Maritime Inventory Routing Problem: Application on Discharge the Load of the Ship in Cement Companies to Minimize the Total Transportation Cost

Febryan Khoirun Yusuf¹³, Ari Yanuar Ridwan¹ and Hardian Kokoh Pambudi²

¹Industrial Engineering Department, School of Industrial Engineering, Telkom University, Bandung, Indonesia
²Logistics Engineering Department, School of Industrial Engineering, Telkom University, Bandung, Indonesia
³febryank@student.telkomuniversity.ac.id

Abstract. Distribution activities are an important part and very considered in the world of logistics because distribution is one of the key drivers of profits earned by companies. One that is related to distribution is transportation. Transportation refers to moving products from one location to another where the product moves from the beginning of the supply chain to consumers where this transportation will incur costs and is one of the costs that affect the price of a product. This research aims to schedule ship transportation from 3 production ports to 6 consumption ports with a heterogeneous fleet of ships to minimize the total transportation costs in the cement industry companies. Maritime Inventory Routing Problem (MIRP) is a problem of ship scheduling which is not only related to the distribution of products from production ports to consumption ports, it also manages the inventory at these ports and is usually used for bulk industrial products. The method used in this research is MIRP with Mixed-Integer Linear Programming (MILP) approach where this method can minimize the total transportation costs. The results show that the method used can reduce the total waiting time so that the total transportation costs are also reduced.

1. Introduction
Nowadays companies in competing change their focus, which at first the focus of competition between the companies turned into a competition between supply chains[1]. Supply chain management is the integration of business processes from end-users through initial suppliers that provide products, services, and information that add value to customers[2]. Included in supply chain management is good coordination and collaboration between suppliers and customers. In other words, supply chain management integrates negotiation and demand management in the company[3].

One of the things related to the supply chain is distribution activities. Distribution is taking steps to move and store products from the supplier stage to the consumer stage in the supply chain[4]. Distribution in the world of logistics has become an important part and very considered, where distribution is the process of moving goods from suppliers to the end customers involved in the supply chain, basically distribution is one of the main drivers of the overall profit earned by the company because it affects the cost of the supply chain[5].

Meanwhile, transportation refers to moving products from one location to another where the product moves from the beginning of the supply chain to the consumers[4]. Transportation costs can
be categorized into two, namely outbound transportation costs and inbound transportation costs. Outbound transportation costs for shipping to customers are usually included in sales, general, and administrative costs, while inbound transportation costs are usually included in the cost of goods sold, therefore this transportation cost is one that affects the price of a product[4].

There are various types of modes of transportation, one of which is sea mode. In general, vehicles used in transportation by sea are ships[4]. The research conducted is in the company engaged in the cement industry in Indonesia. This company in meeting the demands of its customers in Indonesia, the distribution of its products uses several modes of transportation, one of which is the sea mode using vessels. The vessels owned by this company are chartered vessels of different types and capacities or heterogeneous fleets.

The company has 3 production ports (Tarjun, Tanjung Priok and Cirebon Port) and 6 consumption ports (Samarinda, Pontianak, Surabaya, Lombok, Palembang, and Lampung Port) and will distribute its cement by vessel. The vessel loads cement at the production port and will sail to the consumption port followed by discharging the cement at the consumption port. Vessels can discharge their cargo when the inventory storage from the port of consumption is not full. However, in reality, many vessels when arriving at the port of consumption cannot discharge the cargo, due to the storage of cement supplies still full. So, the vessels must wait until the cement they have is sold to consumers.

**Table 1.** Total Idle Time of Vessel in 2018

| No | Month | Total Idle Time (Hours) |
|----|-------|-------------------------|
| I  | Jan   | 163.1                   |
| II | Feb   | 171.3                   |
| III| Mar   | 310.3                   |
| IV | Apr   | 12.7                    |
| V  | May   | 0                       |
| VI | Jun   | 281.8                   |
| VII| Jul   | 21.3                    |
| VIII| Aug  | 66                      |
| IX | Sep   | 173.6                   |
| X  | Oct   | 215.4                   |
| XI | Nov   | 34.7                    |
| XII| Dec   | 210.5                   |
|    | Total | 1660.7                  |

In 2018, the total idle time that occurred was 1660.7 hours in sending cement to all consumption ports. A large amount of idle time due to the vessel being unable to discharge cement. One of the causes of a large idle time is improper scheduling and it impacts a large total transportation cost.

**Table 2.** Existing Total Transportation Cost in 2018 (a)

| No | Month | Total Transportation Cost |
|----|-------|----------------------------|
| I  | Jan   | Rp 24,392,140,341          |
| II | Feb   | Rp 14,284,236,389          |
| III| Mar   | Rp 21,230,310,242          |
| IV | Apr   | Rp 8,961,013,584           |
| V  | May   | Rp 19,310,321,060          |
| VI | Jun   | Rp 15,103,512,463          |
| VII| Jul   | Rp 20,387,184,523          |
| VIII| Aug  | Rp 23,685,842,976          |
### Table 3. Existing Total Transportation Cost in 2018 (b)

| No | Month | Total Transportation Cost |
|----|-------|---------------------------|
| IX | Sep   | Rp 24,441,641,005         |
| X  | Oct   | Rp 25,580,885,240         |
| XI | Nov   | Rp 27,039,256,182         |
| XII| Dec   | Rp 28,385,171,692         |
|    | Total | Rp 252,801,515,696        |

Maritime Inventory Routing Problem is a problem method used for a company that must be responsible for carrying products from the supplier port or loading port to the consumer port or unloading port and also responsible for managing inventory levels at the port, MIRP is usually often used for bulk industrial products[6]. Thus, scheduling cement distribution is solved using the MIRP problem method with a Mixed Integer Linear Programming mathematical formulation to minimize the total transportation cost.

The focus in this paper is the use of the Maritime inventory routing problem method with a mixed-integer linear programming approach that has been widely used in several cases. As in the research conducted by Agra[7], which is formulating a mathematical model that is used by solving the problem using the software Xpress Optimizer version 21.01.00 with Xpress Mosel version 3.2.0 and also research conducted by Diz[6] for solving problems in the case of petroleum in Brazil using the platform commercial optimization called AIMMS 3.13 and also GUROBI 5.5 Solver. So that this research will use the same methods and mathematical models to solve a case in one of the cement industry companies in Indonesia, where the difference with previous research is code that was built using the Python Programming Language with the library PuLP, which is easy to understand for humans and a powerful library for modeling in Python with open-source packages and solved using the GUROBI 9.0.1 solver version of the free academic license. Besides, this research will provide optimal results for a full year by providing sequential monthly results. So, this research is expected to be able to enrich the use of the MIRP method with different cases.

2. **Literature Review**

Maritime Inventory Routing Problem is defined as a combination of ship routing and ship scheduling problems so finding routes and scheduling vessels with minimal transportation costs and inventory management problems so that scheduling does not interrupt production or consumption at the storages[8].

MIRP is a problem method used for a company that must be responsible for carrying products from the supplier port or loading port to the consumer port or unloading port and also responsible for managing inventory levels at the port, MIRP is usually often used for bulk industrial products[6] such as cement, rice, liquid chemicals, and oil.

Pioneering this problem was the work of Dantzig and Fulkerson in 1954[9]. The problem solved was minimizing the number of tankers needed to carry out a certain set of schedules. This can be considered as a matter of fleet size where there is only one type of ship. This shows that the problem is a transportation problem[10]. Next, the MIR problem is to address the ammonia supply chain problem. To overcome this problem, Christiansen in 1999[11] proposed a formulation of mixed-integer linear programming (MILP).

Furthermore, researchers and industry pay attention to the monetary benefits that can be achieved by coordinating inventory management planning activities and ship schedules. Besides, coordination can also increase the robustness and flexibility of operations as done by Christiansen et al. in 2013[12]. This perception has made the focus on MIR issues increase over the past decade[6].

Although researchers and industry recognize that the optimization model can improve efficiency in the maritime inventory routing problem, they also realize that solving this type of problem until optimality for real-world problems is very complicated. Although it is complex, Agra, Andersson, et
al., 2013[7] claims that the MIR problem is usually very focused on capital, and a simple improvement in fleet scheduling and cargo quantity will mean large economic benefits.

In the last few decades, due to complex problem solving it requires the approach used. most approaches in the literature use MILP techniques to deal with these problems. Regarding appropriate methods such as MILP, researchers have investigated decomposition techniques and the development of reformulations to improve computational performance. In 1999 Christiansen[11] proposed decomposing the MIR problem into two types of subproblems: ship routing and inventory management. Agra, Andersson, et al., 2013[7] also proposed a reformulation called the fixed load flow model (FCNF) and has implemented several important valid inequalities that provide more stringent formulations in terms of a linear relaxation. Furthermore, with the formulation carried out by Agra, Andersson, et al.[7], In 2017 Diz[6] used the formulation to resolve the petroleum case in Brazil concerning crude oil offloading and supply problems (COSP).

3. Mathematical Model

The mathematical model used is a model for Maritime Inventory Routing Problem with Mixed Integer Linear Programming (MILP) approach. MILP is a mixture of Linear Program (LP) and Integer Linear Programming (ILP), i.e., a set of variables can be partitioned into two subsets where the first subset contains variables with integer domains and variables in the second subset have real value domains which has a linear objective function[13]. MILP is a linear integer programming model that has a function to optimize the goal of the model[14].

Mathematical formulation using the MILP approach is a mathematical model that was formulated by Agostinho Agra[7] in 2013 which later was also implemented by Gustavo Souto dos Santos Diz[6] in 2017 which was applied to the case of a petroleum company in Brazil.

3.1. Sets

The set used in the formulation of this mathematical model as follows.

\[ N \] Set of all ports indexed by \( p \) and \( q \);
\[ T \] Set of time periods indexed by \( t \);
\[ V \] Set of vessels or ships indexed by \( v \);
\[ NP \] Set of loading or production ports indexed by \( p \) and \( q \);
\[ ND \] Set of discharge or consumption ports indexed by \( p \) and \( q \);

3.2. Parameters

As for the parameters used in the formulation of this mathematical model as follows.

\[ C_{pqv}^T \] Sailing or traveling cost from ports \( p \) to \( q \) using vessel \( v \);
\[ C_{v}^W \] Waiting for costs due to vessels \( v \) for each time period;
\[ C_{pv}^p \] Port cost for vessel \( v \) operating in port \( p \);
\[ \alpha(v) \] The initial position of the vessel \( v \) at the beginning of the planning horizon;
\[ d(v) \] Artificial destination node for each vessel;
\[ T_{pqv} \] Time is taken by vessels \( v \) to sail from port \( p \) to \( q \);
\[ B_{pt} \] Number of vessels that can berth at port \( p \) during time period \( t \);
\[ Q_{v}^0 \] Maximum number of products that can be (un)loaded by vessel \( v \) in one time period;
\[ L_{v}^0 \] Initial inventory in the vessel \( v \) on the planning horizon;
\[ K_{v} \] The capacity of vessel \( v \);
\[ D_{pt} \] Amount of demand for each time period \( t \) at the discharge or consumption port \( p \);
\[ P_{pt} \] The capability of production for each time period \( t \) at the loading or production port \( p \);
3.3. Variables
As for the variables used in the formulation of this mathematical model as follows.

- $SMX_{pt}$: Upper limit or the maximum of inventory level on each time period $t$ in port $p$;
- $SMN_{pt}$: Lower limit or the minimum of inventory level on each time period $t$ in port $p$;
- $S^0_p$: Initial inventory level at the beginning of the planning horizon at port $p$.

3.4. Assumption
As for getting results that can be optimized there are assumptions used in this research as follows.

a. Weather along the time horizon is always good or bad weather does not occur.
b. The speed of the ship during the trip is always considered constant.
c. Inventories of bulk cement at loading ports or loading ports are always considered to be available for distribution to unloading ports.
d. Ships that have been rented are considered always in good condition.
e. The vessel's path in carrying products from the loading port to the loading port is always the same as the distance between ports.
f. The vessel's initial position is at the point the ship is carrying out the first operation and the vessel's final position is at the point where the ship is carrying out the last operation.
g. Ships that have finished operating in that month are immediately off-hired and will be leased again the following month.

3.5. Objective Function
The objective functions are functions that describe the goals or things to be achieved in the problem model[15]. The objective function used in the formulation of this mathematical model as follows.
The minimization function (25) sailing or traveling costs, operating or port costs, and waiting costs.

### 3.6. Constraint Function

Constraint function is a form of mathematical representation of the available capacity limits for optimal allocation[15]. The constraint function used in the formulation of this mathematical model as follows.

**a. Routing Constraints**

\[ \sum_{q \in N \cup \{o(v)\}, t \in T} x_{o(v)qvt} = 1, \forall v \in V, \]  
(2)

\[ \sum_{p \in N \cup \{o(v)\}, t \in T} x_{pd(v)vt} = 1, \forall v \in V. \]  
(3)

Constraints (2) and (3) ensure that each vessel departs from the initial artificial port and completes the voyages at the artificial destination port.

**b. Sailing, Waiting, and Operating Time Constraints**

\[ \sum_{q \in N \cup \{o(v)\}, t \in T} x_{qpv,t-t_{app}}^{A} + w_{pv,t-1}^{A} = w_{pv,t}^{A} + a_{pv,t}^{A}, \forall v \in V, p \in N, t \in T, \]  
(4)

\[ a_{pv,t}^{A} + a_{pv,t-1}^{B} = b_{pv,t}^{B} + \sum_{q \in N \cup \{o(v)\}} x_{pqvt}, \forall v \in V, p \in N, t \in T, \]  
(5)

\[ a_{pv,t}^{A}, b_{pv,t}^{B} \in \{0,1\}, \forall v \in V, p \in N, t \in T, \]  
(6)

\[ a_{pv,t}^{A} + a_{pv,t}^{B} = b_{pv,t}, \forall v \in V, p \in N, t \in T, \]  
(7)

\[ \sum_{v \in V} b_{pv,t} \leq B_{pt}, \forall p \in N, t \in T. \]  
(8)

Constraint (4) represents the vessel arrives at a port and (5) represents when the vessel is sailing from one of the port. Constraint (6) represents the variables \( a_{pv,t}^{A} \) and \( b_{pv,t}^{B} \) are binary. Constraint (7) presents the relation between the old operating variable and the new operating variable. Constraint (8) provides berth limitation at each node and in consequence waiting time.

**c. Loading Constraints**

\[ 0 \leq q_{pv,t}^{A} \leq Q_{v} a_{pv,t}^{A}, \forall v \in V, p \in N, t \in T, \]  
(9)

\[ \sum_{q \in N \cup \{o(v)\}} f_{qpv,t-t_{app}}^{A} + f_{pv,t-1}^{A} = f_{pv,t}^{A} + f_{pv,t}^{OB}, \forall v \in V, p \in N, t \in T, \]  
(10)

\[ f_{pv,t}^{OB} + f_{pv,t-1}^{OB} + q_{pv,t-1}^{OB} = f_{pv,t}^{OB} + \sum_{q \in N \cup \{o(v)\}} f_{qpv,t}^{A}, \forall v \in V, p \in N \cup \{o(v)\}, t \in T, \]  
(11)
The quantity loaded or unloaded \( (q_{pv,t}) \) must not exceed the maximum number of products loaded or unloaded from vessel \( v \) (constraint 9). The flow conservation constraint (10) - (13) ensure a balanced load on board along every arc of the structure. The variables upper bound and non-negative constraints are shown in (14) - (18).

\[
\begin{align*}
    f_{pv,t-1}^{OA} + f_{pv,t-1}^{OB} - q_{pv,t-1} &= f_{pv,t}^{OB} + \sum_{q \in N \cup \{d(v)\}} f_{pqt}^{X} , \quad (12) \\
    \forall v \in V, p \in N D \cup \{o(v)\}, t \in T, \\
    f_{o(v)qvt}^{X} &= l_{o(v)qvt}^{0}, \forall v \in V, q \in N \cup \{d(v)\}, t \in T. \quad (13)
\end{align*}
\]

The inventory level at every port is controlled during every time unit of the planning horizon at the loading and unloading port (constraints 19 and 20). Constraint (21) provides operational ranges that must be at the inventory level, and constraint (22) provide initial inventory at each port. All binary variables are declared in constraints (23) and (24) and constraint (25) gives a continuous variable.

\[
\begin{align*}
    0 \leq f_{pqvt}^{X} \leq K_{q} x_{pqvt}, \forall v \in V, p \in N \cup \{o(v)\}, q \in N \cup \{d(v)\}, t \in T \quad (14) \\
    0 \leq f_{pv,t}^{OA} \leq K_{p} o_{pv,t}^{A}, \forall v \in V, p \in N, t \in T, \quad (15) \\
    0 \leq f_{pv,t}^{OB} \leq K_{p} o_{pv,t}^{B}, \forall v \in V, p \in N, t \in T, \quad (16) \\
    0 \leq q_{pv,t} \leq Q_{v} o_{pv,t}, \forall v \in V, p \in N, t \in T, \quad (17) \\
    0 \leq f_{pvt}^{W} \leq K_{p} w_{pvt}, \forall v \in V, p \in N, t \in T. \quad (18)
\end{align*}
\]

d. Inventory Control Constraints

\[
\begin{align*}
    s_{p,t-1} + \sum_{v \in V} q_{pv,t} &= D_{pt} + s_{pt}, \forall p \in ND, t \in T, \quad (19) \\
    s_{p,t-1} + P_{pt} &= \sum_{v \in V} q_{pv,t} + s_{pt}, \forall p \in NP, t \in T, \quad (20) \\
    SMN_{pt} \leq s_{pt} \leq SMX_{pt}, \forall p \in N, t \in T, \quad (21) \\
    s_{pt} = S_{p}, p \in N, \quad (22) \\
    x_{pqvt} \in \{0,1\}, \forall v \in V, p \in N \cup \{o(v)\}, q \in N \cup \{d(v)\}, t \in T, \quad (23) \\
    o_{pv,t} \in \{0,1\}, \forall v \in V, p \in N, t \in T, \quad (24) \\
    s_{pt}, q_{pv,t} \in \mathbb{R} \forall v \in V, p \in N, t \in T. \quad (25)
\end{align*}
\]

The research methodology in this research uses systematic problem solving, so the problems that occur can be solved appropriately. Systematic problem solving is divided by four-stage such as the first stage named initial identification. At this stage, a field study is carried out, which is to look directly at the existing conditions on the research object in the field. Based on these field conditions and associated with literature studies and various other sources such as books, journals, and previous studies and know the formulation of the problems that occur so that the objectives and benefits of the research conducted. second stage named data collecting and processing, third stage named analysis stage, and the fourth stage named conclusion and suggestion. The second stage to the last stage will be explained later. This following figure is all stage of systematic problem-solving in this research.

4. Research Method

The research methodology in this research uses systematic problem solving, so the problems that occur can be solved appropriately. Systematic problem solving is divided by four-stage such as the first stage named initial identification. At this stage, a field study is carried out, which is to look directly at the existing conditions on the research object in the field. Based on these field conditions and associated with literature studies and various other sources such as books, journals, and previous studies and know the formulation of the problems that occur so that the objectives and benefits of the research conducted. second stage named data collecting and processing, third stage named analysis stage, and the fourth stage named conclusion and suggestion. The second stage to the last stage will be explained later. This following figure is all stage of systematic problem-solving in this research.
Next, the second stage is the data collection and processing stage. At this stage, collecting all the data needed and using the mathematical formulation proposed by Agra[7] and also used by Diz[6]. After that, verify mathematical models using left and right side comparisons to equate units of both left and right sides and also verify mathematical models built-in Python Programming Language version 2.7 with PuLP library. Next, by all the data and source code that built-in Python, solve the
problem using Gurobi 9.0.1 solver with academic license and will produce an output of the optimal total transportation cost and schedule.

The third stage is the analysis stage, which is conducting an analysis of the existing scheduling by scheduling proposals and also analysis of the total existing transportation cost by the total proposed transportation cost that obtained from the output results.

The last stage is the conclusion and suggestion stage. This final stage is concluded from the results of the analysis conducted and provides suggestions for further research.

5. Data Processing and Analysis Result

5.1. Mathematical Model Formulation
The mathematical model used is a mathematical model that has been developed by Agostinho Agra[7] and also has been implemented by Gustavo Souto dos Santos Diz[6] with the assumptions previously described, the difference is in the assumptions used. Because the research conducted has a similar case, so the mathematical model used is also the same as the mathematical model formulated by Agra and implemented by Diz without developing the model.

5.2. Scheduling Result
As for the data after it is complete, then the data is processed using the Python programming language with PuLP library and Gurobi Solver version 9.0 with an academic version license. The results provided from the code that was built in the form of scheduling ships from January to December in 2018.

Table 4. Scheduling Results for January 2018

| Vessel’s Name | From   | To     | Days to- |
|---------------|--------|--------|----------|
| Bellini 7     | Tarjun | Lombok | 8        |
| Sophia        | Tarjun | Samarinda | 5    |
|               | Samarinda | Tarjun | 8        |
|               | Tarjun | Samarinda | 10     |
|               | Samarinda | Tarjun | 13       |
|               | Tarjun | Lombok  | 15       |
|               | Lombok | Tarjun  | 18       |
|               | Tarjun | Samarinda | 21     |
|               | Samarinda | Tarjun | 24       |
|               | Tarjun | Samarinda | 26     |
| Sari Andalas  | Cirebon | Surabaya | 7      |
|               | Surabaya | Tarjun  | 11       |
|               | Tarjun  | Samarinda | 15     |
|               | Samarinda | Tarjun | 19       |
|               | Tarjun  | Lombok  | 22       |
| Meutia Andalas| Tarjun | Lombok  | 6        |
| Tahta         | Tanjung Priok | Pontianak | 6    |
|               | Pontianak | Tanjung Priok | 11 |
|               | Tanjung Priok | Pontianak | 15 |
| Tiro          | Tarjun  | Surabaya | 5      |

This result is the optimal results obtained for January. The total cost of transportation for January is Rp10,174,278.46. This result can save as much as 58% of the total existing transportation costs in January 2018. The output provided by the code built provides total transportation costs from January to December in 2018 which results from each month are added up and will be total transportation costs for 2018.
5.3. Inventory Level Result
The result of scheduling needs to be considered the inventory level of each consumption port, this needs to be considered to ensure that the level of inventory of each port does not exceed or less than its limits or capacity.

![Inventory Level of Samarinda Port in A Year](image)

**Figure 2.** Inventory Level of Samarinda Port in A Year

Based on the picture above, it can be seen that the inventory level (Inv) for Samarinda Port during 2018 using scheduling proposals is never less than the lower limit (BB) or exceeds the upper limit (BA) of the inventory storage capacity at Samarinda Port. Likewise, for the other consumption ports that have never violated that limits

5.4. Waiting / Idle Time Result
In addition to producing scheduling with the optimal total transportation costs for each month, the code that was built also provides results related to waiting time that occurs every month in 2018. The total waiting time that occurs is as follows.

| Table 5. Total Waiting Time with Proposal Scheduling |
|---|---|---|
| No. | Month | Waiting Time (Hours) |
| I  | Mar   | 24            |
| II | May   | 48            |
| III| Jun   | 72            |
| IV | Sep   | 48            |
| V  | Nov   | 48            |
| VI | Dec   | 48            |
| Total Waiting Time | 288 |

The result of the total waiting time by using proposed scheduling is 288 hours. The waiting time that occurs in the months that are not listed in the table indicates that in that month there is no waiting time. In general, this waiting time occurs at the production port where the ship is better to do waiting time in the selected production port compared to other production ports because it allows for a longer time to travel and long distances which can increase sailing costs and thus resulting a total transportation cost will be increased.

5.5. Total Transportation Cost Result
The result of proposal scheduling also contains total transportation costs carried out each month in 2018 which for the total transportation costs each month are summed up and will be the total transportation costs for 2018. The total transportation costs are as follows.
Table 6. Total Transportation with Proposal Scheduling

| No | Month | Transportation Cost  |
|----|-------|---------------------|
| I  | Jan   | Rp 10,174,278,466   |
| II | Feb   | Rp 10,970,001,219   |
| III| Mar   | Rp 12,407,927,742   |
| IV | Apr   | Rp 8,656,906,556    |
| V  | May   | Rp 8,635,742,296    |
| VI | Jun   | Rp 9,042,789,991    |
| VII| Jul   | Rp 14,286,639,970   |
| VIII| Aug | Rp 13,847,001,809  |
| IX | Sep   | Rp 14,533,750,020   |
| X  | Oct   | Rp 16,850,955,124   |
| XI | Nov   | Rp 14,966,809,435   |
| XII| Dec   | Rp 16,451,731,416   |
|    | Total | Rp 150,824,534,044  |

The total transportation cost to deliver cement to all consumption ports owned by the company using the scheduling proposal in 2018 is Rp 150,824,534,044. This can reduce 40% or Rp 101,976,981,652 from the existing transportation costs of Rp 252,801,515,696.

6. Conclusion

Based on research conducted using the Maritime Inventory Routing Problem (MIRP) Method and Mixed-Integer Linear Programming (MILP) approach, it can be concluded that MIRP method with MILP approach can be applied in the case of cement distribution with three production ports and six consumption ports, providing ship scheduling which provides an increase for ships to carry out operations at the Port of Cirebon which allows providing more minimal both sailing time and operational activities. In addition, the proposal scheduling gives a total waiting time reduced by 83% of the existing total waiting time and also the proper scheduling of ships provides lower ship travel costs, fast operating activities, and does not result in ships not being able to lower cargo. Thus, providing a minimum total transportation cost of Rp150,824,534,044 which can reduce total transportation costs by Rp101,976,981,652 or 40% of the total existing transportation costs with the inventory level of all consumption ports never lower than the lower limit or exceeds the upper limit. However, this makes the utilization of some ships low.

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