influence the integration of the distribution network in the islands are time, cost, port, ship, environment (waves and weather), policy and cargo. These factors are then derived into variables that will be used to form the clustering model.

III. PROBLEM DEFINITION AND ASSUMPTIONS

The optimized distribution system in this case is a distribution system served by 3 ships with different networks. The three ships are Sea Tollway ships, Pelni ships and Pioneer ships. The proposed clustering system that will be developed refers to the number of destination ports that must be served. Clustering is focused on ports served by Pioneer ships, but still accommodates ports served by Sea Tollway ships and Pelni ships.

The objective function of this clustering is to maximize profit, the profit is revenue reduced by costs, not profit from shipping operators. By maximizing profits, it is expected that the burden on subsidized PSO can be minimized. The assumptions of the proposed allocation model for clustering are described as follows:

- All feeder ports have the same potential to be included in the same one cluster.
- The objective function of the model (equation 1) is to maximize profit (profit), which is to maximize (income - costs) or can be mathematically expressed in the form of minimizing (- profit) or minimizing (cost - income).
- The objective function represents all ports, whether it's the main port, the collector level and the feeder level
- Pioneer ships only serve vessel trips between the collector port and the feeder port, while the Sea Tollway and Pelni ships only serve shipping between the main port and the collecting port.
- Pioneer ships only sail between ports in one cluster, while Sea Tollway and Pelni ships can sail between ports in different clusters.

IV. PROPOSED ALLOCATION MODEL

The mathematical form of the deterministic allocation model for clustering is as follows:

Objective Function: Maximum Profit (Z) = Revenue – Costs

$$
\begin{aligned}
= &\left[\sum_{u\in U}\sum_{p\in P} w^{up}.\Phi_{TL}\left(\sum_{p\in P}\alpha^{up}\right)-\left(\begin{aligned}&\sum_{u\in U}\sum_{p\in P}\alpha^{up}.B^{p}_{TL}.C^{p}_{bmTL}+\sum_{u\in U}\sum_{p\in P}\alpha^{up}\left\{S^{p}.C^{p}_{st}\right\}+\\ &T_k\sum_{u\in U}\sum_{p\in P}\alpha^{up}\left\{t^{p}_{TL}+\frac{w^{up}}{V_{TL}}\right\}+T_k\sum_{u\in U}\sum_{p\in P}\frac{\alpha^{up}}{C^{p}_{bmTL}}\end{aligned}\right)\right]+\sum_{u\in U}\sum_{p\in P} w^{up}.\varphi_{PL}\left(\sum_{p\in P}\beta^{up}\right)- \\
&\left(\begin{aligned}&\sum_{u\in U}\sum_{p\in P}\beta^{up}.B^{p}_{PL}.C^{p}_{bmPL}+\sum_{u\in U}\sum_{p\in P}\beta^{up}\left\{S^{p}.C^{p}_{st}\right\}+\\ &T_k\sum_{u\in U}\sum_{p\in P}\beta^{up}\left\{t^{p}_{PL}+\frac{w^{up}}{V_{PL}}\right\}+T_k\sum_{u\in U}\sum_{p\in P}\frac{\beta^{up}}{C^{p}_{bmPL}}\end{aligned}\right)-\left(\begin{aligned}&\sum_{u\in U}\sum_{u'\in U'}\gamma^{uu'}.B^{u'}_{PL}.C^{u}_{bmPL}+\sum_{u\in U}\sum_{u'\in U'}\gamma^{uu'}\left\{S^{u'}.C^{u'}_{st}\right\}\\ &+T_k\sum_{u\in U}\sum_{u'\in U'}\gamma^{uu'}\left\{t^{u'}_{PL}+\frac{x^{uu'}}{V_{PL}}\right\}+T_k\sum_{u\in U}\sum_{u'\in U}\frac{\gamma^{uu'}}{C^{u}_{bmPL}}\end{aligned}\right)+ \\
&\left[\sum_{p\in P}\sum_{r\in R} z^{pr}.\Psi_{PR}\left(\sum_{r\in R}\sigma^{pr}\right)-\left(\begin{aligned}&\sum_{p\in P}\sum_{r\in R}\sigma^{pr}.B^{r}_{PR}.C^{r}_{bmPR}+\sum_{p\in P}\sum_{r\in R}\sigma^{pr}\left\{S^{r}.C^{r}_{st}\right\}+\\ &T_g\sum_{p\in P}\sum_{r\in R}\sigma^{pr}\left\{t^{r}_{PR}+\frac{z^{pr}}{V_{PR}}\right\}+T_g\sum_{p\in P}\sum_{r\in R}\frac{\sigma^{pr}}{C^{r}_{bmPR}}\end{aligned}\right)\right] \text{..............................(1)}
\end{aligned}
$$

Set:

U = main port cluster(*u*), *-u = {1,2,3,…n}*
U' = main port cluster ' *(u')*, *-u' = {1,2,3,…m}*
P =collector port cluster, (*p*), *-p = {1,2,3,…p}*
R = feeder port cluster, *(r)*, *-r = {1,2,3,…r}*
TL = Sea Tollway ship
PL = Pelni ship
PR = Pioneer ship

Decision Variable:

α^{up} = quantity of goods that move from -u to -p using the Sea Tollway ship *(Teus)*
β^{up} = quantity of goods that move from -u to -p using the Pelni ship *(Teus)*
$\gamma^{uu'}$ = quantity of goods that move from -*u* ke–*u*' using the Pelni ship *(Teus)*
σ^{pr} = quantity of goods that move from -*p* ke –*r* using the Pioneer ship *(ton)*

Input parameters:

Φ_{TL} = cost per distance unit to move goods using Sea Tollway ship *(Rp/mile/Teus)*
φ_{PL} = cost per distance unit to move goods usingPelni ship *(Rp/mile/Teus)*
Ψ_{PR} = cost per distance unit to move goods using Pioneer ship *(Rp/mile/ton)*
w^{up} = Distance from port-*u* to port-*p (mile)*
z^{pr} = Distance from port-*p* to port-*r (mile)*
D^{u} = Total demand (cargo) from port-*u* to port-*p (Teus)*
D^{p} = Total demand (cargo) from port-*p* to port-*r (Ton)*
t^{p}_{TL} = Docking time average for Sea Tollway ship in port-*p (hour)*
t^{p}_{PL} = Docking time average for Pelni ship at port-*p(hour)*
t^{r}_{PR} = Docking time average for Perintis ship at port-*r(hour)*
B^{p}_{TL} = loading and unloading time of Sea Tollway ship at port-*p* per *unit (hour /Teus)*
B^{p}_{PL} = loading and unloading time of Pelni ship at port-*p* per unit*(hour /Teus)*

$B_{PL}^{u'}$ = loading and unloading time of Pelni ship at port -*u*' per unit *(hour /Teus)*
B_{PR}^{r} = loading and unloading time of Pioneer ship at port -*r* per unit *(hour /ton)*
$S^{u'}$ = goods storage time at port-*u'(day)*
S^{p} = goods storage time at port-*p(day)*
S^{r} = goods storage time at port-*r(day)*
C_{bmTL}^{p} = loading and *unloading* cost of Sea Tollway ship at port-*p* *(Rp/Teus)*
$C_{bmPL}^{u'}$ = loading and *unloading* cost of Pelni ship at port-*u* *(Rp/Teus)*
C_{bmPL}^{p} = loading and *unloading* cost of Pelni ship at port-*p* *(Rp/Teus)*
C_{bmPR}^{r} = loading and *unloading* cost of Pioneer ship at port-*r* *(Rp/ton)*
C_{st}^{u} = goods storage cost at port -*u (Rp/Teus)*
$C_{st}^{u'}$ = goods storage cost at port -*u'(Rp/Teus)*
C_{st}^{p} = goods storage cost at port -*p(Rp/Teus)*
C_{st}^{r} = goods storage cost at port -*r(Rp/ton)*
T_k = container goods inventory cost *(Rp/Teus/ day)*
T_g = general cargo goods inventory cost*(Rp/Ton/day)*
V_{TL} = Sea Tollway ship speed average *(mile/hour)*
V_{PL} = Pelni ship speed average *(mile/hour)*
V_{PR} = Pioneer ship speed average *(mile/hour)*

subject to:

$$D^{u} = \sum_{p\in P}(\alpha^{up} + \beta^{up}) + \sum_{u'\in U'}\gamma^{uu'} \quad \forall\, u \in U \;\ldots\ldots \quad (2)$$

$$D^{p} = \sum_{r\in R}\alpha^{pr} \quad \forall\, p \in P \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

$$\alpha_{up} \geq 0 \quad \forall\, u \in U,\ \forall\, p \in \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

$$\beta_{up} \geq 0 \quad \forall\, u \in U,\ \forall\, p \in P \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

$$\gamma_{uu'} \geq 0 \quad \forall\, u \in U,\ \forall\, u' \in U' \ldots\ldots\ldots\ldots\ldots \quad (6)$$

$$\sigma_{pr} \geq 0 \quad \forall\, p \in P,\ \forall\, r \in R \ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

The descriptions of the allocation model are as follows:

- The 1st and 2nd term of the objective function representthe Sea Tollway ships.
- The 3rd to 6th term represent thePelniships.
- The 7th and 8th term represent Pioneer ships.
- Equation 2 is the load constraint, where the total load demand from the main port is the total load from the collector and feeder ports.
- Equation 3 is the load constraint, where the total load demand from the collector port is the total load from the feeder port.
- Equations 4 - 7 are constraint which states that the number of cargo requests at each port must be ≥ 0.

Algorithm

The tools used in simulating the clustering model optimization are R-tools. The steps for completing the algorithm are explained below:

Step 0: (initialization) the network given is G = (N, A), then the unit cost of each variable is determined in equation 1

Step 1: (data set) determine the data set of each network from the main port (u), main port '(u'), collector port (p) and feeder port (r) covering each of the Sea Tollway, Pelni and Pioneer networks.

Step 2: define routes based on the allocation model traversed by each of the Sea Tollway, Pelni and Pioneer networks based on the problems in Equations 2-7.

Step 3: calculate the profit earned from each formed route. Each route represents port covering.

Step 4: if the maximum profit has been found from the selected allocation model then the process is stopped; otherwise return to step 2

IV. RESULT AND DISCUSSION

Simulations were carried out to implement the model that had been built with a case example of Maluku Province, Indonesia. The simulations were done with 3 models to know the comparison between three simulation models. Each simulation is explained as follows:

- Simulation 1 shows the current conditions without clustering. It consists of 3 main ports: Port of Tanjung Priok, Port of Tanjung Perak and Port of Makassar. Collector ports are 3 ports: Port of Ambon, Port of Tual and Port of Saumlaki. There are 76 feeder ports.
- Simulation 2, by forming 3 clusters with three home base ports, which are Port of Ambon, Port of Tual and Port of Saumlaki. The three ports are designated as homebase port because the three ports are visited by all types of ships, both by the Sea Tollway and Pelni ships.
- Simulation 3, by forming 9 clusters with nine home base ports, which are Port of Ambon, Port of Tual, Port of Saumlaki, Port of Namlea, Port of Namrole, Port of Kisar, Port of Moa, Port of Banda Neira and Port of Dobo. The addition of six ports as home base port is because the six ports are gateway ports for goods to Maluku Province aside from Ambon, Tual and Saumlaki.

IV.I Computational Results

The clustering model is implemented on R tools with Intel (R) Core (TM) i5 CPU, 2.40GHz, 8.00GB RAM. Simulation results have been manually validated to ensure that the developed model is able to explain the process and the obtained results. The results of simulating clustering models for each simulation with a case example can be described as follows:

- **Simulation 1**
  The result of running the R program with the first simulation data input shows that the profit value reaches Rp. 19.102.274.423,- with the current condition of the ship service network (without clustering)
- **Simulation 2**
  Running the R program with the second simulation data input raises 50 alternative cluster iterations. The optimization results show that the most maximum profit value that can be generated is Rp. 22.652.202.087,-
- **Simulation 3**
  Running the R program with the 3rd simulation data input raises 50 alternative cluster iterations. The optimization

results show that the most optimal profit value is Rp. 10.140.814.814,-.

IV.II Interpretation of Simulation Results

The port clustering simulations in Maluku Province use real data from 2017. The results of the simulation with the clustering model show several different findings between one simulation to another. The interpretation is explained below.

1. Simulation 1

There are 3 Pioneer homebase ports in the existing conditions of Maluku Province: Ambon, Tual and Saumlaki. The Pioneer sea transport network is distributed from these ports to other nearby ports. Currently there is no definite system/regulation regarding the freight distribution. The destination port is determined by the government through the Ministry of Transportation based on recommendations from local government. The nature of the network goes back and forth (the ship must return to the previous port if it wants to return to the homebase port), so it feels inefficient. The current pioneering transport routes/networks are shown in Figure 1 below.

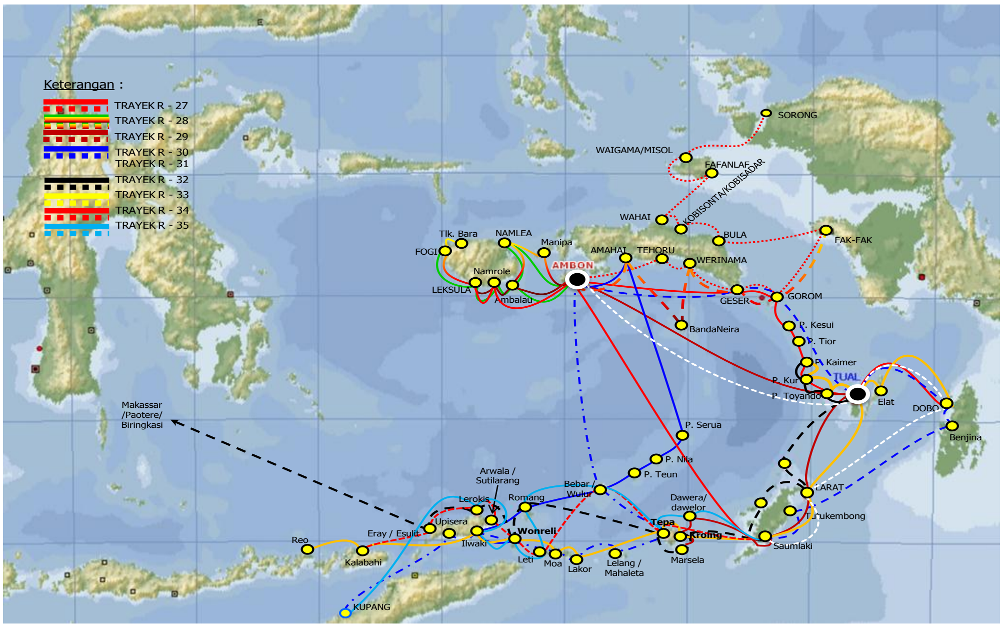

Fig. 1. Pioneer routes / networks for the current freight distribution in Maluku Province (simulation – 1)

The results of the analysis with equation 1 show the total profit (revenue minus costs) earned by the shipping company with the existing conditions without clustering, which is Rp. 19.102.274.423, - for all routes in Maluku Province. This small income, if not subsidized by the government, will burden the people with very high freight costs. Therefore, to ensure the continued freight distribution in remote, outermost and border areas, the government through the Ministry of Transportation provided a very large subsidy of Rp. 1.1 trillion in 2018 for 96 Pioneer routes.

2. Simulation 2

The profit value is obtained randomly from the 50 iterations that have the highest value. Each simulation alternative represents a cluster that can be formed from a collection of collector ports and feeder ports. The comparison of the clustering profit values on simulation 2 can be seen in the Figure 2.

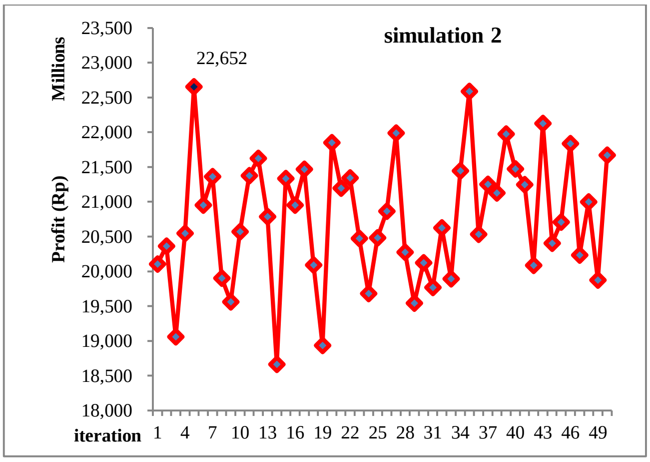

Fig. 2. Comparison of the clustering profit values on simulation 2

The 5th iteration alternative as the most maximized alternative is explained by the following ports:

- Cluster A, also referred as North Cluster with homebase node of Port of Ambon, consists of 20 ports, which are

Namlea, Namrole, Ambalau, Wamsisi, Leksula, Tifu, Waemulang, Fogi, Manipa, Kelang, Buano, Taniwel, Wahai, Kobisadar, Bula, Kelimoi, Geser Island, Kelimuri, Werinama and Amahai.

- Cluster B, also referred as Eastern Cluster with homebase node of Port of Tual, consists of 26 ports, which are Dobo Port, Manawoka Island, Gorom, Kailakat, Kesui Island, Kasiui, Tior Island, Kaimer, Mangur, Fadol, Kur Island, Toyando, Tam, Banda Neira, Holat, Weduar, Elat, Mun, Banda Eli, Benjina, Tabarfane, Jerol, Meror, Longgar, Marlasi and Lelam Kojabi.
- Cluster C, also referred as South Cluster with homebase node of Port of Saumlaki, consists of 30 ports, which are Kisar, Larat, Sofyanin/Rumayaan, Rumean, Wunlah, Seira, Nurkat, Molu, Tutukembong, Adault/Lingat, Marsela, Tepa, Dawera/Dawelor, Kroing, Lewa/Dai, Moa, Serua, Nila, Teon, Wulur, Bebar, Eray, Ilwaki, Romang, Arwala/Sutilirang, Kisar1, Leti Island, Lakor, Luang Island and Lelang.

The illustration of clustering from the highest (optimal) profit value, which is the 5th iteration, is shown in the following figure 3.

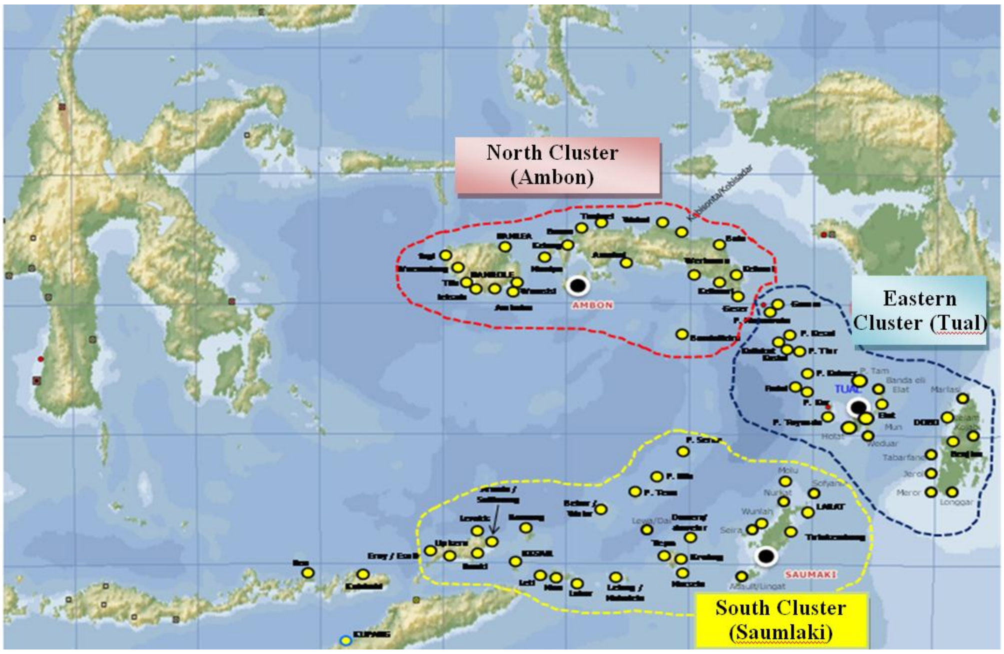

Fig. 3. Port Clustering from the highest Profit Value (simulation - 2)

3. Simulation 3

The profit value is obtained randomly from the 50 iterations that have the highest value. Each simulation alternative represents a cluster that can be formed from a collection of collector ports and feeder ports. The comparison of the clustering profit values on simulation 3 can be seen in Figure 4.

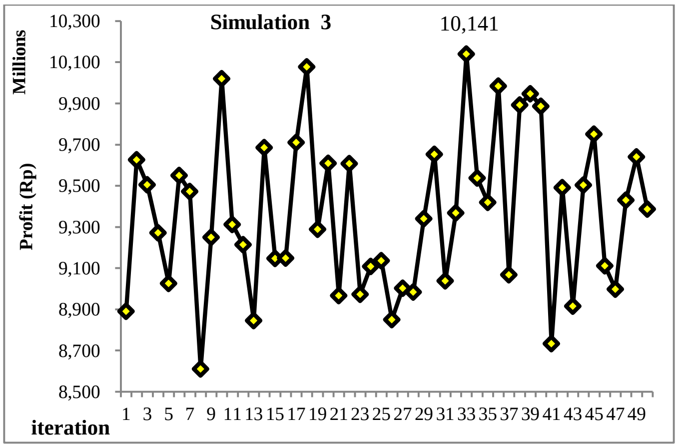

Fig. 4. Comparison of the clustering profit values on simulation 3

The 33rd alternative as the alternative with the most maximum profit is described by the following ports:

- Cluster A with homebase of Port of Namlea consists of 3 ports: Fogi, Kelang and Manipa
- Cluster B with homebase of Port of Namrole consists of 5 ports: Wamsisi, Ambalau, Tifu, Leksula, and Waemulang Ports.
- Cluster C with homebase of Port of Ambon consists of 10 ports: Werinama, Bula, Kobisadar, Wahai, Amahai, Taniwel, Buano, Kelimuri, Kelimoi and Geser Island ports.
- Cluster D with homebase of Port of Banda Neira consists of 6 ports: Tioor Island, Kesui Island, Kasiui, Kailakat, Gorom Island, and Manawoka Island
- Cluster E with homebase of Port of Tual consists of 12 ports: Weduar, Mun, Banda Eli, Elat, Holat, Tayandu, Tam Island, Mangur, Fadol, Kur Island, and Kaimer Ports
- Cluster F with homebase of Port of Dobo consists of 7 ports: Marlasi, Lelam Kojabi, Longgar, Meror, Jerol, Tabarfane, and Benjina Ports
- Cluster G with homebase of Port of Saumlaki consists of 13 ports: Dawera/Dawelor, Kroing, Marsela,

Adault/Lingat, Seira, Tutukembong, Wunlah, Rumean, Sofyanin, Nurkat, Molu, Larat, and Lewa/Dai,

- Cluster H with homebase of Port of Moa consists of 10 ports: Leti Island, Lakor, Bebar, Wulur, Teon, Nila Island, Serua Island, Lelang, Luang Island, and Tepa
- Cluster I with homebase of Port of Kisar consists of 4 ports: Eray, Ilwaki, Arwala/Sutilirang, and Kisar1 Ports

The illustration of clustering from the highest (optimal) profit value in simulation 3, the 33rd iteration, is shown in Figure 5 below.

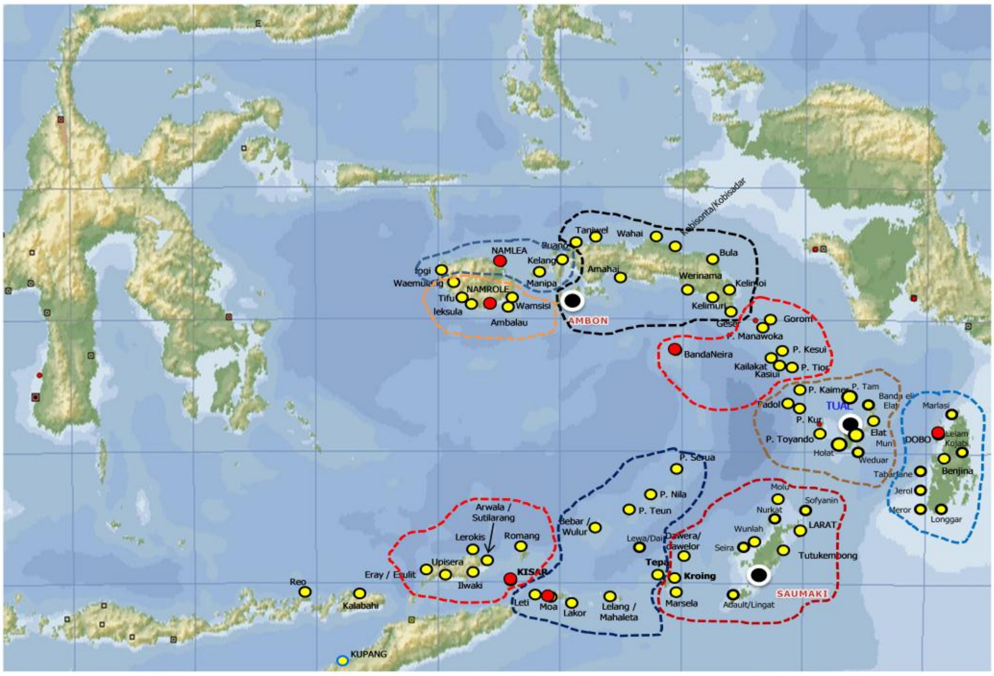

Fig. 5. Port Clustering from the highest Profit Value (simulation - 3)

The results comparison of deterministic allocation model optimization in the three simulations show that there is a difference in profit value. Simulation 2 with the 3 cluster system has the highest profit value and is 15.7% more profitable than simulation 1 (currently). Simulation 2 has a better profit value of 55.2% than simulation 3. Although using clusters is better than not using it, the excessive number of clusters also results in inefficiency. Simulation 3, which used 9 clusters, actually received lower profit value because the number of ports served by each cluster is small, so the transportation demand is small, resulting in reduced revenue. The comparison of profits between the 3 simulations can be seen in Figure 6.

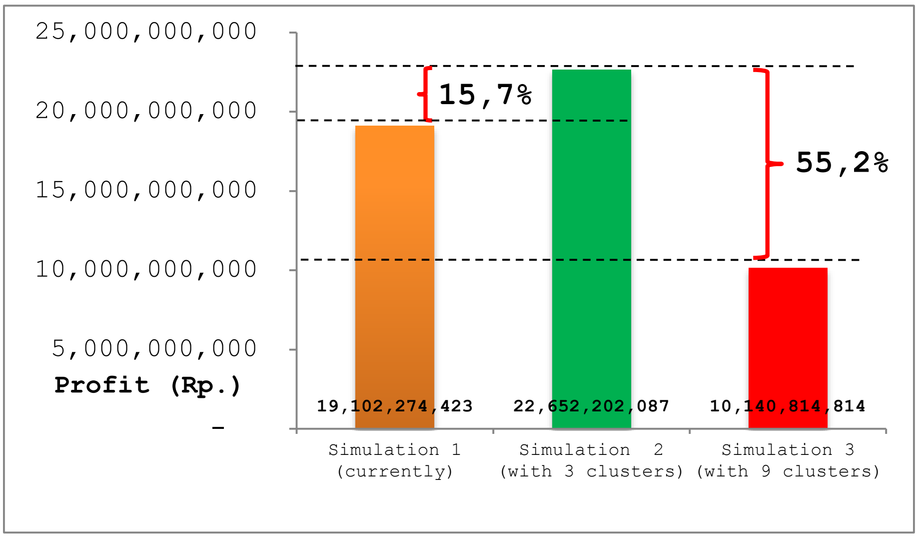

Fig. 6. The profit comparison of the Clustering Optimization Model

V. CONCLUSION

This paper has modeled efficient port clustering in order to increase profits and reduce subsidies/PSO. The cost efficiency that is assumed with the maximum profit through the implementation of a clustering system in the freight distribution system on archipelagic area is highly possible. The comparison of profit optimization resultswith the allocation model between the existing condition and the implementation of the 3 cluster system shows that there is an 15.7% increase in profit, whereas with the 9 cluster profit system the profit is lower. These results indicate that the clustering system does not necessarily increase profit from subsidized/PSO transport services. The more clusters formed, the higher the operational costs of the ship and the less cargo can be transported because the number of ports served is increasingly limited. These result in reduced income. Adopting the current geographical and demand conditions in the Indonesian Maluku province will form 3 optimal clusters: the 1st cluster with homebase of Port of Ambon that consists of 20 ports, the 2nd cluster with homebase of Port of Tual port that consists of 26 ports, and the 3rd cluster with the homebase of Port of Saumlaki that consists of 23 ports. Furthermore, the cluster will be used in integrating the sea transportation network in order to optimize the freight distribution network in Indonesia.

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