_{0j} - C_{ij} \]

\[ S_{sorong,jayapura} (S_{4,22}) = C_{4,0} + C_{0,22} - C_{4,22} \]

\[ = 2243 + 2819 - 555 \]

\[ = 4507 \text{Nm} \]

| Consumer i | Consumer j | Saving (Nm) |
|------------|------------|-------------|
| Sorong     | Jayapura   | 4507        |
| Ambon      | Jayapura   | 4079        |
| Ternate    | Jayapura   | 4064        |
| Sorong     | Ternate    | 4039        |
| Sorong     | Ambon      | 3987        |
| Ternate    | Ambon      | 3768        |
| Kendari    | Jayapura   | 3542        |
| Tenau Kupang | Jayapura | 3519        |

3.2. Creating earlier route
After getting saving list result, a new route can be created by using parallel insertion method which choosing the highest saving list to be executed firstly. A new route has been solved by Ms.Excel and can be outlined below:

| Number of Route | Sequence Route |
|-----------------|----------------|
| First Route     | Depot – Jambi – Panjang – Tj.Priok – Tj. Emas – Palembang - Depot |
| Second Route    | Depot – Pontianak – Samarinda – Balikpapan – Sampit – Depot |
| Third Route     | Depot – Banjarmasin – Pentoloan – Kendari – Tenau Kupang – Tj. Perak - Depot |
| Fourth route    | Depot – Malahayati – Batam - Telukbayur – Depot |
| Fifth route     | Depot – Makassar – Ambon – Jayapura – Sorong – Ternate - Depot |
3.3. Improvement route by using exhaustive search

There are five route that will be processed by exhaustive search algorithm. Firstly the enumeration list should be noted systematically, evaluated every possibility of solution one by one, when all the enumeration list has been proceed then announce the best score. The enumeration list can be created by using formula below:

\[ \text{Number of enumeration} = (n - 1)! \]

So that the numbers enumeration of each route are below:

| Table 6. Enumeration |
|----------------------|
| **Number of Route** | **Calculation** | **Result** |
| First Route          | (6-1)! = 5!    | 120        |
| Second Route         | (5-1)! = 4!    | 24         |
| Third Route          | (6-1)! = 5!    | 120        |
| Fourth Route         | (4-1)! = 3!    | 6          |
| Fifth route          | (6-1)! = 5!    | 120        |

| Table 7. Enumeration fourth route |
|-----------------------------------|
| **Tour route**                    | **Score** |
| Depot – Malahayati – Telukbayur – Batam – Depot | 251 + 490 + 245 + 372 = 1358 |
| Depot – Malahayati – Batam – Telukbayur – Depot | 251 + 573 + 245 + 784 = 1853 |
| Depot – Telukbayur – Malahayati – Batam – Depot | 784 + 490 + 573 + 372 = 2219 |
| Depot – Telukbayur – Batam – Malahayati – Depot | 784 + 245 + 573 + 251 = 1853 |
| Depot – Batam – Malahayati – Telukbayur – Depot | 372 + 573 + 490 + 784 = 2219 |
| Depot – Batam – Telukbayur – Malahayati – Depot | 372 + 245 + 490 + 251 = 1358 |

| Table 8. Enumeration second route |
|-----------------------------------|
| **Tour Route**                    | **Score** |
| Depot – Pontianak – Samarinda - Balikpapan - Sampit – Depot | 2562 |
| Depot – Pontianak – Samarinda – Sampit – Balikpapan – Depot | 3108 |
| Depot – Pontianak – Sampit – Samarinda – Balikpapan – Depot | 2711 |
| Depot – Pontianak – Sampit – Balikpapan – Samarinda – Depot | 2734 |
| Depot – Pontianak – Balikpapan – Sampit – Samarinda – Depot | 3152 |
| Depot – Pontianak – Balikpapan – Samarinda – Sampit – Depot | 2583 |
| Depot – Samarinda – Pontianak – Balikpapan – Sampit – Depot | 3751 |
| Depot – Samarinda – Balikpapan – Pontianak – Sampit – Depot | 3354 |
| Depot – Samarinda – Balikpapan – Sampit – Pontianak – Depot | 2734 |
| Depot – Samarinda – Pontianak – Sampit – Balikpapan – Depot | 3879 |
4. Discussion

From table 7 can be concluded the best solution of sea highway route with the lowest score 1358 are Depot - Malahayati – Telukbayur – Batam – Depot and Depot – Batam – Telukbayur – Malahayati – Depot. The first solution before implementing tour construction obtained score as much as 1853 which is the second lowest route in tabel 6. This might not significant difference before and after implementing exhaustive search but still worthy to try.

Table 8 shown the lowest score is 2562 with the best route Depot – Pontianak – Samarinda – Balikpapan – Sampit – Depot and Depot – Sampit – Samarinda – Balikpapan – Pontianak – Depot. By using exhaustive search also can be seen the other possibility that might be choosen by the researcher. For example, there are slightly different score as much as 2583 which has 18 different score so it can be choosen as consideration. Knowing many possibility has some advantages such as the election of route can be added by some other consideration. The consideration might be the easiest route due to weather in the sea, the schedule of each port or destination and so on. However for some highly possibility of permutation such as first, second, and fifth route, It spent so much time to calculate each enumeration. This prove that exhaustive search is not recommended for higher level of research.

5. Conclusions

Tour construction generate five sea highway route option by using clark and wright saving matriks and parallel instruction. The five sea highway route still able to be improved by using exhaustive search method so that some initial route are changed. The improvement occured on the fourth route which is the route from tour construction was Depot – Malahayati – Batam - Telukbayur – Malahayati – Depot becomes Depot - Malahayati – Telukbayur – Batam – Depot. The second route also spot an interesting highlight, there is no improvement in the second route but there is another option route that can be offered those are Depot – Sampit – Samarinda – Balikpapan – Pontianak – Depot which only 18 score different from earlier route (Depot – Pontianak – Samarinda – Balikpapan – Sampit – Depot). This prove that exhaustive search able to improve the initial route by creating the enumeration. Nonetheless, exhaustive search are not recommend for big permutaion possibility due to time consuming.
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