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DEVELOPMENT OF MODEL AND ALGORITHMS FOR SOLVING MULTI-PRODUCT INVENTORY SHIP ROUTING PROBLEM FOR DEDICATED TANKER FLEET

MUHAMMAD ERZA RAYDIKA

NRP. 2512 100 065

Supervisor

Dr. Eng. Ir. Ahmad Rusdiansyah, M.Eng

External Supervisor

Siti Nurminarsih, S.T., M.T.

Department of Industrial Engineering

Faculty of Industrial Technology

Institut Teknologi Sepuluh Nopember

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MUHAMMAD ERZA RAYDIKA
NRP. 2512 100 065

Dosen Pembimbing
Dr. Eng. Ir. Ahmad Rusdiansyah, M.Eng

Pembimbing Eksternal
Siti Nurminarsih, S.T., M.T.

Jurusan Teknik Industri
Fakultas Teknologi Industri
Institut Teknologi Sepuluh Nopember
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Surabaya

Author:
MUHAMMAD ERZA RAYDIKA
NRP. 2512 100 065

Acknowledged and Approved by,

Final Project Supervisor

Dr. Eng. Ir. Ahmad Rusdiansyah, M.Eng

NIP. 196811091995031003

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DEVELOPMENT OF MODEL AND ALGORITHMS TO SOLVING MULTI-PRODUCT INVENTORY SHIP ROUTING PROBLEM FOR DEDICATED TANKER FLEET

Name : Muhammad Erza Raydika
Student ID : 2512100065
Supervisor : Dr. Eng. Ir. Ahmad Rusdiansyah, M.Eng

ABSTRACT

Many companies use tanker as one of the transportation mode to deliver their products. In order to reach optimum level and high efficiency of product distribution, a comprehensive study regarding distribution is important. In the literature, it is called Inventory Routing Problem (IRP). Based on a real case of oil distribution using tanker fleet in an Indonesian state-owned oil company, this research develops a model and algorithms to solve a Multi-Product Inventory Ship Routing Problem (M-ISRP) for dedicated tanker fleet. The model accommodates some aspects including multi products, multi depots, and flexible tanker initial points. The objective function is to minimize total distribution costs considering some constraints such as inventory, time, loading and unloading. The algorithms built consists of three main modules, which are critical ports selection, ship assignment, and ship routing. A spreadsheet-based decision support tool have been developed to evaluate the proposed algorithms. The results of the numerical experiments showed that the best total tanker number to deliver all the demand on certain case is 9 tankers.

Keywords: Heuristic, Inventory Ship Routing Problem, Model Development, Vehicle Routing Problem, Vendor Managed Inventory.

PENGEMBANGAN MODEL AND ALGORITMA UNTUK MENYELESAIKAN *MULTI-PRODUCT INVENTORY SHIP ROUTING PROBLEM* DENGAN *DEDICATED TANKER FLEET*

Nama	: Muhammad Erza Raydika
NRP	: 2512100065
Dosen Pembimbing	: Dr. Eng. Ir. Ahmad Rusdiansyah, M.Eng

ABSTRAK

Kapal tanker banyak digunakan oleh banyak perusahaan sebagai salah satu moda transporasi untuk mengirimkan produknya. Untuk mencapai efisiensi yang tinggi dalam distribusi produk, diperlukan sebuah studi yang komprehensif tentang distribusi produk, dan salah satunya adalah *Inventory Routing Problem*. Melihat permasalah yang ada, penelitian ini bertujuan untuk membuat model dan algoritma untuk *multi-product inventory routing problem* dengan *dedicated tanker fleet.* Model yang dibuat mampu mengakomodasi *multi product, multi depot, dedicated tanker policy*, dan titik awal kapal yang fleksibel. Beberapa *constraints* dalam penelitian ini antara lain *routing*, inventori, waktu, *loading* dan *unloading* dengan *objective function* minimasi total biaya. Algoritma yang dikembangkan terdiri dari tiga bagian penting yaitu mengitung dan menyortir pelabuhan kritis, pemilihan kapal, dan proses *routing.* Kemudian, model yang algoritma tadi deprogram dengan menggunakan VBA di Microsoft Excel 2013 yang akan menghasilkan detail rute dari tiap kapal, waktu rute, dan biaya yang dikeluarkan. Hasil dari penelitian ini adalah program yang digunakan mampu menyelesaikan *multi-product inventory ship routing problem.* Dari beberapa eksperimen numerik didapat hasil jumlah kapal tanker terbaik untuk skema simulasi tertentu adalah 9 kapal tanker.

Keywords: Heuristic, Inventory Ship Routing Problem, Pengembangan Model, Vehicle Routing Problem, Vendor Managed Inventory.

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CHAPTER I
INTRODUCTION

This chapter discusses introduction of this research, which consists of background, problem formulation, objectives, benefits, scope, limitations, and report outline.

1.1 Background

Maritime transportation is the backbone of global trading. More than 80% of global product distribution are using ship (United Nations Conference on Trade and Development, 2015). Therefore, it has several advantages compared to land and air distribution. Compared to air transportation, maritime transportation is more efficient in terms of cost and quantity. The maritime transportation also can cover sea and have inter-island connection which are cannot be done by maritime transportation. Indonesia, which have 3.544.743,9 km^2 (Kementrian Sekretariat Negara Republik Indonesia, 2010) sea area is responsible to make its maritime as an advantages. Based on the operation type, maritime transportation consists of tramp shipping, industrial shipping, and liner shipping (Lawrence, 1972). Tramp shipping is ship distribution that similar to how taxi works, do not have specified schedule to distribute goods. Industrial shipping ship distribution that run by a company. Liner shipping is ship distribution that has specified schedule, it must sail whether there is a cargo or not.

Product distribution holds important role in running a business. Distribution cost contributes around 30% to the product price, so that if the company can minimize distribution cost as much as possible, it will become a competitive advantage for the company. Especially for ship distribution that have many uncertainty factors that impact to the cost, an effort to make the ship operational more efficient to minimize distribution cost can significantly give an impact to the company.

Vehicle Routing Problem (VRP) designs the most efficient route for vehicles. Basically, the objective function is to minimize total operational cost and the number of vehicles or in other term distribution cost (Pillac, et al., 2011). Therefore, it is known that decision on the distribution route has significant impact to the logistic total cost of a product. In many distribution cases, supplier and customer are both the main players of product distribution. In order to minimize the cost, all players in the distribution should work together and share some information regarding the distribution. Nevertheless, it is hard to apply some kinds of system like that. Therefore, in order to reduce the cost and integrate all players in the distribution, experts develop Vendor Managed Inventory (VMI) concept in purchasing approach. In this concept, a supplier maintains an inventory of certain products in the customer's facility (Arnold & Chapman, 2008). Basically, the customer does not have to order any of the inventory, as the supplier is responsible for maintaining an adequate supply in the inventory of customer.

There are a lot of type of vehicles for distribute the products, and one after another have special characteristic on their own. For ship distribution, several factors that become consideration are ship type, capacity, speed, voyage time, port dwelling time, weather condition, and other uncertainty in ship operation (Romero, et al., 2013). Therefore, there are many of those factors are uncertainty and become one of cause in imprecision of ship distribution planning. One of the problems in ship distribution is Inventory Ship Routing Problem (ISRP). ISRP emerges from Vendor Managed Inventory (VMI) policy that inventory of a customer is in responsibility of the vendor. Furthermore, in ISRP the decision of vehicle routing and inventory control done simultaneously in order to maintain customer inventory level as well as ensure that there is no stock out occur at the customer.

Preceding research about multi product inventory ship routing problem (m-ISRP) had been conducted by Hwang (2005), Cristiansen and Nygreen (2005) that develop model considering vendor managed inventory for ship distribution. Then, Al Khayyal and Hwang (2007) continue by elaborate ISRP research for distribution of liquid chemical material from the supply port to demand port. This research have dedicated compartments policy. It means that one ship can carry more than one type of liquid chemical material with specified placement. The model had to decide how much liquid chemical material that is supposed to be carried by one ship and also determine the destination of the ship. Therefore, the objective function is to minimize transportation cost by still maintaining inventory in every demand port.

From multi product ISRP problem, rise some issue on how is the product placement on the ship. Even if one ship can carry several types of material, thus some materials also have hazardous properties or may contaminate other products. Therefore, this constraint makes some products cannot place side by side on several occasions. Rani (2010) discuss ISRP problem considering product compatibility constraint on undedicated compartments. This research also considering multi-depot for deciding route of the ship. Siswanto et.al. (2011) conduct research about multi-product ISRP considering product compatibility constraint by using heuristic method. Heuristic has faster computational time compared to the exact method, but it needs to develop its own algorithm based on the specify problem. From several research study, there are a difference about 1,96% in the result between using exact method and heuristic method. Nurminarsih (2012) also conducts research similar to Rani (2010) and Siswanto et.al (2011) but using meta-heuristic tabu search algorithm as the method. Even if Siswanto et.al (2011) research only considering single depot in defining the ship routing, but the algorithm developed to accommodate the ship can be started from any points, whether supply or demand points. This constraint makes it even more flexible as in the real case, the ship availability is not always from one place only. However, there is still small number of research about ISRP by using dedicated ship schemes. Thus dedicated ship may inflict larger cost but more efficient in technical aspect and increase the ship reliability.

NP-Hard problem includes multi product and multi depot ISRP. Therefore, for bigger data case, finding the solution by using exact method need long computation time. As well as the real case problem with oil and gas company the complexity of the problem increases. Thus, this research about development of model and algorithms for solving multi-product inventory ship routing problem for dedicated tanker fleet has several limitations and assumptions to accommodate the problem complexity. Researcher select heuristic method because it has lessen process compared to the exact method by using some algorithm for specified problems.

In this research, the model carried out to solve multi-product inventory routing problem for dedicated tanker fleet. The method used is heuristic by elaborating algorithms to gain the result. Based on those model and algorithm, then develop a scheduling program using VBA on Microsoft Excel.

1.2 Problem Formulation

This research problem formulation is to create decision supporting tools by develop model and algorithm of multi product inventory ship routing problem for dedicated tanker fleet. The model defines routing and scheduling of the ships, quantity, and product allocation on every ship by minimizing total cost.

1.3 Objectives

The objectives of this research are:

1. Develop a model of multi product inventory ship routing problem for dedicated tanker fleet.
2. Build heuristic algorithm for multi product inventory ship routing problem model for dedicated tanker fleet.
3. Evaluate scenarios based on the model and algorithm by doing numerical experiments.

1.4 Benefits

The benefits of this research are:

1. As a benchmark model in multi-product inventory ship routing problem for dedicated tanker fleet.
2. Fill a research gap in multi-product inventory ship routing problem for dedicated tanker fleet.
3. Become a reference for the next research in multi-product inventory ship routing problem for dedicated tanker fleet.

1.5 Limitations

The limitations of this research are:

1. Model does not consider natural occurrence or natural disasters such as wind directions, ocean depths, evaporation, etc.
2. Model do not consider loading and unloading operations regulation about the weight of ship visited the port.
3. Data is used in numerical experiments is dummy data.

1.6 Assumptions

The assumptions of this research are:

1. Voyage speed for every ship are constant (10 Knot).
2. Product placement in every ship is already decided or dedicated ship.
3. When handling an unloading process at some ports, that process will be done until all products that should be unloaded are finished even if the port has already passed their time windows.

1.7 Report Structure

A brief description of the content of this report is as follows.

CHAPTER I: INTRODUCTION

This chapter consists of the fundamental aspects that become the basis of the research, which explains background of the research, research's problem, objectives, benefits, limitation, and writing structure of the research.

CHAPTER II: LITERATURE REVIEW

This chapter is the beginning phase of doing the research. This chapter reviews many literatures to find the best method that is the most fit to solve the problems in this research. The literature reviews are coming from various resources, such as books, proceedings, internet or online resources, etc.

CHAPTER III: RESEARCH METHODOLOGY

This chapter consists of structural phases that become a guidance in conducting the research so that the research can be completed systematically. The phase in doing the research is visualized in a flowchart.

CHAPTER IV: MODEL AND ALGORITHM DEVELOPMENT

This chapter covers all explanation of developing the model and algorithm. Details of problem identification explained in this chapter. The development consist of model notation and development, algorithm development, and model verification.

CHAPTER V: NUMERICAL EXPERIMENTS

This chapter consists of numerical experiments from the model and algorithm development. The experiments consist of several scenarios and analysis of result.

CHAPTER VI: CONCLUSION AND RECOMMENDATION

This chapter explains the result from the research based on the objectives. In addition, the suggestions and recommendations are given to implement the result of the research. It also provides recommendations for further researches.

CHAPTER II
LITERATURE REVIEW

This chapter describes the fundamental theories and literature review that supports the research. The main topic of literature discussed are maritime transportation, inventory management and Vendor Managed Inventory (VMI), Vehicle Routing Problem (VRP), Multi-Product Inventory Ship Routing Problem (M-ISRP), heuristic method, and preceding research.

2.1 Maritime Transportation

Approximately 90% of the volume and 70% of the value of all goods transported worldwide is carried by sea (Al-Khayyal & Hwang, 2005). Thus, maritime transportation is the most efficient transportation modes right now. Compare with the air transportation, maritime transportation is more efficient in terms of cost and quantity. As well as compare with land transportation, maritime transportation has its own characteristic to reach another island that land transportation cannot reach. Therefore, maritime transportation is the backbone of global trade. UNCTAD (2010) support that fact by state that more than 80% of global trading were being shipped by sea.

Based on the operation type, maritime transportation is divided into three, which are tramp shipping, industrial shipping, and liner shipping (Lawrence, 1972). Tramp shipping is kind of taxi, have specific routing for specific purposes. Industrial shipping is ship voyage for industrial uses, such as distribute product or deliver raw material. Liner shipping is works carrying cargoes with fixed routes. Several companies are owners of those cargoes. Therefore, industrial shipping becomes the focus of this research because the ship routing is only used for industrial purpose and fully directed by the company.

2.2 Inventory Management and Vendor Managed Inventory (VMI)

Inventories are materials and supplies that a business carries either for sale or to provide input or supplies to the production process. Often they are a substantial part of total assets. On the balance sheet, inventories usually represent about 20% to 60% of total assets (Arnold & Chapman, 2008). As inventories are used, their value is converted into cash, which improves cash flow and return on investment. Therefore, there is a cost for carrying inventory, which increases operating costs and declines profits. So a good inventory management is essential.

The uncertainty in demand of a product is a cause of inventory occurrence. Not only to keep the continuity of the production process, inventory also used as buffer for next demand consumption. This is because there is a time gap or lead time between product order and product receipt. Therefore, lead time itself becomes one of uncertainty factors in inventory management. Besides, inventory buffer function also used to accommodate uncertain demand of a product. Even if the planning of demand already uses forecast in order to anticipate the upcoming uncertain demand, there is still a gap between forecast demand and the real condition.

In order to reduce the cost caused by lead time and uncertain demand, company must perform their inventory management well. Inventory management is responsible for planning and controlling inventory. Several decisions in inventory management are deciding optimal order quantity and the right replenishment time so that all demands are satisfied and still reduce the total cost.

There are several methods to determine the right optimal order quantity and replenishment time. The usage of every method is based on the product demand characteristic and the supplier's policy. Practically, one of the methods is by knowing the days of supply. Days of supply is the total day where the inventory can cover demand. To determine the days of supply the formula is to divide the amount of inventory with the daily demand rate. Usually the daily demand rate is based on the historical demand. Therefore, from the days of supply calculation, company can decide the right time to replenish the stock.

Theoretically, there are several methods to decide the optimal order quantity for replenishment. There are fixed order quantity and periodic review. In fixed order quantity, every replenishment will have the same amount of goods that added to the inventory. This method not considering the remaining level of inventory. In contrast, periodic review decides the amount of replenishment in some time interval by looking at difference of target stock level with the remaining stock level (Waters, 2003). Target stock level is result of multiplying demand for certain periods with the lead time and add by safety stock of the product. Mathematically, target stock level formula is as follows:

$$Target\ Stock\ Level = mean\ demand\ over\ (T + LT) + safety\ stock$$

Then, the formula of safety stock of products is as follows:

$$Safety\ Stock = Z \times standard\ deviation\ of\ demand\ over\ T + LT$$
$$Safety\ Stock = Z \times \sigma \times \sqrt{T + LT}$$

Where:

Z : demand

σ : standard deviation

LT : lead time

In some cases, the replenishment decision also considering the capacity of the inventory. Thus, the capacity becomes the boundary as well as the amount of product that can be carried by the vehicles. Usually the decision of doing replenishment is done by the consumer or the company that have demand. Since, producers cannot control the demand occur because there is no information disclosures from consumers. Considering the complexity of the problem, openness of information to producers will make all parties can integrate and have a better planning to distribute the product. By this means, new concept and polity is developed and called Vendor Managed Inventory (VMI).

Vendor Managed Inventory (VMI) concept has been growth in product purchasing approach. In this concept, a supplier maintains an inventory of certain products in the customer’s facility (Arnold & Chapman, 2008). The supplier managed the inventory until the customer actually withdraws it for use. Basically, the customer does not have to order any of the inventory, as the supplier is responsible for maintaining an adequate supply in the inventory of customer. Therefore, by using this concept

Supplier can reduce production and distribution cost because the supplier know which product that has to be produced and the delivery also done better. Customer is also gaining advantages by reducing their resource tom managed their own inventory.

2.3 Vehicle Routing Problem (VRP)

Dantzig and Ramser (1959) introduce the Vehicle Routing Problem (VRP) formulation as a generalization of the Traveling Salesman Problem (TSP). VRP consider several factors such as distance, travel times, travel cost, depot point, and customer point. Therefore, VRP consists in finding a set of routes for identical vehicles located at the depot, such that each of the customer point is visited exactly once, while minimizing the overall routing cost.

Among the most common are the Capacitated VRP (CVRP), where the vehicles have a capacity; VRP with Time Windows (VRPTW), where each customer must be visited during a specific time frame; VRP with Pick-up and Delivery (VRPDP), where goods gave to be picked-up and delivered in specific amounts at the customer point; and Heterogeneous fleet VRP (HVRP), where vehicles have different capacities. Routing problems that involve moving people between locations are referred to as Dial-A-Ride-Problem (DARP) for land transport; or Dial-A-Flight-Problem (DAFP) for air transport (Pillac, et al., 2011).

Therefore, VRP application may varies not only on several transportation modes, but also vary on the application concepts. Inventory Routing Problem (IRP) is an elaboration between VRP and VMI. Thus, IRP as the advanced application of VMI make the supplier as a handler of customer inventory also take a full responsibility of distribution of product. Although supplier side costs will increase, but the total cost of distribution and inventory from supplier and customer will reduce. This concept has advantage to reduce the total cost of inventory and distribution cost, speed up the product flow in the inventory, and reduce the works of customer because the customer do not have to make an order to retrieve products.

But the drawback is the workload of supplier as main player of VMI and IRP is increasing.

Continuation of IRP application of ship transportation is the Inventory Ship Routing Problem (ISRP). This concept performs route and schedule calculation for distribution using ship as the transportation modes and also consider the level of inventory in every demand point. So the routing destination point determination has to look at the inventory level and consumption rate at each point. Therefore, days of supply become the parameter of deciding the ship route. This research discusses thoroughly about IRP concept, especially in Inventory Ship Routing Problem (ISRP). The model considers capacity, time windows, and delivery pickup constraint.

2.4 Multi-Product Inventory Ship Routing Problem (M-ISRP)

Multi-Product Inventory Ship Routing Problem (M-ISRP) is a continuous development of ISRP. ISRP is basically a joint concept of the Vehicle Routing Problem (VRP) for ship and Vendor Managed Inventory (VMI) for the ship vehicle. ISRP performs ship routing determination by selecting which destination point that should be prioritize first based on their inventory levels.

Single product-ISRP (s-ISRP) that already carried out by Christiansen and Nygreen (2005). In this research explain thoroughly about a product discharge from one port to another by using column generation. Then s-ISRP continuous to develop into multi-product problem which is m-ISRP. Christiansen et. al (2007) conduct research about m-ISRP where a ship have a single loading and unloading port. In this research production and consumption rate can be variate along the planning horizon but still balanced. Time windows constraint also added in the model that make ship cannot come late to a port. There is also penalty cost for late deliveries. This is because production process can be stopped anytime if the ship comes late. The objective function in this research is to minimize the transportation and penalty cost.

Nurminarsih (2012) research about multi product inventory ship routing problem based on Al Khayyal and Hwang (2007). But there are several factors added in the model like multi depot constraint. Model form Nurminarsih (2012) is as follows:

Minimize

$$\sum_v \sum_r \sum_i C_{pc}.z_{ivr} + \sum_v \sum_r \sum_i C_{mf}.z_{ivr} + C_{lb}.\left[\sum_i \sum_j t_{ijv}.x_{ijvr}\right] +$$
$$c_{discharge}.\left[\sum_i \sum_v \sum_r \sum_c \sum_k \frac{q_{ivrck}}{PR_v}\right] + \sum_v \frac{C_{rent}}{\sum_r \sum_c \sum_k q_{0vrck}} + C_{late} \sum_v \sum_m Lt_{m_v} \qquad (1)$$

Subject to

$$\sum_v \sum_{trip} y_{ivkr} = 1 \quad ; y_{ivkr} = \{0,1\} \qquad (2)$$
$$z_{ivr}.M \geq \sum_{k \in K} y_{ikvr} \quad ; z_{ivr} = \{0,1\} \qquad (3)$$
$$\sum_{j \in H_T} x_{jivr} - \sum_{j \in H_T} x_{jivr} = 0 \quad ; \ x_{jivr} = \{0,1\} \qquad (4)$$
$$\sum_{v \in V} \sum_{r \in H_{TV}} \sum_{j \in H_T} x_{jivr} = y_{ikvr} \qquad (5)$$
$$\sum_{v \in V} \sum_{r \in H_{TV}} \sum_{j \in H_T} x_{0jvr} \leq V.H_{TV} \qquad (6)$$
$$\sum_{c \in C_v} q_{0vrck} = \sum_{i \in H_T} \sum_{k \in K} [y_{ikvr}.d_{ik}] \,; c \ \in C_v \qquad (7)$$
$$q_{0vrck} - l_{0vrck} = 0 \qquad (8)$$
$$x_{ijvr}\left[l_{ivrck} - J_{jk}.q_{jvrk} - l_{jvrck}\right] = 0 \qquad (9)$$
$$i_{0vrck} \leq CAP_{vrc} \qquad (10)$$
$$i_{0vrck} \leq CAP_{vrc}.\sum_j x_{jivr} \qquad (11)$$
$$q_{0vrck} \leq CAP_{vrc} \qquad (12)$$
$$q_{ivrck} \leq CAP_{vrc.} \sum_j x_{jivr} \qquad (13)$$
$$\sum_{k \in K} ay_{ivrck} \leq 1 \quad ; \ ay_{ivrck} = \begin{cases} 1, l_{ivrck} > 0 \\ 1, l_{ivrck} = 0 \end{cases} \qquad (14)$$
$$\sum_{c \in C_v} ay_{ivrck} \leq |C_v|.(1 - ay_{ivrds}) \quad ; k \in K, s \in K_k, d \in C_v \qquad (15)$$
$$\sum_{c \in C_{vk}} ay_{ivrck} \leq |C_v|.(1 - ay_{ivrds}) \quad ; k \in K, s \in K_k, d \in C_v, C_{vk} \in \ C_v \qquad (16)$$
$$t_{mp} + \sum_{v \in V} \sum_{r \in H_{TV}} \sum_{c \in V_c} \sum_{k \in K_{vr}} q_{m_p vrck}/PR_v - t_{Emp} = 0 \ ; \ m_p \in H_{vr}k \qquad (17)$$
$$x_{m_p n_{p+1} vr}[t_{Emp} + T_{m_p n_{p+1} v} - t_{n_{p+1}}] \leq 0 \qquad (18)$$
$$a \leq t_{m_p} \leq b \qquad (19)$$
$$t_{m_p} \leq cov_{m_p k} + Lt_{m_v} \qquad (20)$$
$$lnd_{tm_p} = \begin{cases} 1, t - t_{m_v} < 1 \\ 0, t - t_{m_p} \geq 1 \end{cases} \qquad (21)$$

$$S_{m_p k1} = IS_{m_p k} - R_{m_p k} + [lnd_{tm} \cdot q_{m_p vrck}] \quad (22)$$

$$S_{m_p kt} = IS_{m_p kt-1} - R_{m_p k} + [lnd_{tm} \cdot q_{m_p vrck}] \quad (23)$$

$$S_{MNm_p k} \leq S_{m_p kt} \leq S_{MXm_p k} \quad (24)$$

The objective function of this problem is minimized total cost which consists port charge, management fee, bunker cost for ladent and ballast, bunker cost for discharge, renting cost, and lateness cost. While the constraints are about un-split delivery constraint (2), node visited indicator (3), flow conservation constraint (4), supply visiting constraint (5), maximum route constraint (6), depot loading constraint (7), initial ship loads constraint (8), ship load constraint (9), compartment capacity constraint (10-11), load/unload quantity constraint (12-13), homogenous product loading constraint (14), product loading compatibility constraint (15-16), service time constraint (17), route & schedule compatibility constraint (18), time windows constraint (19), coverage constraint (20), product arrival indicator(21), initial inventory level constraint (22), inventory level constraint (23), stock level bound(24).

One of NP-Hard Problem category is Multi-Product Inventory Ship Routing Problem (M-ISRP), so the complexity of the problem and model cause the solution computation needs a long time. By that means, this type of problem solve using heuristic methods.

2.5 Heuristic Method

There are several methods to carry out optimization problem. Therefore, each method have its own advantages and drawbacks since, it is depends on the scope and level of the problem. Those methods are exact optimization, heuristic, meta-heuristic, and simulation. This sub research discusses heuristic because researcher uses heuristic method to conduct the model and algorithm in this research.

Heuristic is approach to problem solving that employs practical method. Where finding an optimal solution is impossible or impractical, heuristic method can be used to speed up the process of finding satisfactory solution. However, the solution given is no optimal or perfect, but sufficient for the immediate goals. The most fundamental heuristic is trial and error. Therefore, heuristic works by make an assumptions and take a shortcut but still result the output that satisfy the objective function.

As opposed to exact optimization methods, which guarantee to give an optimum solution of the problem, heuristic methods only attempt to yield a good, but not necessarily optimal solution. Nevertheless, the time taken by an exact method to find an optimum solution to a difficult problem is taking so long that many cases it is inapplicable. Thus, heuristic methods often resort to solve real optimization problems (Marti & Reinelt, 2011).

2.6 Preceding Research

Vehicle Routing Problem (VRP) first introduced by Dantzig and Ramser (1959). Next, the research is developed into various problems, including capacity, time windows, delivery-pickups, backhauls, etc. Another variation of VRP is the Inventory Routing Problem (IRP). Therefore, other transportation modes like air and sea transportations include in the VRP also. There are a lot of researches regarding sea transportation and Sea Routing Problem (SRP) topics. SRP has unique characteristics and parameters. Those unique characteristics are port dwelling time, weather condition, and other uncertainty in ship operation (Romero, et al., 2013).

Concept of VRP and VMI then elaborate into Inventory ship routing problem (ISRP). Therefore, ISRP categorized into single and multi-product ISRP. Christiansen and Nygreen (2005) conduct research in single product ISRP using column generalization. Al-Khayyal and Hwang (2007) follows with the research of multi-product ISRP using mixed integer linear problem (MILP) optimization and linearization. Regarding the type of loads, ISRP can be divided in bulk and cargo loads. Research about bulk ISRP has done by Rahman (2008), Rani (2010), and Siswanto, et.al. (2011). Rahman (2008)'s research discuss dedicated compartment policy by only using single depot. Therefore, Rani (2010) and Siswanto, et.al. (2011) using undedicated compartment policy in their researches. The difference is Rani (2010) considering multi-depot constraint and focus on product compatibility constraint but Siswanto, et.al (2011) is not. Still, Siswanto, et. al. (2011)'s research is considering the last condition of ships after the routing is done, so the initial point of the routing can be everywhere. Therefore, there are a little of research discuss about dedicated ship policy. Thus, several cases using dedicated ship policy in their practical. So this reseach mainly discuss about multi product inventory ship routing problem for dedicated ship.

The method to approach ISRP is various, some researcher use MILP optimization and some use heuristic and meta-heuristic method. Thus, all of the methods has their own advantages and drawbacks. It is also depends on how the model and algorithm being conducted as well as the scope of the problem. From all of those methods, researcher often use heuristic method due to the short computational time, and makes an optimal output even if the output is not necessarily optimum solution. Therefore, mixed –integer non-linear program (MINLP) method is used for this research. The detail comparison and positioning of this research can be seen in Table 2.1

Table 2.1 Detail Explanation about Research Positioning

No	**Literatu-re**	**Pro-duct**		**Depot**		**Characteristic**	**Objective**	**Solution Techni-que**
		S	**M**	**S**	**M**			
1	(Al-Khayyal & Hwang, 2005)		√	√			minimize total cost	MILP optimization and linearization
2	(Chrisiansen & Nygreen, 2005)	√		√			minimize total cost	Column generalization
3	(Hwang, 2005)		√	√				Lagrangian relaxation, heuristic
4	(Christiansen et.al., 2007)	√		√			minimize total cost	
5	(Siswanto, et al., 2011)		√	√		undedicated compartments, initial point can be everywhere	minimize transportation cost, penalty, and setup cost	multi heuristic

No	Literature	Product		Depot		Characteristic	Objective	Solution Technique
		S	M	S	M			
6	(Rani, et al., 2010)		√		√	undedicated compartments, product loading compatibility constraint	minimize total cost	MILP optimization, branch and bound, lingo
7	(Rahman, Fuadie, 2008)		√	√			minimize port charge, fee management, bunker consumption, ship intrinsic cost	Heuristic
9	(Nurminarsih, Siti, 2012)		√	√		undedicated compartments, product loading compatibility constraint	minimize port charge, fee management, bunker consumption, ship intrinsic cost, lateness cost	Tabu search algorithm
10	(Nurminarsih, et al., 2015)		√		√	dynamic, considering port dwelling time,	minimize operational cost, port charge, loading/unloading cost	Mixed-integer non-linear program (MINLP)
11	This research		√		√	initial point can be everywhere, dedicated tanker	minimize total cost	Heuristic

In this research, the type of loads is bulk load and neglecting the product compatibility constraint. The objective function is to minimize the total cost which is including port charge, management fee, bunker cost for laden and ballast, bunker cost for discharge, and lateness cost. The research uses heuristic method to conduct the model. The connection between this research with preceding research can be seen in Figure 2.1 below.

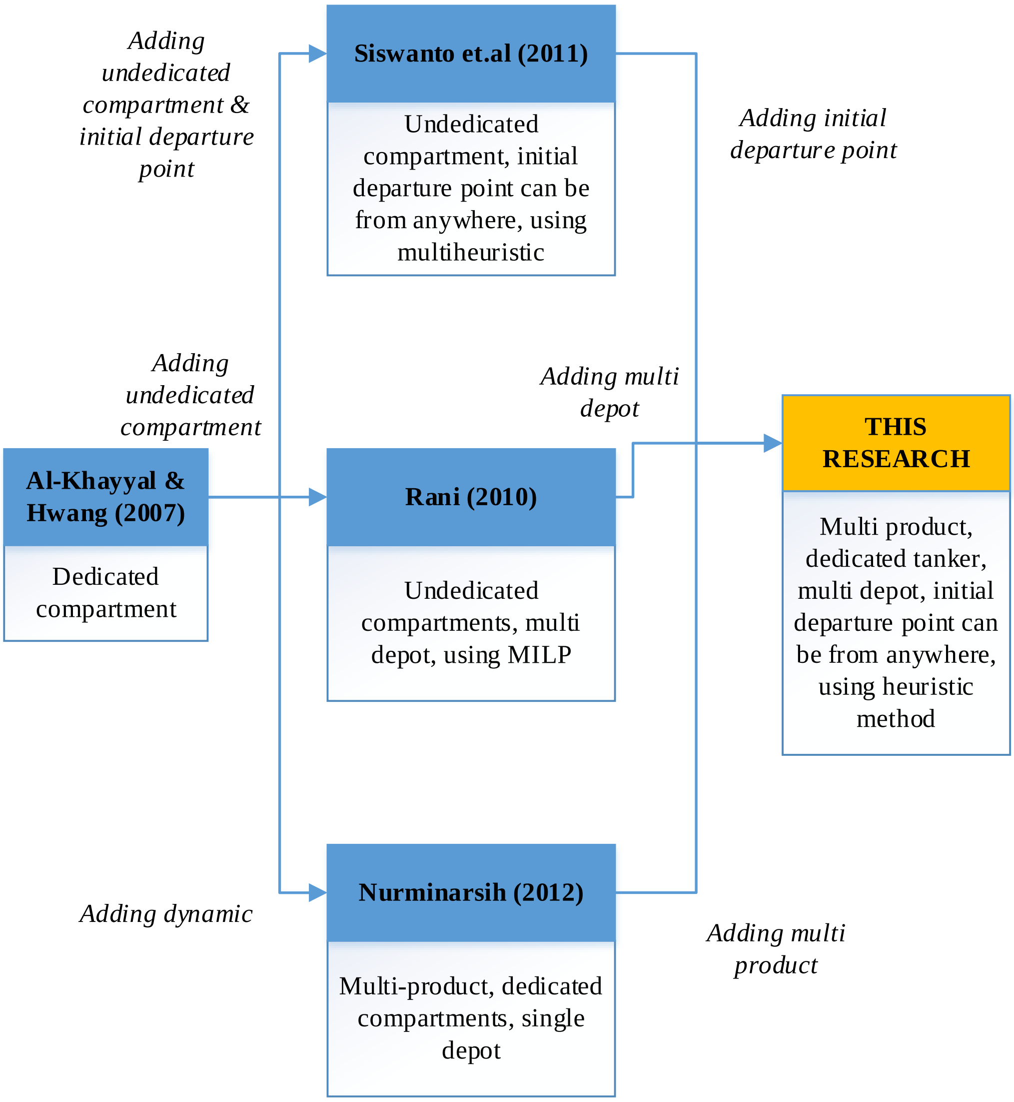

Figure 2.1 Connection with Preceding Research

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CHAPTER III
RESEARCH METHODOLOGY

This chapter explains the methodologies to develop the research. The methodologies will become the guidance for the researcher to address the model in a systematic manner. Research methodology flowchart will represent the methodologies.

3.1 Model and Algorithm Development Phase

In this sub phase, researcher develops the model and algorithm based on the problem formulation. Then a verification done to the developed model and algorithm. Outline of the research methodology can be seen from Figure 3.1 and Figure 3.2 below.

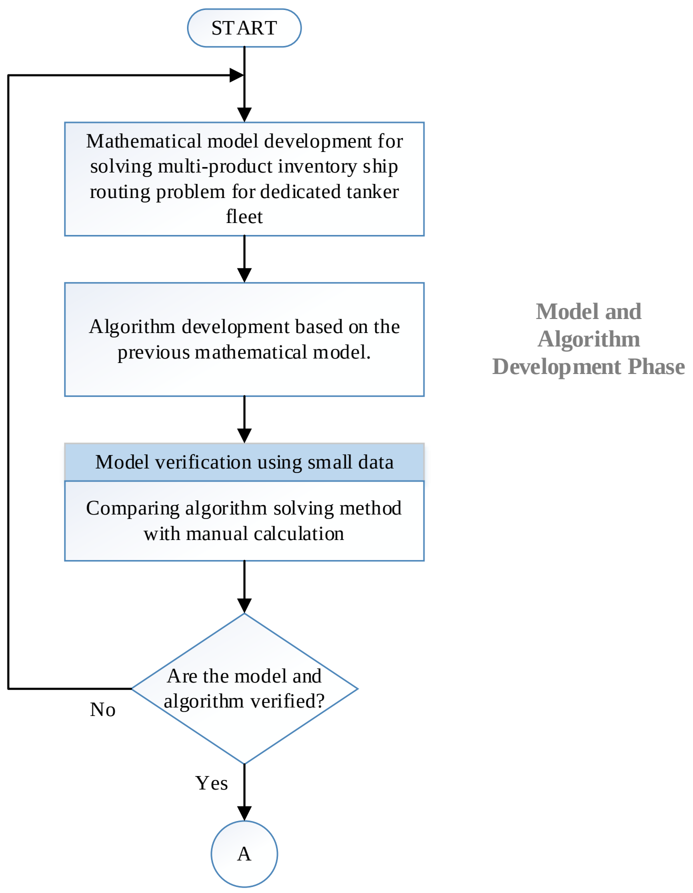

Figure 3.1 Research Methodology Flowchart (1)

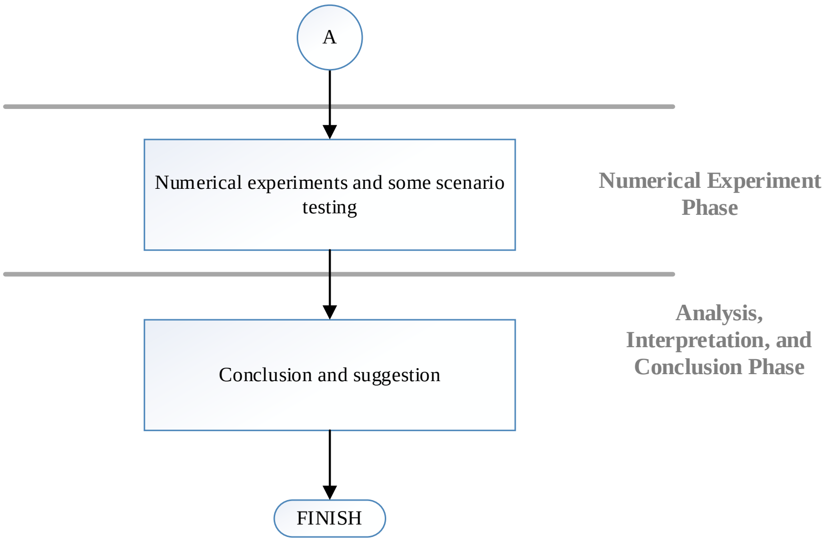

Figure 3.2 Research Methodolgy Flowchart (2)

3.1.1 Mathematical Model Development

In this sub-phase, researcher develops the mathematical model of tanker scheduling from multi product inventory ship routing problem for dedicated tanker fleet. This mathematical model needed to ensure that by doing mathematical calculation, the scheduling meets all constraints, can result tanker routes, and resulting scheduling that has minimum cost.

Therefore, several constraints for the mathematical model includes routing constraints, loading/unloading constraints, time constraints, and inventory constraints.Objective function of this model is to minimize total cost which is consists of tanker bunker cost for laden/ballast and discharge, lateness cost, port charge, and management fee.

3.1.2 Algorithm Development

After model development, the next step is to develop the algorithm. The algorithm divided into 3 big steps which are critical port decision, tanker assignment, and tanker routing process.

Critical port decision phase is to calculate the critical points from every demand ports to decide which port will be supplied first. After knowing the list of critical port by determining their inventory days of supply, then the next is to decide tanker's route from the list. Therefore the improvement determines to search better combination between the routing to result a better cost. Next, determine the decision on which tanker to choose for each route by considering which critical ports should be prioritize first.

After the optimization algorithm is done, then researcher develops the prototype of a decision making tool using visual basic application (VBA) for Microsoft Excel. This decision making tool is adjusted from the developed model and algorithm.

3.1.3 Model and Algorithm Verification

Verification of model and algorithm done by running the program using small data samples. Then researcher compare the output of this program with the result of manual calculation using the same algorithm. If there is any difference comparing results, then checking and repairing of program coding will be done.

Then, verification done in order to see if the program is able to solve the problem with specified constraints. If the result is already solved the problem and constraint, then define the model and algorithm as valid and proceed to numerical experiments.

3.2 Numerical Experiments Phase

Numerical experiments use dummy data to test the model and algorithm. Therefore, research needs to do numerical experiments and consider several scenarios with its own purposes regarding tanker scheduling for dedicated tanker fleet. Numerical experiments perform several experiments and try to solve several scenarios with different datasets. Thus, dataset for numerical experiments consist of dummy data and real data. Some of experiments are to find the best scheme regarding the number of tanker available, experiments with demand rate, and compare dedicated tanker policy with dedicated compartment policy.

3.3 Analysis, Interpretation and Conclusion Phase

In this phase, researcher discusses analysis and interpretation of numerical experiments. Then determine the conclusion and suggestion for the research.

3.3.1 Analysis and Interpretation Numerical Experiments Result on Several Experiments

In this phase, researcher performs an analysis from the result of numerical experiments. The analysis also comply the constraint from model and algorithm to know the effect to the result from several different scenarios.

3.3.2 Conclusion and Suggestion

After the analysis and numerical experiments result interpretation, then determine the conclusion from the result of the numerical experiments. Next, suggestion also given as recommendation for the next future research.

CHAPTER IV
MODEL AND ALGORITHM DEVELOPMENT

This chapter consists of detail problem description, model development, algorithm development, system prototype development, verification of the model.

4.1 Problem Description

This research develops model and algorithm for multi-product inventory ship routing problem for dedicated tanker fleet. The delivery involves multiple bulk liquid products which cannot be mixed. From the problem formulation, there are no exact demand for a certain period, but the information available are stock level and daily demand rate in each port. Therefore, the decision of inventory replenishment in every port is made by the company itself, considering there is a minimum and maximum amount of the inventory in each port.

In order to fulfill all the demand and dismissed stock out, supplier have to make a good planning for schedule the replenishment. However, not all the ports have the same quantity of products demanded and the type of product also different. All ports also have specific operational time and the tanker visited the port can only be served at the operational time.

Product loaded into the tanker must obey the capacity constrain of the tanker as well as the minimum quantity of product in the tanker to be departed. Therefore, the placement of the product is already decided or dedicated compartment. Also, the type of the tanker used can be varied and each type of tankers has different capacity and different arrangement of product placement in the compartment. However, the initial point of tanker departure is not exactly the same. This constraint follows the real case problem since tanker movement must be as minimum as possible, therefore the initial point of tanker departure can be anywhere. It is assumed that each port can receive more than one tanker for a different product at a time.

The daily demand rate is various for each product in each port. Therefore, daily demand rate is sued to determine the demand quantity for the port and the critical level of the port. Parameter used to determine the critical level of the port is days of supply. Days of supply is the number of days that the inventory can cover. The inventory in each port also has safety stock at certain levels. Therefore, this safety stock affects the calculation of days of supply. The formula of safety stock and days of supply is as follows:

$$Safety\ Stock = (Depot{\sim}Port\ Travel\ Time + Tanker\ Travel\ Time) \times Daily\ Demand\ Rate$$

$$Days\ of\ Supply = \frac{(Inventory\ Level - Safety\ Stock)}{Daily\ Demand\ Rate}$$

The quantity of product delivered in the port is depends on the quantity and remaining stock level because the replenishment is assumed to cover the demand as long as possible. Therefore the formula of product's quantity delivered is:

$$Product's\ Quantity\ Delivered = Capacity - Stock\ Level$$

This problem considering certain period of operational planning. Researcher assumes the number of the tankers available in the beginning of the planning. Therefore, the fixed cost of the tanker such as leasing or investment cost is ignored. The inventory cost is also ignored because products, both in the production and consumption storages are owned by the same company. However, the condition of inventory affect the routing decision that also have an impact to the operational cost.

This research model and algorithm only considering the operational cost and penalty for late deliveries. Therefore, the operational cost including port charge, management fee, bunker cost for traveling (laden/ballast), bunker cost for servicing (discharge), and lateness cost. The objective function is to minimize all the total cost.

4.2 Model Development

M-ISRP model in this research is done by heuristic method to minimize the objective function. The model consist of many constraints that represent the rules and objection of the real problem. Therefore, the model will be explained in this sub-chapter.

4.2.1 Mathematical Model References

In conducting mathematical model for this research, there are several references. Thus, in this research the mathematical model is the development of several previous mathematical model for identical research. There are three mathematical model taken as reference which are from Rani (2010), Siswanto (2011), and Nurminarsih (2012). As the mathematical model references,

4.2.1.1 Rani's Mathematical Model (2010)

Fitri Kurnia Rani's research about "Mixed Integer Linear Programming Model for Multi-Product Inventory Ship Routing Problem Considering Product Loading Compability Constraint" is the basis of this research mathematical model. However, there are several different characteristics in the problem itself. Therefore, Rani's mathematical model is as follows:

Notations

- Variables of Network Flows
  - x_{imjnv}: arc flow variable. It has value 1 if ships v travels from node (i,m) to (j,n). Otherwise 0.
  - z_{imv}: it has value 1 if node (i,m) is the last node of the route of ship v, otherwise 0.
  - y_{im}: slack variable is 1 if (i,m) is not visited, otherwise 0.
- Variables for loading and unloading
  - l_{imvck}: load onboard in the compartment c for product k of ship v when leaving (i,m).

- q_{imvck}: quantity of product k loaded into or unloaded from ship v's compartments c in position (i,m)
- o_{imvck}: binary variable is 1 if product k is loaded or discharged at harbor arrival (i,m) by ship v; otherwise,0.

- Variables for time aspect
  - t_{Eim}: ending service time at (i,m).
- Variables for inventories
  - s_{imk}: stock level of product k in harbor i when service starts at (i,m)
  - SE_{imk}: stock level of product k in harbor i when service finishes at (i,m)
- Variables for stock levels
  - p_{im}: binary variable is 0 of there are two or more ships at harbor i during the m^{th} arrival; otherwise 0.
- Non-binary variable indicator
  - ay_{imvck}: indicator variable if $l_{imvck} > 0$, thus ay_{imvck} will be 1 and respectively.
- Sets for network flows
  - S_T: set of all harbor arrivals (i,m) for all H_T and M_i.
  - H_T: set of total harbors
  - M_i: set of arrival numbers at harbor i
  - S_0: set of initial positions (i_v,m_v). if more than one ship starts from the same harbor then they are assigned a departure sequence number mv; otherwise, mv=1
  - V: set of available ship indexed by v
  - Hv: set of harbors that can be visited by ship v.
- Sets for loading and unloading
  - Av: set of all feasible arcs for ship v
  - K: set of products
  - Kk: set of products that ship v can carry
  - KHi: set of products that harbor i handles
  - Cv: set of compartments c of ship v
  - Cvk: the set of compartmentsin which products k cannot be loaded into it
- Parameters for network flows

- i_v: starting harbor vessel v
- m_v: assigned arrival sequence number for vessel v in harbor iv

- Parameters for laoding and unloading
  - J_{jk}: indicator variable is 1 (if product k is loaded at harbor k), 0 (if product k passes through harbor j), or -1 (if product k is unloaded at harbor j)
  - Q_{vck}: quantity of product k on compartment c of ship v at start of planning horizon
  - CAP_{vc}: capacity of the compartment c in ship v
- Parameters for time aspect
  - TQ_{ik}: time required to load a unit of product k at harbor i
  - W_i: setup time to change products for loading and unaloading at harbor i.
  - T_{ijv}: sailing time from harbor i to harbor j
- Parameters for inventories
  - IS_{ik}: initial stock level of product k at harbor i
  - R_{ik}: the consumption or production rate for product k in harbor i.
  - SMN_{ik}: minimum stock level at harbor i
  - SMX_{ik}: maximum stock level at harbor i
  - T: length of planning period
- Parameters for objective function
  - C_{ijv}: cost for ship v to sail from harbor i to harbor j
  - CW_{ik}: loading and unloading charges incurred at harbor i for product k

Minimize

$$\sum_{v \in V} \sum_{(i,m,j,n)} C_{ijv} x_{imjnv} + \sum_{(i,m) \in ST} \sum_{v \in V} \sum_{c \in V_c} \sum_{k \in K_v} C_{Wik} o_{imvck} \quad (1)$$

Subject to

$$\sum_{(j,n) \in Sn} x_{i_v m_v jnv} = 1 \ \ ; \ v \in V \quad (2)$$

$$\sum_{(j,n) \in St} x_{jnimv} - \sum_{(j,n) \in Sn} x_{imjnv} - z_{imv} = 0 \ ; (v, i, m) \quad (3)$$

$$\sum_{(j,n) \in S_N} z_{imv} = 1 \ ; v \in V \quad (4)$$

$$\sum_{v \in V} \sum_{(j,n) \in S_T} x_{jnimv} + y_{im} = 1; (i, m) \in S_N \quad (5)$$

$$y_{im} - y_{i(m-1)} \geq (i, m) \in S_N \quad (6)$$

$$= x_{imjnv}\left[l_{imvck} + J_{jk}.\, q_{jnvck} - l_{jnvck}\right] = 0\ ;c\ \in C_v, v \in V, imjnk \in A_v \qquad (7)$$

$$Q_{vck} + j_{ik} q_{i_v m_v vck} - l_{i_v m_v vck} = 0\ ; c \in C_v, v \in V, and\ k \in K \qquad (8)$$

$$l_{imvck} \leq CAP_{vc}.\sum_{(j,n)\in S_T} x_{jnimv} = 0; v \in V, (k, i, m) \in K \times S_N \qquad (9)$$

$$q_{imvck} \leq CAP_{vc}.\, o_{imvck}; v \in V\ and\ (k, i, m) \in K \times S_T \qquad (10)$$

$$\sum_{k\in K} ay_{imvck} \leq 1; v \in V, and\ (k, i, m) \in K \times S_T \qquad (11)$$

$$\sum_{C\in C_v} ay_{imvck} \leq |C_v|(1 - ay_{imvds}); k \in K, s \in K, d \in Cv, v \in V, (k, i, m) \in K \times S_T \qquad (12)$$

$$\sum_{C\in C_{vk}} ay_{imvck} \leq |C_v|(1 - ay_{imvds}); k \in K, s \in K, d \in Cv, v \in V, (k, i, m) \in K \times S_T \qquad (13)$$

$$t_{im} - t_{i(m-1)} \geq 0; (i, m) \in S_N \qquad (14)$$

$$x_{imjnv}\left[t_{Eim} + T_{ijv} - t_{jn}\right] \leq v \in Vand\ (i, m, j, n) \in A_v \qquad (15)$$

$$t_{im} + \sum_{v\in V}\sum_{c\in V_c}\sum_{k\in K_v} TQ_{ik} q_{imvck} + W_i \sum_{v\in V}\sum_{c\in V_c}\sum_{k\in K_v} o_{imvck} - t_{Eim} = 0\ \ ; (i, m) \in\ S_T \qquad (16)$$

$$S_{i1k} = IS_{ik} + J_{ik} R_{ik} t_{i1}\ ;\ (i, k) \in H_n \times K \qquad (17)$$

$$S_{imk} - \sum_{v\in V}\sum_{c\in Cv} j_{ik} q_{imvck} + J_{ik} R_{ik}(t_{Eim} - t_{im}) - S_{Eimk} = 0; (i, m, k) \in H_N \times K \qquad (18)$$

$$S_{Ei(m-1)k} + J_{ik} R_{ik}\left(t_{im} - t_{Ei(m-1)}\right) p_{im} - S_{imk} = 0; (i, m, k) \in S_N \times K \qquad (19)$$

$$t_{im} - t_{Ei(m-1)} \geq [p_{im} - 1]T; (i, m) \in S_N \qquad (20)$$

$$[t_{im} - t_{Ei(m-1)}] \leq Tp_{im}; (i, m) \in S_N \qquad (21)$$

$$S_{MNik} \leq s_{imk} \leq S_{MXik}; (i, m, k) \in S_T \times K \qquad (22)$$

$$S_{MNik} \leq se_{imk} \leq S_{MXik}; (i, m, k) \in S_T \times K \qquad (23)$$

$$S_{MNik} \leq S_{Eimlastk} + J_{ik} R_{ik}(T - t_{Eimlast}) \leq S_{MXik} \qquad (24)$$

Objective function (1) is a minimization function of the total operating cost during the planning horizon that consists of traveling cost and setup cost for loading and unloading. Routing constraints consist of initial position constraint (2), flow conservation constraints (3), route finishing constraints (4), one time visit constraint (5), and arrival sequence constraint (6). Loading and unloading activities constraints consists of: ship load constraint (7), initial ship load constraints (8), compartment capacity constraint (9), and product servicing constraint (10). Lading product homogenous constraints (11) product loading compatibility constraints (12-13). Constraints related to time aspects consist of service time sequence constraints (14), route and schedule compatibility constraints (15) and servicing finishing time constrains (16). Constraints related to inventory aspects consist of initial inventory constraint (17), inventory level constraints (18) level stock constrains 1 (19) overlapping visiting constrains 1 (20), overlapping visiting constraints 2(21), stock level bound of initial service (22), stock level bound of ending service (23), stock levels of ending planning horizon (24).

This mathematical model is the basis of Nurminarsih (2012)'s which have same problem characteristics. Therefore, from this mathematical model there are several aspects that become reference for this research's model, which are:

a. Constraint (9) and (10) about compartment capacity constraint. These two constraint need to modified by adding initial capacity constraint to ensure that the initial data input not exceed the capacity.
b. Constraint (16) about servicing time become the basic formula for this research, but need to modified because there is pumping rate variable in this research.

4.2.1.2 Siswanto's Mathematical Model (2011)

This mathematical is taken from Nurhadi Siswanto's research about "Solving the Ship Inventory Routing and Scheduling Problem with Undedicated Compartments". The unique characteristics in this model is the initial position of the ship can be everywhere. Therefore, Siswanto's mathematical model is as follows:

Minimize

$$\sum_{v\in V}\sum_{(i,m,j,n)\in A_v} CT_{ijv}x_{imjnv} + \sum_{v\in V}\sum_{(i,m)\in N} CW_{iv}w_{imv} + \sum_{v\in V}\sum_{(i,m)\in N}\sum_{k\in P_v}\sum_{c\in C_v} CO_{ik}o_{imvkc} \quad (1)$$

Subject to

$$\sum_{(j,n)\in N} x_{o(v)1jnv} + z_{0(v)1v} = 1 \quad ; v \in V \quad (2)$$

$$\sum_{(j,n)\in N} x_{jnimv} - \sum_{(j,n)\in N} x_{imjnv} - z_{imv} = 0\,;\ (v,i,m) \quad (3)$$

$$\sum_{(i,m)\in N} z_{imv} = 1; v \in V \quad (4)$$

$$\sum_{v\in V}\sum_{(j,n)\in N} x_{jnimv} + y_{im} = 1; (i,m) \in N \quad (5)$$

$$y_{im} - y_{i(m-1)} \geq 0, (i,m) \in N, m \neq 1 \quad (6)$$

$$x_{imjnv} \in \{0,1\}; v\ \in V, (i,m,j,n) \in A_v \quad (7)$$

$$z_{imv} \in \{0,1\}; v\ \in V, (i,m) \in N \quad (8)$$

$$y_{im} \in \{0,1\}; (i,m) \in N \quad (9)$$

$$x_{imjnv}\left(l_{imvkc} + J_{jk}q_{jnvkc} - l_{jnvkc}\right) = 0 \quad (10)$$

$$x_{imjnv}(l_{imvck}) = 0 \quad (11)$$

$$QQ_{imvkc} = l_{0(v)1vkc}; v \in V, (k,c) \in P_v \times C_v \quad (12)$$

$$q_{imvkc} \leq \sum_{(j,n)\in N} CM_{vc}x_{jnimv}\,; v \in V, (i,m) \in N, (k,c) \in P_v \times C_v \quad (13)$$

$$l_{imvkc} \leq \sum_{(j,n)\in N} CM_{vc}x_{jnimv}\,; v \in V, (i,m) \in N, (k,c) \in P_v \times C_v \quad (14)$$

$$q_{imvkc} \leq CM_{vc}x_{jnimv}; v \in V, (i,m) \in N, (k,c) \in P_v \times C_v \quad (15)$$

$$\sum_{k\in P_v}\sum_{c\in Cv} o_{imvkc} \leq 100w_{imv}\ \ ; v \in V, (i,m) \in N \quad (16)$$

$$l_{imvk\prime c} \leq CM_{vc}(1 - o_{imvk'c});\ v \in V, (i,m) \in N_p, (k', k'') \in P_v c \in C_v \quad (17)$$

$$\sum_{k\in P_v} o_{imvkc} \leq 1;\ v \in V, (i,m) \in N, c \in C_v \quad (18)$$

$$\sum_{k\in P_v} w_{imv} \leq 1; (i,m) \in N \quad (19)$$

$$o_{imvkc} \in \{0,1\}, v \in V, (i,m) \in N, (k,c) \in P_v \times C_v \quad (20)$$

$$w_{imv} \in \{0,1\}, v \in V, (i,m) \in N \quad (21)$$

$$l_{imvkc}, q_{imvkc} \geq 0; v \in V, (i,m) \in N, (k,c) \in P_v \times C_v \quad (22)$$

$$t_{im} - t_{i(m-1)} \geq 0; (i,m) \in N \quad (23)$$

$$t_{im} \leq TH; (i,m) \in N \quad (24)$$

$$x_{imjnv}[t_{im} + TW_iw_{imv} + \sum_{k\in P_v}\sum_{c\in C_v}(TQ_{ik}q_{imvkc} + TO_{ik}o_{imvkc}) + TT_{ijv} - t_{jn}] \leq 0; v \in V, (i,m,j,n) \in A_v \quad (25)$$

$$t_{im} \geq 0; (i,m) \in N \quad (26)$$

$$q_{imvkc} \leq s_{imk} + J_{jk}R_{ik}[TW_iw_{imv} + \sum_{k\in P_v}\sum_{c\in C_v}(TQ_{ik}q_{imvkc} + TO_{ik}o_{imvkc})]\,; v \in V, (i,m) \in N, k \in P_v, c \in C_v \quad (27)$$

$$s_{i1k} = IS_{ik} + J_{ik}R_{ik}t_{i1}; (i,k) \in H \times K \quad (28)$$

$$s_{i(m-1)k} - \sum_{v\in V}\sum_{c\in C_v} J_{ik} q_{i(m-1)vkc} + J_{ik}R_{ik}\big(t_{im} - t_{i(m-1)}\big) - s_{imk} = 0; (i,m,k) \in N \times K \quad (29)$$

$$SM_{ik} \le s_{imk} \le SX_{ik}; (i,m,k) \in N \times K \quad (30)$$

$$SM_{ik} \le s_{imk} - \sum_{v\in V}\sum_{c\in C_v} j_{ik} q_{imvkc} + \sum_{v\in V} J_{ik}R_{ik}[TW_i w_{imv} + \sum_{k\in P_v}\sum_{c\in C_v}(TQ_{ik} q_{imvkc} + TO_{ik} o_{imvkc})] \le SX_{ik}; (i,m,k) \in N \times K \quad (31)$$

$$SM_{ik} \le s_{imk} - \sum_{v\in V}\sum_{c\in C_v} j_{ik} q_{imvkc} + J_{ik}R_{ik}(TH - t_{im}) \le SX_{ik}; (i,m,k) \in N \times K \quad (32)$$

$$s_{imk} \ge 0; v \in V, (i,m) \in N \quad (33)$$

The objective function (1) of this model is to minimize the total cost of traveling, port setup, and loading (or unloading) setup. Constraint (2) ensures that each ship departs from or remains at its initial position. Constraints (3) and (4) enforce that a ship either leaves or finishes its route at node (i,m). Constraint (5) restricts so that only one ship can occupy node (i,m). Constraint (6) imposes that the precedence constraint is not violated. Then, constraints (7)–(9) declare the binary values for the variables involved in routing constrains.

Constraint (10) tracks the quantity onboard before and after a visit at node (i, m). Constraint (11) imposes that compartments on board must be empty if ship v goes to production ports. Constraint (12) ensures that the quantity onboard ship v at the beginning of the period is the same as the initial quantity of product k loaded in compartment c. Constraints (13) and (14) restrict the quantity loaded (or unloaded) and the quantity onboard within their limits. Constraints (15) and (16) enforce that if there are loading (or unloading) activities, a loading (or unloading) setup and a port setup must be considered, respectively. Constraint (17) assures that if ship v has a product in its compartment, only the same product can be loaded into there. Constraints (18) and (19) restricts so that only one ship can perform a loading (or unloading) setup and port setup, respectively. Constraint (20) declares the binary variables for the variables involved in loading (or unloading) activity. Then, constraints (21) and (22) state the continuous variables of loading (or unloading) quantity. Constraint (23) ensures that the time precedence constraints are not violated. Constraint (24) restricts the arrival time within the planning horizon.

Constraint (25) tracks the routing time from a node to another node. Constraint (26) declares the continuous variables of arrival time.

Constraint (27) imposes that the loading quantity must not exceed the available product in the storage. Constraint (28) tracks the storage level at the time of first arrival. Constraint (29) tracks the storage level of the current and previous visit. Constraint (30) and (31) guarantee that the storage level will be within its limits at the time a ship arrives at and departs from a port, respectively. Constraint (32) bounds the storage level at the end of the planning horizon. Finally, constraint (33) declares the continuous variables of inventory level.

The only aspects that become main references for this research is the initial ship position constraint. This research consider the ship must not start from depot which is similar with this research's problem. Constraint (2) need to modified by changing the index to suit this research's model.

4.2.1.3 Nurminarsih's Mathematical Model (2012)

Nurminarsih (2012) research about multi product inventory ship routing problem is development of Al Khayyal and Hwang (2007) and Rani (2010). Thus, Nurminarsih's research have similar characteristics with Rani's which are using undedicated compartments and focus onproduct compatibility constraints. Therefore, the mathematical model form Nurminarsih (2012) is as follows:

Minimize

$$\sum_v \sum_r \sum_i C_{pc}. z_{ivr} + \sum_v \sum_r \sum_i C_{mf}. z_{ivr} + C_{lb}. \left[\sum_i \sum_j t_{ijv}. x_{ijvr}\right] + c_{discharge}. \left[\sum_i \sum_v \sum_r \sum_c \sum_k \frac{q_{ivrck}}{PR_v}\right] + \sum_v \frac{C_{rent}}{\sum_r \sum_c \sum_k q_{ovrck}} + C_{late} \sum_v \sum_m Lt_{m_v} \quad (1)$$

Subject to

$$\sum_v \sum_{trip} y_{ivkr} = 1 \quad ; y_{ivkr} = \{0,1\} \quad (2)$$

$$z_{ivr}. M \geq \sum_{k \in K} y_{ikvr} \quad ; z_{ivr} = \{0,1\} \quad (3)$$

$$\sum_{j \in H_T} x_{jivr} - \sum_{j \in H_T} x_{jivr} = 0 \quad ; \; x_{jivr} = \{0,1\} \quad (4)$$

$$\sum_{v\in V}\sum_{r\in H_{TV}}\sum_{j\in H_T} x_{jivr} = y_{ikvr} \quad (5)$$

$$\sum_{v\in V}\sum_{r\in H_{TV}}\sum_{j\in H_T} x_{0jvr} \leq V.H_{TV} \quad (6)$$

$$\sum_{c\in C_v} q_{0vrck} = \sum_{i\in H_T}\sum_{k\in K}[y_{ikvr}.d_{ik}]\ ; c\ \in C_v \quad (7)$$

$$q_{0vrck} - l_{0vrck} = 0 \quad (8)$$

$$x_{ijvr}\left[l_{ivrck} - J_{jk}.q_{jvrk} - l_{jvrck}\right] = 0 \quad (9)$$

$$i_{0vrck} \leq CAP_{vrc} \quad (10)$$

$$i_{0vrck} \leq CAP_{vrc}.\sum_j x_{jivr} \quad (11)$$

$$q_{0vrck} \leq CAP_{vrc} \quad (12)$$

$$q_{ivrck} \leq CAP_{vrc.}\sum_j x_{jivr} \quad (13)$$

$$\sum_{k\in K} ay_{ivrck} \leq 1\ \ ;\ ay_{ivrck} = \begin{cases}1, l_{ivrck} > 0\\ 1, l_{ivrck} = 0\end{cases} \quad (14)$$

$$\sum_{c\in C_v} ay_{ivrck} \leq |C_v|.(1 - ay_{ivrds})\ \ ; k\in K, s\in K_k, d\in C_v \quad (15)$$

$$\sum_{c\in C_{vk}} ay_{ivrck} \leq |C_v|.(1 - ay_{ivrds})\ \ ; k\in K, s\in K_k, d\in C_v, C_{vk}\in\ C_v \quad (16)$$

$$t_{mp} + \sum_{v\in V}\sum_{r\in H_{TV}}\sum_{c\in V_c}\sum_{k\in K_{vr}} q_{m_pvrck}/PR_v - t_{Emp} = 0\ ;\ m_p\in H_{vr}k \quad (17)$$

$$x_{m_pn_{p+1}vr}[t_{Emp} + T_{m_pn_{p+1}v} - t_{n_{p+1}}] \leq 0 \quad (18)$$

$$a \leq t_{m_p} \leq b \quad (19)$$

$$t_{m_p} \leq cov_{m_pk} + Lt_{m_v} \quad (20)$$

$$lnd_{tm_p} = \begin{cases}1, t - t_{m_v} < 1\\ 0, t - t_{m_p} \geq 1\end{cases} \quad (21)$$

$$S_{m_pk1} = IS_{m_pk} - R_{m_pk} + [lnd_{tm}\cdot q_{m_pvrck}] \quad (22)$$

$$S_{m_pkt} = IS_{m_pkt-1} - R_{m_pk} + [lnd_{tm}\cdot q_{m_pvrck}] \quad (23)$$

$$S_{MNm_pk} \leq S_{m_pkt} \leq S_{MXm_pk} \quad (24)$$

The objective function of this problem is minimized total cost which consists port charge, management fee, bunker cost for ladent and ballast, bunker cost for discharge, renting cost, and lateness cost. While the constraints are about un-split delivery constraint (2), node visited indicator (3), flow conservation constraint (4), supply visiting constraint (5), maximum route constraint (6), depot loading constraint (7), initial ship loads constraint (8), ship load constraint (9), compartment capacity constraint (10-11), load/unload quantity constraint (12-13), homogenous product loading constraint (14), product loading compatibility constraint (15-16), service time constraint (17), route & schedule compatibility constraint (18), time windows constraint (19), coverage constraint (20), product arrival indicator(21), initial inventory level constraint (22), inventory level constraint (23), stock level bound(24).

This mathematical model becomes fundamental references for this reseach model. However, the main different is at index c which is compartment. This research does not consider compartment compatibility so that the index will be removed. Detail development from this mathematical model is as follows:

a. Constraint (4) about flow conservation constraint modified to more simple formula.
b. Removing constraint (6) about maximum route constraint to ensure that the ship can move back to depot to load the product in the middle of planning horizon.
c. Moving initial load constraint (8) to inventory constraint because the modification of minimum ship inventory constraint.
d. Removing product compability constraint constraint (14)-(16) because this research not using compartments.
e. Modifying constraint (24) about stock level bound to make the minimum level of inventory 0.
f. Modifying lateness cost formula.
g. Adding new variable to ensure each port supplied by each assigned depot.

4.2.2 Explanation of Notation

This research use many notation to as a symbol of the constraints. In order to ease the understanding process of the model, each constraints and notations is grouped based on the usage. These are the definition of each notation used in this research model.

- Routing variables

- y_{ikvr}: indicator variable if product k at node i being carried by tanker v at visitation r.
- z_{ivr}: binary variable, the value is 1 if y_{ikvr} also have 1 value, it means node i visited by tanker v at visitation r.
- x_{ijvr}: binary variable, the value is 1 if node j directly visited after node i by tanker v at visitation r.
- w_{di}: binary variable, the value is 1 if port i being supplied by depot d.

- Loading and unloading variables
  - l_{ivrk}: load of product k that carried by tanker v visitation r when leaves node i.
  - q_{idvrk}: quantity of product k that load/unload in tanker v from depot d at visitation r on node i.
  - ay_{ivrk}: indicator variable if $l_{ivrk} > 0$ then ay_{ivrk} is 1, otherwise if $l_{ivrk} = 0$ then ay_{ivrk} also have 0 value.
- Time constraints variables
  - m_p: port that visited by tanker v at visitation r on sequence p^{th}.
  - t_{mp}: arrival time at mp
  - te_{mp}: end of process time in mp
  - Lt_{mp}: lateness of tanker v at visitation r on port that have p^{th} sequence.
- Inventory variables
  - ind_{ti}: indicator of tanker arrival at t periods on port i.
  - S_{ikt}: stock level of product k at port i on period t.
- Model set
  - Ht: set of total port
  - K: set of product total amount
  - V: set of tanker total number
  - H_{TV}: set of number of visitation of tanker v
  - H_{vr}: set of port that visited by tanker v on visitation r.
  - Dep: set of total depot
- Loading and unloading parameter.
  - d_{ik}: amount of product k demand from node i

- J_{jk}:.indicator variable that have 0 value if product k do not unloaded at port j, otherwise 1.
- CAP_{vr}: product capacity at tanker v on visitation r.

- Time constraint parameter
  - t_{ijv}: sailing time from port I to port j with tanker v.
  - a: beginning of service time at port.
  - b: end of service time at port.
  - cov_{ik}: coverage day inventory of product k at port i.
- Inventory parameter
  - IS_{ik}: initial inventory of product k at port i.
  - R_{ik}: daily demand rate of product k at port i.
  - S_{MNik} : minimum stock level of product k at port i.
  - S_{MXik}: maximum stock level of product k at port i.
  - L_{MNivk}: minimum inventory level of product k at tanker v
- Objective function parameter
  - C_{pcmf}: port charge and management fee
  - C_{lb} : bunker consumption l/b
  - $C_{discharge}$: cost of bunker consumption discharge
  - $Cprod_k$: cost of each product k

4.2.3 *Mathematical Model*

Based on the references from sub-chapter 4.2.1, the mathematical model of this M-ISRP is divided into five parts, which are:

4.2.3.1 Routing Constraints

$$\sum_{v\in V} x_{ijv0} + z_{ivr'} = 1 \quad (1)$$

$$\sum_{j\in Ht} x_{jivr} = 1 \;\; ; \quad x_{jivr} = \{0,1\} \quad (2)$$

$$z_{ivr} \cdot M \geq \sum_{k\in K} y_{ikvr} ; z_{ivr} = \{0,1\} \quad (3)$$

$$\sum_{v} \sum_{trip} y_{ikvr} = 1 \;\; ; \; y_{ikvr} = \{0,1\} \quad (4)$$

$$\sum_{v \in V} \sum_{r \in H_{TV}} \sum_{j \in H_T} x_{jivr} = y_{ikvr} \quad (5)$$

$$\sum_{v \in V} \sum_{r \in H_{TV}} \sum_{k \in K} \sum_{d \in Dep} y_{ikvr} \cdot w_{di} = 1 \quad (6)$$

Explanation

(1) Tanker Initial Position Constraint. Ensures that each tanker departs from or remains at its initial position.
(2) Flow Conservation Constraint. Enforce that a tanker either leaves or finishes its route at node (i, m)
(3) Node Visited Indicator. Have value 1 if $y_{ikvtrip}$ also have value 1, which means that tanker v is sailing to visit port i.
(4) Un-split delivery constraint. Ensure that each product at each port only satisfied by one tanker.
(5) Supply Visiting Constraint. Restrict that tanker v must have a trip to visit node that have value of $y_{ikvtrip}$ 1.
(6) Assigned Depot Constraint. To ensure that all ports supplied from each of their assigned depot.

4.2.3.2 Loading and Unloading Constraint

$$\sum_{v \in V} q_{0vrk} = \sum_{i \in H_T} \sum_{k \in K} [y_{ikvr} \cdot d_{ik}] \quad (7)$$

$$x_{ijvr}\left[l_{ivrk} - J_{jk} \cdot q_{vrk} - l_{jvrk}\right] = 0 \quad (8)$$

$$l_{0vrk} \leq CAP_{vr} \quad (9)$$

$$l_{ivrk} \leq CAP_{vr.} \sum_j x_{jivr} \quad (10)$$

$$q_{0vrk} \leq CAP_{vr} \quad (11)$$

$$q_{ivrk} \leq CAP_{vr.} \sum_j x_{jivr} \quad (12)$$

Explanation

(7) Depot Loading Constraint. Constraint that decide the quantity of product that should be loaded at depot d.

(8) Tanker Load Constraint. Constraint that keep inventory in the tanker balance.

(9) Tanker Inventory Quantity Constraint. Constraint to ensure that quantity inventory in the tanker not exceed capacity of the tanker.

(10) Tanker Inventory Quantity Constraint. Constraint to ensure that quantity inventory in the tanker not exceed capacity of the tanker.

(11) Load/Unload Quantity Constraint. Constraint to ensure that quantity load/unload not exceed the inventory in the tanker.

(12) Load/Unload Quantity Constraint. Constraint to ensure that quantity load/unload not exceed the inventory in the tanker.

4.2.3.3 Time Constraints

$$t_{mp} + \sum_{v \in V} \sum_{r \in H_{TV}} \sum_{k \in K_{vr}} q_{m_p vrk} / PR_v - t_{Emp} = 0 \ ; \ m_p \in H_{vr} k \tag{13}$$

$$x_{m_p n_{p+1} vr} [t_{Emp} + T_{m_p n_{p+1} v} - t_{n_{p+1}}] \leq 0 \tag{14}$$

$$a \leq t_{m_p} \leq b \tag{15}$$

$$t_{m_p} \leq cov_{m_p k} + Lt_{m_v} \tag{16}$$

Explanation

(13) Service Time Constraint. To adjust time between beginning of service until the end of the service at port visit p from tanker route.

(14) Route and Schedule Compatibility Constraint. Restrict that beginning time of service at port visit p+1 is the end of time at port visit p plus sailing time from port visit p to port visit p+1.

(15) Time Windows Constraint. Ensure that beginning time of service at port must between certain operational time.

(16) Coverage Constraint. Ensure that tanker that carry product k from one port must arrive before coverage day of that product at passed port.

4.2.3.4 Inventory Constraints

$$lnd_{tm_p} = \begin{cases} 1, t - t_{m_v} < 1 \\ 0, t - t_{m_p} \geq 1 \end{cases} \quad (17)$$

$$S_{m_pk1} = IS_{m_pk} - R_{m_pk} + [lnd_{tm} \cdot q_{m_pvrk}] \quad (18)$$

$$S_{m_pkt} = IS_{m_pkt-1} - R_{m_pk} + [lnd_{tm} \cdot q_{m_pvrk}] \quad (19)$$

$$0 \leq S_{m_pkt} \leq S_{MXm_pk} \quad (20)$$

$$\sum_{v \in V} l_{0vrk} \geq L_{MNivk} \quad (21)$$

Explanation

(17) Product Arrival Indicator. Indicator that shows if tanker that carry the product has arrived at period t then this constraint will have value 1.

(18) Initial Inventory Level Constraint. To decide the initial inventory in first period of a port. The formula is initial inventory of that port minus daily demand plus incoming stock.

(19) Initial Level Constraint. To decide the value of inventory on every period from one port. The formula is initial inventory of that port minus daily demand plus incoming stock.

(20) Stock Level Bound. Ensure that the remains of its inventory at every periods must be between 0 and maximum level even it surpass minimum level.

(21) Initial Inventory Tanker Constraint. Ensure that initial inventory of the tanker do not exceed minimum inventory of the tanker.

4.2.3.5 Objective Function

$$\sum_{v}\sum_{r}\sum_{i} C_{pcmf}.z_{ivr} + C_{lb}.\left[\sum_{i}\sum_{j} t_{ijv}.x_{ijvr}\right] + c_{discharge}.\left[\sum_{i}\sum_{v}\sum_{r}\sum_{k}\frac{q_{ivrk}}{PR_v}\right] + \sum_{v}\sum_{m}\sum_{k} Cprod_k * R_{ik} * Lt_{m_v}$$

This objective function is to minimize total cost that include port charge, management fee, bunker cost for laden and ballast (traveling), bunker cost for discharge (loading and unloading) and lateness cost.

4.3 Algorithm Development

Multi-product Inventory Ship Routing Problem (M-ISRP) algorithm build up based on the tanker delivery problem at one of energy company in Indonesia for East Java, Bali, NTT and NTB area. Therefore from the general algorithm basically can be divided into several parts, which are sorting critical ports algorithm, tanker assignment algorithm, and tanker routing algorithm. The general algorithm can be seen in figure 4.1 below.

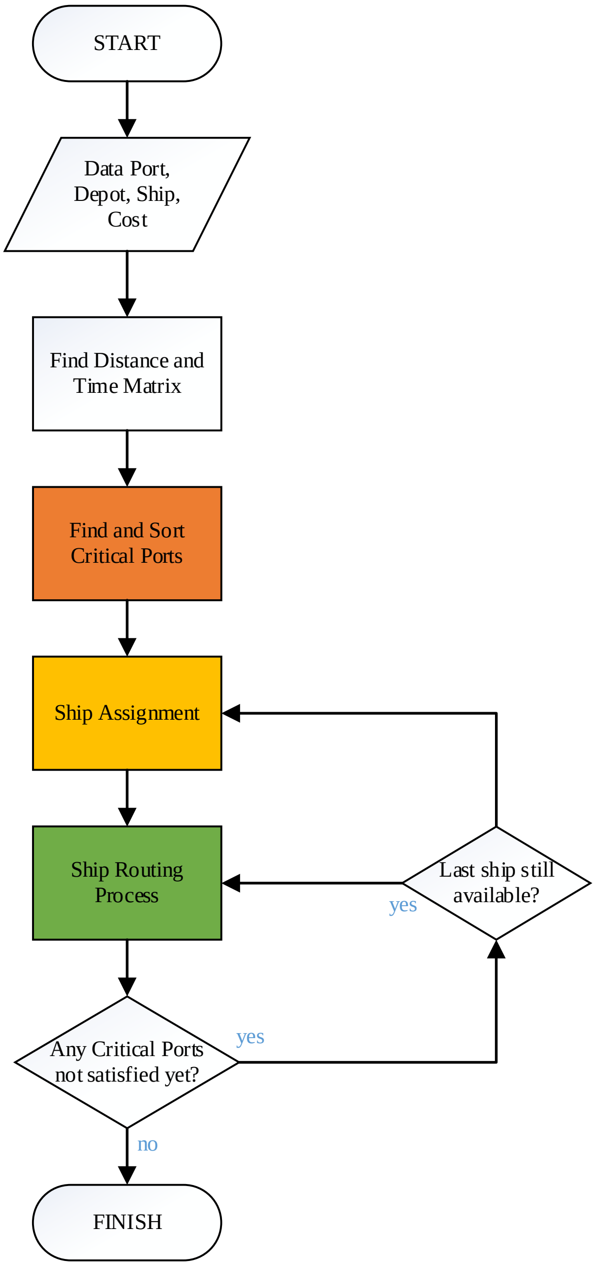

Figure 4.1 General M-ISRP Algorithm

The algorithm start from calculating distance matrix and time matrix in order to make it easier for next calculation. Distance and Time matrix are needed in tanker assignment and tanker routing process. Then continue with calculating and sorting critical ports. Next, continue with tanker assignment. After knowing which tanker that should be used based on the sequence of the critical ports and the condition of the tanker, then run the tanker routing process. There are a lot to do in this process. Therefore, tanker routing process must ensure that all critical ports can be satisfied on time and effectively. If there is any critical ports that not satisfied yet, the tanker routing process is repeated until all ports is satisfied.

4.3.1 Critical Ports Sorting Algorithm

In order to classify the ports and to know which ports that should be delivered first, there must be a critical ports calculation. Therefore, researcher assume that a port can be categorized as critical if the days of supply value is under planning horizon. Otherwise, the port is not critical or did not have to be supplied for this planning horizon. The algorithm for calculation and sorting critical ports can be seen in figure 4.2 below.

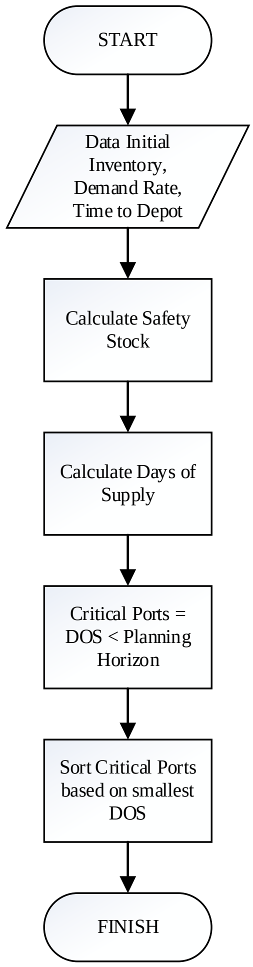

Figure 4.2 Calculating and Sorting Critical Ports Algorithm

Researcher assume that the minimum level of inventory should be decided by calculating safety stock. Therefore, the formula of safety stock itself is the amount of product loss by two times depot-port delivery. Thus, by knowing the safety stock, initial inventory, and daily demand rate, the days of supply of each port can be calculated. Next, define every port whether it is critical or not and sorting it based on the smallest days of supply.

4.3.2 Tanker Assignment Algorithm

In order to make an effective routing, the tanker selection is also crucial. Therefore, there must be several rules regarding the tanker assignment. Note that the tanker can start the planning either from the sea or at the port. According to the algorithm, to minimize the cost, the tanker that prioritized to be chosen first is the closest one. However, still need to asses other condition of the tanker such as the product carried and the tanker availability. The tanker assignment algorithm can be seen in figure 4.3 below.

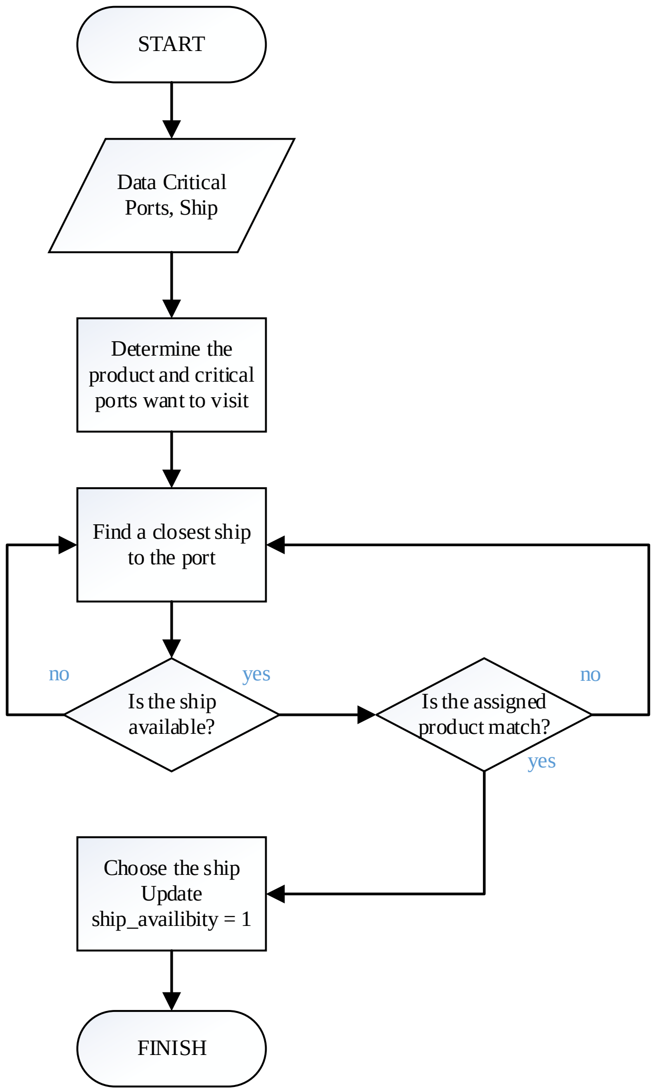

Figure 4.3 Tanker Assignment Algorithm

4.3.3 Routing Algorithm

The main part of all algorithm is the routing algorithm. Therefore, this algorithm done after tanker assignment and critical ports sorting is done. In order to make a comprehensive route, the algorithm need to accommodate all the possibilities. The routing algorithm can be seen in figure 4.4 below

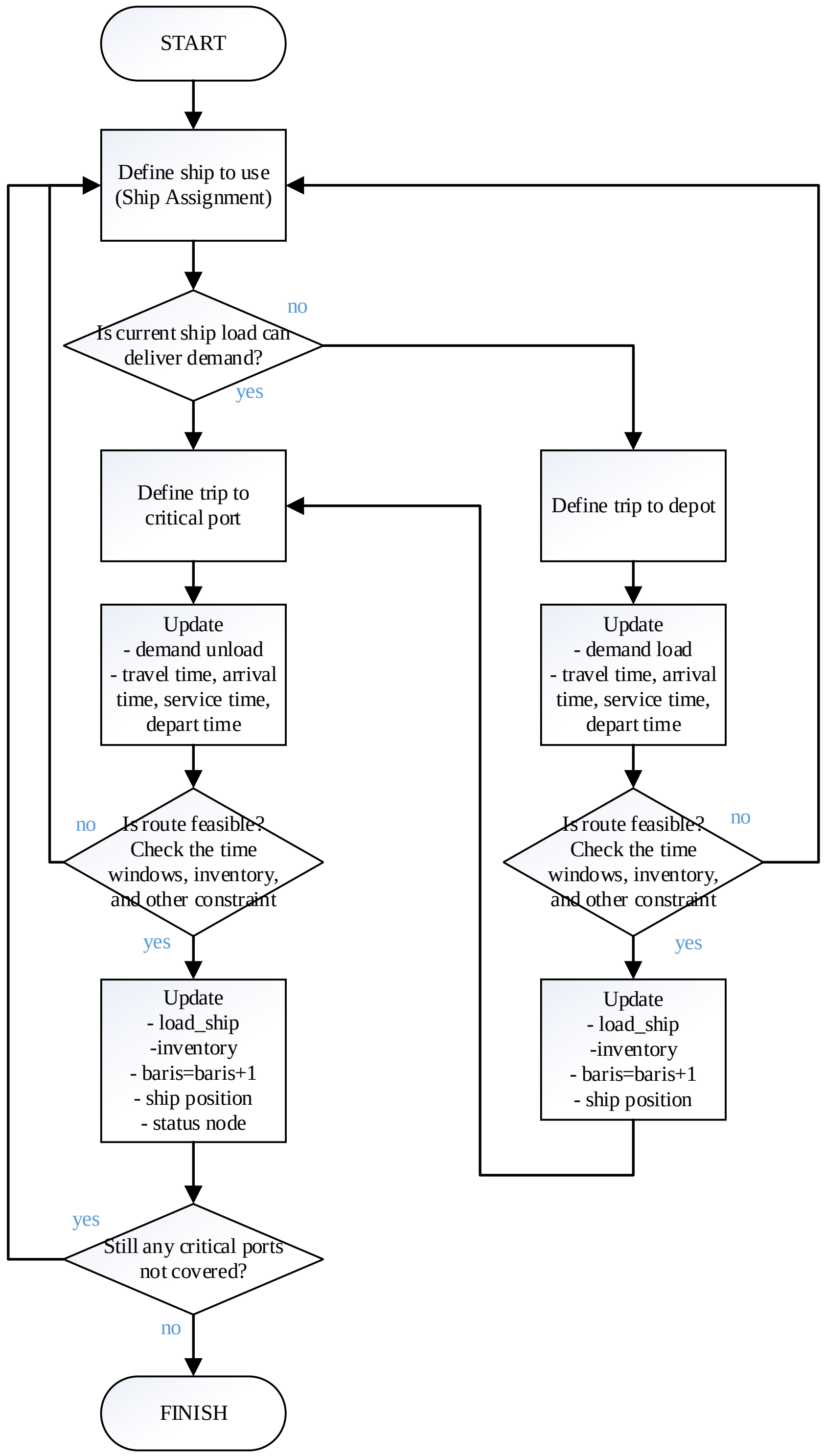

Figure 4.4 Routing Algorithm

So there is a possibility that a tanker can deliver demand even if still not come to the depot yet, depend on the load on the tanker in current time. Then, the route check is to check the feasibility of the route regarding the time windows constraint, inventory constraint, etc. Still if a route exceed days of supply for certain ports, then the route will be penalized.

4.4 System Prototype Development

After the algorithm is done, then the algorithm has developed into a system prototype program to make it easier to run the algorithm as well as gaining the result. The system prototype gives the result of tanker scheduling, detail of route for every tanker, and the cost needed for the routing. Therefore the system prototype developed by using Visual Basic for Application on Microsoft Excel 2013. The home screen interface of the system prototype program can be seen in figure 4.5 below.

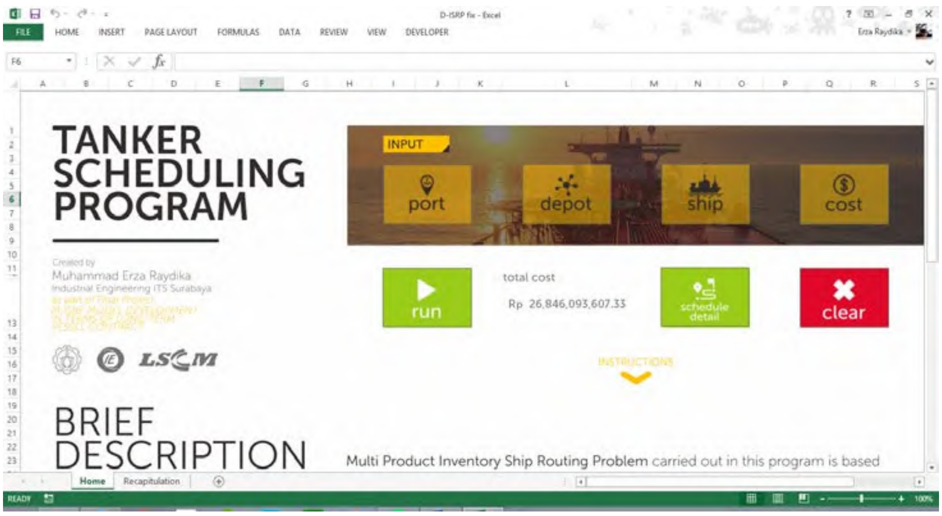

Figure 4.5 Prototype Program Home Interface

Basically this system prototype program consist of input, process, and output. Although, the process part is hidden by the researcher to ensure that the system is pleasantly for the user. Therefore, the input consists of port, depot, ship, and cost. The output consists of the detail of route for every tanker as well as the cost included and the total cost of entire tanker scheduling.

4.4.1 *Input*

Input section in the system prototype program is the part where the user has to fill the data regarding the tanker scheduling. Therefore, the data will be used as the parameter to run the process. However, the user must aware that all the data entered is already correct and feasible to be processed. Input section consists of four parts, which are port input, depot input, ship input, and cost input. The interface of input section can be seen in figure 4.6, 4.7, 4.8, 4.9 below.

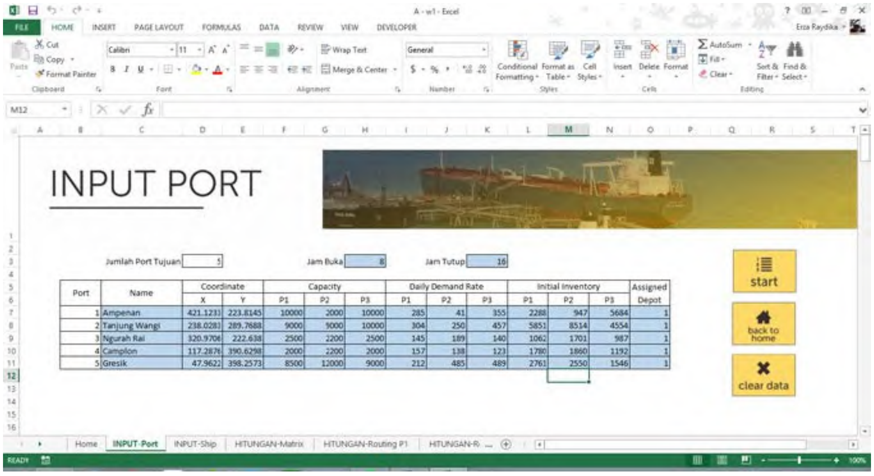

Figure 4.6 Port Input Section Interfaces

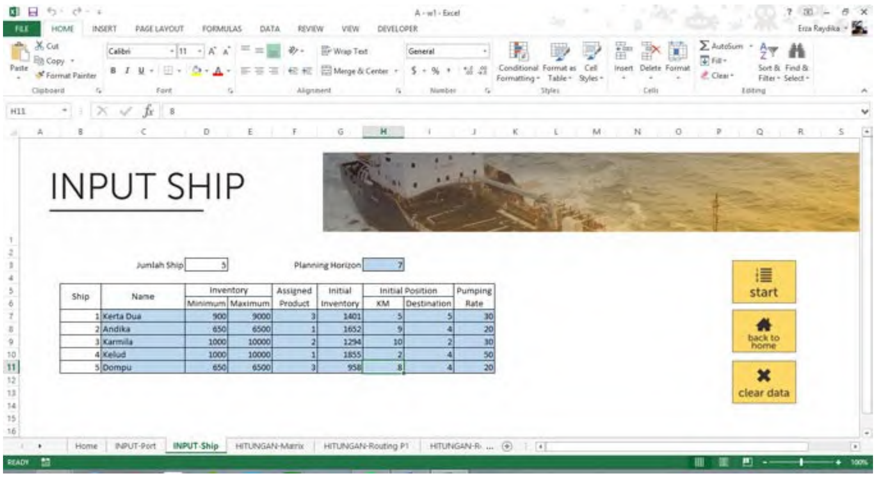

Figure 4.7 Ship Input Section Interfaces

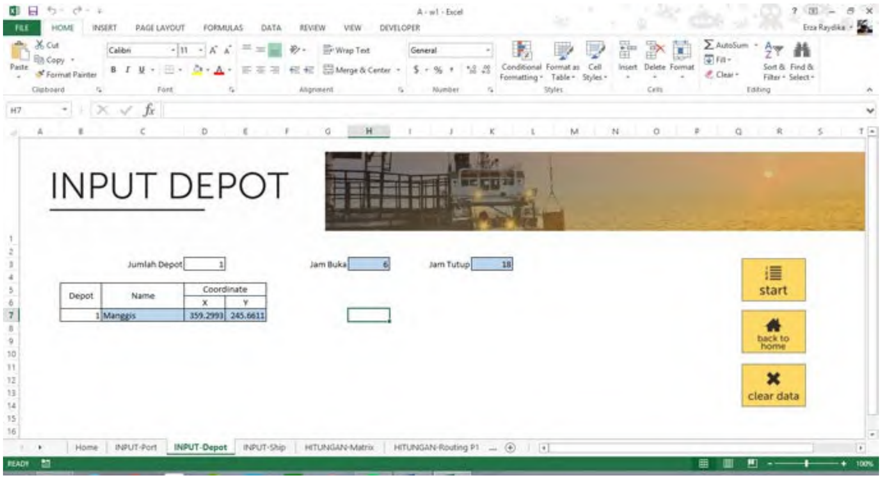

Figure 4.8 Depot Input Section Interfaces

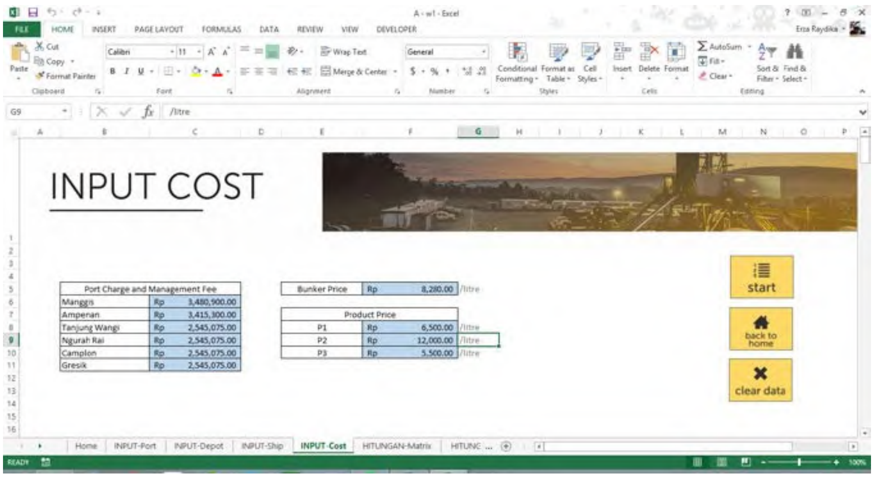

Figure 4.9 Cost Input Section Interfaces

Port input basically is the main input for this system. In this part user must input the number of ports, coordinates of ports, time window, assigned depot, inventory boundary, initial inventory, and daily demand rate for each product. Depot input only consists of number of depots to supply all the ports, coordinate of each, and the time window. Ship input consists of all tanker details including assigned product, inventory of tanker, and the initial position of the tankers. Cost input consists of all cost regarding the routing such as bunker (tanker fuel) cost, product's price, port charge, and management fee.

4.4.2 *Process*

In the process section, the data that has been entered by the user become the basis of running the algorithm. Entire process part is a work based on the algorithm. Because the algorithm is complex and the process is long, so researcher decide to hide the process part in order to make the program more pleasant for the user. Thus, the user still can access the process part to see how the tanker scheduling being conducted. The screenshot of process section can be seen in the figure 4.7 below.

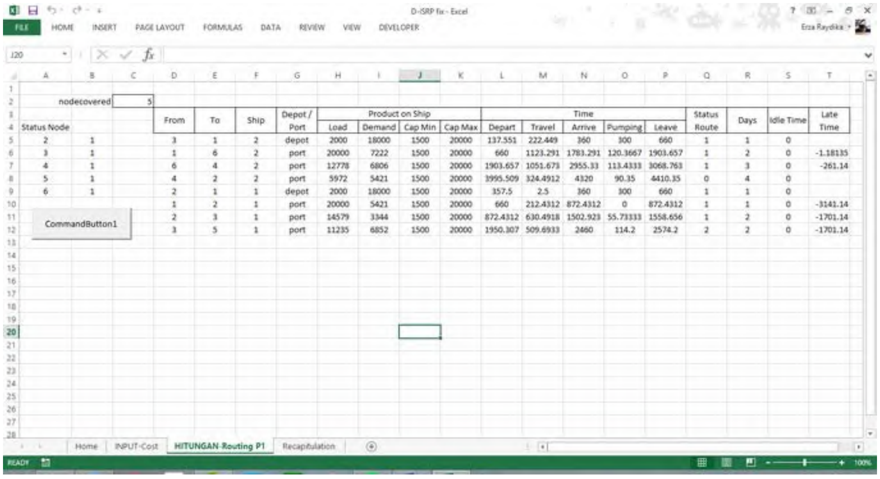

Figure 4.10 Process Screenshot

4.4.3 *Output*

The output section is the result of the process which is all the tanker routing and cost included. Therefore, the routing detail of every tanker will present in this section also the cost of every tanker. The interface of output section can be seen in figure 4.9 below.

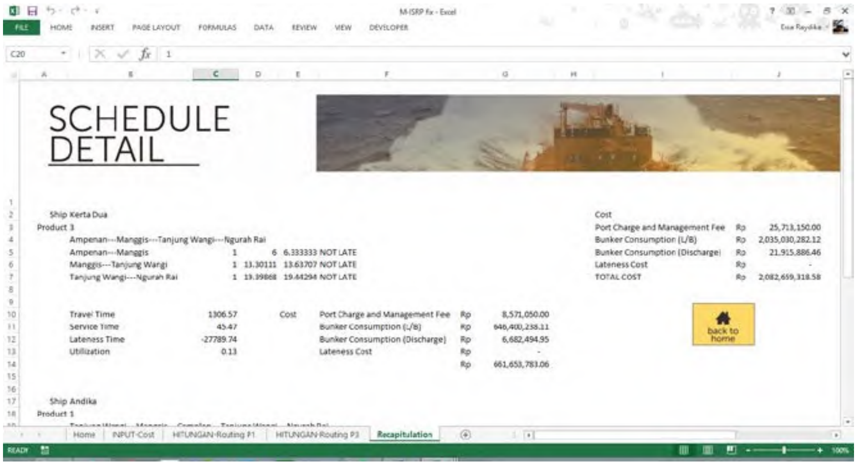

Figure 4.11 Output Interface

4.5 Verification and Robustness Test

The verification process is done by comparing the result of the program with manual calculation. Therefore, the dataset for verification is small a dataset, whether run by a program or manual calculation using the same algorithm.

In this verification process, the program have to find the best ship scheduling for five ports with one depot. Each port will have different demand for each product. Therefore, each port also has different days of supply because it has a different daily demand rate as well as different inventory condition. The minimum inventory for each port is determined using safety stock calculation which is the amount of product depleted when travel from port to depot two times. Each port coordinates are exactly the same as the real case, by using longitude and longitude conversion. The input data for ports can be seen in table 4.1 and 4.2 below

Table 4.1 Port Coordinate and Capacity Data

Port	Coordinate		Capacity		
	X	Y	P1	P2	P3
Ampenan	421.12	223.81	12547	1365	10517
Tanjung Wangi	238.03	289.77	9155	9767	10837
Ngurah Rai	320.97	222.64	2107	2201	2304
Camplon	117.29	390.63	2010	2128	2096
Gresik	47.96	398.26	8778	12188	9208

Table 4.2 Port Daily Demand Rate and Initial Inventory Data

Port	Daily Demand Rate			Initial Inventory		
	P1	P2	P3	P1	P2	P3
Ampenan	57.41	1	330.78	1585	99999	4183
Tanjung Wangi	456.11	528.78	556.79	3750	2308	3225
Ngurah Rai	88.7	56.86	174.63	748	1107	1200
Camplon	89.81	56.48	168.78	545	655	3320
Gresik	454.74	271.33	218.89	4421	9437	3944

As shown in table 4.2 that Ampenan has 1 demand rate and 99999 initial inventory. This number is dummy data, thus the program will crashed if encounter 0 value in the input. Because demand rate becomes the divider variable in determining days of supply.

There are three tankers available to make the deliveries. Therefore, those three tanker are dedicated each of it for each product. Tanker's initial position is different from one and another and can be started in the middle of the sea. It is also that every tanker have maximum and minimum inventory to make a sail. Pumping rate also different from one and another. The detail input data for tankers can be seen in table 4.3 below.

Table 4.3 Tanker Data

Tanker	Inventory		Assigned Product	Initial Inventory	Initial Position		Pumping Rate
	Min	Max			KM	Destination	
Kerta Dua	900	9000	3	2000	2.5	2	35
Andika	950	9500	1	2000	3.6	3	30
Karmila	900	9000	2	1200	6.1	4	30

Costs included in the calculation is port charge and management fee, bunker cost for traveling, bunker cost for loading/unloading, and lateness cost. Therefore, this research sets bunker price at Rp 8,280.00 based on the price of bunker in Indonesia June 2016 (BunkerBBM.co.id, 2016). Other detail of cost can be seen in table 4.4 below.

Table 4.4 Port Charge and Management Fee Data

Port Charge and Management Fee	
Manggis	Rp 3,480,900.00

Port Charge and Management Fee		
Ampenan	Rp	3,415,300.00
Tanjung Wangi	Rp	2,545,075.00
Ngurah Rai	Rp	2,545,075.00
Camplon	Rp	2,545,075.00
Gresik	Rp	2,545,075.00

Based on the manual calculation, there are 4 critical ports for all products. The details are ports Camplon for product 1; port Tanjung Wangi for product 2, and port Tanjung Wangi and Ngurah Rai for product 3. All those ports will become priorities in the deliveries. Therefore, after this step is tanker assignment and routing process. The result compares with the output of the program, can be seen in table 4.5 below.

Table 4.5 Route Comparison between Manual Calculation and Program Output

Tanker	Manual Calculation Route	Program Output Route
Kerta Dua	Ampenan---Manggis---Tanjung Wangi---Manggis---Ngurah Rai	Ampenan---Manggis---Tanjung Wangi---Manggis---Ngurah Rai
Andika	Tanjung Wangi---Manggis---Camplon	Tanjung Wangi---Manggis---Camplon
Karmila	Ngurah Rai---Manggis---Tanjung Wangi	Ngurah Rai---Manggis---Tanjung Wangi

From the route comparison, can be seen that between manual calculation and program output are having the same result based on the same algorithm. Therefore the cost comparison should be present the same value. The cost comparison can be seen in table 4.6 below.

Table 4.6 Cost Comparison between Manual Calculation and Program Output

Tanker	Manual Calculation Cost	Program Output Cost
Tanker 1	Rp 603,595,106.26	Rp 603,595,106.26
Tanker 2	Rp 581,723,829.65	Rp 581,723,829.65
Tanker 3	Rp 343,417,895.64	Rp 343,417,895.64
Total	Rp 1,528,736,831.56	Rp 1,528,736,831.56

By doing the verification of the model and algorithm, it can be concluded that the model and algorithm is already verified and capable of resulting tanker schedule, total cost needed, and tanker utilization regarding the model and algorithm have been built. Therefore, the next step is a running robustness test in order to know the consistency of algorithm in resulting tanker route.

The robustness test involves several datasets. There are three datasets that different from each other and each have its own characteristics. The first dataset consists of many ports and divided into several areas which is the tanker and depot are dedicated for ports in those areas only. Consist of 15 ports with 3 depots and 9 tankers. The second dataset has less port than dataset 1, and only consist of 1 depot. The purpose of this dataset is to know the performance of the program in resulting schedule by using only one depot but with many ports. The third dataset basically is the same with the second one, but it has two depots with different condition of inventory. However, all three datasets have same bunker and product cost. Port charges and management fee are different, but not in large range. All input data for robustness test can be seen in appendix A.

4.5.1 Dataset 1 Scheduling

In first dataset scheduling, there are several critical port that have to be supplied in interval of the planning horizon. Those critical ports grouped by product and sorted based on the smallest Days of Supply. Therefore, table 4.7 below shows the critical port that need to be supplied in Dataset 1.

Table 4.7 Critical Port of Dataset 1

Product 1	Product 2	Product 3
Port 3	Port 2	Port 5
Port 6	Port 4	Port 6
Port 12	Port 6	Port 9
	Port 12	Port 12
	Port 15	Port 14

Noted that all those ports are dedicated to its own area. Port 1-5 in area A, port 6-10 in area B, and port 11-15 in area C. Therefore, the program will find the route based on the algorithm. The program also calculates the utilization of the tanker in routing. However, the calculation of tanker utilization is based on the planning horizon time length. Because the program sets the planning horizon is 7, then the tanker utilization is the utilization of the tanker on those 7 days of work. The scheduling result can be seen in table 4.8 below.

Table 4.8 Scheduling Result of Dataset 1

Tanker	Product	Area	Route	Utilization
Tanker 1	1	A	P1---D1---P3	0.22
Tanker 2	2	A	P2---P4	0.30
Tanker 3	3	A	P3---D1---P5	0.21
Tanker 4	1	B		0.00
Tanker 5	2	B	P8---D2---P6	0.22
Tanker 6	3	B	P6---D2---P6---P9	0.44
Tanker 7	1	C	P15---D3---P12	0.20
Tanker 8	2	C	P14---D3---P12---P15	0.49
Tanker 9	3	C	P12---D3---P14	0.35

From all the route, there is no late delivery. Therefore, there is no lateness cost imposed to the tanker. The cost imposed are port charge and management fee, bunker cost for traveling and bunker cost for discharging. The cost recapitulation can be seen in table 4.9 below.

Table 4.9 Dataset 1 Cost Recapitulation

Cost		
Port Charge and Management Fee	Rp	77,000,000.00
Bunker Consumption (L/B)	Rp	9,311,545,364.13
Bunker Consumption (Discharge)	Rp	392,527,476.00
Lateness Cost	Rp	-
TOTAL COST	Rp	9,781,072,840.13

Table 4.7 is quite revealing in several ways that the ports involved in delivery process are not all. There are 9 ports that have need to be supplied in interval of 7 days of planning horizon.

4.5.2 Dataset 2 Scheduling

In second dataset scheduling, from 8 ports there are several critical port. Same as dataset 1, those critical ports grouped by product and sorted based on the smallest Days of Supply. Therefore, the result of critical port selection of Dataset 2 can be seen in table 4.10 below.

Table 4.10 Critical Ports in Dataset 2

Product 1	Product 2	Product 3
Port 5	Port 2	Port 2
Port 3	Port 1	Port 3
Port 1	Port 5	

After determining and sort all critical ports, the program will continue to find the optimal route. The number of tanker in Dataset 2 is 6 tankers dedicated for 2 for each product. Hence, from the result we can see that not all the tanker is being used in the specific planning horizon. It means that by the current condition of the inventory and such, there are only 4 tankers needed to run the routing for 7 days of planning horizon. The routing result can be seen in table 4.11 below.

Table 4.11 Routing Result of Dataset 2

Tanker	Product	Route	Utilization
Tanker 1	1	P8---D1---P5	0.02
Tanker 2	1	P7---D1---P5---P3---D1---P1	0.60
Tanker 3	2	--	0.00
Tanker 4	2	P8---D1---P2---P1---P5	0.62
Tanker 5	3	P3---D1---P2---P3	0.47
Tanker 6	3	--	0.00

Overall routing operation in dataset 2 need Rp 6,091,820,702.71 based on the sum of port charge and management fee, traveling and discharging bunker consumption, and lateness cost. The cost recapitulation can be see in table 5.8 below.

Table 4.12 Cost Recapitulation of Dataset 2

Cost		
Port Charge and Management Fee	Rp	66,000,000.00
Bunker Consumption (L/B)	Rp	5,852,778,469.66
Bunker Consumption (Discharge)	Rp	173,042,233.05
Lateness Cost	Rp	-
TOTAL COST	Rp	6,091,820,702.71

If the routing is done optimally, there should be no minus stock in the inventory of every port. Therefore, condition of last stock inventory of all ports in Dataset 2 can be seen in table 4.13 below.

Table 4.13 Last Stock in Dataset 2

	Product 1	Product 2	Product 3
Port 1	3416	1880	492
Port 2	2611	5624	1503
Port 3	4822	2339	2076
Port 4	988	1230	247
Port 5	1612	828	1414
Port 6	1746	1623	1240
Port 7	340	4264	4785
Port 8	1810	6755	2545

4.5.3 Dataset 3 Scheduling

As mentioned before that Dataset 3 different is not too far with Dataset 2. Both have the same number of ports and tankers, but the differences are the number of depots and the condition of the inventory. In consequence, the critical ports from Dataset 3 can be seen in table 4.14 below.

Table 4.14 Critical Ports in Dataset 3

Product 1	Product 2	Product 3
Port 6	Port 8	Port 3
Port 2	Port 7	Port 6
	Port 6	Port 2
	Port 5	

Even if there are 2 depots, the depot selection is based on the nearest depot from the current location of the tanker. Therefore, between one depot and another can be any difference in the usage. Thus, there is no restriction area for the tanker so that the tanker from depot 1 can also have a route to depot 2 and vice versa. The routing result of Dataset 3 can be seen in table 4.15 below.

Table 4.15 Routing Result of Dataset 3

Tanker	Product	Route	Utilization
Tanker 1	1	P8---D1---P6	0.19
Tanker 2	1	P7---D1---P2	0.27
Tanker 3	2	--	0.00
Tanker 4	2	P8---D2---P8---P7---D1---P6---P5	0.54
Tanker 5	3	P3---D1---P3---P6---P2	0.59
Tanker 6	3	--	0.00

Same as before, the cost arrangement also the same. Dataset 3 needs Rp 5,559,921,378.48 to run the optimal routing. Therefore, the cost recapitulation can be seen in table 4.16 below.

Table 4.16 Cost Recapitulation of Dataset 3

Cost		
Port Charge and Management Fee	Rp	62,500,000.00
Bunker Consumption (L/B)	Rp	5,270,347,094.63
Bunker Consumption (Discharge)	Rp	227,074,283.85
Lateness Cost	Rp	-
TOTAL COST	Rp	5,559,921,378.48

If the routing is done optimally, there should be no minus stock in the inventory of every port. Hence, the last stock condition of all ports in Dataset 3 can be seen in table 4.17 below.

Table 4.17 Last Stock of Dataset 3

	Product 1	Product 2	Product 3
Port 1	848	1392	1691
Port 2	2220	477	1240
Port 3	709	4967	340
Port 4	4432	370	1096

	Product 1	Product 2	Product 3
Port 5	1441	1612	719
Port 6	5440	7140	3032
Port 7	5253	2992	6308
Port 8	3886	1756	1612

From the several datasets it can be concluded that the model and algorithm always can result the optimal route. Therefore, even if all the tanker is not being used for the routing, but it is can be because of the inventory condition and the less of critical ports in the planning horizon. It can be seen from Dataset 2 and Dataset 3 by having a different condition of inventory, the program still can result the route. However, despite the condition of the inventory and demand rate, the algorithm still can result an optimal route. So the algorithm is consistent enough to result the schedule and it can be concluded that the model and algorithm is robust to solve inventory ship routing problem for dedicated tanker fleet.

4.6 Real Case Data Solving

The real case data are taken based on the condition at one of Energy Company in Indonesia for tanker delivery scheme on Jawa Timur, Bali, NTB, and NTT provinces. Therefore, there are total of 17 ports with 3 depots and 1 depot for each area. Each area is dedicated for itself, it means the responsibility of supply and delivery as well as the tanker can only deliver to the area itself. However, this dedicated area delivery scheme based on the location of the ports. Thus, the assumption is by reducing the possibility of far delivery it will reduce the cost significantly because the highest cost is the traveling cost (bunker cost). The area scheme of this scenario can be seen in figure 4.12 below.

Figure 4.12 Scenario 2 Delivery Area Scheme

In order to conduct all the delivery works, there are 12 tankers available, 4 for each area. Therefore, each tanker are dedicated for certain product. So there will be at least one tanker for each product at each area. The allocation for each area can be seen in table 4.18 below.

Table 4.18 Area Allocation for each Port

Area A	Area B	Area C
Depot Manggis	Depot Reo Reo	Depot Kalabahi
Ampenan	Bima	Dilli
Tanjung Wangi	Badas	Larantuka
Ngurah Rai	Maumere	Tenau
Camplon	Ende Ende	Atutupu
Gresik	Waingapu	

However the performance of delivery depends on the condition of inventory. Thus, the program need to run the scheme for a month or four weeks. The inventory and tankers position of the last week will become the input for the next run period. By using this scheme, at least all the condition of the inventory can be covered. All ports need to be supplied at least once a month depend on the inventory condition. The input data for initial inventory can be seen in table. 4.19 below.

Table 4.19 Initial Inventory for Scenario 2

Tanker	P1	P2	P3
Ampenan	2288	947	5684
Tanjung Wangi	5851	8514	4554
Ngurah Rai	1062	1701	987
Camplon	1780	1860	1192
Gresik	2761	2550	1546
Bima	7450	2876	7139
Badas	5446	1261	3341
Maumere	2159	337	2197
Ende Ende	1693	1012	1630
Waingapu	2028	4883	5616
Dilli	6024	296	4859
Larantuka	4779	1108	2600
Tenau	5513	1616	6109
Atutupu	2379	1231	1683

All other details of the port, depot, and tanker for real data case provided in Appendix D. Therefore, the initial inventory of each tanker and the cost detail can be seen in table 4.20, 4.21, and 4.22 respectively.

Table 4.20 Tanker Initial Inventory for Scenario 2

Tanker	Assigned Product	Initial Inventory
Kerta Dua	3	1401
Andika	1	1652
Karmila	2	1294
Kelud	1	1855
Cakra Bahana	1	1837
Mundu	2	1427
Ketaling	3	1125
Dorolonda	2	884
Kurau	1	1069
Egon	3	1321
Alor	2	1854
Dompu	3	958

Table 4.21 Port Charge and Management Fee for Scenario 2

Port Charge and Management Fee			
Depot Manggis	Rp 3,480,900.00	Maumere	Rp 2,545,075.00
Ampenan	Rp 3,415,300.00	Ende Ende	Rp 2,545,075.00
Tanjung Wangi	Rp 2,545,075.00	Waingapu	Rp 2,750,000.00
Ngurah Rai	Rp 2,545,075.00	Depot Kalabahi	Rp 2,985,000.00
Camplon	Rp 2,545,075.00	Dilli	Rp 2,545,075.00
Gresik	Rp 2,545,075.00	Larantuka	Rp 2,545,075.00
Depot Reo Reo	Rp 3,100,900.00	Tenau	Rp 2,545,075.00
Bima	Rp 3,415,300.00	Atutupu	Rp 2,045,000.00
Badas	Rp 2,545,075.00		

Table 4.22 Bunker Price and Product Price for Scenario 2

Bunker Price	Rp 8,280.00
Product Price	
P1	Rp 6,500.00
P2	Rp 12,000.00
P3	Rp 5,500.00

For the first period of scheduling, the input data are still based on the first one. But for the next period, the input is the output of the previous period of scheduling. Accordingly, data that become input for the next period are inventory condition and tanker position. This repetition is done until four times or one month of scheduling. Thus, the routing result for all 12 tankers in for periods of scheduling can be seen in table 4.23, 4.24, 4.25, and 4.26.

Table 4.23 Period 1 Tanker Route

Tanker	Route
Kerta Dua	Camplon---Manggis---Gresik---Manggis---Ngurah Rai
Andika	
Karmila	Ampenan---Manggis---Gresik
Kelud	Ngurah Rai---Manggis---Ngurah Rai
Cakra Bahana	Bima---Reo Reo---Waingapu
Mundu	
Ketaling	
Dorolonda	
Kurau	

Tanker	Route
Egon	
Alor	Tenau---Kalabahi---Dilli
Dompu	

Table 4.24 Period 2 Tanker Route

Tanker	Route
Kerta Dua	Ngurah Rai---Manggis---Camplon---Manggis---Tanjung Wangi
Andika	Ngurah Rai---Manggis
Karmila	Gresik---Manggis---Ngurah Rai---Camplon
Kelud	Ngurah Rai---Manggis---Ampenan---Manggis---Camplon---Gresik
Cakra Bahana	Waingapu---Reo Reo---Maumere---Ende Ende
Mundu	Badas---Reo Reo---Ende Ende--Badas---Reo Reo--Bima
Ketaling	Waingapu---Reo Reo---Ende EndeEnde Ende---Reo Reo---Badas
Dorolonda	Badas---Reo Reo
Kurau	Larantuka---Kalabahi---Atutupu
Egon	Kalabahi---Kalabahi---Atutupu
Alor	Dilli---Kalabahi---Tenau---Atutupu---Larantuka
Dompu	

Table 4.25 Period 3 Tanker Route

Tanker	Route
Kerta Dua	Tanjung Wangi---Manggis--Ampenan---Manggis---Gresik---Manggis---Ngurah Rai
Andika	Ngurah Rai---Manggis---Ngurah Rai
Karmila	Camplon---Manggis---Gresik---Ngurah Rai
Kelud	Gresik---Manggis---Tanjung Wangi---Camplon
Cakra Bahana	Ende Ende---Reo Reo---Bima---Maumere---Waingapu---Badas
Mundu	
Ketaling	Badas---Reo Reo---Maumere---Reo Reo---Bima
Dorolonda	
Kurau	Atutupu---Kalabahi---Larantuka---Atutupu---Tenau
Egon	Atutupu---Kalabahi---DilliDilli---Kalabahi---Atutupu
Alor	
Dompu	

Table 4.26 Period 4 Tanker Route

Tanker	Route
Kerta Dua	Ngurah Rai---Manggis---Camplon---Manggis---Tanjung Wangi
Andika	
Karmila	Ngurah Rai---Manggis---Camplon---Ampenan---Ngurah Rai
Kelud	Camplon---Manggis---Camplon
Cakra Bahana	Badas---Reo Reo---Ende Ende---Bima---Maumere---Badas---Waingapu
Mundu	Ende Ende---Reo Reo---MaumereEnde Ende---Reo Reo
Ketaling	Bima---Reo Reo---Ende Ende
Dorolonda	Bima---Reo Reo---Ende Ende
Kurau	Tenau---Kalabahi---Atutupu---Dilli---Tenau---Larantuka
Egon	Atutupu---Kalabahi---Atutupu
Alor	Larantuka---Kalabahi---Atutupu---Tenau---Kalabahi--Larantuka
Dompu	Tenau---Kalabahi---Larantuka

Due to the condition of the inventory, there are various conditions of route, whether the tanker is idle or even force to deliver late deliveries. The definition of late deliveries itself is when the current inventory level reach zeroes level before any tanker can make the delivery. From the tables there are no late deliveries occurred for 4 periods of scheduling. Therefore, tanker Dompu is idle for three periods. This happened because delivery frequency and demand for area C is small for the assigned product. It is the same condition with tanker Mundu for period 1 and 3. However, those tankers are still needed in other period. The recapitulation of total cost for all 4 periods can be seen in table 4.27 below.

Table 4.27 Cost Recapitulation of Real Case Data Solving

Period	
1	Rp 2,792,822,102.33
2	Rp 9,430,366,462.52
3	Rp 10,917,820,052.02
4	Rp 12,396,603,012.01
Total Cost	Rp 35,537,611,628.88

From the cost it can be concluded that frequency of delivery is raised from time to time. This happened because the inventory condition at some point will deplete and need to be supplied.The high cost does not include the penalty cost due to late deliveries. So, from the route and cost seen that 12 tanker is sufficient to cover all deliveries in area A, B, and C. Thus, another output that can be a consideration is tanker utilization. The recapitulation of tankers utilization can be seen in table 4.28 below.

Table 4.28 Tanker Utilization Recapitulation

Tanker	Period				Average
	1	2	3	4	
Kerta Dua	0.27	0.29	0.38	0.29	0.31
Andika	0.00	0.03	0.05	0.00	0.02
Karmila	0.21	0.30	0.44	0.40	0.34
Kelud	0.03	0.31	0.23	0.16	0.18
Cakra Bahana	0.20	0.24	0.74	0.90	0.52
Mundu	0.00	0.21	0.01	0.17	0.10
Ketaling	0.00	0.53	0.56	0.19	0.32
Dorolonda	0.00	0.28	0.00	0.47	0.19
Kurau	0.00	0.09	0.54	0.54	0.29
Egon	0.00	0.07	0.29	0.09	0.11
Alor	0.20	0.62	0.00	0.50	0.33
Dompu	0.00	0.00	0.00	0.20	0.05
Average	0.08	0.25	0.27	0.33	0.23

Tanker utilization calculation is based on the planning horizon. It means that the tanker operational time divided by the time of the entire planning horizon. However, not all tankers fully operated for 7 days. Many deliveries are done in day one or two which is good that port can be supplied as fast as possible, but in other way make the tanker utilization is not so high. The exact parameter to see is when the tanker utilization is zero. It means that the tanker is idle for the entire planning horizon. If the tanker has too many idle periods, it become a strong consideration in evaluating the area. From table 4.28, the number of idle tankers for 4 periods is 11 times with tanker Dompu is idle for entire 3 periods. Therefore, the decision to increase or reduce the number of tanker available also needs to consider about the number of late delivery as well as the cost implied. If the scheduling done well, there will be no extreme inventory condition in the ports. Therefore, example of port's inventory graph can be seen in figure 4.13, 4.14, and 4.15 below.

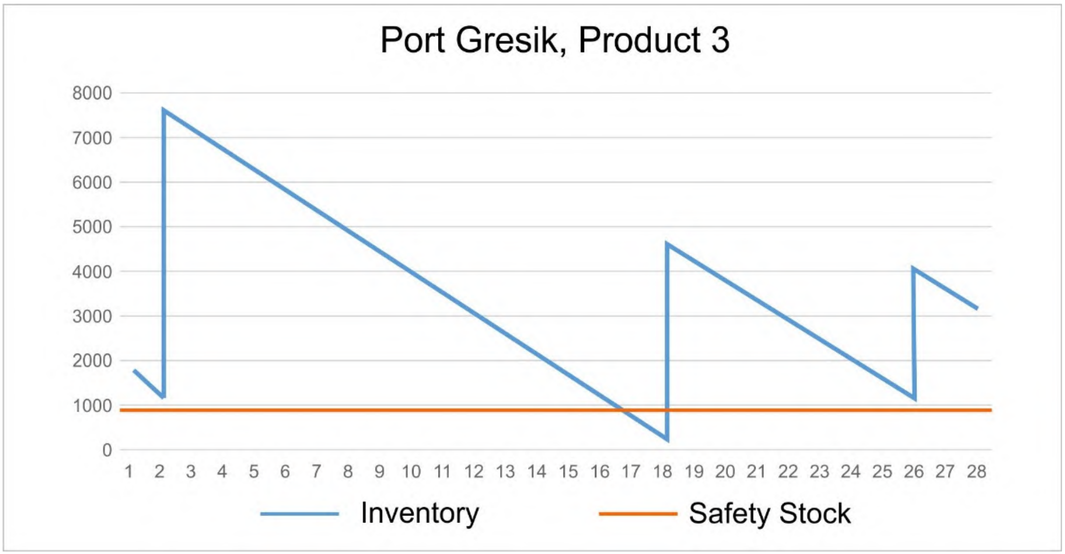

Figure 4.13 Inventory Flow of Port Gresik, Product 3

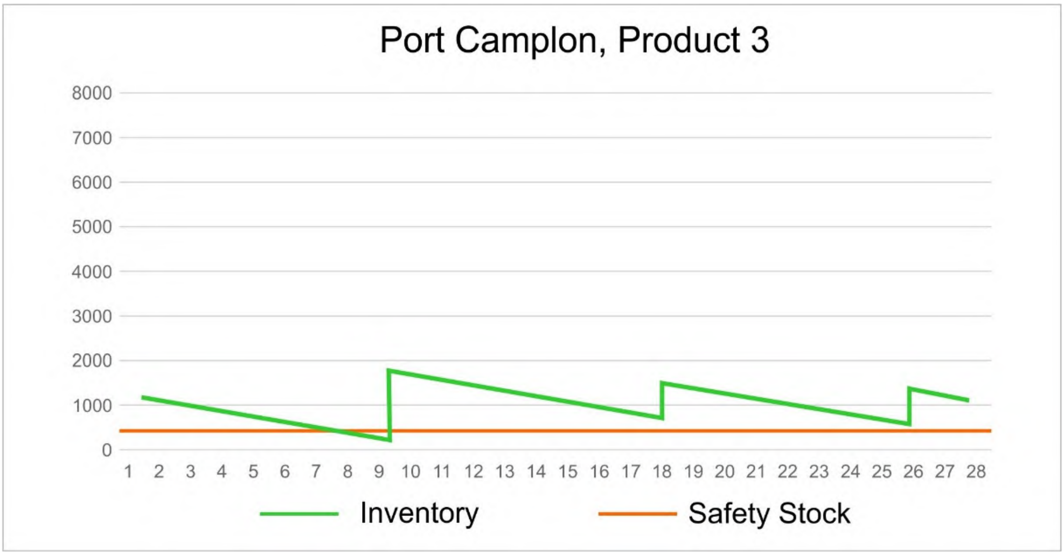

Figure 4.14 Inventory Flow of Port Camplon, Product 3

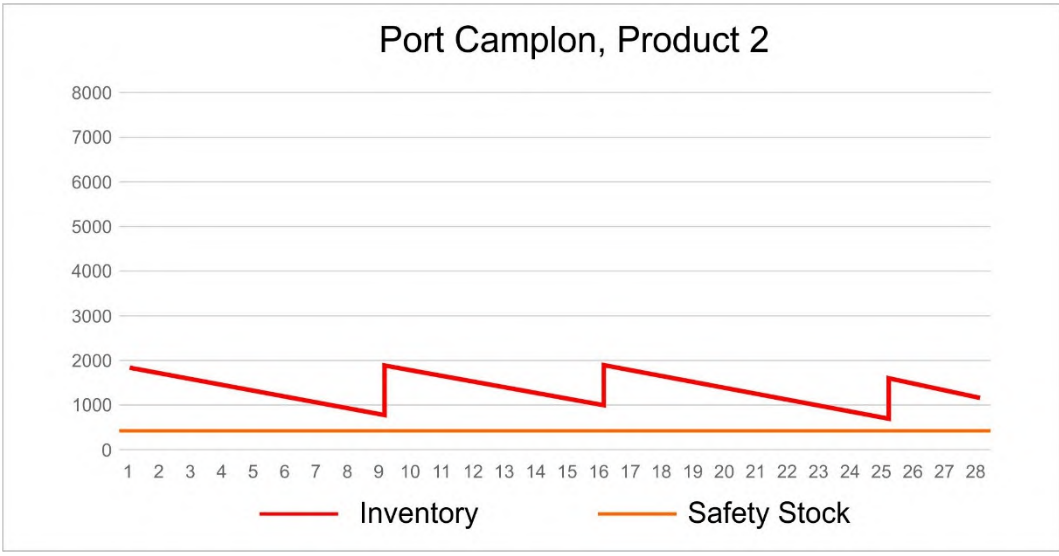

Figure 4.15 Inventory Flow of Port Camplon, Product 2

CHAPTER V
NUMERICAL EXPERIMENTS

This chapter conducts the numerical experiments regarding the model and algorithm. All numerical experiments consist of solving several experiments with its own purposes and then analyze the result. The list of experiments and its purposes can be seen in table 5.1 below.

Table 5.1 List of Experiments

Experiments	Purpose	Decision Variable	Parameter
1	To decide the best number of tankers required to fulfill a certain demand.	Number of Tanker Required	Port and Depot Location, Capacity, Daily Demand Rate, Tanker Position, Initial Inventory, Cost, Real case data, Area allocation scheme
2	To evaluate the performance of 12 tankers in order to fulfill deliveries with various demand rate	Daily Demand Rate	Port and Depot Location, Capacity, Number of tanker available, Tanker Position, Initial Inventory, Cost, Real case data, Area allocation scheme

5.1 Experiment 1

The key aspect to this experiment is to decide the best number of tanker required to fulfill certain demand. Demand data, input, and other parameter for this experiment is using real data case that the same as sub-chapter 4.6. The decision variable in this experiments is to modify the number of tanker in the beginning of the planning horizon.

5.1.1 Description

This experiment uses input and parameter from real data case. Therefore, in order to find the best number of tankers required, perform analysis based on the result for each scenario with its own changing condition. Thus, every scenario in this experiment is affected by another scenario. Table 5.2 below shows the list of scenarios for this experiments.

Table 5.2 Scenario's List in Experiment 1

Scenario	Number of Tanker	Changing Condition
1	11	Removing tanker Dompu
2	10	Removing tanker Mundu
3	9	Removing tanker Andika

5.1.1.1 Scenario 2: 11 Tankers

Due to the result of using 12 tankers, there is a lot of idle tankers and a small number of utilization. Therefore, this scenario is try the same demand scheme by removing tanker Dompu from Area C. So the number of tankers available in the beginning of planning horizons is 11 tankers. Same as before, scheduling done in 4 periods and compare it with real data case's result. The tanker allocation for scenario 1 can be seen in table 5.3 below.

Table 5.3 Tanker Allocation for Scenario 1 Experiment 1

Area		
A	B	C
Kerta Dua	Cakra Bahana	Kurau
Andika	Mundu	Egon
Karmila	Ketaling	Alor
Kelud	Dorolonda	

After running the program in scenario 1 for 4 periods, then compare the result with result from the real data case. The comparison of tanker utilization and idle tankers recapitulation of scenario 1 with real data case can be seen in table 5.4 and 5.5 below.

Table 5.4 Tanker Utilization Comparison for Scenario 1 Experiment 1

Tanker	Real Data Case	Experiment 1, Scenario 1
Kerta Dua	0.31	0.31
Andika	0.02	0.02
Karmila	0.34	0.34

Tanker	Real Data Case	Experiment 1, Scenario 1
Kelud	0.18	0.18
Cakra Bahana	0.52	0.52
Mundu	0.10	0.10
Ketaling	0.32	0.32
Dorolonda	0.19	0.19
Kurau	0.29	0.22
Egon	0.11	0.17
Alor	0.33	0.33
Dompu	0.05	-
Average	0.23	0.25

Table 5.5 Number of Idle Tanker Comparison for Scenario 2 Experiment 1

Period	Real Data Case	Experiment 1, Scenario 2
1	7	6
2	1	0
3	3	2
4	1	1
Total	12	9

Dompu tanker previously only had 0.05 utilization and only supply the product in 1 period. Therefore, in removing Dompu it has less impact to the utilization which is only increase 0.02 from 0.23. Although, the number of idle tankers is decreasing from 12 to 9.

Table 5.6 Total Cost Comparison for Scenario 1 Experiment 1

Period	Real Data Case		Experiment 1, Scenario 1	
1	Rp	2,792,822,102.33	Rp	2,792,967,097.62
2	Rp	9,430,366,462.52	Rp	9,430,366,462.52
3	Rp	10,917,820,052.02	Rp	10,917,820,052.02
4	Rp	12,396,603,012.01	Rp	11,486,055,335.46
Total Cost	Rp	35,537,611,628.88	Rp	34,627,208,947.62

From table 5.10 can be seen that the total cost for scenario 2 is lower than real data case. This occurred because Dompu's route in real data case must be covered by another tanker which is causing the more efficient than before. However in this scenario, there are no late deliveries occurred. So by using 11 tanker is sufficient to fulfill all the demand and deliveries. But still the average tanker utilization is still small and there are a lot of idle tanker in 4 periods of scheduling. Figure 5.1 below presents the inventory summary for port Atutupu, product 3.

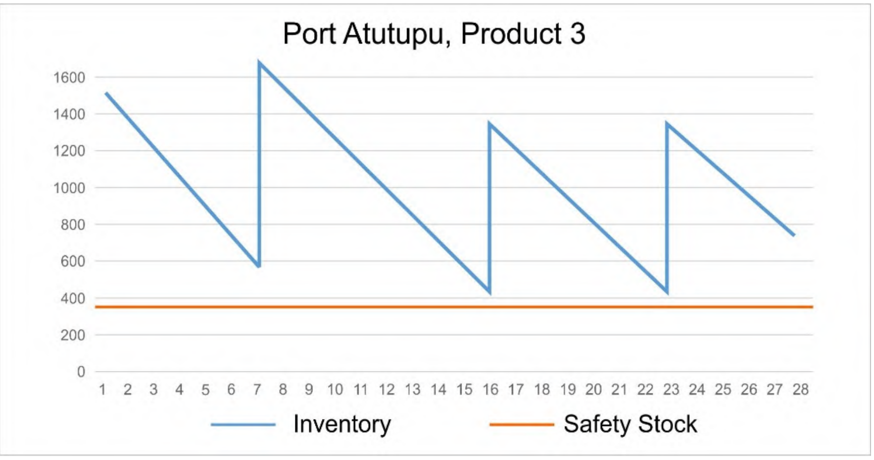

Figure 5.1 Inventory Flow of Port Atutupu, Product 3 using 11 Tankers

5.1.1.2 Scenario 2: 10 Tankers

In scenario 2, Scenario 1 is not significantly different from the real data case. Thus, scenario 2 performed to evaluate is 10 tankers sufficient to fulfill all deliveries. The changing is removing tanker Mundu from Area B. So the tanker allocation become like in table 5.7 below.

Table 5.7 Tanker Allocation for Scenario 2 Experiment 1

Area		
A	B	C
Kerta Dua	Cakra Bahana	Kurau
Andika	Ketaling	Egon
Karmila	Dorolonda	Alor
Kelud		

Same as the previous scenarios, the program runs the scheduling for 4 periods. Therefore, the result of tankers utilization and number of idle tankers can be seen in table 5.8 and 5.9 below.

Table 5.8 Tanker Utilization Comparison for Scenario 2 Experiment 1

Tanker	Real Data Case	Experiment 1, Scenario 2
Kerta Dua	0.31	0.31
Andika	0.02	0.02
Karmila	0.34	0.34
Kelud	0.18	0.18
Cakra Bahana	0.52	0.48
Mundu	0.10	-
Ketaling	0.32	0.32
Dorolonda	0.19	0.41
Kurau	0.29	0.29
Egon	0.11	0.17
Alor	0.33	0.33
Dompu	0.05	-
Average	0.23	0.30

Table 5.9 Idle Tanker Comparison for Scenario 3 Experiment 1

Period	Real Data Case	Experiment 1, Scenario 3
1	7	4
2	1	0
3	3	2
4	1	1
Total	12	7

Refering to table 5.8, the tanker utilization is increasing from 0.23 to 0.30. Tanker Mundu removal give slightly changes in tanker utilization. Therefore, the number of idle tanker is decreasing from 12 to 7. The total cost for this scenario can be seen in table 5.10 below.

Table 5.10 Total Cost Comparison for Scenario 2 Experiment 1

Period	Real Data Case		Experiment 1, Scenario 2	
1	Rp	2,792,822,102.33	Rp	5,096,560,294.94
2	Rp	9,430,366,462.52	Rp	9,488,203,427.23
3	Rp	10,917,820,052.02	Rp	10,709,776,913.72
4	Rp	12,396,603,012.01	Rp	10,666,879,976.05
Total Cost	Rp	35,537,611,628.88	Rp	35,961,420,611.93

There are no late deliveries occurred in this scenario. Thus, there are no lateness cost given to the total cost. By using 10 tankers, the total cost is increasing about Rp 424,465,901,34 from the total cost in the real data case. It is because the route in period 1 for area B is less efficient than before. So, 10 tankers are sufficient to fulfill all demand and deliveries.

5.1.1.3 Scenario 3: 9 Tankers

By using dedicated tanker policy, the limit of 3 Areas with 3 products scheduling for real data case is 1 for each. So that makes the number of tankers is 9 tankers for this scenario. This scenario runs by removing tanker Andika from Area A. Therefore, the result of tankers utilization and number of idle tankers can be seen in table 5.11 and 5.12 below.

Table 5.11 Tanker Utilization in Scenario 3 Experiment 1

Tanker	Real Data Case	Experiment 1, Scenario 3
Kerta Dua	0.31	0.31
Andika	0.02	-
Karmila	0.34	0.34
Kelud	0.18	0.24
Cakra Bahana	0.52	0.48
Mundu	0.10	-
Ketaling	0.32	0.31
Dorolonda	0.19	0.41
Kurau	0.29	0.22
Egon	0.11	0.17
Alor	0.33	0.25

Tanker	Real Data Case	Experiment 1, Scenario 3
Dompu	0.05	-
Average	0.23	0.33

Table 5.12 Idle Tanker Comparison of Scenario 3 Experiment 1

Period	Real Data Case	Experiment 1, Scenario 3
1	7	3
2	1	0
3	2	2
4	1	0
Total	12	5

By removing tanker Andika, the tanker utilization is increasing from 0.23 to 0.33. Even at some period the tanker utilization can reach to 0.70. Along with that, the number of idle tanker also declines into 5. This occurred because at some point, there are no deliveries that need to be fulfilled. So that the program forces the tanker to have no route or idle. Therefore, the total cost for this scenario can be seen in table 5.13 below.

Table 5.13 Total Cost Comparison of Scenario 3 Experiment 1

Period	Real Data Case	Experiment 1, Scenario 3
1	Rp 2,792,822,102.33	Rp 5,106,358,294.94
2	Rp 9,430,366,462.52	Rp 8,796,265,429.82
3	Rp 10,917,820,052.02	Rp 11,064,487,661.56
4	Rp 12,396,603,012.01	Rp 11,531,238,527.97
Total Cost	Rp 35,537,611,628.88	Rp 36,498,349,914.29

The concerned issue of using 9 tankers is late deliveries. Therefore, from the inventory flow indicates that there are no late deliveries occurred in 4 periods. From the total cost indicates that it has less route efficiency. So by using 9 tankers is sufficient to fulfill all demand and deliveries. Proven by one of example of inventory summary in port Bima, product 1. It can be seen in figure 5.2 below.

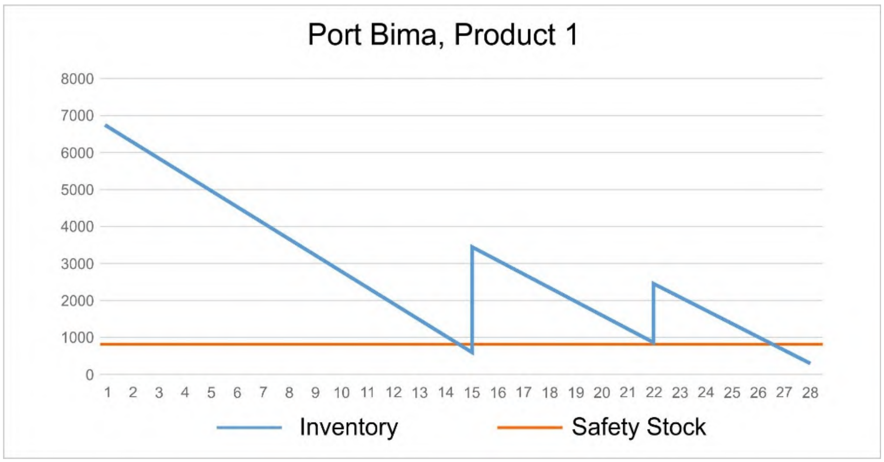

Figure 5.2 Inventory Flow of Port Bima, Product 1, using 9 Tankers

5.1.2 Analysis of Experiment 1

By elaborating all the scenarios, the result recapitulation of experiment 1 can be seen in table 5.14 below.

Table 5.14 Comparison of Each Scenario in Experiment 1

Scenario	Number of Tanker	Tanker Utilization	Idle Tanker	Total Cost
Real Case Data	12	0.23	12	Rp 35,537,611,628.88
1	11	0.25	9	Rp 35,961,420,611.93
2	10	0.30	7	Rp 35,961,420,611.93
3	9	0.33	5	Rp 36,498,349,914.29

From result of all 3 scenarios, by removing several tankers it still sufficient to fulfill all demands. Because there are no late deliveries occurred in all scenarios. Still in all scenarios, there are conditions when the stock is below safety stock, but always there is a route to fulfill those demands. However, by referring to tanker utilization, even by minimizing the number of tanker, the average tanker utilization is still small about 0.33. This is because almost all deliveries are done in the middle of the week. Causing the work hours of the tanker only until the middle even before that. Compared to the work hours in all planning horizon, makes the tanker utilization is small. Eventhough some tanker in certain period has utilization more than 0.50.

Minimum number of tanker required to deliver all demand with current Area scheme is 9 tankers. Therefore, the result of running scheduling using 9 tankers shows good result.Tanker utilization increase 0.10, and there is no late deliveries occurred. So the best number of tanker required to deliver all demand in real data case is 9 tankers.

5.2 Experiment 2

In this experiment, the aim is to know the limit of 12 tankers in order to fulfill deliveries with various demand rates. So the changing variable is the daily demand rate with other input and parameter still the same with the real data case.

5.2.1 Description

The demand is various from 125% to 150% from real case data demand rate. The comparison data which is 100% demand rate, is already provided in sub-chapter 4.6. So it will not repeat again. Demand rate is the parameter that can determine how much inventory has depleted each day as well as determine is the port critical or not based on the inventory condition.

The number of tankers available is 12 tankers with 4 tankers for each area. Therefore, the scheduling performed in 4 periods or 4 weeks. Thus, real case data daily demand rate can be seen in table 5.15 below.

Table 5.15 100% Demand Rate as Basis

Port	Daily Demand Rate		
	P1	P2	P3
Ampenan	285	41	355
Tanjung Wangi	304	250	457
Ngurah Rai	145	189	140
Camplon	157	138	123
Gresik	212	485	489
Bima	447	250	365

Port	Daily Demand Rate		
	P1	P2	P3
Badas	254	167	227
Maumere	178	77	129
Ende Ende	136	89	149
Waingapu	380	200	183
Dilli	231	236	298
Larantuka	287	85	101
Tenau	290	180	140
Atutupu	285	106	153

5.2.1.1 Scenario 1: 125% Demand Rate

Logically, if the demand rate higher than before, it will affect to the increasing frequency of delivery. Therefore, the route condition will not be the same as before. The big question is 12 tankers sufficient to cover delivery area with high demand rates. So the demand rate used for this scenario can be seen in table 5.16 below.

Table 5.16 125% Demand Rate for Scenario 1 Experiment 2

Port	Daily Demand Rate		
	P1	P2	P3
Ampenan	357	52	444
Tanjung Wangi	380	313	572
Ngurah Rai	182	237	175
Camplon	197	173	154
Gresik	265	607	612
Bima	559	313	457
Badas	318	209	284
Maumere	223	97	162
Ende Ende	170	112	187
Waingapu	475	250	229
Dilli	289	295	373
Larantuka	359	107	127
Tenau	363	225	175
Atutupu	357	133	192

From the recapitulation, it is known that the number of idle tanker total only 8. This number is low because the frequency of delivery is more than original. Therefore, the tankers utilization also increases to 0.32. This indicates a good use of 12 tankers. Thus, the recapitulation of late deliveries, lateness cost, and total cost of this scenario can be seen in table 5.17 below.

Table 5.17 Recaptulation for Scenario 1 Experiment 2

Period	Late Deliveries	Lateness Cost	Operational Cost	Total Cost
1	0	Rp -	Rp 8,678,304,195	Rp 8,678,304,195
2	0	Rp -	Rp 13,939,668,938	Rp 13,939,668,938
3	1	Rp 116,025,000	Rp 13,258,315,565	Rp 13,374,340,565
4	0	Rp -	Rp 14,601,974,903	Rp 14,601,974,903
Total	1	Rp 116,025,000	Rp 50,478,263,601	Rp 50,594,288,601

In this scenario, there are late deliveries occured. 1 late delivery for port Atutupu in period 3. All this late deliveries happened in the first day because the condition of the inventory is so low in the beginning of the planning horizon. Force the program to do late deliveries. Port Atutupu have only 3000 capacity with demand rate of 357. Logically, the stock will be depleted with only 6 days. Even if the deliveries made in every period.

Due to late deliveries, there is lateness cost charged for the cost. In this scenario, by increasing the demand rate, the frequency of delivery also increased. The increasing of delivery frequency have a significant impact to cost which is higher than 100% demand rate. Therefore, 12 tankers are sufficient to fulfill almost all demand and delivery with 4 late deliveries.

5.2.1.2 Scenario 2: 150% Demand Rate

This scenario is extreme condition, which is the demand rate is increase about a half from the normal one. Therefore, demand rate for this scenario can be seen in table 5.18 below.

Table 5.18 150% Demand Rate for Scenario 2 Experiment 2

Port	Daily Demand Rate		
	P1	P2	P3
Ampenan	428	62	533
Tanjung Wangi	456	375	686
Ngurah Rai	218	284	210
Camplon	236	207	185
Gresik	318	728	734
Bima	671	375	548
Badas	381	251	341
Maumere	267	116	194
Ende Ende	204	134	224
Waingapu	570	300	275
Dilli	347	354	447
Larantuka	431	128	152
Tenau	435	270	210
Atutupu	428	159	230

Therefore, there are a lot of late deliveries in this scenario. Because the inventory condition is extreme that many ports have small value of days of supply at the same period forced the program to make a late deliveries. At some point, because the demand is too high and the capacity of the tanker are limited, forced the tanker to reduce the amount of product delivered to the port. So that all ports can be supplied, even not at the maximum point.

There are only about 6 idle tanker for all periods with tanker utilization average of 0.40. Due to many late deliveries, there are penalty cost embedded in the total cost. Therefore, the recapitulation of this scenario as seen in table 5.19 below.

Table 5.19 Recapitulation for Scenario 2 Experiment 2

Period	Late Deliveries	Lateness Cost	Operational Cost	Total Cost
1	1	Rp 212,400,000	Rp 11,834,885,168	Rp 12,047,285,168
2	4	Rp 462,200,000	Rp 14,140,091,994	Rp 14,602,291,994
3	5	Rp 1,070,000,000	Rp 16,293,548,954	Rp 17,363,548,954
4	8	Rp 1,968,775,000	Rp 16,531,127,426	Rp 18,499,902,426
Total	18	Rp 3,713,375,000	Rp 58,799,653,541	Rp 62,513,028,541

Different with scenario 1, late deliveries occurred in this scenario because tanker was coming late after the stock runs out. Therefore, there are lost in sales at that day so there are lateness cost. In this scenario, total of lateness cost is Rp 3,713,375,000 which is a high cost. Thus, operational cost is increasing due to increasing of delivery frequency as the impact of high demand rate. In this condition, 12 tankers are not sufficient to deliver all demand on time because there are 18 late deliveries in this scenario. Figure 5.3 below provides the condition of inventory in port Bima for product 1.

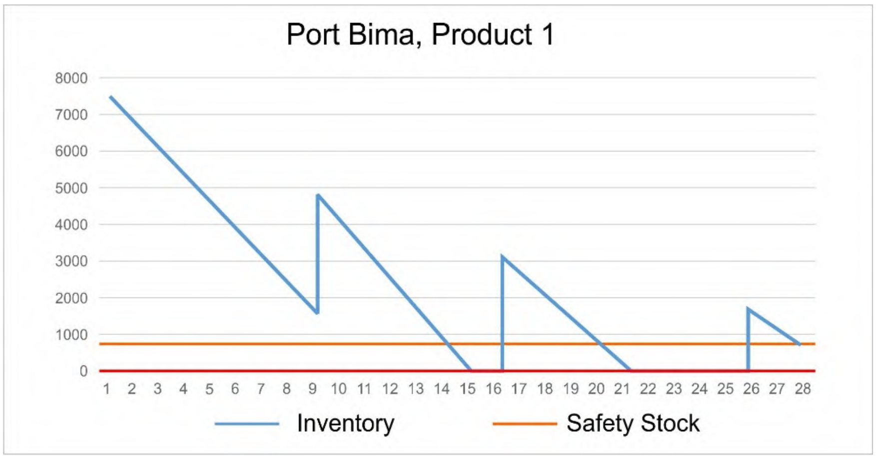

Figure 5.3 Inventory Flow of Port Bima, Product 1, Experiment 2

5.2.2 *Analysis of Experiment 2*

From the all two scenarios, 12 tanker is actually not sufficient to deliver all deliveries on time especially for 150% demand rate. The recapitulation of results in experiment 2 presented in table 5.20 below.

Table 5.20 Recapitulation of Experiment 2

Scenario	125% Demand Rate	150% Demand Rate
Idle Tanker	8	9
Utilization	0.32	0.39
Late Deliveries	1	18
Lateness Cost	Rp 116,025,000	Rp 3,713,375,000
Operational Cost	Rp 50,478,263,601	Rp 58,799,653,541
Total Cost	Rp 50,594,288,601	Rp 62,513,028,541

In 150% demand rate, the tanker utilization only 0.39 but there are late 18 late deliveries. The issue of late deliveries in this experiment has received considerable critical attention. It is because dedicated tanker policy, make the tanker only can cover other tanker deliveries if have same product assigned. However, in this case many products only covered by one tanker. Which makes the tanker not flexible in terms of routing. Causing many late deliveries for several ports. Therefore, 12 tankers is sufficient to fulfill almost all demand and deliveries for 125% demand rate, but not sufficient for 150% demand rate.

ATTACHMENT

ATTACHMENT A

Dataset 1 Input

Port Coordinates and Capacity

Port	Coordinate		Capacity			Assigned Depot
	X	Y	P1	P2	P3	
P1	59	387	5000	8500	2500	1
P2	380	78	12000	2500	12000	1
P3	470	266	8000	3000	12000	1
P4	33	91	8500	2500	7000	1
P5	188	487	8500	10000	8500	1
P6	473	387	3500	8000	3500	2
P7	461	215	2500	12000	5000	2
P8	34	100	7000	8500	7000	2
P9	110	45	6000	8500	5000	2
P10	465	462	6000	8500	10000	2
P11	144	428	12000	7000	6000	3
P12	140	86	7000	3500	2500	3
P13	160	369	3500	10000	2500	3
P14	306	355	6000	12000	8000	3
P15	351	235	7000	7000	7000	3

Port Demand Rate and Initial Inventory

Port	Daily Demand Rate			Initial Inventory		
	P1	P2	P3	P1	P2	P3
P1	93	68	62	4024	4210	2325
P2	332	424	12	11846	2396	2411
P3	475	29	279	1277	1613	3038
P4	451	239	200	4613	1894	6416
P5	178	95	432	7208	8133	2332
P6	395	457	293	3372	1866	1195
P7	53	292	423	2109	9405	4864
P8	471	498	472	5820	5878	4877
P9	268	59	434	5686	6593	3255

Port	Daily Demand Rate			Initial Inventory		
	P1	P2	P3	P1	P2	P3
P10	111	20	278	2675	7867	9210
P11	20	146	338	5146	3000	3732
P12	299	427	408	1736	1485	1265
P13	160	354	187	1508	5447	2500
P14	365	105	411	5582	3098	1682
P15	200	361	176	6674	2425	3901

Depot Coordinates

Depot	Coordinate	
	X	Y
D1	260	118
D2	123	244
D3	496	109

Ship Input Detail

Ship	Name	Inventory		Assigned Product	Initial Inventory	Initial Position		Pumping Rate
		Minimum	Maximum			KM	Destination	
1	S1	900	9000	1	1500	5	2	30
2	S2	650	6500	2	6500	0	1	35
3	S3	900	9000	3	2000	6.7	4	30
4	S4	650	6500	1	6500	8	5	30
5	S5	800	8000	2	2000	8	4	35
6	S6	750	7500	3	1500	9	2	30
7	S7	600	6000	1	1000	4	6	30
8	S8	650	6500	2	1000	2	5	30
9	S9	1000	10000	3	5000	6	6	35

Port Charge and Management Fee

Port	Port Charge and Management Fee	Port	Port Charge and Management Fee
P1	Rp 2,500,000	P10	Rp 4,500,000
P2	Rp 3,500,000	P11	Rp 2,500,000

Port	Port Charge and Management Fee	Port	Port Charge and Management Fee
P3	Rp 4,500,000	P12	Rp 3,500,000
P4	Rp 2,500,000	P13	Rp 4,500,000
P5	Rp 4,500,000	P14	Rp 2,500,000
P6	Rp 2,500,000	P15	Rp 4,500,000
P7	Rp 3,500,000	D1	Rp 4,500,000
P8	Rp 2,500,000	D2	Rp 4,500,000
P9	Rp 3,500,000	D3	Rp 4,500,000

Bunker and Product Cost

Bunker Price	Rp 8,280
Product Price	
P1	Rp 6,500
P2	Rp 12,000
P3	Rp 5,500

Time Windows

	Port	Depot
Open	8	6
Close	16	18

ATTACHMENT B

Dataset 2 Input

Port Coordinates and Capacity

Port	Coordinate		Capacity			Assigned Depot
	X	Y	P1	P2	P3	
P1	416	455	5000	3500	5000	1
P2	355	316	3500	2500	3000	1
P3	481	43	2500	8000	2500	1
P4	151	38	7000	8000	6000	1
P5	82	151	8000	3500	7000	1
P6	60	212	7000	8500	5000	1
P7	27	25	7000	5000	10000	1
P8	87	141	7000	3500	6000	1

Port Initial Inventory and Demand Rate

Port	Daily Demand Rate			Initial Inventory		
	P1	P2	P3	P1	P2	P3
P1	198	178	212	1098	1193	3107
P2	160	189	220	3000	648	825
P3	251	254	270	800	3008	2002
P4	108	106	141	3367	989	5251
P5	297	236	184	766	1807	6073
P6	195	170	246	2868	2018	3532
P7	122	251	258	5676	3171	8561
P8	297	218	292	4418	3272	4589

Depot Coordinates

Depot	Name	Coordinate	
		X	Y
1	D1	176	432

Ship Input Detail

Ship	Inventory		Assigned Product	Initial Inventory	Initial Position		Pumping Rate
	Minimum	Maximum			KM	Destination	
S1	600	6000	1	1616	1	9	30

Ship	Inventory		Assigned Product	Initial Inventory	Initial Position		Pumping Rate
	Minimum	Maximum			KM	Destination	
S2	1000	10000	1	1008	10	8	50
S3	600	6000	2	826	9	8	30
S4	1200	12000	2	1905	4	9	50
S5	850	8500	3	966	9	4	40
S6	1000	10000	3	1054	10	7	50

Port Charge and Management Fee

Port	Port Charge and Management Fee
P1	Rp 2,500,000
P2	Rp 4,500,000
P3	Rp 4,500,000
P4	Rp 3,500,000
P5	Rp 4,500,000
P6	Rp 2,500,000
P7	Rp 3,500,000
P8	Rp 4,500,000

Bunker and Product Price

Bunker Price	Rp 8,280
Product Price	
P1	Rp 6,500
P2	Rp 12,000
P3	Rp 5,500

Time Windows

	Port	Depot
Open	8	6
Close	15	18

ATTACHMENT C

Dataset 3 Input

Port Coordinates and Capacity

Port	Coordinate		Capacity			Assigned Depot
	X	Y	P1	P2	P3	
P1	416	455	5000	3500	5000	1
P2	355	316	3500	2500	3000	1
P3	481	43	2500	8000	2500	1
P4	151	38	7000	8000	6000	1
P5	82	151	8000	3500	7000	2
P6	60	212	7000	8500	5000	2
P7	27	25	7000	5000	10000	2
P8	87	141	7000	3500	6000	2

Port Demand Rate and Initial Inventory

Port	Daily Demand Rate			Initial Inventory		
	P1	P2	P3	P1	P2	P3
P1	198	178	212	2234	2638	3175
P2	160	189	220	1281	1800	1391
P3	251	254	270	2466	6745	795
P4	108	106	141	5188	1112	2083
P5	297	236	184	3520	1691	2007
P6	195	170	246	1221	1187	1452
P7	122	251	258	6107	995	8114
P8	297	218	292	5965	600	3656

Depot Coordinates

Depot	Name	Coordinate	
		X	Y
1	D1	176	432
2	D2	451	23

Ship Input Detail

Ship	Inventory		Assigned Product	Initial Inventory	Initial Position		Pumping Rate
	Minimum	Maximum			KM	Destination	
S1	800	8000	1	1616	1	9	30
S2	1000	10000	1	1008	10	8	50
S3	600	6000	2	826	9	8	30
S4	1200	12000	2	1905	4	9	50
S5	850	8500	3	966	9	4	40
S6	1000	10000	3	1054	10	7	50

Port Charge and Management Fee

Port	Port Charge and Management Fee	Bunker Price	Rp 8,280
		Product Price	
P1	Rp 2,500,000	P1	Rp 6,500
P2	Rp 4,500,000	P2	Rp 12,000
P3	Rp 4,500,000	P3	Rp 5,500
P4	Rp 3,500,000		
P5	Rp 4,500,000		
P6	Rp 2,500,000		
P7	Rp 3,500,000		
P8	Rp 4,500,000		

Time Window

	Port	Depot
Open	8	6
Close	15	18

ATTACHMENT D

Real Case Data Input and Output

Port Coordinate and Capacity

Name	Coordinate		Capacity			Assigned Depot
	X	Y	P1	P2	P3	
Ampenan	421.123	223.815	10000	2000	10000	1
Tanjung Wangi	238.028	289.769	9000	9000	10000	1
Ngurah Rai	320.971	222.638	2500	2200	2500	1
Camplon	117.288	390.63	2000	2200	2000	1
Gresik	47.9622	398.257	8500	12000	9000	1
Bima	179.765	180.647	12000	10000	10000	1
Badas	32.8838	178.435	6000	6000	8000	1
Maumere	564.505	162.951	2500	2000	2500	1
Ende Ende	499.834	138.618	2500	2000	2500	1
Waingapu	348.568	49.0308	8000	6000	7500	1
Dilli	310.952	210.148	6500	6500	6000	1
Larantuka	21.898	232.269	7000	2000	6000	1
Tenau	89.7818	26.545	7000	3500	6500	1
Atutupu	235.404	160.376	3000	2000	2000	1

Port Initial Inventory and Capacity

Name	Daily Demand Rate			Initial Inventory		
	P1	P2	P3	P1	P2	P3
Ampenan	285	41	355	2288	947	5684
Tanjung Wangi	304	250	457	5851	8514	4554
Ngurah Rai	145	189	140	1062	1701	987
Camplon	157	138	123	1780	1860	1192
Gresik	212	485	489	2761	2550	1546
Bima	447	250	365	7450	2876	7139
Badas	254	167	227	5446	1261	3341
Maumere	178	77	129	2159	337	2197
Ende Ende	136	89	149	1693	1012	1630
Waingapu	380	200	183	2028	4883	5616
Dilli	231	236	298	6024	296	4859
Larantuka	287	85	101	4779	1108	2600
Tenau	290	180	140	5513	1616	6109

Name	Daily Demand Rate			Initial Inventory		
	P1	P2	P3	P1	P2	P3
Atutupu	285	106	153	2379	1231	1683

Depot Coordinates and Time Windows

Name	Coordinate	
	X	Y
Manggis	359.299	245.661
Reo Reo	370.49	199.45
Kalabahi	197.082	245.541

	Port	Depot
Buka	8	6
Tutup	16	18

Cost Detail

Port Charge and Management Fee	
Manggis	Rp 3,480,900.00
Reo Reo	Rp 3,100,900.00
Kalabahi	Rp 2,985,000.00
Ampenan	Rp 3,415,300.00
Tanjung Wangi	Rp 2,545,075.00
Ngurah Rai	Rp 2,545,075.00
Camplon	Rp 2,545,075.00
Gresik	Rp 2,545,075.00
Bima	Rp 3,415,300.00
Badas	Rp 2,545,075.00
Maumere	Rp 2,545,075.00
Ende Ende	Rp 2,545,075.00
Waingapu	Rp 2,750,000.00
Dilli	Rp 2,545,075.00
Larantuka	Rp 2,545,075.00
Tenau	Rp 2,545,075.00
Atutupu	Rp 2,045,000.00

Bunker Price	Rp 8,280.00

Product Price	
P1	Rp 6,500.00
P2	Rp 12,000.00
P3	Rp 5,500.00

Period 1 Output

Ship	Route	Number of Late Deliveries
Kerta Dua	Camplon---Manggis---Gresik---Manggis---Ngurah Rai	0
Andika		0
Karmila	Ampenan---Manggis---Gresik	0
Kelud	Ngurah Rai---Manggis---Ngurah Rai	0
Cakra Bahana	Bima---Reo Reo---Waingapu	0
Mundu		0
Ketaling		0
Dorolonda		0
Kurau		0
Egon		0
Alor	Tenau---Kalabahi---Dilli	0
Dompu		0

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,019,170,304.54	0.27
Andika	Rp -	0.00
Karmila	Rp 839,839,086.74	0.21
Kelud	Rp 106,847,774.21	0.03
Cakra Bahana	Rp 421,217,461.40	0.20
Mundu	Rp -	0.00
Ketaling	Rp -	0.00
Dorolonda	Rp -	0.00
Kurau	Rp -	0.00
Egon	Rp -	0.00
Alor	Rp 405,747,475.44	0.20
Dompu	Rp -	0.00
	Rp 2,792,822,102.33	0.08

Period 2 Output

Ship	Route	Number of Late Deliveries
Kerta Dua	Ngurah Rai---Manggis---Camplon---Manggis---Tanjung Wangi	0
Andika	Ngurah Rai---Manggis	0
Karmila	Gresik---Manggis---Ngurah Rai---Camplon	0

Ship	Route	Number of Late Deliveries
Kelud	Ngurah Rai---Manggis---Ampenan---Manggis---Camplon---Gresik	0
Cakra Bahana	Waingapu---Reo Reo---Maumere---Ende Ende	0
Mundu	Badas---Reo Reo---Ende Ende--Badas---Reo Reo--Bima	0
Ketaling	Waingapu---Reo Reo---Ende EndeEnde Ende---Reo Reo---Badas	0
Dorolonda	Badas---Reo Reo	0
Kurau	Larantuka---Kalabahi---Atutupu	0
Egon	Kalabahi---Kalabahi---Atutupu	0
Alor	Dilli---Kalabahi---Tenau---Atutupu---Larantuka	0
Dompu		0

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,142,454,718.23	0.29
Andika	Rp 88,658,391.84	0.03
Karmila	Rp 1,153,174,263.51	0.30
Kelud	Rp 1,114,098,618.69	0.31
Cakra Bahana	Rp 728,669,498.03	0.24
Mundu	Rp 515,055,100.30	0.21
Ketaling	Rp 1,703,406,733.90	0.53
Dorolonda	Rp 760,533,599.62	0.28
Kurau	Rp 317,839,486.61	0.09
Egon	Rp 249,174,964.63	0.07
Alor	Rp 1,657,301,087.17	0.62
Dompu	Rp -	0.00
	Rp 9,430,366,462.52	0.27

Period 3 Output

Ship	Route	Number of Late Deliveries
Kerta Dua	Tanjung Wangi---Manggis--Ampenan---Manggis---Gresik---Manggis---Ngurah Rai	0
Andika	Ngurah Rai---Manggis---Ngurah Rai	0
Karmila	Camplon---Manggis---Gresik---Ngurah Rai	0
Kelud	Gresik---Manggis---Tanjung Wangi---Camplon	0

Ship	Route	Number of Late Deliveries
Cakra Bahana	Ende Ende---Reo Reo---Bima---Maumere---Waingapu---Badas	0
Mundu		0
Ketaling	Badas---Reo Reo---Maumere---Reo Reo---Bima	0
Dorolonda		0
Kurau	Atutupu---Kalabahi---Larantuka---Atutupu---Tenau	0
Egon	Atutupu---Kalabahi---DilliDilli---Kalabahi---Atutupu	0
Alor		0
Dompu		0

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,440,222,595.73	0.38
Andika	Rp 128,233,027.01	0.05
Karmila	Rp 1,730,287,414.67	0.44
Kelud	Rp 860,940,640.49	0.23
Cakra Bahana	Rp 2,712,271,658.64	0.74
Mundu	Rp 203,054,388.30	0.01
Ketaling	Rp 1,457,995,824.70	0.56
Dorolonda	Rp -	0.00
Kurau	Rp 1,490,243,873.73	0.54
Egon	Rp 894,570,628.75	0.29
Alor	Rp -	0.00
Dompu	Rp -	0.00
	Rp 10,917,820,052.02	0.29

Period 4 Output

Ship	Route	Number of Late Deliveries
Kerta Dua	Ngurah Rai---Manggis---Camplon---Manggis---Tanjung Wangi	0
Andika		0
Karmila	Ngurah Rai---Manggis---Camplon---Ampenan---Ngurah Rai	0
Kelud	Camplon---Manggis---Camplon	0
Cakra Bahana	Badas---Reo Reo---Ende Ende---Bima---Maumere---Badas---Waingapu	0

Ship	Route	Number of Late Deliveries
Mundu	Ende Ende---Reo Reo---MaumereEnde Ende---Reo Reo	0
Ketaling	Bima---Reo Reo---Ende Ende	0
Dorolonda	Bima---Reo Reo---Ende Ende	0
Kurau	Tenau---Kalabahi---Atutupu---Dilli---Tenau---Larantuka	0
Egon	Atutupu---Kalabahi---Atutupu	0
Alor	Larantuka---Kalabahi---Atutupu---Tenau---Kalabahi--Larantuka	0
Dompu	Tenau---Kalabahi---Larantuka	0

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,142,974,012.23	0.29
Andika	Rp -	0.00
Karmila	Rp 1,548,398,157.87	0.40
Kelud	Rp 485,361,522.10	0.16
Cakra Bahana	Rp 3,671,126,504.91	0.90
Mundu	Rp 405,412,483.00	0.17
Ketaling	Rp 443,245,304.31	0.19
Dorolonda	Rp 1,007,891,419.17	0.47
Kurau	Rp 1,673,213,589.10	0.54
Egon	Rp 344,502,262.74	0.09
Alor	Rp 1,198,886,658.02	0.50
Dompu	Rp 475,591,098.55	0.20
	Rp 11,921,011,913.46	0.34

Inventory Flow of Product 1

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	2003	1718	1433	1148	863	578	293	7715	7430	7145	6860	6575	6290	6005	5720	5435	5150	4865	4580	4295	4010	3725	3440	3155	2870	2585	2300	2015
Tanjung Wangi	5547	5243	4939	4635	4331	4027	3723	3419	3115	2811	2507	2203	1899	1595	8696	8392	8088	7784	7480	7176	6872	6568	6264	5960	5656	5352	5048	4744
Ngurah Rai	2355	2210	2065	1920	1775	1630	1485	1340	1195	1050	905	760	615	470	2355	2210	2065	1920	1775	1630	1485	1340	1195	1050	905	760	615	470
Camplon	1623	1466	1309	1152	995	838	681	524	367	1529	1372	1215	1058	901	744	1686	1529	1372	1215	1058	901	744	1686	1529	1372	1215	1058	901
Gresik	2549	2337	2125	1913	1701	1489	1277	1065	853	7864	7652	7440	7228	7016	6804	6592	6380	6168	5956	5744	5532	5320	5108	4896	4684	4472	4260	4048
Bima	7003	6556	6109	5662	5215	4768	4321	3874	3427	2980	2533	2086	1639	1192	745	4106	3659	3212	2765	2318	1871	1424	977	3659	3212	2765	2318	1871
Badas	5192	4938	4684	4430	4176	3922	3668	3414	3160	2906	2652	2398	2144	1890	1636	1382	1128	874	2730	2476	2222	1968	1714	1460	1206	2476	2222	1968
Maumere	1981	1803	1625	1447	1269	1091	913	735	1966	1788	1610	1432	1254	1076	898	720	1788	1610	1432	1254	1076	898	720	542	1610	1432	1254	1076
Ende Ende	1557	1421	1285	1149	1013	877	741	605	2228	2092	1956	1820	1684	1548	1412	1276	1140	1004	868	732	596	460	2092	1956	1820	1684	1548	1412
Waingapu	1648	7240	6860	6480	6100	5720	5340	4960	4580	4200	3820	3440	3060	2680	2300	1920	1540	4480	4100	3720	3340	2960	2580	2200	1820	1440	3340	2960
Dilli	4176	3945	3714	3483	3252	3021	2790	4176	3945	3714	3483	3252	3021	2790	2559	2328	2097	1866	1635	1404	1173	942	4538	4307	4076	3845	3614	3383
Larantuka	2483	2196	1909	1622	1335	1048	761	2483	2196	1909	1622	1335	1048	761	474	3426	3139	2852	2565	2278	1991	1704	1417	1130	2852	2565	2278	1991
Tenau	3193	2903	2613	2323	2033	1743	1453	3193	2903	2613	2323	2033	1743	1453	1163	873	583	2840	2550	2260	1970	1680	1390	3130	2840	2550	2260	1970
Atutupu	2715	2430	2145	1860	1575	1290	1005	2715	2430	2145	1860	1575	1290	1005	720	435	2145	1860	1575	1290	1005	720	2145	1860	1575	1290	1005	720

Inventory Flow of Product 2

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	906	865	824	783	742	701	660	619	578	537	496	455	414	373	332	291	250	209	168	127	86	45	4	1877	1836	1795	1754	1713
Tanjung Wangi	8264	8014	7764	7514	7264	7014	6764	6514	6264	6014	5764	5514	5264	5014	4764	4514	4264	4014	3764	3514	3264	3014	2764	2514	2264	2014	1764	1514
Ngurah Rai	1512	1323	1134	945	756	567	378	1822	1633	1444	1255	1066	877	688	499	310	1633	1444	1255	1066	877	688	499	1633	1444	1255	1066	877
Camplon	1722	1584	1446	1308	1170	1032	894	756	1924	1786	1648	1510	1372	1234	1096	958	820	682	544	406	268	130	1924	1786	1648	1510	1372	1234
Gresik	2065	7030	6545	6060	5575	5090	4605	4120	3635	3150	2665	2180	1695	1210	725	6545	6060	5575	5090	4605	4120	3635	3150	2665	2180	1695	1210	725
Bima	2626	2376	2126	1876	1626	1376	1126	876	9500	9250	9000	8750	8500	8250	8000	7750	7500	7250	7000	6750	6500	6250	6000	5750	5500	5250	5000	4750
Badas	1094	927	5332	5165	4998	4831	4664	4497	4330	4163	3996	3829	3662	3495	3328	3161	2994	2827	2660	2493	2326	2159	1992	1825	1658	1491	1324	1157
Maumere	260	1769	1692	1615	1538	1461	1384	1307	1230	1153	1076	999	922	845	768	691	614	537	460	383	306	229	1769	1692	1615	1538	1461	1384
Ende Ende	923	834	745	656	567	478	389	300	1733	1644	1555	1466	1377	1288	1199	1110	1021	932	843	754	665	576	487	1733	1644	1555	1466	1377
Waingapu	4683	4483	4283	4083	3883	3683	3483	3283	3083	2883	2683	2483	2283	2083	1883	1683	1483	1283	1083	883	683	483	5600	5400	5200	5000	4800	4600
Dilli	4612	4376	4140	3904	3668	3432	3196	4612	4376	4140	3904	3668	3432	3196	2960	2724	2488	2252	2016	1780	1544	1308	1072	836	5556	5320	5084	4848
Larantuka	428	343	258	1660	1575	1490	1405	428	343	258	1660	1575	1490	1405	1320	1235	1150	1065	980	895	810	725	640	555	470	385	300	215
Tenau	176	3140	2960	2780	2600	2420	2240	176	3140	2960	2780	2600	2420	2240	2060	1880	1700	1520	1340	1160	980	800	3140	2960	2780	2600	2420	2240
Atutupu	383	277	1682	1576	1470	1364	1258	383	277	1682	1576	1470	1364	1258	1152	1046	940	834	728	622	516	1894	1788	1682	1576	1470	1364	1258

Inventory Flow of Product 3

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	5329	4974	4619	4264	3909	3554	3199	2844	2489	2134	1779	1424	1069	714	7645	7290	6935	6580	6225	5870	5515	5160	4805	4450	4095	3740	3385	3030
Tanjung Wangi	4097	3640	3183	2726	2269	1812	1355	898	441	6629	6172	5715	5258	4801	4344	3887	3430	2973	2516	2059	1602	1145	688	6629	6172	5715	5258	4801
Ngurah Rai	847	707	2080	1940	1800	1660	1520	1380	1240	1100	960	820	680	540	400	260	120	1940	1800	1660	1520	1380	1240	1100	960	820	680	540
Camplon	1069	946	823	700	577	454	331	208	1754	1631	1508	1385	1262	1139	1016	893	770	647	524	401	278	155	1754	1631	1508	1385	1262	1139
Gresik	1057	7533	7044	6555	6066	5577	5088	4599	4110	3621	3132	2643	2154	1665	1176	687	7533	7044	6555	6066	5577	5088	4599	4110	3621	3132	2643	2154
Bima	6774	6409	6044	5679	5314	4949	4584	4219	3854	3489	3124	2759	2394	2029	1664	1299	934	8540	8175	7810	7445	7080	6715	6350	5985	5620	5255	4890
Badas	3114	2887	2660	2433	2206	1979	1752	1525	1298	1071	7092	6865	6638	6411	6184	5957	5730	5503	5276	5049	4822	4595	4368	4141	3914	3687	3460	3233
Maumere	2068	1939	1810	1681	1552	1423	1294	1165	1036	907	778	649	520	391	262	2113	1984	1855	1726	1597	1468	1339	1210	1081	952	823	694	565
Ende Ende	1481	1332	1183	1034	885	736	587	438	2202	2053	1904	1755	1606	1457	1308	1159	1010	861	712	563	414	265	2202	2053	1904	1755	1606	1457
Waingapu	5433	5250	5067	4884	4701	4518	4335	4152	3969	3786	3603	3420	3237	3054	2871	2688	2505	2322	2139	1956	1773	1590	1407	1224	1041	858	675	492
Dilli	2475	2177	1879	1581	1283	985	687	2475	2177	1879	1581	1283	985	687	389	5404	5106	4808	4510	4212	3914	3616	3318	3020	2722	2424	2126	1828
Larantuka	1792	1691	1590	1489	1388	1287	1186	1792	1691	1590	1489	1388	1287	1186	1085	984	883	782	681	580	479	378	5798	5697	5596	5495	5394	5293
Tenau	4989	4849	4709	4569	4429	4289	4149	4989	4849	4709	4569	4429	4289	4149	4009	3869	3729	3589	3449	3309	3169	3029	2889	2749	2609	2469	2329	2189
Atutupu	1847	1694	1541	1388	1235	1082	929	1847	1694	1541	1388	1235	1082	929	776	623	1541	1388	1235	1082	929	1847	1694	1541	1388	1235	1082	929

ATTACHMENT E

Experiment 1 Output

Scenario 1: 11 Tankers

Period 1 Output

Ship	Route
Kerta Dua	Camplon---Manggis---Gresik---Manggis---Ngurah Rai
Andika	
Karmila	Ampenan---Manggis---Gresik
Kelud	Ngurah Rai---Manggis---Ngurah Rai
Cakra Bahana	Bima---Reo Reo---Waingapu
Mundu	
Ketaling	
Dorolonda	
Kurau	
Egon	
Alor	Tenau---Kalabahi---Dilli

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,019,170,304.54	0.27
Andika	Rp -	0.00
Karmila	Rp 839,839,086.74	0.21
Kelud	Rp 106,847,774.21	0.03
Cakra Bahana	Rp 421,217,461.40	0.20
Mundu	Rp -	0.00
Ketaling	Rp -	0.00
Dorolonda	Rp -	0.00
Kurau	Rp -	0.00
Egon	Rp -	0.00
Alor	Rp 405,892,470.73	0.20
	Rp 2,792,967,097.62	0.08

Period 2 Output

Ship	Route
Kerta Dua	Ngurah Rai---Manggis---Camplon---Manggis---Tanjung Wangi
Andika	Ngurah Rai---Manggis
Karmila	Gresik---Manggis---Ngurah Rai---Camplon

Ship	Route
Kelud	Ngurah Rai---Manggis---Ampenan---Manggis---Camplon---Gresik
Cakra Bahana	Waingapu---Reo Reo---Maumere---Ende Ende
Mundu	Badas---Reo Reo---Ende Ende--Badas---Reo Reo--Bima
Ketaling	Waingapu---Reo Reo---Ende EndeEnde Ende---Reo Reo---Badas
Dorolonda	Badas---Reo Reo
Kurau	Larantuka---Kalabahi---Atutupu
Egon	Kalabahi---Kalabahi---Atutupu
Alor	Dilli---Kalabahi---Tenau---Atutupu---Larantuka

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,142,454,718.23	0.29
Andika	Rp 88,658,391.84	0.03
Karmila	Rp 1,153,174,263.51	0.30
Kelud	Rp 1,114,098,618.69	0.31
Cakra Bahana	Rp 728,669,498.03	0.24
Mundu	Rp 515,055,100.30	0.21
Ketaling	Rp 1,703,406,733.90	0.53
Dorolonda	Rp 760,533,599.62	0.28
Kurau	Rp 317,839,486.61	0.09
Egon	Rp 249,174,964.63	0.07
Alor	Rp 1,657,301,087.17	0.62
	Rp 9,430,366,462.52	0.27

Period 3 Output

Ship	Route
Kerta Dua	Tanjung Wangi---Manggis--Ampenan---Manggis---Gresik---Manggis---Ngurah Rai
Andika	Ngurah Rai---Manggis---Ngurah Rai
Karmila	Camplon---Manggis---Gresik---Ngurah Rai
Kelud	Gresik---Manggis---Tanjung Wangi---Camplon
Cakra Bahana	Ende Ende---Reo Reo---Bima---Maumere---Waingapu---Badas
Mundu	
Ketaling	Badas---Reo Reo---Maumere---Reo Reo---Bima
Dorolonda	
Kurau	Atutupu---Kalabahi---Larantuka---Atutupu---Tenau

Egon	Atutupu---Kalabahi---DilliDilli---Kalabahi---Atutupu
Alor	

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,440,222,595.73	0.38
Andika	Rp 128,233,027.01	0.05
Karmila	Rp 1,730,287,414.67	0.44
Kelud	Rp 860,940,640.49	0.23
Cakra Bahana	Rp 2,712,271,658.64	0.74
Mundu	Rp 203,054,388.30	0.01
Ketaling	Rp 1,457,995,824.70	0.56
Dorolonda	Rp -	0.00
Kurau	Rp 1,490,243,873.73	0.54
Egon	Rp 894,570,628.75	0.29
Alor	Rp -	0.00
	Rp 10,917,820,052.02	0.29

Period 4 Output

Ship	Route
Kerta Dua	Ngurah Rai---Manggis---Camplon---Manggis---Tanjung Wangi
Andika	
Karmila	Ngurah Rai---Manggis---Camplon---Ampenan---Ngurah Rai
Kelud	Camplon---Manggis---Camplon
Cakra Bahana	Badas---Reo Reo---Ende Ende---Bima---Maumere---Badas---Waingapu
Mundu	Ende Ende---Reo Reo---MaumereEnde Ende---Reo Reo
Ketaling	Bima---Reo Reo---Ende Ende
Dorolonda	Bima---Reo Reo---Ende Ende
Kurau	Tenau---Kalabahi---Atutupu---Dilli
Egon	Atutupu---Kalabahi---LarantukaLarantuka---Kalabahi---Atutupu
Alor	Larantuka---Kalabahi---Atutupu---TenauTenau---KalabahiLarantuka---Kalabahi

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,142,974,012.23	0.29
Andika	Rp -	0.00
Karmila	Rp 1,548,398,157.87	0.40
Kelud	Rp 485,361,522.10	0.16
Cakra Bahana	Rp 3,671,126,504.91	0.90

Ship	Total Cost	Utilization
Mundu	Rp 405,412,483.00	0.17
Ketaling	Rp 443,245,304.31	0.19
Dorolonda	Rp 1,007,891,419.17	0.47
Kurau	Rp 647,085,620.86	0.26
Egon	Rp 935,673,652.99	0.31
Alor	Rp 1,198,886,658.02	0.50
	Rp 11,486,055,335.46	0.33

Product 1 Inventory Flow

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	2003	1718	1433	1148	863	578	293	7715	7430	7145	6860	6575	6290	6005	5720	5435	5150	4865	4580	4295	4010	3725	3440	3155	2870	2585	2300	2015
Tanjung Wangi	5547	5243	4939	4635	4331	4027	3723	3419	3115	2811	2507	2203	1899	1595	8696	8392	8088	7784	7480	7176	6872	6568	6264	5960	5656	5352	5048	4744
Ngurah Rai	2355	2210	2065	1920	1775	1630	1485	1340	1195	1050	905	760	615	470	2355	2210	2065	1920	1775	1630	1485	1340	1195	1050	905	760	615	470
Camplon	1623	1466	1309	1152	995	838	681	524	367	1529	1372	1215	1058	901	744	1686	1529	1372	1215	1058	901	744	1686	1529	1372	1215	1058	901
Gresik	2549	2337	2125	1913	1701	1489	1277	1065	853	7864	7652	7440	7228	7016	6804	6592	6380	6168	5956	5744	5532	5320	5108	4896	4684	4472	4260	4048
Bima	7003	6556	6109	5662	5215	4768	4321	3874	3427	2980	2533	2086	1639	1192	745	4106	3659	3212	2765	2318	1871	1424	977	3659	3212	2765	2318	1871
Badas	5192	4938	4684	4430	4176	3922	3668	3414	3160	2906	2652	2398	2144	1890	1636	1382	1128	874	2730	2476	2222	1968	1714	1460	1206	2476	2222	1968
Maumere	1981	1803	1625	1447	1269	1091	913	735	1966	1788	1610	1432	1254	1076	898	720	1788	1610	1432	1254	1076	898	720	542	1610	1432	1254	1076
Ende Ende	1557	1421	1285	1149	1013	877	741	605	2228	2092	1956	1820	1684	1548	1412	1276	1140	1004	868	732	596	460	2092	1956	1820	1684	1548	1412
Waingapu	1648	7240	6860	6480	6100	5720	5340	4960	4580	4200	3820	3440	3060	2680	2300	1920	1540	4480	4100	3720	3340	2960	2580	2200	1820	1440	3340	2960
Dilli	60	-176	-412	-648	-884	-1120	-1356	4612	4376	4140	3904	3668	3432	3196	2960	2724	2488	2252	2016	1780	1544	1308	1072	836	5556	5320	5084	4848
Larantuka	1023	938	853	768	683	598	513	428	343	258	1660	1575	1490	1405	1320	1235	1150	1065	980	895	810	725	640	555	470	385	300	215
Tenau	1436	1256	1076	896	716	536	356	176	3140	2960	2780	2600	2420	2240	2060	1880	1700	1520	1340	1160	980	800	3140	2960	2780	2600	2420	2240
Atutupu	1125	1019	913	807	701	595	489	383	277	1682	1576	1470	1364	1258	1152	1046	940	834	728	622	516	1894	1788	1682	1576	1470	1364	1258

Product 2 Inventory Flow

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	906	865	824	783	742	701	660	619	578	537	496	455	414	373	332	291	250	209	168	127	86	45	4	1877	1836	1795	1754	1713
Tanjung Wangi	8264	8014	7764	7514	7264	7014	6764	6514	6264	6014	5764	5514	5264	5014	4764	4514	4264	4014	3764	3514	3264	3014	2764	2514	2264	2014	1764	1514
Ngurah Rai	1512	1323	1134	945	756	567	378	1822	1633	1444	1255	1066	877	688	499	310	1633	1444	1255	1066	877	688	499	1633	1444	1255	1066	877
Camplon	1722	1584	1446	1308	1170	1032	894	756	1924	1786	1648	1510	1372	1234	1096	958	820	682	544	406	268	130	1924	1786	1648	1510	1372	1234
Gresik	2065	7030	6545	6060	5575	5090	4605	4120	3635	3150	2665	2180	1695	1210	725	6545	6060	5575	5090	4605	4120	3635	3150	2665	2180	1695	1210	725
Bima	2626	2376	2126	1876	1626	1376	1126	876	9500	9250	9000	8750	8500	8250	8000	7750	7500	7250	7000	6750	6500	6250	6000	5750	5500	5250	5000	4750
Badas	1094	927	5332	5165	4998	4831	4664	4497	4330	4163	3996	3829	3662	3495	3328	3161	2994	2827	2660	2493	2326	2159	1992	1825	1658	1491	1324	1157
Maumere	260	1769	1692	1615	1538	1461	1384	1307	1230	1153	1076	999	922	845	768	691	614	537	460	383	306	229	1769	1692	1615	1538	1461	1384
Ende Ende	923	834	745	656	567	478	389	300	1733	1644	1555	1466	1377	1288	1199	1110	1021	932	843	754	665	576	487	1733	1644	1555	1466	1377
Waingapu	4683	4483	4283	4083	3883	3683	3483	3283	3083	2883	2683	2483	2283	2083	1883	1683	1483	1283	1083	883	683	483	5600	5400	5200	5000	4800	4600
Dilli	5793	5562	5331	5100	4869	4638	4407	4176	3945	3714	3483	3252	3021	2790	2559	2328	2097	1866	1635	1404	1173	942	4538	4307	4076	3845	3614	3383
Larantuka	4492	4205	3918	3631	3344	3057	2770	2483	2196	1909	1622	1335	1048	761	474	4426	4139	3852	3565	3278	2991	2704	2417	2130	1843	1556	1269	982
Tenau	5223	4933	4643	4353	4063	3773	3483	3193	2903	2613	2323	2033	1743	1453	1163	873	583	3840	3550	3260	2970	2680	2390	2100	1810	1520	1230	940
Atutupu	2094	1809	1524	1239	954	669	384	2715	2430	2145	1860	1575	1290	1005	720	435	2145	1860	1575	1290	1005	720	2145	1860	1575	1290	1005	720

Product 3 Inventory Flow

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	5329	4974	4619	4264	3909	3554	3199	2844	2489	2134	1779	1424	1069	714	7645	7290	6935	6580	6225	5870	5515	5160	4805	4450	4095	3740	3385	3030
Tanjung Wangi	4097	3640	3183	2726	2269	1812	1355	898	441	6629	6172	5715	5258	4801	4344	3887	3430	2973	2516	2059	1602	1145	688	6629	6172	5715	5258	4801
Ngurah Rai	847	707	2080	1940	1800	1660	1520	1380	1240	1100	960	820	680	540	400	260	120	1940	1800	1660	1520	1380	1240	1100	960	820	680	540
Camplon	1069	946	823	700	577	454	331	208	1754	1631	1508	1385	1262	1139	1016	893	770	647	524	401	278	155	1754	1631	1508	1385	1262	1139
Gresik	1057	7533	7044	6555	6066	5577	5088	4599	4110	3621	3132	2643	2154	1665	1176	687	7533	7044	6555	6066	5577	5088	4599	4110	3621	3132	2643	2154
Bima	6774	6409	6044	5679	5314	4949	4584	4219	3854	3489	3124	2759	2394	2029	1664	1299	934	8540	8175	7810	7445	7080	6715	6350	5985	5620	5255	4890
Badas	3114	2887	2660	2433	2206	1979	1752	1525	1298	1071	7092	6865	6638	6411	6184	5957	5730	5503	5276	5049	4822	4595	4368	4141	3914	3687	3460	3233
Maumere	2068	1939	1810	1681	1552	1423	1294	1165	1036	907	778	649	520	391	262	2113	1984	1855	1726	1597	1468	1339	1210	1081	952	823	694	565
Ende Ende	1481	1332	1183	1034	885	736	587	438	2202	2053	1904	1755	1606	1457	1308	1159	1010	861	712	563	414	265	2202	2053	1904	1755	1606	1457
Waingapu	5433	5250	5067	4884	4701	4518	4335	4152	3969	3786	3603	3420	3237	3054	2871	2688	2505	2322	2139	1956	1773	1590	1407	1224	1041	858	675	492
Dilli	4561	4263	3965	3667	3369	3071	2773	2475	2177	1879	1581	1283	985	687	389	5404	5106	4808	4510	4212	3914	3616	3318	3020	2722	2424	2126	1828
Larantuka	2499	2398	2297	2196	2095	1994	1893	1792	1691	1590	1489	1388	1287	1186	1085	984	883	782	681	580	479	378	5798	5697	5596	5495	5394	5293
Tenau	5969	5829	5689	5549	5409	5269	5129	4989	4849	4709	4569	4429	4289	4149	4009	3869	3729	3589	3449	3309	3169	3029	2889	2749	2609	2469	2329	2189
Atutupu	1530	1377	1224	1071	918	765	612	1847	1694	1541	1388	1235	1082	929	776	623	1541	1388	1235	1082	929	776	623	1541	1388	1235	1082	929

Scenario 2: 10 Tankers

Period 1 Output

Ship	Route
Kerta Dua	Camplon---Manggis---Gresik---Manggis---Ngurah Rai
Andika	
Karmila	Ampenan---Manggis---Gresik
Kelud	Ngurah Rai---Manggis---Ngurah Rai
Cakra Bahana	Bima---Reo Reo---Waingapu
Ketaling	
Dorolonda	Waingapu---Reo Reo---Maumere---Badas
Kurau	
Egon	
Alor	Tenau---Kalabahi---Dilli

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,019,170,304.54	0.27
Andika	Rp -	0.00
Karmila	Rp 839,839,086.74	0.21
Kelud	Rp 106,847,774.21	0.03
Cakra Bahana	Rp 421,217,461.40	0.20
Ketaling	Rp -	0.00
Dorolonda	Rp 2,303,593,197.31	0.50
Kurau	Rp -	0.00
Egon	Rp -	0.00
Alor	Rp 405,892,470.73	0.20
	Rp 5,096,560,294.94	0.14

Period 2 Output

Ship	Route
Kerta Dua	Ngurah Rai---Manggis---Camplon---Manggis---Tanjung Wangi
Andika	Ngurah Rai---Manggis
Karmila	Gresik---Manggis---Ngurah Rai---Camplon
Kelud	Ngurah Rai---Manggis---Ampenan---Manggis---Camplon---Gresik
Cakra Bahana	Waingapu---Reo Reo---Maumere---Ende Ende
Ketaling	Waingapu---Reo Reo---Ende Ende---Reo Reo---Badas
Dorolonda	Badas---Reo Reo---Ende Ende---Reo Reo---Bima

Ship	Route
Kurau	Larantuka---Kalabahi---Atutupu
Egon	Kalabahi---Kalabahi---Atutupu
Alor	Dilli---Kalabahi---Tenau---Atutupu---Larantuka

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,142,454,718.23	0.29
Andika	Rp 88,658,391.84	0.03
Karmila	Rp 1,153,174,263.51	0.30
Kelud	Rp 1,114,098,618.69	0.31
Cakra Bahana	Rp 728,669,498.03	0.24
Ketaling	Rp 1,703,406,733.90	0.53
Dorolonda	Rp 1,461,631,744.62	0.54
Kurau	Rp 317,839,486.61	0.09
Egon	Rp 249,174,964.63	0.07
Alor	Rp 1,657,301,087.17	0.62
	Rp 9,616,409,507.23	0.30

Period 3 Output

Ship	Route
Kerta Dua	Tanjung Wangi---Manggis--Ampenan---Manggis---Gresik---Manggis---Ngurah Rai
Andika	Ngurah Rai---Manggis---Ngurah Rai
Karmila	Camplon---Manggis---Gresik---Ngurah Rai
Kelud	Gresik---Manggis---Tanjung Wangi---Camplon
Cakra Bahana	Ende Ende---Reo Reo---Bima---Maumere---Waingapu---Badas
Ketaling	Badas---Reo Reo---Maumere---Reo Reo---Bima
Dorolonda	
Kurau	Atutupu---Kalabahi---Larantuka---Atutupu---Tenau
Egon	Atutupu---Kalabahi---DilliDilli---Kalabahi---Atutupu
Alor	

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,440,222,595.73	0.38
Andika	Rp 128,233,027.01	0.05
Karmila	Rp 1,730,287,414.67	0.44
Kelud	Rp 860,940,640.49	0.23
Cakra Bahana	Rp 3,430,773,863.50	0.74

Ship	Total Cost	Utilization
Ketaling	Rp 1,457,995,824.70	0.56
Dorolonda	Rp -	0.00
Kurau	Rp 1,490,243,873.73	0.54
Egon	Rp 894,570,628.75	0.29
Alor	Rp -	0.00
	Rp 11,433,267,868.58	0.32

Period 4 Output

Ship	Route
Kerta Dua	Ngurah Rai---Manggis---Camplon---Manggis---Tanjung Wangi
Andika	
Karmila	Ngurah Rai---Manggis---Camplon---Ampenan---Ngurah Rai
Kelud	Camplon---Manggis---Camplon
Cakra Bahana	Badas---Reo Reo---Ende Ende---Maumere---Bima---Badas---Waingapu
Ketaling	Bima---Reo Reo---Ende Ende
Dorolonda	Bima---Reo Reo---Maumere---Waingapu---Ende Ende
Kurau	Tenau---Kalabahi---Atutupu---Dilli
Egon	Atutupu---Kalabahi---LarantukaLarantuka---Kalabahi---Atutupu
Alor	Larantuka---Kalabahi---Atutupu---TenauTenau---KalabahiLarantuka---Kalabahi

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,142,974,012.23	0.29
Andika	Rp -	0.00
Karmila	Rp 1,548,398,157.87	0.40
Kelud	Rp 485,361,522.10	0.16
Cakra Bahana	Rp 2,652,370,009.47	0.75
Ketaling	Rp 443,245,304.31	0.19
Dorolonda	Rp 1,612,885,038.20	0.61
Kurau	Rp 647,085,620.86	0.26
Egon	Rp 935,673,652.99	0.31
Alor	Rp 1,198,886,658.02	0.50
	Rp 10,666,879,976.05	0.35

Product 1 Inventory Flow

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	2003	1718	1433	1148	863	578	293	7715	7430	7145	6860	6575	6290	6005	5720	5435	5150	4865	4580	4295	4010	3725	3440	3155	2870	2585	2300	2015
Tanjung Wangi	5547	5243	4939	4635	4331	4027	3723	3419	3115	2811	2507	2203	1899	1595	8696	8392	8088	7784	7480	7176	6872	6568	6264	5960	5656	5352	5048	4744
Ngurah Rai	2355	2210	2065	1920	1775	1630	1485	1340	1195	1050	905	760	615	470	2355	2210	2065	1920	1775	1630	1485	1340	1195	1050	905	760	615	470
Camplon	1623	1466	1309	1152	995	838	681	524	367	1529	1372	1215	1058	901	744	1686	1529	1372	1215	1058	901	744	1686	1529	1372	1215	1058	901
Gresik	2549	2337	2125	1913	1701	1489	1277	1065	853	7864	7652	7440	7228	7016	6804	6592	6380	6168	5956	5744	5532	5320	5108	4896	4684	4472	4260	4048
Bima	7003	6556	6109	5662	5215	4768	4321	3874	3427	2980	2533	2086	1639	1192	745	4106	3659	3212	2765	2318	1871	2424	1977	4659	4212	3765	3318	2871
Badas	5192	4938	4684	4430	4176	3922	3668	3414	3160	2906	2652	2398	2144	1890	1636	1382	1128	874	3730	3476	3222	1968	1714	1460	2730	2476	2222	1968
Maumere	1981	1803	1625	1447	1269	1091	913	735	1966	1788	1610	1432	1254	1076	898	720	1788	1610	1432	1254	1076	898	1966	1788	1610	1432	1254	1076
Ende Ende	1557	1421	1285	1149	1013	877	741	605	2228	2092	1956	1820	1684	1548	1412	1276	1140	1004	868	732	596	460	2092	1956	1820	1684	1548	1412
Waingapu	1648	6860	6480	6100	5720	5340	4960	4960	4580	4200	3820	3440	3060	2680	2300	1920	1540	3480	3100	2720	2340	2960	2580	2200	1820	3720	3340	2960
Dilli	5793	5562	5331	5100	4869	4638	4407	4176	3945	3714	3483	3252	3021	2790	2559	2328	2097	1866	1635	1404	1173	942	4538	4307	4076	3845	3614	3383
Larantuka	4492	4205	3918	3631	3344	3057	2770	2483	2196	1909	1622	1335	1048	761	474	4426	4139	3852	3565	3278	2991	2704	2417	2130	1843	1556	1269	982
Tenau	5223	4933	4643	4353	4063	3773	3483	3193	2903	2613	2323	2033	1743	1453	1163	873	583	3840	3550	3260	2970	2680	2390	2100	1810	1520	1230	940
Atutupu	2094	1809	1524	1239	954	669	384	2715	2430	2145	1860	1575	1290	1005	720	435	2145	1860	1575	1290	1005	720	2145	1860	1575	1290	1005	720

Product 2 Inventory Flow

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	906	865	824	783	742	701	660	619	578	537	496	455	414	373	332	291	250	209	168	127	86	45	4	1877	1836	1795	1754	1713
Tanjung Wangi	8264	8014	7764	7514	7264	7014	6764	6514	6264	6014	5764	5514	5264	5014	4764	4514	4264	4014	3764	3514	3264	3014	2764	2514	2264	2014	1764	1514
Ngurah Rai	1512	1323	1134	945	756	567	378	1822	1633	1444	1255	1066	877	688	499	310	1633	1444	1255	1066	877	688	499	1633	1444	1255	1066	877
Camplon	1722	1584	1446	1308	1170	1032	894	756	1924	1786	1648	1510	1372	1234	1096	958	820	682	544	406	268	130	1924	1786	1648	1510	1372	1234
Gresik	2065	7030	6545	6060	5575	5090	4605	4120	3635	3150	2665	2180	1695	1210	725	6545	6060	5575	5090	4605	4120	3635	3150	2665	2180	1695	1210	725
Bima	2626	2376	2126	1876	1626	1376	1126	876	626	376	9000	8750	8500	8250	8000	7750	7500	7250	7000	6750	6500	6250	6000	5750	5500	5250	5000	4750
Badas	1094	927	5332	5165	4998	4831	4664	4664	4497	4330	4163	3996	3829	3662	3495	3328	3161	2994	2827	2660	2493	2326	2159	1992	1825	1658	1491	1324
Maumere	260	1769	1692	1615	1538	1461	1384	1307	1230	1153	1076	999	922	845	768	691	614	537	460	383	306	229	1769	1692	1615	1538	1461	1384
Ende Ende	923	834	745	656	567	478	389	300	1733	1644	1555	1466	1377	1288	1199	1110	1021	932	843	754	665	576	487	398	1644	1555	1466	1377
Waingapu	4683	4483	4283	4083	3883	3683	3483	3283	3083	2883	2683	2483	2283	2083	1883	1683	1483	1283	1083	883	683	483	283	5400	5200	5000	4800	4600
Dilli	60	6028	5792	5556	5320	5084	4848	4612	4376	4140	3904	3668	3432	3196	2960	2724	2488	2252	2016	1780	1544	1308	1072	836	5556	5320	5084	4848
Larantuka	1023	938	853	768	683	598	513	428	343	258	1660	1575	1490	1405	1320	1235	1150	1065	980	895	810	725	640	555	470	385	300	215
Tenau	1436	1256	1076	896	716	536	356	176	3140	2960	2780	2600	2420	2240	2060	1880	1700	1520	1340	1160	980	800	3140	2960	2780	2600	2420	2240
Atutupu	1125	1019	913	807	701	595	489	383	277	1682	1576	1470	1364	1258	1152	1046	940	834	728	622	516	1894	1788	1682	1576	1470	1364	1258

Product 3 Inventory Flow

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	5329	4974	4619	4264	3909	3554	3199	2844	2489	2134	1779	1424	1069	714	7645	7290	6935	6580	6225	5870	5515	5160	4805	4450	4095	3740	3385	3030
Tanjung Wangi	4097	3640	3183	2726	2269	1812	1355	898	441	6629	6172	5715	5258	4801	4344	3887	3430	2973	2516	2059	1602	1145	688	6629	6172	5715	5258	4801
Ngurah Rai	847	707	2080	1940	1800	1660	1520	1380	1240	1100	960	820	680	540	400	260	120	1940	1800	1660	1520	1380	1240	1100	960	820	680	540
Camplon	1069	946	823	700	577	454	331	208	1754	1631	1508	1385	1262	1139	1016	893	770	647	524	401	278	155	1754	1631	1508	1385	1262	1139
Gresik	1057	7533	7044	6555	6066	5577	5088	4599	4110	3621	3132	2643	2154	1665	1176	687	7533	7044	6555	6066	5577	5088	4599	4110	3621	3132	2643	2154
Bima	6774	6409	6044	5679	5314	4949	4584	4219	3854	3489	3124	2759	2394	2029	1664	1299	934	8540	8175	7810	7445	7080	6715	6350	5985	5620	5255	4890
Badas	3114	2887	2660	2433	2206	1979	1752	1525	1298	1071	7092	6865	6638	6411	6184	5957	5730	5503	5276	5049	4822	4595	4368	4141	3914	3687	3460	3233
Maumere	2068	1939	1810	1681	1552	1423	1294	1165	1036	907	778	649	520	391	262	2113	1984	1855	1726	1597	1468	1339	1210	1081	952	823	694	565
Ende Ende	1481	1332	1183	1034	885	736	587	438	2202	2053	1904	1755	1606	1457	1308	1159	1010	861	712	563	414	265	2202	2053	1904	1755	1606	1457
Waingapu	5433	5250	5067	4884	4701	4518	4335	4152	3969	3786	3603	3420	3237	3054	2871	2688	2505	2322	2139	1956	1773	1590	1407	1224	1041	858	675	492
Dilli	4561	4263	3965	3667	3369	3071	2773	2475	2177	1879	1581	1283	985	687	389	5404	5106	4808	4510	4212	3914	3616	3318	3020	2722	2424	2126	1828
Larantuka	2499	2398	2297	2196	2095	1994	1893	1792	1691	1590	1489	1388	1287	1186	1085	984	883	782	681	580	479	378	5798	5697	5596	5495	5394	5293
Tenau	5969	5829	5689	5549	5409	5269	5129	4989	4849	4709	4569	4429	4289	4149	4009	3869	3729	3589	3449	3309	3169	3029	2889	2749	2609	2469	2329	2189
Atutupu	1530	1377	1224	1071	918	765	612	1847	1694	1541	1388	1235	1082	929	776	623	1541	1388	1235	1082	929	776	623	1541	1388	1235	1082	929

Scenario 3: 9 Tankers

Period 1 Output

Ship	Route
Kerta Dua	Camplon---Manggis---Gresik---Manggis---Ngurah Rai
Karmila	Ampenan---Manggis---Gresik
Kelud	Ngurah Rai---Manggis---Ngurah Rai
Cakra Bahana	Bima---Reo Reo---Waingapu
Ketaling	
Dorolonda	Waingapu---Reo Reo---Maumere---Badas
Kurau	
Egon	
Alor	Tenau---Kalabahi---Dilli

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,019,170,304.54	0.27
Karmila	Rp 849,637,086.74	0.22
Kelud	Rp 106,847,774.21	0.03
Cakra Bahana	Rp 421,217,461.40	0.20
Ketaling	Rp -	0.00
Dorolonda	Rp 2,303,593,197.31	0.50
Kurau	Rp -	0.00
Egon	Rp -	0.00
Alor	Rp 405,892,470.73	0.20
	Rp 5,106,358,294.94	0.16

Period 2 Output

Ship	Route
Kerta Dua	Ngurah Rai---Manggis---Camplon---Manggis---Tanjung Wangi
Karmila	Gresik---Manggis---Ngurah Rai---Camplon
Kelud	Ngurah Rai---Manggis---Ampenan---Camplon---Gresik
Cakra Bahana	Waingapu---Reo Reo---Maumere---Ende Ende
Ketaling	Waingapu---Reo Reo---Ende Ende---Badas
Dorolonda	Badas---Reo Reo---Ende EndeEnde Ende---Reo ReoBadas---Reo Reo
Kurau	Atutupu---Kalabahi---Atutupu
Egon	Kalabahi---Kalabahi---Atutupu
Alor	Tenau---Kalabahi---Atutupu---Larantuka

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,142,454,718.23	0.29
Karmila	Rp 1,153,174,263.51	0.30
Kelud	Rp 1,501,002,926.21	0.23
Cakra Bahana	Rp 727,336,970.03	0.24
Ketaling	Rp 1,935,303,665.13	0.49
Dorolonda	Rp 1,333,425,664.62	0.54
Kurau	Rp 203,342,164.62	0.06
Egon	Rp 248,050,644.13	0.07
Alor	Rp 1,035,450,949.12	0.28
	Rp 9,279,541,965.59	0.28

Period 3 Output

Ship	Route
Kerta Dua	Tanjung Wangi---Manggis---Ampenan---Manggis---Gresik---Manggis---Ngurah Rai
Karmila	Camplon---Manggis---Ngurah Rai---Gresik
Kelud	Gresik---Manggis---Ngurah Rai---Tanjung Wangi---Camplon
Cakra Bahana	Ende Ende---Reo Reo---Bima---Maumere---Waingapu---Badas
Ketaling	Badas---Reo Reo---Maumere---Reo Reo---Bima
Dorolonda	
Kurau	Atutupu---Kalabahi---Larantuka---Atutupu---Tenau
Egon	Atutupu---Kalabahi---DilliDilli---Kalabahi---Atutupu
Alor	

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,990,819,591.04	0.38
Karmila	Rp 1,365,822,501.27	0.33
Kelud	Rp 984,858,373.88	0.38
Cakra Bahana	Rp 3,430,773,863.50	0.74
Ketaling	Rp 1,457,995,824.70	0.56
Dorolonda	Rp -	0.00
Kurau	Rp 1,490,243,873.73	0.54
Egon	Rp 894,570,628.75	0.29
Alor	Rp -	0.00
	Rp 11,615,084,656.87	0.36

Period 4 Output

Ship	Route
Kerta Dua	Ngurah Rai---Manggis---Camplon---Manggis---Tanjung Wangi
Karmila	Gresik---Manggis---Camplon---Ampenan---Ngurah Rai
Kelud	Camplon---Manggis---Ampenan---Camplon
Cakra Bahana	Badas---Reo Reo---Ende Ende---Maumere---Bima---Badas---Waingapu
Ketaling	Bima---Reo Reo---Ende Ende
Dorolonda	Bima---Reo Reo---Maumere---Waingapu---Ende Ende
Kurau	Tenau---Kalabahi---Atutupu---Dilli
Egon	Atutupu---Kalabahi---LarantukaLarantuka---Kalabahi---Atutupu
Alor	Larantuka---Kalabahi---Atutupu---TenauTenau---KalabahiLarantuka---Kalabahi

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,142,974,012.23	0.29
Karmila	Rp 2,311,188,606.30	0.38
Kelud	Rp 1,447,687,545.65	0.30
Cakra Bahana	Rp 2,652,370,009.47	0.75
Ketaling	Rp 443,245,304.31	0.19
Dorolonda	Rp 1,612,885,038.20	0.61
Kurau	Rp 647,085,620.86	0.26
Egon	Rp 935,673,652.99	0.31
Alor	Rp 1,198,886,658.02	0.50
	Rp 12,391,996,448.02	0.40

Product 1 Inventory Flow

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	2003	1718	1433	1148	863	578	293	4715	4430	4145	3860	3575	3290	3005	2720	2435	2150	1865	1580	1295	1010	4715	4430	4145	3860	3575	3290	3005
Tanjung Wangi	5547	5243	4939	4635	4331	4027	3723	3419	3115	2811	2507	2203	1899	1595	1291	8392	8088	7784	7480	7176	6872	6568	6264	5960	5656	5352	5048	4744
Ngurah Rai	2355	2210	2065	1920	1775	1630	1485	1340	1195	1050	905	760	615	470	2210	2065	1920	1775	1630	1485	1340	1195	1050	905	760	615	470	325
Camplon	1623	1466	1309	1152	995	838	681	524	1686	1529	1372	1215	1058	901	744	587	1529	1372	1215	1058	901	744	1686	1529	1372	1215	1058	901
Gresik	2549	2337	2125	1913	1701	1489	1277	1065	4576	4364	4152	3940	3728	3516	3304	3092	2880	2668	2456	2244	2032	1820	1608	1396	1184	972	760	548
Bima	7003	6556	6109	5662	5215	4768	4321	3874	3427	2980	2533	2086	1639	1192	745	4106	3659	3212	2765	2318	1871	2424	1977	4659	4212	3765	3318	2871
Badas	5192	4938	4684	4430	4176	3922	3668	3414	3160	2906	2652	2398	2144	1890	1636	1382	1128	874	3730	3476	3222	1968	1714	1460	2730	2476	2222	1968
Maumere	1981	1803	1625	1447	1269	1091	913	735	1966	1788	1610	1432	1254	1076	898	720	1788	1610	1432	1254	1076	898	1966	1788	1610	1432	1254	1076
Ende Ende	1557	1421	1285	1149	1013	877	741	605	2228	2092	1956	1820	1684	1548	1412	1276	1140	1004	868	732	596	460	2092	1956	1820	1684	1548	1412
Waingapu	1648	6860	6480	6100	5720	5340	4960	4960	4580	4200	3820	3440	3060	2680	2300	1920	1540	3480	3100	2720	2340	2960	2580	2200	1820	3720	3340	2960
Dilli	5793	5562	5331	5100	4869	4638	4407	4176	3945	3714	3483	3252	3021	2790	2559	2328	2097	1866	1635	1404	1173	942	4538	4307	4076	3845	3614	3383
Larantuka	4492	4205	3918	3631	3344	3057	2770	2483	2196	1909	1622	1335	1048	761	474	4426	4139	3852	3565	3278	2991	2704	2417	2130	1843	1556	1269	982
Tenau	5223	4933	4643	4353	4063	3773	3483	3193	2903	2613	2323	2033	1743	1453	1163	873	583	3840	3550	3260	2970	2680	2390	2100	1810	1520	1230	940
Atutupu	2094	1809	1524	1239	954	669	384	2715	2430	2145	1860	1575	1290	1005	720	435	2145	1860	1575	1290	1005	720	2145	1860	1575	1290	1005	720

Product 2 Inventory Flow

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	906	865	824	783	742	701	660	619	578	537	496	455	414	373	332	291	250	209	168	127	86	45	4	1877	1836	1795	1754	1713
Tanjung Wangi	8264	8014	7764	7514	7264	7014	6764	6514	6264	6014	5764	5514	5264	5014	4764	4514	4264	4014	3764	3514	3264	3014	2764	2514	2264	2014	1764	1514
Ngurah Rai	1512	1323	1134	945	756	567	378	1822	1633	1444	1255	1066	877	688	2011	1822	1633	1444	1255	1066	877	688	499	1444	1255	1066	877	688
Camplon	1722	1584	1446	1308	1170	1032	894	756	1924	1786	1648	1510	1372	1234	1096	958	820	682	544	406	268	130	1924	1786	1648	1510	1372	1234
Gresik	2065	9030	8545	8060	7575	7090	6605	6120	5635	5150	4665	4180	3695	3210	2725	8545	8060	7575	7090	6605	6120	5635	5150	4665	4180	3695	3210	2725
Bima	2626	2376	2126	1876	1626	1376	1126	876	626	376	9000	8750	8500	8250	8000	7750	7500	7250	7000	6750	6500	6250	6000	5750	5500	5250	5000	4750
Badas	1094	927	5332	5165	4998	4831	4664	4664	4497	4330	4163	3996	3829	3662	3495	3328	3161	2994	2827	2660	2493	2326	2159	1992	1825	1658	1491	1324
Maumere	260	1769	1692	1615	1538	1461	1384	1307	1230	1153	1076	999	922	845	768	691	614	537	460	383	306	229	1769	1692	1615	1538	1461	1384
Ende Ende	923	834	745	656	567	478	389	300	1733	1644	1555	1466	1377	1288	1199	1110	1021	932	843	754	665	576	487	398	1644	1555	1466	1377
Waingapu	4683	4483	4283	4083	3883	3683	3483	3283	3083	2883	2683	2483	2283	2083	1883	1683	1483	1283	1083	883	683	483	283	5400	5200	5000	4800	4600
Dilli	60	6028	5792	5556	5320	5084	4848	4612	4376	4140	3904	3668	3432	3196	2960	2724	2488	2252	2016	1780	1544	1308	1072	836	5556	5320	5084	4848
Larantuka	1023	938	853	768	683	598	513	428	343	258	1660	1575	1490	1405	1320	1235	1150	1065	980	895	810	725	640	555	470	385	300	215
Tenau	1436	1256	1076	896	716	536	356	176	3140	2960	2780	2600	2420	2240	2060	1880	1700	1520	1340	1160	980	800	3140	2960	2780	2600	2420	2240
Atutupu	1125	1019	913	807	701	595	489	383	277	1682	1576	1470	1364	1258	1152	1046	940	834	728	622	516	1894	1788	1682	1576	1470	1364	1258

Product 3 Inventory Flow

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	5329	4974	4619	4264	3909	3554	3199	2844	2489	2134	1779	1424	1069	714	7645	7290	6935	6580	6225	5870	5515	5160	4805	4450	4095	3740	3385	3030
Tanjung Wangi	4097	3640	3183	2726	2269	1812	1355	898	441	6629	6172	5715	5258	4801	4344	3887	3430	2973	2516	2059	1602	1145	688	6629	6172	5715	5258	4801
Ngurah Rai	847	707	2080	1940	1800	1660	1520	1380	1240	1100	960	820	680	540	400	260	120	1940	1800	1660	1520	1380	1240	1100	960	820	680	540
Camplon	1069	946	823	700	577	454	331	208	1754	1631	1508	1385	1262	1139	1016	893	770	647	524	401	278	155	1754	1631	1508	1385	1262	1139
Gresik	1057	7533	7044	6555	6066	5577	5088	4599	4110	3621	3132	2643	2154	1665	1176	687	7533	7044	6555	6066	5577	5088	4599	4110	3621	3132	2643	2154
Bima	6774	6409	6044	5679	5314	4949	4584	4219	3854	3489	3124	2759	2394	2029	1664	1299	934	8540	8175	7810	7445	7080	6715	6350	5985	5620	5255	4890
Badas	3114	2887	2660	2433	2206	1979	1752	1525	1298	1071	7092	6865	6638	6411	6184	5957	5730	5503	5276	5049	4822	4595	4368	4141	3914	3687	3460	3233
Maumere	2068	1939	1810	1681	1552	1423	1294	1165	1036	907	778	649	520	391	262	2113	1984	1855	1726	1597	1468	1339	1210	1081	952	823	694	565
Ende Ende	1481	1332	1183	1034	885	736	587	438	2202	2053	1904	1755	1606	1457	1308	1159	1010	861	712	563	414	265	2202	2053	1904	1755	1606	1457
Waingapu	5433	5250	5067	4884	4701	4518	4335	4152	3969	3786	3603	3420	3237	3054	2871	2688	2505	2322	2139	1956	1773	1590	1407	1224	1041	858	675	492
Dilli	4561	4263	3965	3667	3369	3071	2773	2475	2177	1879	1581	1283	985	687	389	5404	5106	4808	4510	4212	3914	3616	3318	3020	2722	2424	2126	1828
Larantuka	2499	2398	2297	2196	2095	1994	1893	1792	1691	1590	1489	1388	1287	1186	1085	984	883	782	681	580	479	378	5798	5697	5596	5495	5394	5293
Tenau	5969	5829	5689	5549	5409	5269	5129	4989	4849	4709	4569	4429	4289	4149	4009	3869	3729	3589	3449	3309	3169	3029	2889	2749	2609	2469	2329	2189
Atutupu	1530	1377	1224	1071	918	765	612	1847	1694	1541	1388	1235	1082	929	776	623	1541	1388	1235	1082	929	776	623	1541	1388	1235	1082	929

ATTACHMENT F

Experiment 2 Output

Scenario 1: 125% Demand Rate

Period 1 Output

Ship	Route
Kerta Dua	Camplon---Manggis---Gresik---Manggis---Ngurah Rai---Camplon---Tanjung Wangi
Andika	
Karmila	Ampenan---Manggis---Gresik---Ngurah Rai
Kelud	Ngurah Rai---Manggis---Ngurah Rai---Ampenan
Cakra Bahana	Bima---Reo Reo---Waingapu
Mundu	
Ketaling	
Dorolonda	Waingapu---Reo Reo---Maumere---Badas
Kurau	Larantuka---Kalabahi---Atutupu
Egon	
Alor	Tenau---Kalabahi---Dilli---Tenau
Dompu	

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,936,205,498.42	0.69
Andika	Rp -	0.00
Karmila	Rp 1,890,406,401.86	0.47
Kelud	Rp 468,329,119.81	0.21
Cakra Bahana	Rp 421,217,461.40	0.19
Mundu	Rp -	0.00
Ketaling	Rp -	0.00
Dorolonda	Rp 2,300,374,554.31	0.50
Kurau	Rp 311,034,361.61	0.08
Egon	Rp -	0.00
Alor	Rp 1,350,736,797.09	0.46
Dompu	Rp -	0.00
	Rp 8,678,304,194.50	0.22

Period 2 Output

Ship	Route
Kerta Dua	Tanjung Wangi---Manggis---Ampenan---Manggis---Camplon---Gresik---Ngurah Rai
Andika	Ngurah Rai---Manggis---Camplon
Karmila	Ngurah Rai---Manggis---Ngurah Rai---Camplon---Gresik
Kelud	Ampenan---Manggis---Gresik---Ngurah Rai
Cakra Bahana	Waingapu---Reo Reo---Maumere---Ende Ende---Bima
Mundu	Badas---Reo Reo---Ende EndeBadas---Reo Reo
Ketaling	Waingapu---Reo Reo---Ende EndeEnde Ende---Reo Reo---Badas---Maumere
Dorolonda	Badas---Reo Reo---Bima
Kurau	Atutupu---Kalabahi---Atutupu---Larantuka
Egon	Kalabahi---Kalabahi---Atutupu---Dilli
Alor	Tenau---Kalabahi---Atutupu---Larantuka
Dompu	

Ship	Total Cost	Utilization
Kerta Dua	Rp 2,143,908,361.56	0.53
Andika	Rp 636,185,460.15	0.19
Karmila	Rp 832,078,435.09	0.23
Kelud	Rp 1,842,650,660.06	0.45
Cakra Bahana	Rp 1,699,523,269.14	0.46
Mundu	Rp 516,069,193.30	0.21
Ketaling	Rp 2,883,772,706.06	0.67
Dorolonda	Rp 760,533,599.62	0.28
Kurau	Rp 979,456,047.50	0.26
Egon	Rp 606,904,896.74	0.30
Alor	Rp 1,038,586,309.12	0.28
Dompu	Rp -	0.00
	Rp 13,939,668,938.32	0.32

Period 3 Output

Ship	Route
Kerta Dua	Ngurah Rai---Manggis---Tanjung Wangi---Manggis---Camplon---Ngurah Rai---Gresik
Andika	Camplon---Manggis---Ngurah Rai
Karmila	Gresik---Manggis---Ngurah Rai---Ampenan---Gresik---Camplon
Kelud	Ngurah Rai---Manggis---Tanjung Wangi---Camplon
Cakra Bahana	Bima---Reo Reo---Maumere---Waingapu---Badas---Bima---Ende Ende
Mundu	Ende Ende---Reo Reo---MaumereEnde Ende---Reo Reo
Ketaling	Maumere---Reo Reo---BimaBima---Reo Reo---Ende Ende---Maumere
Dorolonda	Bima---Reo Reo---Waingapu
Kurau	Larantuka---Kalabahi---Tenau---Atutupu---Dilli
Egon	Dilli---Kalabahi---Atutupu
Alor	Larantuka---Kalabahi---Tenau---Atutupu
Dompu	Tenau---Kalabahi---Larantuka

Ship	Total Cost	Utilization
Kerta Dua	Rp 2,436,733,304.18	0.82
Andika	Rp 318,144,688.16	0.08
Karmila	Rp 1,381,720,224.15	0.39
Kelud	Rp 570,301,056.40	0.17
Cakra Bahana	Rp 2,860,600,357.81	0.88
Mundu	Rp 403,509,221.50	0.17
Ketaling	Rp 1,246,086,241.82	0.46
Dorolonda	Rp 666,010,893.20	0.29
Kurau	Rp 1,206,115,240.20	0.40
Egon	Rp 247,406,937.19	0.07
Alor	Rp 1,202,533,202.60	0.46
Dompu	Rp 719,154,197.33	0.30
	Rp 13,258,315,564.54	0.37

Period 4 Output

Ship	Route
Kerta Dua	Gresik---Manggis---Camplon---Ngurah Rai---Gresik
Andika	
Karmila	Camplon---Manggis---Ngurah Rai---Gresik---Camplon---Manggis---Tanjung Wangi
Kelud	Camplon---Manggis---Ampenan---Camplon---Manggis---Ngurah Rai
Cakra Bahana	Ende Ende---Reo Reo---Maumere---Waingapu---Bima---Badas---Ende Ende
Mundu	Maumere---Reo Reo---Ende EndeMaumere---Reo Reo
Ketaling	Maumere---Reo Reo---Waingapu---Ende EndeEnde Ende---Reo Reo---Maumere
Dorolonda	Waingapu---Reo Reo---Badas
Kurau	Dilli---Kalabahi---Atutupu---Tenau---Larantuka---Dilli
Egon	Atutupu---Kalabahi---DilliDilli---Kalabahi---Atutupu
Alor	Atutupu---Kalabahi---Dilli---Larantuka
Dompu	

Ship	Total Cost	Utilization
Kerta Dua	Rp 2,047,722,903.91	0.61
Andika	Rp -	0.00
Karmila	Rp 1,463,109,881.45	0.52
Kelud	Rp 1,184,138,549.20	0.27
Cakra Bahana	Rp 2,972,330,872.59	0.89
Mundu	Rp 318,548,373.53	0.17
Ketaling	Rp 1,445,939,448.47	0.62
Dorolonda	Rp 1,325,750,729.44	0.30
Kurau	Rp 1,886,664,018.76	0.55
Egon	Rp 701,936,746.82	0.28
Alor	Rp 1,255,833,379.22	0.44
Dompu	Rp -	0.00
	Rp 14,601,974,903.38	0.39

Period 1 Inventory Flow

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	1931	7286	6929	6572	6215	5858	5501	5144	4787	4430	4073	3716	3359	3002	2645	2288	1931	1574	1217	860	503	7643	7286	6929	6572	6215	5858	5501
Tanjung Wangi	5471	5091	4711	4331	3951	3571	3191	2811	2431	2051	1671	1291	911	531	7620	7240	6860	6480	6100	5720	5340	4960	4580	4200	3820	3440	3060	2680
Ngurah Rai	2318	2136	1954	1772	1590	1408	1226	1044	862	1954	1772	1590	1408	1226	2318	2136	1954	1772	1590	1408	1226	1044	862	1954	1772	1590	1408	1226
Camplon	1583	1386	1189	992	795	598	401	204	1606	1409	1212	1015	818	621	424	1606	1409	1212	1015	818	621	424	1606	1409	1212	1015	818	621
Gresik	2496	2231	1966	1701	1436	1171	906	641	7470	7205	6940	6675	6410	6145	5880	5615	5350	5085	4820	4555	4290	4025	3760	3495	3230	2965	2700	2435
Bima	6891	6332	5773	5214	4655	4096	3537	2978	2419	6323	5764	5205	4646	4087	3528	2969	2410	1851	3205	2646	2087	1528	969	410	3764	3205	2646	2087
Badas	5128	4810	4492	4174	3856	3538	3220	2902	2584	2266	1948	1630	1312	994	676	358	40	2728	2410	2092	1774	1456	1138	820	502	2410	2092	1774
Maumere	1936	1713	1490	1267	1044	821	598	375	1831	1608	1385	1162	939	716	493	1831	1608	1385	1162	939	716	493	1831	1608	1385	1162	939	716
Ende Ende	1523	1353	1183	1013	843	673	503	333	2160	1990	1820	1650	1480	1310	1140	970	800	630	460	1480	1310	1140	970	800	630	460	1480	1310
Waingapu	1553	7050	6575	6100	5625	5150	4675	4200	3725	3250	2775	2300	1825	1350	875	400	3575	3100	2625	2150	1675	1200	725	3575	3100	2625	2150	1675
Dilli	5735	5446	5157	4868	4579	4290	4001	3712	3423	3134	2845	2556	2267	1978	1689	1400	3133	2844	2555	2266	1977	1688	1399	1110	1844	1555	1266	977
Larantuka	4420	4061	3702	3343	2984	2625	2266	1907	6282	5923	5564	5205	4846	4487	4128	3769	3410	3051	2692	2333	1974	1615	1256	2923	2564	2205	1846	1487
Tenau	5150	4787	4424	4061	3698	3335	2972	2609	2246	1883	1520	1157	794	431	68	3274	2911	2548	2185	1822	1459	1096	3274	2911	2548	2185	1822	1459
Atutupu	2643	2286	1929	1572	1215	858	501	2643	2286	1929	1572	1215	858	501	144	-213	1929	1572	1215	858	501	2643	2286	1929	1572	1215	858	501

Period 2 Inventory Flow

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	895	843	791	739	687	635	583	531	479	427	375	323	271	219	167	1896	1844	1792	1740	1688	1636	1584	1532	1480	1428	1376	1324	1272
Tanjung Wangi	8201	7888	7575	7262	6949	6636	6323	6010	5697	5384	5071	4758	4445	4132	3819	3506	3193	2880	2567	2254	1941	1628	1315	1002	6748	6435	6122	5809
Ngurah Rai	1464	1227	1489	1252	1015	778	541	1963	1726	1489	1252	1015	778	541	1726	1489	1252	1015	778	541	304	1963	1726	1489	1252	1015	778	541
Camplon	1687	1514	1341	1168	995	822	649	476	1854	1681	1508	1335	1162	989	816	643	1681	1508	1335	1162	989	816	1854	1681	1508	1335	1162	989
Gresik	1943	6786	6179	5572	4965	4358	3751	3144	6786	6179	5572	4965	4358	3751	3144	2537	5572	4965	4358	3751	3144	2537	6179	5572	4965	4358	3751	3144
Bima	2563	2250	1937	1624	1311	998	685	372	7374	7061	6748	6435	6122	5809	5496	5183	4870	4557	4244	3931	3618	3305	2992	2679	2366	2053	1740	1427
Badas	1052	843	5164	4955	4746	4537	4328	4119	3910	3701	3492	3283	3074	2865	2656	2447	2238	2029	1820	1611	1402	1193	5582	5373	5164	4955	4746	4537
Maumere	240	1709	1612	1515	1418	1321	1224	1127	1030	933	836	739	642	545	448	1709	1612	1515	1418	1321	1224	1127	1030	933	836	739	642	545
Ende Ende	900	788	676	564	452	340	228	116	1664	1552	1440	1328	1216	1104	992	880	768	656	544	432	320	208	1776	1664	1552	1440	1328	1216
Waingapu	4633	4383	4133	3883	3633	3383	3133	2883	2633	2383	2133	1883	1633	1383	1133	5500	5250	5000	4750	4500	4250	4000	3750	3500	3250	3000	2750	2500
Dilli	1	5910	5615	5320	5025	4730	4435	4140	3845	3550	3255	2960	2665	2370	2075	1780	1485	1190	895	600	305	10	5910	5615	5320	5025	4730	4435
Larantuka	1001	894	787	680	573	466	359	252	1786	1679	1572	1465	1358	1251	1144	1037	930	823	716	609	502	395	288	1679	1572	1465	1358	1251
Tenau	1391	1166	2825	2600	2375	2150	1925	1700	1475	1250	1025	800	575	350	125	3050	2825	2600	2375	2150	1925	1700	1475	1250	1025	800	575	350
Atutupu	1098	965	832	699	566	433	300	1734	1601	1468	1335	1202	1069	936	803	670	1601	1468	1335	1202	1069	936	803	670	537	404	271	138

Period 3 Inventory Flow

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	5240	4796	4352	3908	3464	3020	2576	9556	9112	8668	8224	7780	7336	6892	6448	6004	5560	5116	4672	4228	3784	3340	2896	2452	2008	1564	1120	676
Tanjung Wangi	3982	3410	2838	2266	7140	6568	5996	5424	4852	4280	3708	3136	2564	1992	1420	8856	8284	7712	7140	6568	5996	5424	4852	4280	3708	3136	2564	1992
Ngurah Rai	812	637	1975	1800	1625	1450	1275	1100	925	750	1800	1625	1450	1275	1100	925	750	575	1625	1450	1275	1100	925	1800	1625	1450	1275	1100
Camplon	1038	884	730	1384	1230	1076	922	768	614	1538	1384	1230	1076	922	768	614	460	1384	1230	1076	922	768	1692	1538	1384	1230	1076	922
Gresik	934	7164	6552	5940	5328	4716	4104	3492	2880	7164	6552	5940	5328	4716	4104	3492	2880	2268	1656	5328	4716	4104	3492	2880	5940	5328	4716	4104
Bima	6682	6225	5768	5311	4854	4397	3940	3483	3026	2569	2112	1655	1198	741	284	7086	6629	6172	5715	5258	4801	4344	3887	3430	2973	2516	2059	1602
Badas	3057	2773	2489	2205	1921	1637	1353	1069	785	501	6864	6580	6296	6012	5728	5444	5160	4876	4592	4308	4024	3740	3456	3172	2888	2604	2320	2036
Maumere	2035	1873	1711	1549	1387	1225	1063	901	739	577	415	1528	1366	1204	1042	880	718	1690	1528	1366	1204	1042	880	718	1690	1528	1366	1204
Ende Ende	1443	1256	1069	882	695	508	321	134	2126	1939	1752	1565	1378	1191	1004	817	630	1752	1565	1378	1191	1004	817	1939	1752	1565	1378	1191
Waingapu	5387	5158	4929	4700	4471	4242	4013	3784	3555	3326	3097	2868	2639	2410	2181	1952	1723	1494	1265	1036	807	578	7042	6813	6584	6355	6126	5897
Dilli	4486	4113	3740	3367	2994	2621	2248	1875	5627	5254	4881	4508	4135	3762	3389	3016	2643	2270	1897	1524	1151	778	5254	4881	4508	4135	3762	3389
Larantuka	2473	2346	2219	2092	1965	1838	1711	1584	1457	1330	1203	1076	949	822	695	5746	5619	5492	5365	5238	5111	4984	4857	4730	4603	4476	4349	4222
Tenau	5934	5759	5584	5409	5234	5059	4884	4709	4534	4359	4184	4009	3834	3659	3484	3309	3134	2959	2784	2609	2434	2259	2084	1909	1734	1559	1384	1209
Atutupu	1491	1299	1107	915	723	531	339	1808	1616	1424	1232	1040	848	656	1808	1616	1424	1232	1040	848	656	464	272	1424	1232	1040	848	656

Scenario 2: 150% Demand Rate

Period 1 Output

Ship	Route
Kerta Dua	Camplon---Manggis---Gresik---Ngurah Rai---CamplonCamplon---Manggis---Tanjung Wangi
Andika	
Karmila	Ampenan---Manggis---Gresik---Ngurah Rai
Kelud	Ngurah Rai---Manggis---Ngurah Rai---Ampenan---Camplon
Cakra Bahana	Bima---Reo Reo---Waingapu---Maumere
Mundu	Badas---Reo Reo
Ketaling	Waingapu---Reo Reo---Ende Ende
Dorolonda	Waingapu---Reo Reo---Maumere---Badas---Ende EndeWaingapu---Reo Reo
Kurau	Larantuka---Kalabahi---Atutupu
Egon	
Alor	Tenau---Kalabahi---Dilli---Tenau---Atutupu
Dompu	

Ship	Total Cost	Utilization
Kerta Dua	Rp 2,175,309,784.45	0.74
Andika	Rp -	0.00
Karmila	Rp 1,890,406,401.86	0.47
Kelud	Rp 1,405,085,903.44	0.41
Cakra Bahana	Rp 1,209,660,178.70	0.40
Mundu	Rp 734,286,724.12	0.30
Ketaling	Rp 365,546,185.96	0.18
Dorolonda	Rp 2,171,612,502.63	0.47
Kurau	Rp 311,034,361.61	0.08
Egon	Rp 54,534,989.01	0.00
Alor	Rp 1,517,408,136.30	0.61
Dompu	Rp -	0.00
	Rp 11,834,885,168.06	0.30

Period 2 Output

Ship	Route
Kerta Dua	Tanjung Wangi---Manggis---Gresik---Manggis---Ampenan---Camplon---Manggis---Tanjung Wangi---Ngurah Rai
Andika	
Karmila	Ngurah Rai---Manggis---Ngurah Rai---Camplon---Gresik
Kelud	Camplon---Manggis---Gresik---Manggis---Camplon---Ngurah Rai---Tanjung Wangi
Cakra Bahana	Maumere---Reo Reo---Maumere---Ende Ende---Bima---Waingapu---Badas
Mundu	
Ketaling	Ende Ende---Reo Reo---BadasBadas---Reo Reo---Maumere---Ende Ende---Bima
Dorolonda	Ende Ende---Reo Reo---Ende Ende
Kurau	Atutupu---Kalabahi---Atutupu---Larantuka---Tenau
Egon	Atutupu---Kalabahi---AtutupuAtutupu---Kalabahi---Dilli
Alor	Atutupu---Kalabahi---Larantuka---Atutupu---Tenau
Dompu	

Ship	Total Cost	Utilization
Kerta Dua	Rp 2,355,884,600.67	0.64
Andika	Rp -	0.00
Karmila	Rp 843,155,074.09	0.24
Kelud	Rp 1,950,435,947.49	0.56
Cakra Bahana	Rp 2,513,192,935.95	0.71
Mundu	Rp -	0.00
Ketaling	Rp 2,681,110,665.31	0.72
Dorolonda	Rp 309,605,867.61	0.16
Kurau	Rp 1,326,776,766.78	0.53
Egon	Rp 651,513,261.09	0.16
Alor	Rp 1,469,310,446.73	0.61
Dompu	Rp -	0.00
	Rp 14,100,985,565.73	0.36

Period 3 Output

Ship	Route
Kerta Dua	Ngurah Rai---Manggis---Camplon---GresikGresik---Manggis---Tanjung Wangi---Ngurah Rai
Andika	Gresik---Manggis---Camplon---Ngurah Rai
Karmila	Gresik---Manggis---Ngurah Rai---Ampenan---Gresik---Camplon
Kelud	Tanjung Wangi---Manggis---Ampenan
Cakra Bahana	Badas---Reo Reo---Maumere---Waingapu---Bima---Ende Ende---Badas
Mundu	Bima---Reo Reo---Ende Ende
Ketaling	Bima---Reo Reo---Maumere---Ende EndeEnde Ende---Reo Reo---WaingapuWaingapu---Reo Reo---Bima
Dorolonda	Ende Ende---Reo Reo---Maumere---WaingapuEnde Ende---Reo Reo
Kurau	Tenau---Kalabahi---Atutupu---Dilli---Tenau---Larantuka
Egon	Dilli---Kalabahi---Atutupu---Larantuka---Dilli
Alor	Tenau---Kalabahi---Dilli---Atutupu---Tenau
Dompu	

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,484,425,253.13	0.48
Andika	Rp 977,393,022.79	0.31
Karmila	Rp 1,384,777,200.15	0.40
Kelud	Rp 340,725,368.26	0.08
Cakra Bahana	Rp 3,485,076,117.77	0.94
Mundu	Rp 1,401,251,375.80	0.45
Ketaling	Rp 1,833,744,551.78	0.69
Dorolonda	Rp 868,309,640.15	0.33
Kurau	Rp 1,680,052,593.10	0.55
Egon	Rp 1,630,315,002.82	0.59
Alor	Rp 1,207,478,827.78	0.43
Dompu	Rp -	0.00
	Rp 16,293,548,953.52	0.44

Period 4 Output

Ship	Route
Kerta Dua	Ngurah Rai---Manggis---AmpenanAmpenan---Manggis---Camplon---GresikGresik---Manggis---Tanjung Wangi---Ngurah Rai
Andika	Ngurah Rai---Manggis---Camplon
Karmila	Camplon---Manggis---Ngurah Rai---GresikGresik---ManggisCamplon---Manggis---Camplon
Kelud	Ampenan---Manggis---Tanjung Wangi---Ngurah Rai
Cakra Bahana	Badas---Reo Reo---Waingapu---Maumere---Badas---Bima---Ende Ende
Mundu	
Ketaling	Bima---Reo Reo---Maumere---Ende Ende---Bima
Dorolonda	Waingapu---Reo Reo---Badas---Ende Ende
Kurau	Tenau---Kalabahi---Atutupu---Dilli---Tenau---Larantuka
Egon	Dilli---Kalabahi---Atutupu---Larantuka---Dilli
Alor	Tenau---Kalabahi---Dilli---Atutupu---Tenau
Dompu	

Ship	Total Cost	Utilization
Kerta Dua	Rp 1,808,983,115.85	0.56
Andika	Rp 636,574,930.65	0.19
Karmila	Rp 1,690,898,419.00	0.67
Kelud	Rp 689,191,999.91	0.21
Cakra Bahana	Rp 3,084,253,587.45	0.87
Mundu	Rp -	0.00
Ketaling	Rp 1,758,053,102.13	0.47
Dorolonda	Rp 2,345,325,847.23	0.46
Kurau	Rp 1,680,052,593.10	0.55
Egon	Rp 1,630,315,002.82	0.59
Alor	Rp 1,207,478,827.78	0.43
Dompu	Rp -	0.00
	Rp 16,531,127,425.92	0.42

Product 1 Inventory Flow

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	1860	7144	6716	6288	5860	5432	5004	4576	4148	3720	3292	2864	2436	2008	7572	7144	6716	6288	5860	5432	5004	4576	4148	3720	3292	2864	2436	2008
Tanjung Wangi	5395	4939	4483	4027	3571	3115	2659	2203	1747	1291	6176	5720	5264	4808	4352	3896	3440	2984	2528	2072	1616	7544	7088	6632	6176	5720	5264	4808
Ngurah Rai	2282	2064	1846	1628	1410	1192	974	756	538	320	1628	1410	1192	974	756	538	1846	1628	1410	1192	974	756	2064	1846	1628	1410	1192	974
Camplon	1544	1308	1292	1056	820	584	348	112	-124	1292	1056	820	584	348	112	1528	1292	1056	820	584	348	112	1528	1292	1056	820	584	348
Gresik	2443	2125	1807	1489	1171	853	535	217	7546	7228	6910	6592	6274	5956	5638	5320	5002	4684	4366	4048	3730	3412	3094	2776	2458	2140	1822	1504
Bima	6779	6108	5437	4766	4095	3424	2753	2082	1411	3987	3316	2645	1974	1303	632	-39	-710	3316	2645	1974	1303	632	-39	-710	-1381	1645	974	303
Badas	5065	4684	4303	3922	3541	3160	2779	2398	2017	1636	1255	4095	3714	3333	1952	1571	1190	809	428	1333	952	571	190	-191	2095	1714	1333	952
Maumere	1892	1625	1432	1165	898	631	364	97	1699	1432	1165	898	631	364	97	1699	1432	1165	898	631	364	97	-170	1432	1165	898	631	364
Ende Ende	1489	1285	1081	877	673	469	265	61	2092	1888	1684	1480	1276	1072	868	664	460	256	1276	1072	868	664	460	256	52	-152	1072	868
Waingapu	1458	6860	6290	5720	5150	4580	4010	3440	2870	2300	3720	3150	2580	2010	440	-130	2720	2150	1580	1010	440	-130	3290	2720	2150	1580	1010	440
Dilli	5677	5330	4983	4636	4289	3942	3595	3248	2901	2554	2207	1860	1513	1166	819	3306	2959	2612	2265	1918	1571	819	3306	2959	2612	2265	1918	1571
Larantuka	4348	3917	3486	3055	2624	2193	1762	1331	900	3707	3276	2845	2414	1983	1552	1121	690	2776	2345	1914	1483	1552	1121	690	2776	2345	1914	1483
Tenau	5078	4643	4208	3773	3338	2903	2468	2033	1598	1163	3260	2825	2390	1955	1520	1085	3195	2760	2325	1890	1455	1520	1085	3195	2760	2325	1890	1455
Atutupu	2572	2144	1716	1288	860	432	4	-424	2144	1716	1288	860	432	4	-424	1716	1288	860	432	4	-424	-424	1716	1288	860	432	4	-424

Product 2 Inventory Flow

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	885	823	761	699	637	575	513	451	389	327	265	203	141	79	17	1876	1814	1752	1690	1628	1566	1504	1442	1380	1318	1256	1194	1132
Tanjung Wangi	8139	7764	7389	7014	6639	6264	5889	5514	5139	4764	4389	4014	3639	3264	2889	2514	2139	1764	1389	1014	639	264	-111	-486	5500	5125	4750	4375
Ngurah Rai	1417	1133	1348	1064	780	496	212	1916	1632	1348	1064	780	496	212	1632	1348	1064	780	496	212	-72	1916	1632	1348	1064	780	496	212
Camplon	1653	1446	1239	1032	825	618	411	204	1786	1579	1372	1165	958	751	544	337	1579	1372	1165	958	751	544	337	130	-77	1165	958	751
Gresik	1822	6544	5816	5088	4360	3632	2904	2176	6544	5816	5088	4360	3632	2904	2176	1448	4088	3360	2632	1904	1176	448	4816	4088	3360	2632	1904	1176
Bima	2501	7250	6875	6500	6125	5750	5375	5000	4625	4250	3875	3500	3125	2750	2375	5250	4875	4500	4125	3750	3375	3000	2625	2250	1875	1500	1125	750
Badas	1010	759	4996	4745	4494	4243	3992	3741	3490	3239	2988	2737	2486	2235	1984	1733	1482	1231	980	729	478	227	5498	5247	4996	4745	4494	4243
Maumere	221	1652	1536	1420	1304	1188	1072	956	840	724	608	492	376	260	144	1652	1536	1420	1304	1188	1072	956	840	724	608	492	376	260
Ende Ende	878	744	610	1330	1196	1062	928	794	1732	1598	1464	1330	1196	1062	928	794	1598	1464	1330	1196	1062	928	794	1598	1464	1330	1196	1062
Waingapu	4583	4283	3983	3683	3383	3083	2783	2483	2183	1883	1583	1283	983	683	383	83	5100	4800	4500	4200	3900	3600	3300	3000	2700	2400	2100	1800
Dilli	-58	4792	4438	4084	3730	3376	3022	2668	2314	1960	1606	1252	898	544	190	4792	4438	4084	3730	3376	3022	190	4792	4438	4084	3730	3376	3022
Larantuka	980	852	724	596	468	340	212	84	1744	1616	1488	1360	1232	1104	976	848	720	592	464	336	208	976	848	720	592	464	336	208
Tenau	1346	1076	2690	2420	2150	1880	1610	1340	1070	800	2420	2150	1880	1610	1340	1070	2690	2420	2150	1880	1610	1340	1070	2690	2420	2150	1880	1610
Atutupu	1072	913	754	1205	1046	887	728	569	410	1523	1364	1205	1046	887	728	1523	1364	1205	1046	887	728	728	1523	1364	1205	1046	887	728

Product 3 Inventory Flow

Port	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Ampenan	5151	4618	4085	3552	3019	2486	1953	1420	887	6401	5868	5335	4802	4269	3736	3203	2670	2137	1604	1071	538	7467	6934	6401	5868	5335	4802	4269
Tanjung Wangi	3868	3182	2496	1810	1124	3884	3198	2512	1826	1140	454	-232	3884	3198	2512	1826	1140	5256	4570	3884	3198	2512	1826	1140	454	4570	3884	3198
Ngurah Rai	777	567	1870	1660	1450	1240	1030	820	610	400	190	-20	1240	1030	820	610	400	1660	1450	1240	1030	820	610	400	190	1450	1240	1030
Camplon	1007	822	637	1260	1075	890	705	520	335	150	1260	1075	890	705	520	1630	1445	1260	1075	890	705	520	335	1445	1260	1075	890	705
Gresik	812	5798	5064	4330	3596	2862	2128	1394	6532	5798	5064	4330	3596	2862	2128	6532	5798	5064	4330	3596	2862	2128	1394	5798	5064	4330	3596	2862
Bima	6591	6043	5495	4947	4399	3851	3303	2755	2207	1659	1111	5260	4712	4164	3616	3068	2520	1972	1424	4712	4164	3616	3068	6356	5808	5260	4712	4164
Badas	3000	2659	2318	1977	1636	1295	954	613	7318	6977	6636	6295	5954	5613	5272	4931	4590	4249	3908	3567	3226	2885	2544	2203	1862	1521	1180	839
Maumere	2003	1809	1615	1421	1227	1033	839	645	451	257	1530	1336	1142	948	754	1918	1724	1530	1336	1142	948	754	1918	1724	1530	1336	1142	948
Ende Ende	1406	2052	1828	1604	1380	1156	932	708	484	260	1604	1380	1156	932	708	2052	1828	1604	1380	1156	932	708	2052	1828	1604	1380	1156	932
Waingapu	5341	5066	4791	4516	4241	3966	3691	3416	3141	2866	2591	2316	2041	1766	1491	1216	941	6400	6125	5850	5575	5300	5025	4750	4475	4200	3925	3650
Dilli	4412	3965	3518	3071	2624	2177	1730	1283	5106	4659	4212	3765	3318	2871	2424	1977	1530	3212	2765	2318	1871	2424	1977	1530	3212	2765	2318	1871
Larantuka	2448	2296	2144	1992	1840	1688	1536	1384	1232	1080	928	776	624	472	320	168	4544	4392	4240	4088	3936	320	168	4544	4392	4240	4088	3936
Tenau	5899	5689	5479	5269	5059	4849	4639	4429	4219	4009	3799	3589	3379	3169	2959	2749	2539	2329	2119	1909	1699	2959	2749	2539	2329	2119	1909	1699
Atutupu	1770	1540	1310	1080	850	620	390	1770	1540	1310	1080	850	620	390	160	1540	1310	1080	850	620	390	160	1540	1310	1080	850	620	390

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CHAPTER VI
CONCLUSION AND SUGGESTION

In this chapter explains about conclusion gain from the entire research as well as the suggestion that can be given to the next research.

6.1 Conclusion

Several conclusions that can be taken from this research is as follows:

1. This research can make a model for multi-product inventory ship routing problem with multi depot using dedicated tanker policy. The model developed objective function is to minimize cost. Several constraints in the model are routing constraint, loading and unloading constraint, time constraint, and inventory constraint.
2. Heuristic algorithm developed for this research model can solve the problem and can be applied to the program developed by using VBA in Microsoft Excel. Algorithm developed consist of three big steps which are critical port selection and sorting, tanker assignment, and routing process.
3. From the results of numerical experiments, shows that the developed algorithm fulfill the constraints in the model.
4. There are several conclusions that can be taken from the numerical experiments, such as:
    a. From the first experiment which is to determine the best number of tankers available. This experiment confirmed that the best number of tankers available for the real case data is 9 tankers.
    b. Second experiment has shown that by using 12 tankers is sufficient to deliver almost all the products in 125% demand rate. However, further analysis showed that 12 tankers is not sufficient for 150% demand rate due to a lot of late deliveries occurred.

c. It is better to anticipate critical ports by using long planning horizon and it will make the inventory last longer. But this must also within the consideration of the ability of tankers to supply the port.
d. Overall, the developed model and algorithm can accommodate problem solving by providing supporting decision tools in order to know the best number of tanker available.

6.2 Suggestion

In conducting this research, there were several evaluation regarding the research. Therefore, several suggestion taken from this research are:

1. Further research might add more constraint regarding technical port loading/unloading regulation and dynamic routing that make the model and algorithm more complex.
2. Furthere research could also develop more by adding inventory cost and load/unload setup to the objective function.

REFERENCES

Al-Khayyal, F. & Hwang, S.-J., 2005. Inventory constrained maritime routing and scheduling for multi-commodity liquid bulk, Part I: Applications and model. *Science Direct*, Volume 176, pp. 106-130.

Arnold, T. & Chapman, S., 2008. *Introduction to Material Management.* 6th ed. New Jersey: Pearson Education.

BunkerBBM.co.id, 2016. *Price | Bunker BBM.* [Online] Available at: http://www.bunkerbbm.co.id/pricelist/ [Accessed 17 June 2016].

Huber, M., 2001. *Tanker operations: a handbook for the person-in-charge (PIC).* Cambridge: Cornell Maritime Press.

Kementrian Sekretariat Negara Republik Indonesia, 2010. *Geografi Indonesia.* [Online].

Lawrence, S., 1972. *International Sea Transport: the years ahead.* Lexington: Lextington Books.

Marti, R. & Reinelt, G., 2011. *The Linear Ordering Problem: Exact and Heuristic Methods in Combinatorial Optimization.* s.l.:s.n.

Nurminarsih, S., 2012. *Pengembangan Model dan Algoritma Tabu Search untuk Penjadwalan Kapal Tanker dengan Memperhatikan Kompabilitas Muatan,* Surabaya: Tugas Akhir ITS.

Nurminarsih, S., Rusdiansyah, A., Siswanto, N. & Gani, A. Z., 2015. Dynamic-inventory ship routing problem (D-ISRP) model considering port dwelling time information. *Procedia Manufacturing,* pp. 344-351.

Pillac, V., Gendreau, M., Gueret, C. & Medaglia, A. L., 2011. A Review of Dynamic Vehicle Routing Problems. *CIRRELT,* Volume 62.

Rahman, F., 2008. *Pengembangan Algortima Inventory Routing Problem (IRP) untuk Penjadwalan Kapal Tanker BBM Multi-Compartment (Studi Kasus PT Pertamina UPMS V Surabaya),* Surabaya: Tugas Akhir, Teknik Industri, Institut Teknologi Sepuluh Nopember.

Rani, F. K., Rusdiansyah, A., Wiratno, S. E. & Siswanto, N., 2010. Mixed Integer Linear Programming Model for Multi-Product Inventory Ship Routing Considering Product Loading Compability Constraint. *APIEMS (Asia Pacific Industrial Engineering and Management Systems Conference).*

Rodrigue, D. J.-P., 2013. *Maritime Transportation.* [Online] Available at: https://people.hofstra.edu/geotrans/eng/ch3en/conc3en/ch3c4en.html

Romero, G., Duran, G., Marenco, J. & Weintraub, A., 2013. An approach for efficient ship routing. *International Transactions in Operaational Research,* pp. 1-28.

Siswanto, N., Essam, D. & Sarkaer, R., 2011. Solving the ship inventory routing and scheduling problem with undedicated compartments. *Elsevier, Computers & Industrial Engineering,* Volume 61, pp. 289-299.

United Nations Conference on Trade and Development, 2015. *Review of Maritime Transport 2015.* [Online] Available at: http://unctad.org/en/pages/PublicationWebflyer.aspx?publicationid=1374

Waters, D., 2003. *Inventory Control and Management.* 2nd ed. West Sussex: John Wiley & Sons.

BIOGRAPHY

Muhammad Erza Raydika atau yang akrab dipanggil Erza/Dika lahir di Surabaya, pada tanggal 11 November 1993. Penulis merupakan anak pertama dari tiga bersaudara pasangan Sugianto dan Peni Palupi. Pendidikan formal yang ditempuh penulis berawal dari SD Muhammadiyah 1 Sidoarjo, SMP Negeri 1 Sidoarjo, SMA Negeri 1 Sidoarjo, hingga ke jenjang sarjana di Institut Teknologi Sepuluh Nopember pada tahun 2012.

Selama menjadi mahasiswa, penulis aktif dalam berbagai kepanitiaan, organisasi, event, serta berwirausaha. Penulis menjadi staf Divisi IE Fair BPH HMTI ITS 2013/2014 dan Koordinator Media dan Kreatif Divisi IE Fair BPH HMTI ITS 2014/2015. Penulis juga berkesempatan menjadi salah satu asisten Laboratorium Logistics & Supply Chain Management (LSCM) Jurusan Teknik Industri ITS. Selama kuliah, penulis pernah menjadi asisten mata kuliah Pengantar Teknik Sistem Industri dan Manajemen Distribusi. Selain itu penulis menjadi asisten dalam beberapa riset yang dikerjakan oleh dosen di bawah naungan laboratorium LSCM. Penulis banyak mengikuti pelatihan pengembangan diri, kepemimpinan, dan skill serta banyak juga mengikuti kegiatan event kepanitiaan. Dari semua kegiatan diluar kelas itu penulis mendapatkan team work, leadership, dan communication skill.

Dalam rangka pengaplikasian keilmuan, penulis pernah melakukan praktek di PT Medion pada Departemen Marketing. Penelitian yang dilakukan berjudul “Building System to Accommodate The Role of Technical Sales Representative (TSR) in Minimizing Sales Plan Error of Pt Medion”. Penulis dapat dihubungi melalui email di erzaraydika@gmail.com.