Vessel Routing Model in an Archipelago Crude Oil Distribution Problem

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***Abstract*—as the population in Indonesia grows, the need of energy in forms of fuel, electricity, asphalt, or wax which were distilled through the refinery process of crude oil, has been consistently increasing for the past several years. In addition, with the continuous entrance of foreign companies penetrating the Indonesia gas market, increases the stringent of the competition. In order to be able to stay competitive, PT. PERTAMINA, an Indonesian state-owned oil and natural gas corporation, is required to be able to support such continuously increasing needs. The Shipping Division in the firm is expected to be able to deliver crude oil from the load port crude to refinery unit by using available owned and chartered vessels. In the current crude oil distribution system, every day the company assigned total of 49 vessels where three of them are owned and the remaining are chartered. Due to the archipelagic nature of Indonesia in addition to the variety of the sea and strait depths, some refinery areas are remote and reachable on by selected types of vessels. Integer programming model combined with CDS algorithm for *m*-machine are used to provide better crude distribution system for the company. As a result, the company can save up to 51% on the number of vessels needed to be used to transport the crude oil.**

Keywords—crude oil, integer programming, CDS algorithm, load port crude, refinery unit, archipelago

I. Introduction

According to Badan Pusat Statistik Republik Indonesia, the annual population growth rate in Indonesia is expected to be 1.4% from 2010 to 2015 [1]. Such increase contributes significant impact to the growth of the consumption on commodities and energy. In fact, the increase in the consumption of crude oil coincided with the population growth (Fig. 1).

Unfortunately, production cannot keep pace with such increase in domestic crude oil demand of in Indonesia [2]. In fact, oil production has been continuously declining for the past five years. Such declining trend is contributed by the inability of the state-owned oil and natural gas corporation to deliver the right amount of crude oil quantity to be processed in each refinery unit in addition to its limited availability of refinery units. As the largest and most varied archipelago which compromises over 18,000 islands separated with seas and straits, this corporation constantly experiences difficulty in delivering crude oils to refineries located spread out around the country. The high variance on the sea and straight depths between islands adds complication to its crude oil distribution system.

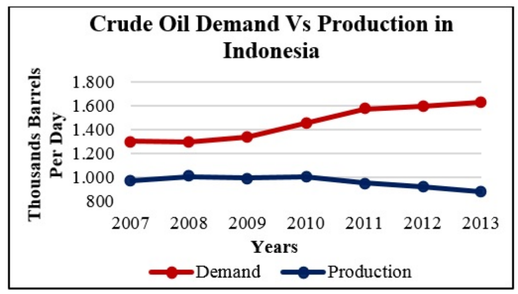


Fig. 1. Crude Oil Demand Vs Production in Indonesia

II. Problem Formulation

The upstream process consists of production which includes onshore and offshore drilling and transportation to the nearest load port crude and distribution from load port crude to refinery units (RU). The corporation owned six active RUs throughout Indonesia which are Dumai, Plaju, Balongan, Cilacap, Balikpapan CDU IV, and Balikpapan CDU V which can refine crude oil into more useful products.

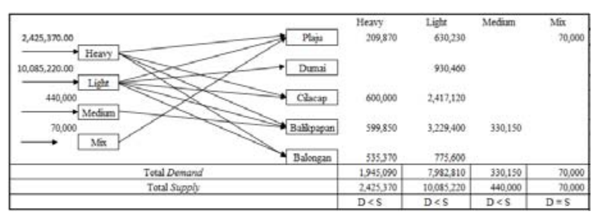


Fig. 2. Supply and Demand Comparison of Crude Oil (per Month)

There are four types of crude oil (heavy, light, medium, and mix) which need to be delivered to refinery units. The available supply of each type of crude oil is mostly greater than or equal to its demand (Fig. 2). The oil is transported using vessels which can be categorized into three according to the size which are GP (General Purpose), MR (Medium Range), and LR (Large Range). The various depth of the straits and seas in addition to not all types of vessel can harbor in any port limit the flexibility of vessel assignment to minimize total transportation cost. Moreover, allocating the same type of crude oil from different ports may jeopardize the product quality as same type of crude oil coming from different ports have different boiling ranges.

One challenge in the formulation is to plan the crude oil distribution system which transport crude oil from multiple origins (ports) to fulfill demand on each type of crude oil requested by each destinations (RUs) which has to come from specific type of vessel within 30 days duration while complying additional restriction such as vessel temperature according to safety and standardization policy.

The following data are used in the model formulation.

- The coordinates of all drilling location, offshore, and refinery unit.
- Crude oil shipping Master Plan including composition data for each refinery unit and available supply in each drilling location and offshore.
- Vessel information and constraints such as the types, speed, and capacity

III. Literature Review

A. Capacitated Vehicle Routing Problem (CVRP)

Management of a fleet of vehicles are subject to a number of constraints such as vehicle availability and capacity, time windows, service constraints and precedence constraints [2], [3].Vehicle routing problem (VRP) is a variant of fleet management in which route of *m* vehicles has to be determined with a number of predetermined constraints. The basic data needed for VRP consists of the number of destination points, the location of all the destination points or the pairwise distances between the destination points, and the number of the available vehicles and its capacity [15].

A capacitated VRP (CVRP) is a deterministic optimization problem as it postulates that customer demands and transportation costs are known with certainty. The vehicle routes originating and terminating at a depot with the assumptions that vehicles are having certain capacity [14],[19],[21] with objective to minimize the number of vehicles used or total travel cost or time [4].

B. Sweep Variant A (Cluster First Route Second)

Sweep method is one of the simplest two-phase constructive methods for CVRP and it belongs to the cluster-first, route-second algorithm [22]. Sweep variant A clusters the region first whilst complying with the vehicle capacity constraint [23] then optimize the routing within each cluster separately by solving the corresponding TSP [5]. This method is the simplest method yet provide good solution with an average error of ten percent [24].

C. Integer Programming

The modeling process starts with establishment of the objectives and system constraints [25]. More advanced techniques such as goal programming, tree search methods, and dynamic programming, among others are efficient solution procedures can be utilized to deal with large, complex problem frequently encountered in logistics network design. However, the most promising of this class is the integer linear programming (ILP) approach due to its ability to handle fixed costs in an optimal way [24] with applicable result [6]. In addition, linear programming for the approximation of the dynamic programming relaxes the restriction to lower bounding approximations while remaining computationally tractable [26]. Although it is quite appealing, integer programming requires longer solution times which can be bothersome [27],[28] and the interpretation and formulation of integer programming is not an easy task considering it has implicit logical meanings in some of the variables and constraints [29]. IP can be classified into three categories (pure, mixed, and binary) and the differences among these three lie in the types of the variables [7],[8].

D. CDS Algorithm for m-machines

Scheduling problems can be classified into batch scheduling, flow shop scheduling, and job shop scheduling [9]. Job shop scheduling can be further classified into two, namely job shop loading and sequencing. Job shop sequencing involves a sequence of priority rule and applied to all existing jobs in the queue. Job shop has a static pattern of arrivals as a process of scheduling the same sequence, or commonly referred to as flow shop scheduling.

A simple heuristic extension of Johnson's rule to *m*-machine flow shop problem is CDS algorithm [11]. This heuristic scheduling method is developed by Campbell, Dudek, and Smith, generates a set of *(m-1)* by aggregating *m* machines into two groups systematically [18] with focus to minimize the make-span in a deterministic flow shop problem. This algorithm generates several schedules from which the best schedule can be chosen.

E. Netpas Distance software

This software is used to determine the shortest distance between ports, refinery, and port to refinery while integrating the sea or strait depth and vessel weight in addition to weather forecast, vessel maximum speed, and vessel sailing position [10] (Fig. 3).

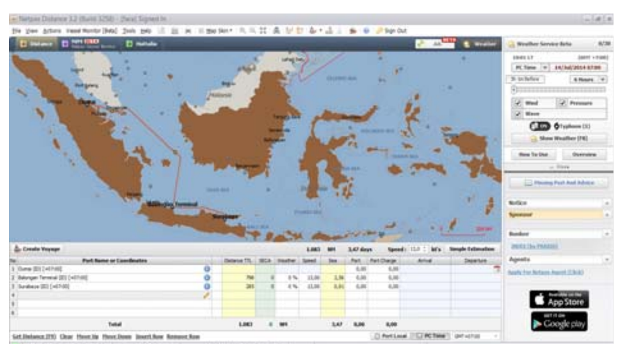


Fig. 3. Netpas User Interface

- Column “port name of coordinates “serves to indicate a port and terminal.
- Column “distance TTL” shows distances between a port or terminal to other ports or terminals.
- Column “speed” shows the speed of a vessel which is set to 11, 12 and 13 knot.

IV. Preliminary Data

A. Port to RU distances

Offshore, load port crude, and refinery units (RU) coordinates are drawn up in a map (Fig. 4). By taken into consideration sea or strait depth and vessel type and capacity, vessel types which are feasible to anchor in each RU is determined and shortest distance among offshore, load port crude, and refinery unit is computed.

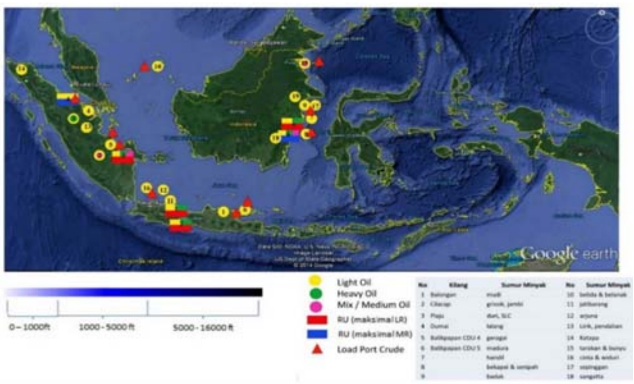


Fig. 4. Offshore, Load Port Crude, and RU Location

Table I shows the type of crude oil produced by each offshore. Note that each RU required specific amount of crude oil coming from specific offshore which are collected in nearby port, same type of crude oil produced from different offshore cannot be easily allocated to fill in any shortage in any RU for the same type of crude oil. Table II shows the computed distance from port to RU using Netpas software upon consideration on each RU’s demand specific requirement.

TABLE I. Crude Oil Name and Type

No.	Offshore	Crude oil type	No.	Offshore	Crude oil type
1	Arjuna	Light	14	Grissik Mix	Medium
2	Badak	Light	15	Handil	Light
3	Bekapai	Light	16	Jatibarang	Light
4	Belanak	Light	17	Katapa	Mix
5	Belida	Light	18	Lalang	Light
6	Bunyu	Light	19	Lirik	Light
7	Cinta	Light	20	Madura	Light
8	Duri	Heavy	21	Mudi	Light
9	Geragai	Light	22	Pendalian	Light
10	Sangatta	Light	23	Widuri	Light
11	Senipah	Light	24	Jambi	Light
12	SLC	Light	25	Sepinggan	Light
13	Tarakan	Light			

TABLE II. Distance from Port to RU (in Kilometer)

Port \ RU	Balongan	Plaju	Cilacap	Balikpapan CDU IV	Balikpapan CDU V
Arjuna	-	560.00	447.00	1.025.00	1.025.00
Petrochina	-	154.00	958.00	-	-
Grissik	-	154.00	958.00	-	-
Belanak	-	-	1.007.00	887.00	-
Surabaya	526.59	705.00	687.00	890.81	891.00
Madura	-	-	652.00	447.00	-
Bekapai	-	-	887.00	37.00	-
Senipah	-	-	885.00	49.00	37.00
Bunyu	-	-	-	-	401.00
Dumai	1,256.59	484.00	1,900.17	1,198.00	1,198.00

B. Vessel capacity and travel time

Each vessel can carry the same type of crude oil from maximum three different offshores. Maximum capacity of each type of vessel is available in Table III. A total of 190 vessels are available to be used to transport crude oil in which 36 of them are owned by the corporation while the remaining are chartered vessels. Considering vessel has to be regularly maintained and cleaned, slack time is allocated into the schedule to avoid any tardiness. The average cleaning and maintenance time are 4.56 hours or equivalent to 0.19 day and 18.96 hours or equivalent to 0.79 day, respectively. These two times is summed up to approximately one day, which is allocated into scheduling for each vessel trip.

TABLE III. Crude Oil Loading Time

Vessel Type	Vessel Capacity
LR	600,000 barrel
MR	220.000 barrel
GP	110.000 barrel

Travel time for each vessel is computed by dividing the shortest distance computed using Netpas with the vessel speed. The vessel speeds according to the types are 13 knots (LR), 12 knots (MR), and 11 knots (GP).

C. Loading and unloading time

Crude oil lifted from the offshore, flows through the pipeline to the port and ready to be loaded into the vessel at a pumping rate of DWT (deadweight ton) per hour. The time required to fill in an LR vessel with a minimum of 45,001 DWT in a port with pumping rate of 2,400 DWT per hour is 18.75 hour or equivalent to 0.8 day. Table IV shows the summary of the loading time for each type of vessel.

TABLE IV. Crude Oil Loading Time

Jenis Kapal		DWT (*Deadweight Ton*)	*Loading/ Pumping Rate*	*Loading Time (/day)*
LR	Min	45,001	2,400	0.8
	Max	80,000		1.4
MR	Min	25,001	1,500	0.7
	Max	45,000		1.25
GP	Min	6,501	1,000	0.27
	Max	16,500		0.69

TABLE V. RU CAPACITY

RU Name	***Unloading* Capacity**
RU III Plaju	133.700
RU IV Cilacap	348.000
RU V Balikpapan CDU IV	260.000
RU V Balikpapan CDU V	260.000
RU VI Balongan	125.000

TABLE VI. CRUDE OIL NAMES FOR EACH RU (NAMES REPRESENT THE DRILLING LOCATION)

Refinery Unit	***Port* / Pipe**	**Names**
Balongan	**Pipe**	Jatibarang
	Port Surabaya	Mudi
	Port Dumai	Duri
		SLC
Dumai	**Pipe**	SLC
		Duri
		Pendalian
		Lirik
	Tongkang	Selat Panjang
Plaju	**Pipe**	Jambi
		Tampi
	Port Dumai	Duri
		SLC
		Lalang
	Port Arjuna	Arjuna
	Port Petrochina	Geragai
	Port Grissik	Grissik *Mix*
	Port Surabaya	Mudi
Balikpapan CDU IV	**Pipe**	Sepinggan
		Sanga-sanga
	Port Arjuna	Arjuna
		Jatibarang
	Port Dumai	Duri
		SLC
		Katapa
	Port Bekapai	Bekapai
	Port Senipah	Senipah
		Handil
	Port Madura	Madura
	Port Surabaya	Mudi
	Port Belanak	Belida
Balikpapan CDU V	**Pipe**	Tanjung
	Port Arjuna	Cinta
		Widuri
	Port Bunyu	Bunyu
		Tarakan
	Port Bekapai	Sangatta
Cilacap	*Port* Arjuna	Arjuna
		Jatibarang
	Port Surabaya	Mudi
	Port Dumai	Duri
	Port Petrochina	Geragai
	Port Bekapai	Bekapai
		Badak
	Port Senipah	Handil
		Senipah
	Port Belanak	Belida
		Belanak
	Port Madura	Madura

Crude oil carried by the vessel extracted through pipe available in each RU at an unloading rate listed in Table V.

Unloading time is then computed by dividing the amount of crude oil carried in a vessel with RU's unloading capacity.

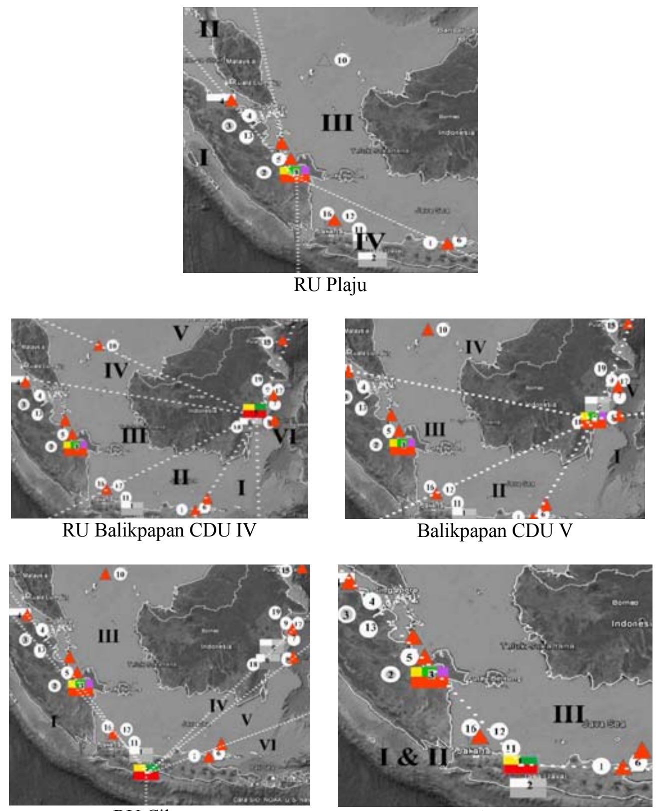
D. Refinery units demand

Crude oil demand of each RU are different because it can only process certain types of crude oil from specific offshores (Table VI).

V. FORMULATION AND COMPUTATIONAL RESULT

A. Clustering: Sweep variant A

In this algorithm, ports are ordered and added in the counterclockwise direction starting from the south with RU as the depot and vessel capacity as the cut off constraint. Each cluster should have the same type of crude oil. The resulting clusters of each RU is shown in Fig. 5.



RU Plaju

RU Balikpapan CDU IV

Balikpapan CDU V

RU Cilacap

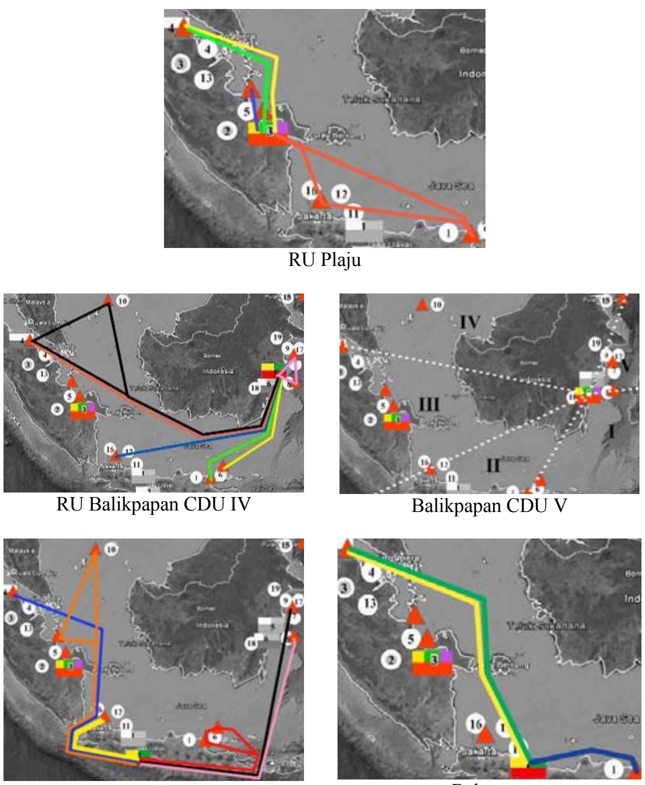
Balongan

Fig. 5. Clusters for each refinery unit

Route in each cluster is determined using triangle insertion method and the resulting route of all clusters in each RU can be seen in Table VIII and Fig. 6.

TABLE VII. Refinery Unit Routes

RU	Route		*Demand (Barrel)*	Distance (KM)	Color
Plaju	1	Dumai–Plaju–Dumai	210,000	484.0	Yellow
	2	Dumai–Petrochina–Plaju– Dumai	210,000	391.0	Green
	3	Grissik–Plaju–Grissik	70,000	874.0	Blue
	4	Surabaya–Arjuna–Plaju–Surabaya	840,000	154.0	Orange
Balikpapan CDU IV	1	Madura–Balikpapan–Madura	400,000	447.0	Yellow
	2	Surabaya–Balikpapan–Surabaya	340,000	478.0	Green
	3	Arjuna–Balikpapan–Arjuna	750,000	1025.0	Blue
	4	Dumai–Balikpapan–Dumai	600,000	1198.0	Orange
	5	Belanak–Dumai–Balikpapan–Belanak	479,000	1467.0	Black
	6	Bekapai–Senipah–Balikpapan–Bekapai	580,000	49.0	Pink
Balikpapan CDU V	1	Surabaya–Balikpapan–Surabaya	185,000	478.0	Yellow
	2	Arjuna–Balikpapan–Arjuna	800,000	1025.0	Green
	3	Dumai–Balikpapan–Dumai	150,000	1198.0	Blue
	4	Bunyu–Balikpapan–Bunyu	440,000	401.0	Orange
	5	Bunyu–Senipah–Balikpapan–Bunyu	270,000	406.0	Pink
Cilacap	1	Arjuna–Cilacap–Arjuna	750,000	447.0	Yellow
	2	Dumai–Cilacap–Dumai	600,000	1201.0	Blue
	3	Belanak–Petrochina–Cilacap–Belanak	500,000	1430.0	Orange
	4	Bekapai–Cilacap–Bekapai	390,000	887.0	Black
	5	Senipah–Cilacap–Senipah	500,000	885.0	Pink
	6	Madura–Surabaya–Cilacap–Madura	900,000	735.0	Red
Balongan	1	Dumai–Balongan–Dumai	1,084,000	1256.6	Yellow
	2	Dumai–Balongan–Dumai	300,000	1256.9	Green
	3	Surabaya–Balongan–Surabaya	696,000	526.6	Blue



RU Plaju

RU Balikpapan CDU IV

Balikpapan CDU V

RU Cilacap

Balongan

Fig. 6. Routes of each refinery unit

B. Vessel Routing Model

The following notation is used to formulate the model used to compute the frequency of each route for each RU.

Sets and indices

I: set of routes, indexed by i
J: set of vessel types, indexed by j where j = {LR, MR, GP}
K: set of refinery units, indexed by k where k = {Plaju, CDU IV, DCU V, Cilacap, Balongan}

Decision variables

X_{ijk}: number of trips of route i using vessel type j for RU k

Trip frequency model for each refinery unit *k*

$$\text{Minimize } z = \textstyle\sum_i \sum_j X_{ijk} \quad (1)$$

subject to:

$$552{,}000X_{i1k} + 210{,}000X_{i2k} + 110{,}000X_{i3k} \geq D_{ik}\ \forall i \quad (2)$$

$$X_{ijk} \geq 0, \text{ INT } \forall i,j \quad (3)$$

In the vessel routing model, the objective function (1) minimizes the number of trips required to fulfill demand of each RU. Constraint (2) ensures demand of specific type of crude oil from specific offshores using predetermined route are fulfilled for each RU. Summary of results from the trip frequency model can be seen in Table VIII. The result obtained from the trip frequency model is used as inputs for the second model to determine the total time needed to fulfill demand for each RU. The set of trips, T, equals to the z-value obtained in the first model.

TABLE VIII. OPTIMAL SOLUTION OF TRIP FREQUENCY MODEL

RU	Vessel Type	Route 1	Route 2	Route 3	Route 4	Route 5	Route 6
Plaju	LR				2		
	MR	1	1				
	GP			1			
Balikpapan CDU IV	LR	1	1	2	2	1	2
	MR						
	GP						
Balikpapan CDU V	LR						
	MR	1	4	1	3	2	
	GP						
Cilacap	LR	2	2	1	1	1	2
	MR						
	GP						
Balongan	LR	2	1	2			
	MR						
	GP						

The notation used for the second model is as follow.

Sets and indices

T: set of trips, indexed by t
J: set of vessel types, indexed by j where j = {LR, MR, GP}

Decision variables

Y_{tj}: number of days required for trip t using vessel type j
W_{tj}: number of barrels carried in trip t using vessel type j

Transport time model

Plaju refinery unit

$$\text{Minimize } z = Y_{12} + Y_{22} + Y_{33} + Y_{41} + Y_{51} \quad (4)$$

subject to:

$$W_{41} + W_{51} = 840{,}000 \quad (5)$$
$$W_{12} = 210{,}000 \quad (6)$$
$$W_{22} = 210{,}000 \quad (7)$$
$$W_{33} = 70{,}000 \quad (8)$$
$$W_{41} \le 552{,}000 \quad (9)$$
$$W_{51} \le 552{,}000 \quad (10)$$
$$W_{tj} \le 133{,}700\, Y_{tj},\ \forall\, t,j \quad (11)$$
$$Y_{tj} \ge 0,\ \text{INT}\ \forall\, t,j \quad (12)$$
$$W_{tj} \ge 0 \quad (13)$$

Balikpapan CDU IV refinery unit

$$\text{Minimize } z = Y_{11} + Y_{21} + Y_{33} + Y_{41} + Y_{51} + Y_{61} + Y_{71} + Y_{81} + Y_{91} \quad (14)$$

subject to:

$$W_{11} = 400{,}000 \quad (15)$$
$$W_{21} = 340{,}000 \quad (16)$$
$$W_{31} + W_{41} = 750{,}000 \quad (17)$$
$$W_{51} + W_{61} = 600{,}000 \quad (18)$$
$$W_{71} = 479{,}000 \quad (19)$$
$$W_{81} + W_{91} = 580{,}000 \quad (20)$$
$$W_{t1} \le 552{,}000,\ \forall\, t \quad (21)$$
$$W_{tj} \le 260{,}000\, Y_{tj},\ \forall\, t,j \quad (22)$$
$$Y_{tj} \ge 0,\ \text{INT}\ \forall\, t,j \quad (23)$$
$$W_{tj} \ge 0 \quad (24)$$

Balikpapan CDU V refinery unit

$$\text{Minimize } z = Y_{12} + Y_{22} + Y_{32} + Y_{42} + Y_{52} + Y_{62} + Y_{72} + Y_{82} + Y_{92} + Y_{102} + Y_{112} \quad (25)$$

subject to:

$$W_{12} = 185{,}000 \quad (26)$$
$$W_{22} + W_{32} + W_{42} + W_{52} = 800{,}000 \quad (27)$$
$$W_{62} = 150{,}000 \quad (28)$$
$$W_{72} + W_{82} + W_{92} = 440{,}000 \quad (29)$$
$$W_{102} + W_{112} = 270{,}000 \quad (30)$$
$$W_{t2} \le 210{,}000,\ \forall\, t \quad (31)$$
$$W_{tj} \le 260{,}000\, Y_{tj},\ \forall\, t,j \quad (32)$$
$$Y_{tj} \ge 0,\ \text{INT}\ \forall\, t,j \quad (33)$$
$$W_{tj} \ge 0 \quad (34)$$

Cilacap refinery unit

$$\text{Minimize } z = Y_{11} + Y_{21} + Y_{33} + Y_{41} + Y_{51} + Y_{61} + Y_{71} + Y_{81} + Y_{91} \quad (35)$$

subject to:

$$W_{11} + W_{21} = 750{,}000 \quad (36)$$
$$W_{31} + W_{41} = 600{,}000 \quad (37)$$
$$W_{51} = 500{,}000 \quad (38)$$
$$W_{61} = 390{,}000 \quad (39)$$
$$W_{71} = 500{,}000 \quad (40)$$
$$W_{81} + W_{91} = 900{,}000 \quad (41)$$
$$W_{t1} \le 552{,}000,\ \forall\, t \quad (42)$$
$$W_{tj} \le 348{,}000\, Y_{tj},\ \forall\, t,j \quad (43)$$
$$Y_{tj} \ge 0,\ \text{INT}\ \forall\, t,j \quad (44)$$
$$W_{tj} \ge 0 \quad (45)$$

Balongan refinery unit

$$\text{Minimize } z = Y_{11} + Y_{21} + Y_{31} + Y_{41} + Y_{51} \quad (46)$$

subject to:

$$W_{11} + W_{21} = 1{,}085{,}000 \quad (47)$$

$$W_{31} = 300{,}000 \quad (48)$$

$$W_{41} + W_{51} = 696{,}000 \quad (49)$$

$$W_{t1} \leq 552{,}000, \forall\, t \quad (50)$$

$$W_{tj} \leq 125{,}000\, Y_{tj}, \forall\, t,j \quad (51)$$

$$Y_{tj} \geq 0, \text{INT}\ \forall\, t,j \quad (52)$$

$$W_{tj} \geq 0 \quad (53)$$

In the transport time model, the objective function (4), (14), (25), (35), (46) minimizes the number of days required to transport crude oil to each RU. Constraint (5-8), (15-20), (26-30), (36-41), (47-49) ensure barrels of crude oil for each trip are delivered. Constraint (9-10), (21), (31), (42), (50) ensure vessel used in each trip cannot exceed vessel's maximum capacity. Lastly, constraint (11), (22), (32), (43), (51) enforce the total barrels delivered of the selected trip cannot exceed its maximum loading capacity.

Solution generated from the transport time model combined with the travel time and loading time are used as inputs to generate the transportation schedule. For example, the optimal solution according to the transport time model for Plaju RU is:

z = 12 is the number of days required to unload the vessels used to deliver the required amount of crude oil for Plaju RU

X_{12} = 210,000 and Y_{12} = 2 imply the first vessel (MR) carries 210,000 barrels of oil requires two days to unload

X_{22} = 210,000 and Y_{22} = 2 imply the second vessel (MR) carries 210,000 barrels of oil requires two days to unload

X_{33} = 70,000 and Y_{33} = 1 imply the third vessel (GP) carries 70,000 barrels of oil requires one day to unload

X_{41} = 438,900 and Y_{41} = 4 imply the fourth vessel (LR) carries 438,900 barrels of oil requires four days to unload

X_{51} = 401,100 and Y_{51} = 3 imply fifth vessel (LR) carries 401,100 barrels of oil requires three days to unload

C. *Vessel Scheduling*

Loading, delivery, and unloading times (Table IX) are computed and used to determine the optimal schedule for each vessel. The first sequence is determined by comparing the loading and unloading times using Johnson's rule.

Sequence 1 (Fig. 7): D – LG – MA1 – MA2 – GM

TABLE IX. PLAJU RU: LOAD, DELIVERY, AND UNLOAD

Trip	Code	Route	*Load*	*Delivery*	*Unload*
1	D	Duri	1.3	0.9	1.6
2	LG	Lalang & Geragai	1.3	0.7	1.6
3	MA1	Mudi & Arjuna 1	1.4	1.5	3.3
4	MA2	Mudi & Arjuna 2	1.4	1.5	3.0
5	GM	Grisik mix	0.7	0.3	0.5

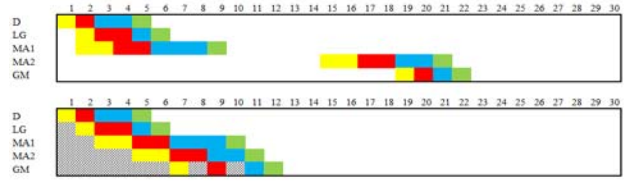


Fig. 7. Gantt Chart (D–LG–MA1–MA2–GM)

The second sequence is determined using Johnson's rule through comparing the loading + delivery times and delivery + unloading times (Table X).

Sequence 2 (Fig. 8): LG – D – MA1 – MA2 – GM

TABLE X. PLAJU RU: LOAD+DELIVERY AND UNLOAD+DELIVERY

Trip	Route	*Dummy* 1 (L+D)	*Dummy* 2 (U+D)
1	Duri	2.2	2.5
2	Lalang & Geragai	2.0	2.3
3	Mudi & Arjuna 1	2.9	4.8
4	Mudi & Arjuna 2	2.9	4.5
5	Grisik Mix	1.0	0.8

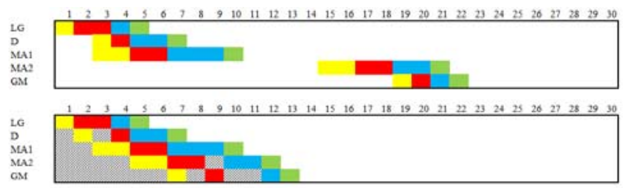


Fig. 8. Gantt Chart (LG–D–MA1–MA2–GM)

Lastly, the two sequences generated are compared and the minimum makespan (loading, delivery, and unloading) is selected upon taking into consideration the vessel maintenance and cleaning activities. The CDS algorithm is utilized to ensure that the new vessel distribution model does not violate the maximum 30-day constraint imposed by the corporation. Similar computation procedure is used for the remaining RUs.

Fig. 9 shows the proposed distribution model which will allow the corporation to save up to 51% on the total number of vessels needed to transport crude oil. This reduction compromise 33.33% reduction in LR, 12.5% in MR, and 94.11% in GP which reduce the charter cost per day from US$590,700 to US$ 262,800 (Table XI).

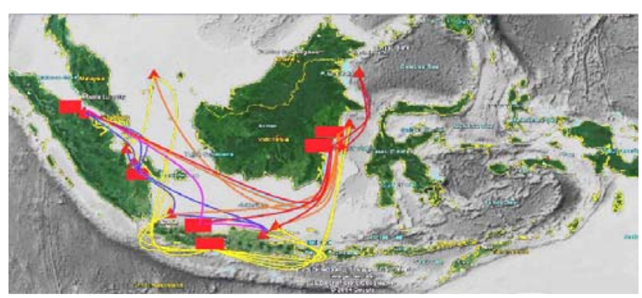


Fig. 9. Proposed Vessel Operational System Pattern

TABLE XI. CURRENT SYSTEM VS. NEW MODEL (IP & CDS)

NUMBER OF VESSEL

Refinery Unit	*Current System* Types LR	MR	GP	Total	*New Model: IP combined with CDS heuristic* Types LR	MR	GP	Total
Balikpapan CDU IV	7	-	-	7	6	-	-	6
Balikpapan CDU V	-	7	6	13	-	5	-	5
Balongan	5	-	-	5	3	-	-	4
Cilacap	10	1	-	11	6	-	-	6
Plaju	2	-	11	13	1	2	1	4
Total	**24**	**8**	**17**	**49**	**16**	**7**	**1**	**24**

CHARTER COST

Vessel Type	Fee per day	Current System # of Vessels	Total Fee	New Model # of Vessels	Total Fee
LR	US$ 15,000	21	US $ 315,000	13	US $ 195,000
MR	US $ 7,900	8	US $ 63,200	7	US $ 55,300
GP	US $12.500	17	US $ 212,500	1	US $ 12,500
TOTAL		46	**US $ 590,700**	21	**US $ 262,800**

VI. CONCLUSIONS AND FURTHER WORKS

The proposed model shows different routes should be considered by the corporation in order to increase the vessel capacity utilization level. To do so, the model load crude oil from more than one port in any trip. Solution generated from the IP model combined with CDS scheduling heuristic for *m*-machine modified the whole crude oil distribution system which allows the corporation to reduce the number of vessel used to transport crude oil from 49 to 24 vessels. This leads to a total saving of 55.51% of the total cost each day.

Further work may also consider alternative option such as allocating FSO (Floating Storage & Offloading) in narrow straits where it is difficult for LR vessels to pass through as it can reduce the total trips carried out by MR vessels.

REFERENCES

[1] B. Dudley, “BP Statistical Review of World Energy June 2014,” p.9, 2014, in press.

[2] M. Goetschalckx, Supply Chain Engineering, New York: Springer, 2011.

[3] T. Caric, H. Gold, “Vehicle Routing Problem,” in Vehicle Routing problem, p.5, 2008

[4] Moh. Abd. M. El Aziz, A.H. El-Ghareeb, M.S.M. Ksasy, “Review in Finding Path Problem Classification and Algorithms in Vehicle Routing,” in International Journal of Information Science and Intelligent System, p. 5, 2014.

[5] M. Chiarandini, “Vehicle Routing,” in Scheduling, Timetabling, and Routing., Denmark, Southern Denmark Univ., 2013, p. 23.

[6] D. Mishra, “Theory of Integer Programming,” in Personal Collection of D. Mishra, India Statistical Institue, 2001, pp. 1-2.

[7] J. Sobel, “Linear Programming Notes X: Integer Programming,” in Personal Collection of J. Sobel, University of California, pp. 1-2, 2013.

[8] S.H. Ranut, “Mixed Integer Model Optimization for Multilevel problems of Mean-Varians Post Tax,” in Model Optimasi Integer Campuran untuk Persoalan Multi-Tahap Mean-varians Pasca-pajak, Medan: Sumatera Utara Univ., p. 6, 2013.

[9] A.H. Nasution, “Production Control and Planning,” Perencanaan dan Pengendalian Produksi, Surabaya: Prima Printing, pp. 176-180, 2003.

[10] Seafuture Inc., NETPAS: Smart Maritime Business, at http://netpas.net/products/product_detail_DT_EN.php, accessed on July 2014.

[11] Campbell, H. G., Dudek, R. A., Smith, M. L., A Heuristic Algorithm for the n Job, m Machine Sequencing Problem, Management Science, 16, 10(1970), pp. 630-637.

[12] DITJEN Kementrian Perdagangan Republik Indonesia, “Prosedur Notifikasi WTO Untuk Transparansi Kebijakan Impor Terkait Bidang Perdagangan,” WTO Notification Procedure for Import Trading Transparance Policy, Ministry of Trading Republic of Indonesia, in “Kewajiban Pokok Indonesia Sebagai Anggota Organisasi Perdagangan Dunia”, p.v & p.8, 2011, in press,

[13] E. Hutagalung, “World Trade Organization and UNCTAD,” at academia.edu: https://www.academia.edu/5774495/World_Trade_Organization_and_UNCTAD.

[14] Aziz Ezzatneshan, “A Algorithm For The Vehicle Problem,” in Inernational Journal of Advanced Robotic System, p. 1, 2010.

[15] V. Pillac, M. Gendreau, C. Gueret, A. Medaglia, “A Review Of Dynamic Vehicle Routing Problems,” in European Journal of Operational Research, Elsevier, 2013, 225 (1), pp. 1-11. <hal-00739779>, p. 3, 2012.

[16] Dipak Laha, “Heuristics and Metaheuristics For Solving Scheduling Problems,” p. 4, 2008.

[17] Velpur Gopi Krishna, P. Vijay, “A Proposed Method For Permutation Flow Shop Scheduling,” in Inernational Journal of Emerging Technology and Advanced Engineering, 2013.

[18] Jen-Shiang Chen, J. Chao-Hsien Pan, Chien-Min Lin, “Solving the Reentrant Permutation Flow-Shop Scheduling Problem with a Hybrid Genetic Algorithm,” in International Journal of Industrial Engineering, p.24, 2009.

[19] L. Caccetta, M. Alameen, Moh. Ahdul-Niby, “An Improved Clarke and Wright Algorithm to Solve the Capacity Vehicle Routing Problem,” in ETASR – Engineering, Technology & Applied Science Research Journal Vol. 3 No.2, pp 413 – 415, 2013.

[20] T. Pichpibul, R. Kawtummachai, “A Heuristic Approach Based on Clarke-Wright Algorith for Open Vehicle Routing Problem,” in The Scientific World Journal, p.1, 2013.

[21] A. Ezzatneshan, "A algorithm for the Vehicle Problem," *International Journal of Advanced Robotics Systems,* pp. 125-132, 2010.

[22] R. Matai, S. P. Singh and M. L. Mittal, "Traveling salesman problem: An overview of applications, formulations, and solution approaches," *Traveling Salesman Problem, Theory and Applications,* pp. 1-24, 2010.

[23] B. E. Gillett and L. R. Miller, "A Heuristic Algorithm for the Vehicle-Dispatch Problem," *Operation Research,* pp. 340-349, 1974.

[24] R. H. Ballou, Business Logistics Management, New Jersey: Prentice Hall, 1999.

[25] Murphy, Jr., Paul, R., and Wood, D., Contemporary Logistics, New Jersey: Prentice Hall, 2004.

[26] Desai, V., Farias, V., and Moallemi, C., Approximate dynamic programming via a smoothed linear program, *Operations Research*, vol. 60, no. 3, pp. 655-674, 2012.

[27] Winston, W., and Venkataramanan, M. Operation Research Volume One: Introduction to Mathematical Programming, Thomson Learning, 2003.

[28] Rardin, R., Optimization in Operation Research, New Jersey: Prentice Hall, 1997.

[29] Yeom, K., and Lee, J., Logical representation of integer programming models, *Decision Support Systems*, vol. 18, no. 3-4, pp. 227-251, 1996

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