Chapter 7

Dynamic Approach for Delivering LNG: Dynamic Simulation

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Chapter 7

Dynamic Approach for Delivering LNG: Dynamic Simulation

1. Data Required for Simulation

1.1. Basic concept of the simulation model

The dynamic simulation (DS) model to simulate LNG delivery from LNG production sites to demand sites was developed using the simulator 'WITNESS'. The model features are:

- It simulates LNG delivery by the tankers dynamically.
- It pages an LNG tanker when the LNG stock reaches a certain LNG amount in the storage tank.
- The minimum time unit for the simulation is 'minute'.
- The simulation period is 1 year (365 days).

The major simulation parameters are as follows:

- LNG tanker (type, storage capacity, speed, origin, and destination port)
- LNG onshore storage (capacity, initial LNG storage level, criteria for calling tanker)
- Water depth of each LNG receiving port
- Route (distance) is the same as the LP model
- Location of LNG shipping terminal (origin)
- Location of LNG receiving terminal (destination)
- Delivery route from origin to destination
- Capacity of LNG tanker (weight: tonne)
- Time for loading/unloading, etc.

1.2. LNG onshore storage capacity and LNG tanker size

a. LNG onshore storage capacity

- Initial LNG stock shall need more than 10 days of gas consumption for power generation.
- The maximum storage capacity (days) shall be 1.5 times the number of days needed for LNG delivery (round trip)
- The four kinds of storage and a secondary port storage are assumed for the DS and the characteristics are summarised in Table 7.1.

Table 7.1: Characteristics of LNG Onshore Storage

Size	MTPA	Storage (CBM)	Weight (kiloton)	CAPEX (million US$)	OPEX (million US$ per year)
SS	～0.06	5,000	2.30	75	1.88
S	0.7～0.2	20,000	9.20	121	3.02
M	0.21～0.4	30,000	13.80	139	3.49
L	0.41～	50,000	23.00	177	4.43
Second port storage		150,000	69.00	366	9.15

Note: OPEX = CAPEX * 2.5%.
Source: Author.

b. LNG tanker size

Four kinds of LNG tanker and the tanker to transport LNG from the primary port to the secondary port (second port tanker) and their characteristics are listed in Table 7.2.

Table 7.2: Characteristics of LNG Tanker

Type	Gross Tonnage (ton)	LNG Storage Capacity (CBM)	LNG Storage Weight (kiloton)	Water Depth (m)	Average Speed (kilo knot)	Calculated CAPEX (Million US$)	OPEX (Million US$/year)
SS	7,403	5,000	2.3	5.28	9.7	36.9	2.4
S	16,336	18,000	8.3	6.05	10.0	48.7	4.2
M	22,887	27,500	12.7	8.8	13.2	52.5	4.8
L	27,546	35,000	16.1	10.08	13.4	54.8	5.1
Second port tanker	83,846	70,000	32.2	12.00	13.4	81.1	9.3

Note: OPEX is calculated by daily cost x 300 days; OPEX's calculation excludes fuel cost.
Source: Author.

1.3. Other necessary data

a. Water depth per port

The water depth of each LNG receiving site (port) is shown in Table 7.3. The table also indicates the available LNG tanker size, such as L size, at the Manado LNG receiving port.

Table 7.3: Water Depth at Each LNG Receiving Port

Unit: metre

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Water Depth	MND	PAL	MKS	BNO	LMB	BDS	LBJ	KPG	AMB	NLA	WED	TTE	SRU	BIK	MNK	SON	MRK	JAP
	12	12	9	9	7	7	10	17	26	8	-	12	10	9	12	15	7	9
Tanker Type	L	L	M	L	S	S	L	L	L	S	S	L	M	M	L	L	S	M

Source: Author.

b. Time of loading and unloading of LNG

Unloading time: 12 hours, Loading time: 12 hours.

2. LNG Delivery Simulation by Each Group

For LNG delivery, the following three cases are simulated per each group (Bontang–Donggi, Masela, and Tangguh).

Case 1: Apply the hub & spoke method

Assign an LNG tanker to each route from an LNG origin as a hub to all LNG destinations.

Case 2: Apply sharing LNG tanker method

Apply the hub & spoke method but assign an LNG tanker to many routes from an LNG origin to plural LNG destinations.

Case 3: Apply the milk-run method

This method delivers LNG to several destinations from an LNG origin per navigation. The destinations should be close each other.

2.1. Bontang–Donggi group

Figure 7.1 shows the image of LNG deliveries in the Bontang–Donggi group. Bontang ships LNG to Palu and Donggi ships LNG to Manado and Makassar.

Figure 7.1: Image of the Simulation on PC screen (Bontang–Donggi Group)

Source: Author.

Conditions of LNG shipping and receiving ports, LNG onshore storages, and LNG tankers

Water depth, annual LNG consumption, LNG onshore storage capacity, and type of LNG tanker to be initially assigned are summarised in Table 7.4. The number of LNG tankers and their sizes are shown in Table 7.5.

Table 7.4: Input Conditions for Simulation

Production Base	No.	Port abbreviation	Port Water Depth	Annual Consumption (kiloton)	Onshore Storage			Tanker Sstorage			
					Type	Capacity (CBM)	Weight (kiloton)	Water Depth (m)	Type	Capacity (CBM)	Weight (kiloton)
BON	1	PAL	9	247	M	30,000	13.80	6.05	S	18,000	8.28
DSL	0	MND	12	192	M	30,000	13.80	6.05	S	18,000	8.28
	2	MND	12	230	M	30,000	13.80	6.05	S	18,000	8.28

CBM = cubic metre, m = metre.
Source: Author.

Table 7.5: Number and Size of Tankers (Cases 1–3)

	BON-DSL		
	1.PAL	0.MND	2.MKS
Case 1	S	S	S
Case 2	S	S	
Case 3	M		

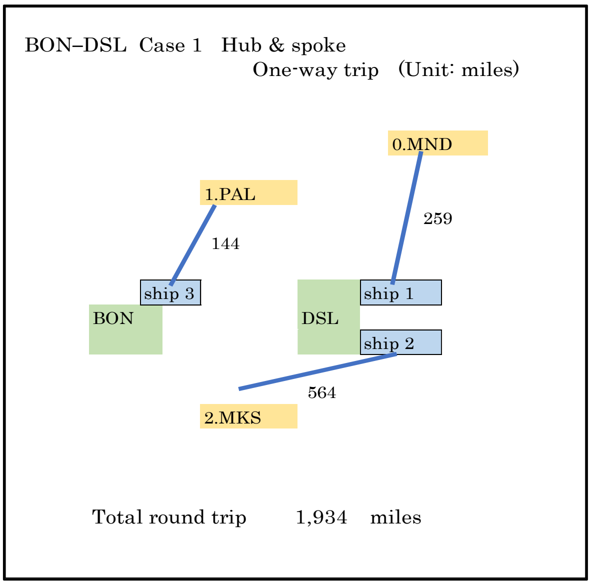
Source: Author.

a. Case 1: Hub & spoke method

1) Image of tanker operation

Figure 2.7 shows a conceptual picture of LNG delivery from Bontang to Palu and Donggi–Senoro to Manado and Makassar.

Figure 7.2: LNG Delivery from Terminal, BON–DSL, Hub & Spoke Method (Case 1)



Source: Author.

2) Operational status of storage

The simulation results of case 1 show several useful information of LNG onshore storages at three LNG receiving ports (Table 7.6) such as:

- No shortage has happened at the three receiving ports.
- In terms of the storage capacity at the three ports, 30,000 CBM is appropriate per the simulation results of three indicators, which are maximum, minimum, and average levels of storage.

Figure 7.3 also shows the storage level of the three LNG receiving ports. It indicates that the capacity of the storage will be oversized if contingency is ignored. Table 7.6 shows that the contingency level will be 15%. Theoretically, we can reduce the capacity of the storages to around 22,000 CBM but in case of emergencies, such as accidents and natural disasters, black out will occur due to LNG shortage. Thus, 30,000 CBM will be appropriate including contingency.

Table 7.6: Operational Status of LNG Onshore Storage, BON–DSL (Case 1)

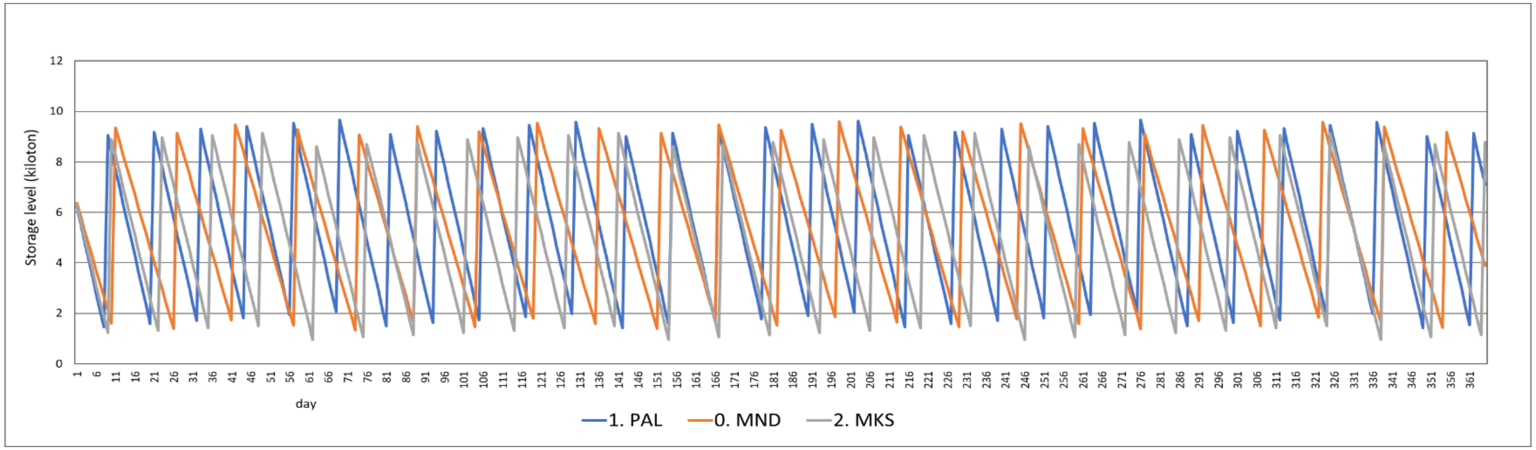
Operational Status of Storage	1.PAL	0.MND	2.MKS	Total
Storage size	M	M	M	
Storage capacity (CBM)	30,000	30,000	30,000	
Storage capacity (kiloton)	13.8	13.8	13.8	41.4
①Initial value of storage (kilotons)	6.9	6.9	6.9	20.7
②Unloading weight (kiloton/year)	248.4	190.4	231.8	670.7
Tanker unloading volumes (kiloton/time)	8.28	8.28	8.28	
Level of calling a tanker (kiloton)	3.45	3.45	3.45	
Number of unloading (times)	30	23	28	
Maximum level of storage (kiloton)	11.73	11.73	11.73	
Minimum level of storage (kiloton)	1.42	1.33	0.96	
Average level of storage (kiloton)	9.66	9.6	9.15	
Maximum level/Storage capacity	0.85	0.85	0.85	
③Stock at end of period (kiloton)	7.1	3.89	8.79	19.8
④Total supply (kiloton) ①＋②－③	248.2	193.5	230.0	671.6
⑤Annual consumption （kiloton）	247.5	191.8	229.6	668.9
⑥Comparison ④/⑤	1.00	1.01	1.00	1.00

Source: Author.

3) Operational status of LNG tankers

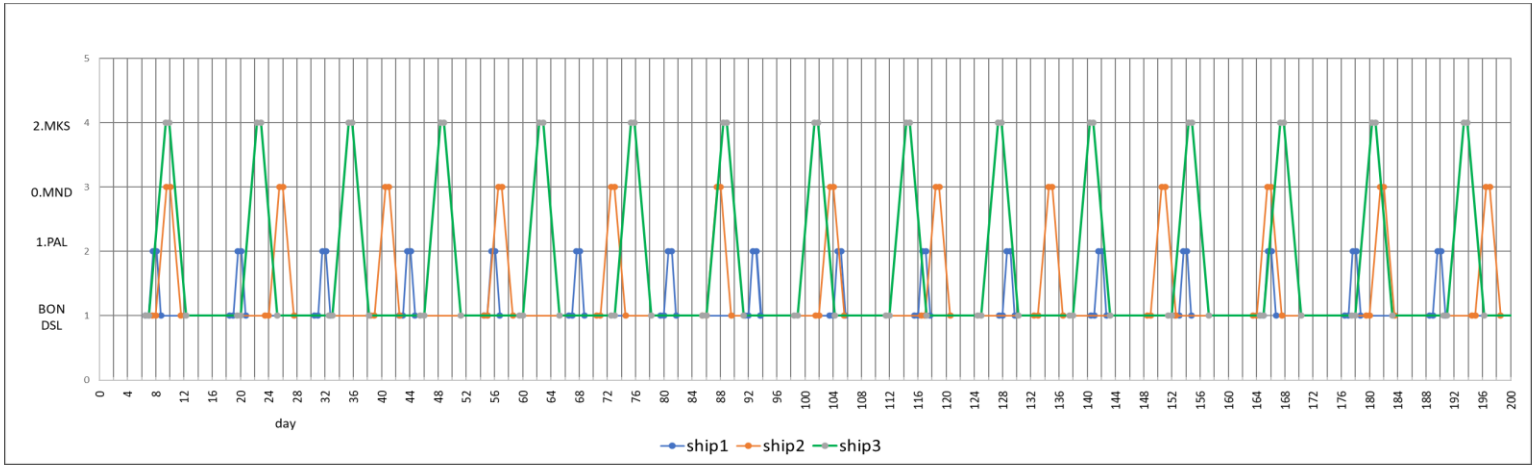
Figure 7.4 shows the operation of LNG tankers. This diagram covers the simulation results for 100 days of three tankers engaged to deliver LNG to three LNG demand sites. Due to different LNG consumption amounts in each destination, the number of LNG delivery to Makassar is seven times, six times for Manado, and eight times for Palu.

Figure 7.3: Storage Level of Each Port, BON–DSL (Case 1)



Source: Author's analysis.

Figure 7.4: Diagram of Tanker Operations, BON–DSL (Case 1)



Source: Author's analysis.

4) Key findings

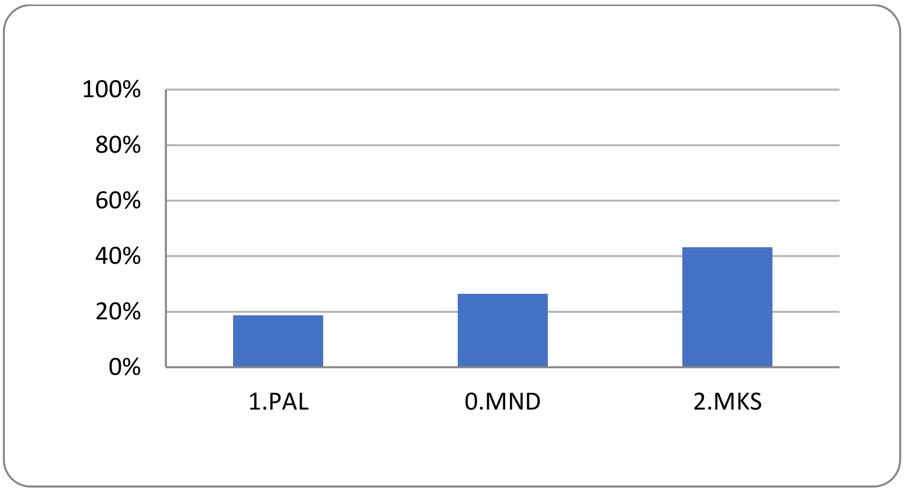
Table 7.7 shows the operational status of an LNG tanker per each route. The table also includes total annual data of waiting time (idling time), loading time, transporting time, unloading time, operating time, total time, operating rate, and the number of loading and unloading times. The operating rate of each tanker is quite low (19%–43%) especially the LNG tanker navigating between Bontang and Palu. This result shows the possibility of reducing the number of ships.

Table 7.7: Operational Status of LNG Tankers, BON–DSL, Hub & Spoke (Case 1)

Home Port Terminal	Destination	Tanker Number	Waiting Time for Shipment (hour)	Loading Time (hour)	Transport Time (hour)	Unloading Time (hour)	Operating Time (hour)	Total Time (hour)	Rate of Operation	Number of Loading (times)	Number of Unloading (times)
BON	1.PAL	1	7,068	360	894	360	1,614	8,682	19%	30	30
DSL	0.MND	2	6,287	276	1,695	276	2,247	8,534	26%	23	23
	2.MKS	3	4,951	336	3,077	336	3,749	8,700	43%	28	28
Total			**18,306**	**972**	**5,666**	**972**	**7,610**	**25,916**	**29%**	**81**	**81**

Source: Author.

Figure 7.5: Operation Rate of Each LNG Tanker, BON–DSL (Case 1)



Source: Author.

In addition, the operation cost of an LNG tanker per each route is estimated based on cruising distances, unloading volumes, and assumed unit of OPEX, which is fixed operating expense referring to Japanese statistics. The operation cost of a route between Donggi and Makassar is highest due to longer distance and remarkable unloading amount of LNG.

Table 7.8: Operation Cost of LNG Tankers, BON–DSL, Hub & Spoke (Case 1)

						Tanker OPEX	
Home Port Terminal	**Destination**	**Tanker Size**	**Cruise Distance (round-trip miles)**	**Unloading Weight (kiloton)**	**Tonne Miles (1,000 tonne miles)**	**Unit Price (US$/1,000 tonne miles)**	**Ship Operating Costs (million US$/ year)**
BON	1.PAL	S	8,640	248	35,770	5.9	0.21
DSL	0.MND	S	11,914	190	49,324	5.9	0.29
	2.MKS	S	31,584	232	130,758	5.9	0.77
Total			**52,138**	**671**	**215,851**		**1.27**

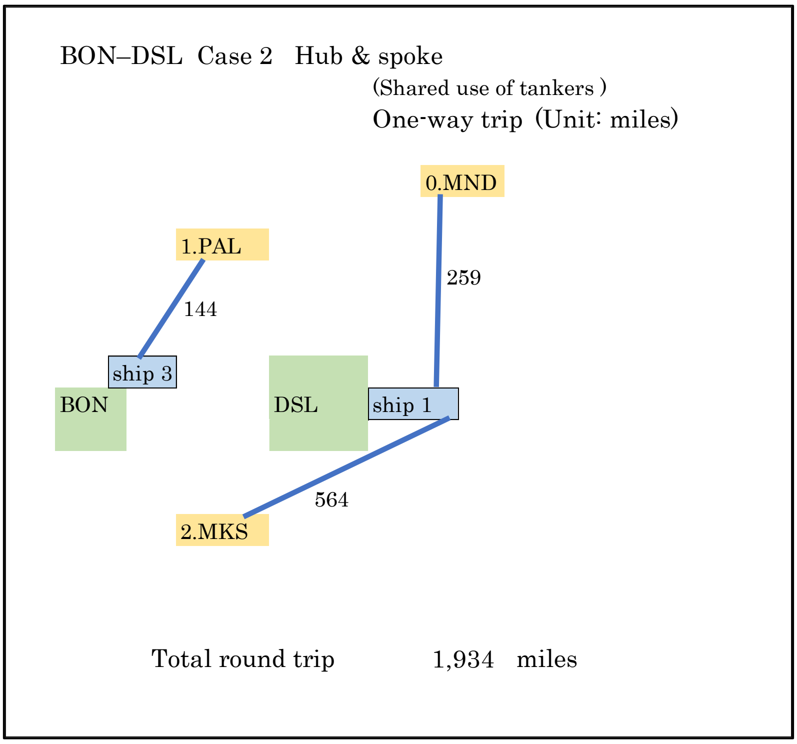
Source: Author.

b. Case 2: Sharing LNG tanker method

1) Operation of two LNG tankers

Table 7.5 shows the number and size of LNG tankers. Case 2 assumes one tanker operation from Donggi to Manado and Makassar. The image is shown in Figure 7.6.

Figure 7.6: LNG Delivery from LNG Terminals, BON–DSL, Hub & Spoke Method (Case 2)



Source: Author.

2) Operational status of LNG storages

The simulation results of case 2 are shown in Table 7.9. Table 7.9 and Figure 7.7 suggest the following:

- The maximum storage level at Manado and Makassar increases to 13.03 kilotons and 12.62 kilotons, respectively, from case 1 and they are close to their capacities (13.8). But the storage capacity of 30,000 CBM is still feasible.
- The initial volume of LNG onshore storages at Manado and Makassar must increase from 6.9 kilotons to 9.2 kilotons to avoid fuel shortage resulting from a longer delivery time of LNG than case 1.
- The storage level to page an LNG tanker increases from 3.45 kilotons to 6.9 kilotons due to longer delivery time of LNG.
- The minimum storage level at Makassar is lower than Palu, 2.0 kilotons and 2.82 kilotons, respectively, depending on the distance from the LNG origin. Donggi and Makassar are 564 miles apart, much farther than Donggi and Manado at 259 miles. (Figure 7.6).

Table 7.9: Operational Status of Onshore Storage, BON–DSL (Case 2)

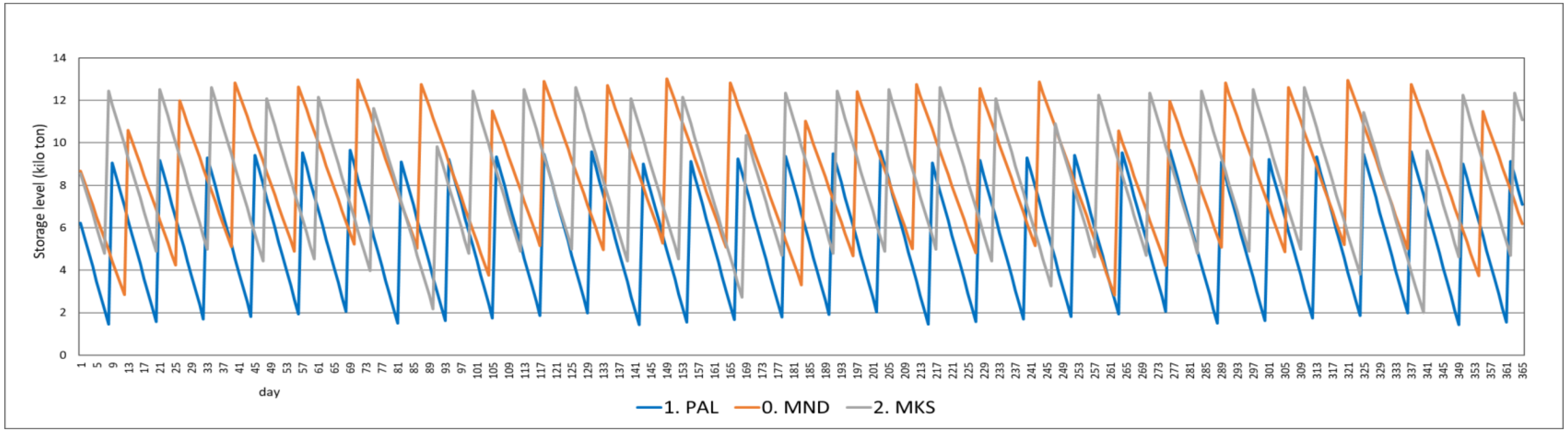
Operational status of storage	1.PAL	0.MND	2.MKS	Total
Storage size	M	M	M	
Storage capacity (m^3)	30,000	30,000	30,000	
Storage capacity (kiloton)	13.8	13.8	13.8	41.4
①Initial value of storage (kilo tons)	6.9	9.2	9.2	25.3
②Unloading weight (kiloton/year)	248.4	190.4	231.8	670.7
Tanker unloading volumes (kiloton/time)	8.28	8.28	8.28	
Level of calling a tanker (kiloton)	3.45	6.9	6.9	
Number of unloading (times)	30	23	28	
Maximum level of storage (kiloton)	9.66	13.03	12.62	
Minimum level of storage (kiloton)	1.42	2.82	2.0	
Average level of storage (kiloton)	5.5	8.4	8.2	
Maximum level / Storage capacity	0.70	0.94	0.91	
③Stock at end of period (kiloton)	7.1	6.19	11.09	24.4
④Total supply (kiloton) ①＋②－③	248.2	193.5	230.0	671.6
⑤Annual consumption （kilo ton）	247.5	191.8	229.6	668.9
⑥Comparison ④/⑤	1.00	1.01	1.00	1.00

Source: Author.

3) Operational status of tankers

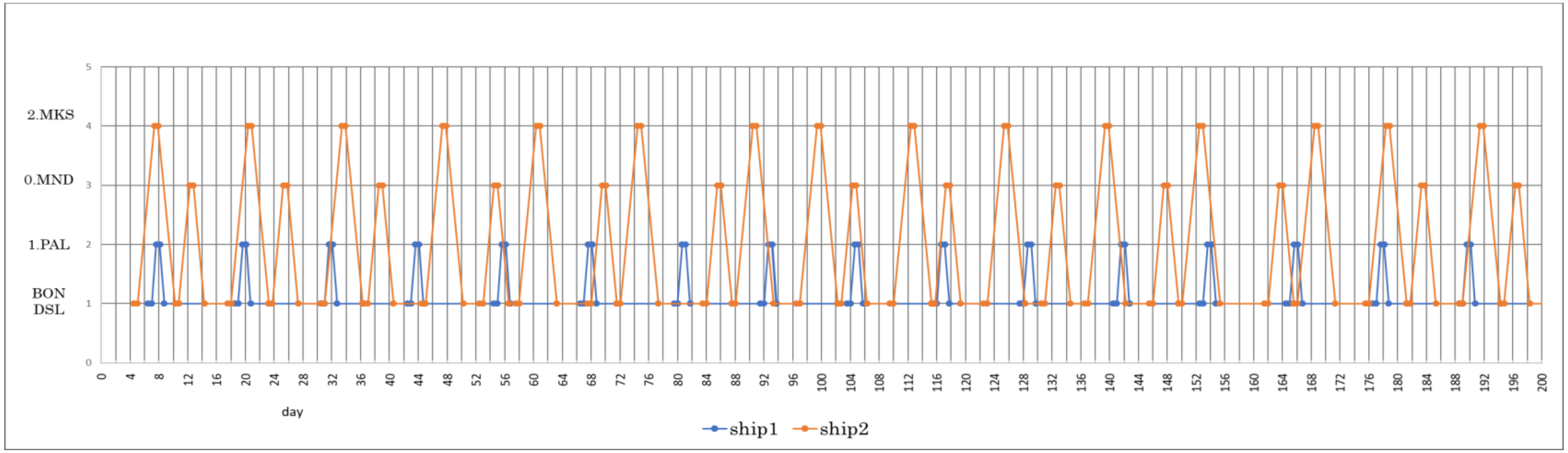
Figure 7.8 shows the operation of two LNG tankers: one between Bontang–Palu and other, between Donggi–Senoro and Manado and Makassar. The orange line is a diagram to monitor the LNG delivery of an LNG tanker (ship 2) to Manado and Makassar from Donggi–Senoro. The number of deliveries to Makassar in the first 100 days is eight times and its increase 1 time from 7 times of Case 1. Since one LNG tanker covers two ports – Manado and Makassar – which consume LNG at a different pace, the delivery timing to Makassar may be faster than case 1. But in case of a whole year, the number of deliveries to Makassar is 28 and it is the same as case 1.

Figure 7.7: Storage Level of Each Port, BON–DSL (Case 2)



Source: Author's analysis.

Figure 7.8: Diagram of Tanker Operation, BON–DSL (Case 2)



Source: Author's analysis.

4) Key findings

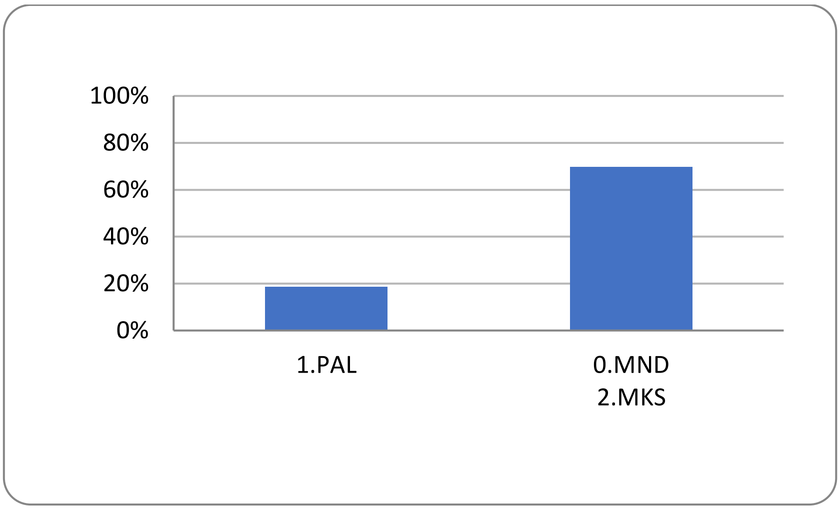
The operation rate of an LNG tanker to deliver LNG to the Manado and Makassar route has risen up to 70% due to the reduced number of ships from two to one.

Table 7.10: Results of Tanker Operations, BON–DSL (Case 2)

Home port terminal	Destination	Tanker number	Waiting time for shipment (hour)	Loading time (hour)	Transport time (hour)	Unloading time (hour)	Operating time (hour)	Total time (hour)	Rate of operation	Number of loading (times)	Number of unloading (times)
BON	1.PAL	1	7,068	360	894	360	1,614	8,682	19%	30	30
DSL	0.MND 2.MKS	2	2,660	612	4,883	612	6,107	8,767	70%	51	51
Total			**9,727**	**972**	**5,777**	**972**	**7,721**	**17,449**	**44%**	**81**	**81**

Source: Author.

Figure 7.9: Rate of Operation of LNG Tankers, BON–DSL (Case 2)



Source: Author.

Thus, the operation costs of the LNG tanker at Donggi highly increase to US$1.06 million. Since the distance and unloading amount are the same as case 1, the total operation cost is also the same as case 1. But case 2 can surely reduce the number of LNG tankers to one and the CAPEX of the tanker will not be needed.

The operation cost of the LNG tanker at Donggi is the same as case 1 (US$1.06 million) because the cruising distance and unloading amount are the same as case 1. But case 2 can surely reduce the number of LNG tankers from two to one, so that the CAPEX of the tanker will largely go down.

Table 7.11: Cruising Distance and OPEX of Tankers, BON–DSL (Case 2)

						Tanker OPEX	
Home port terminal	Destination	Tanker Size	Cruise distance (round-trip miles)	Unloading weight (kiloton)	Ton miles (1,000 tonne miles)	Unit price (US$/1,000 tonne miles)	Ship operating costs (Million US$/ year)
BON	1.PAL	S	8,640	248	35,770	5.9	0.21
DSL	0.MND 2.MKS	S	43,498	422	180,082	5.9	1.06
Total			**52,138**	**671**	**215,851**		**1.27**

Source: Author.

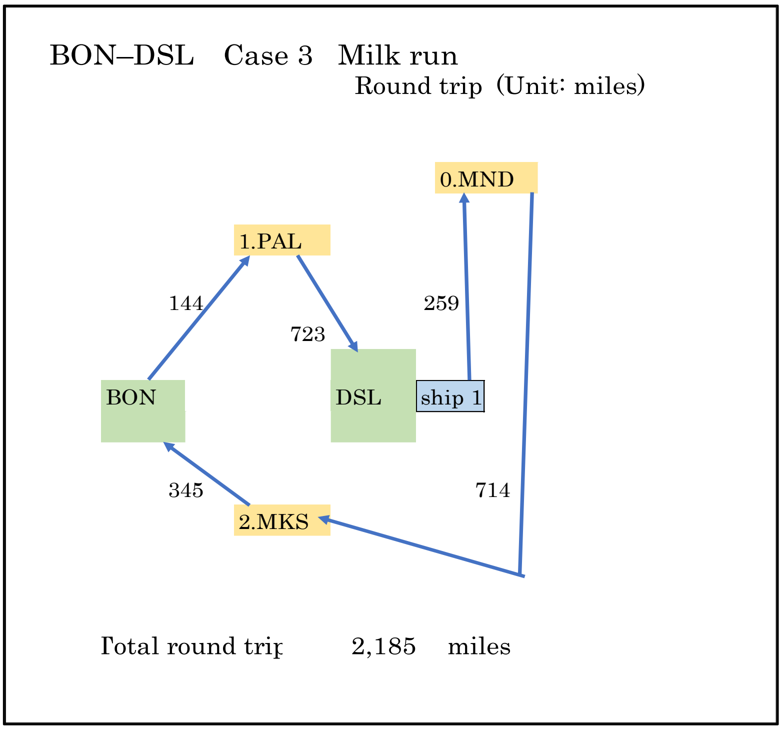
c. Case 3: Milk-run method

Case 3 applies the milk-run method; one LNG tanker moves from two LNG origins to three LNG destinations.

1) Image of an LNG tanker operation

The milk-run method operates an LNG tanker from Donggi Senoro–Manado–Makassar–Bontang–Palu–Donggi Senoro (Figure 7.10). The cruising distance of case 1 is 1,934 miles. On the other hand, the distance of case 3 is 2,185 miles (refer to Table 7.12). But the merit of the milk-run method is that it reduces the number of LNG tankers from two to one.

Figure 7.10: LNG Delivery, BON–DSL, Milk-Run Method (Case 3)



Source: Author.

Table 7.12: Comparison of Hub & Spoke and Milk-Run Distance

BON-DSL Group	City Name	H&S Round-trip
DSL	0.MND	518
DSL	2.MKS	1128
BON	1.PAL	288
	Total	**1,934**

Don–Bon Group		Milk-Run Round-trip
DSL	DSL—MND	259
	DSL—MND	714
	MKS—BON	345
BON	BON—PAL	144
	PAL—DSL	723
	Total	**2,185**

Source: Author.

2) Operational status of LNG storage

The simulation results of the LNG onshore storage of each port are shown in Table 7.13. One LNG tanker operation using the milk-run method is still feasible because there is no shortage of LNG as a power generation fuel. Table 7.13 suggests the following:

- The initial volume of the storages must increase from 6.9 kilotons to 9.2 kilotons and it is 4/3 times of case 1.
- The number of unloading times is also the same amongst the three ports because one LNG tanker uses the milk-run method.
- The minimum level of storage at Manado is too high (5.32 kilotons) compared to other ports (1.04 and 2.69 kilotons, respectively). The reason is the application of the milk-run method. The LNG tanker arrives in Manado first and then in Makassar and Palu.

Figure 7.11 shows the stock level of LNG storage at the three ports. The diagram suggests the following:

- The capacity of LNG onshore storage at Manado can be reduced around half of the assumption of LNG onshore storage. In addition, the capacity at other ports, Palu and Makassar, can be cut by around 20%–30% of the assumption.

Table 7.13: Operational Status of LNG Onshore Storage, BON–DSL (Case 3)

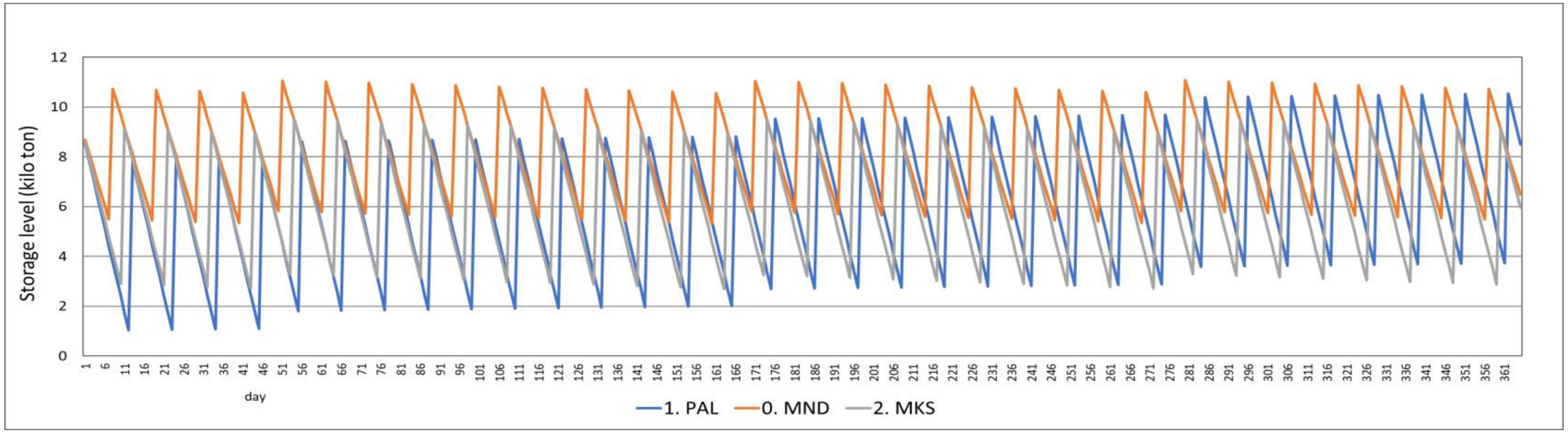
Operational Status of Storage	1.PAL	0.MND	2.MKS	Total
Storage size	M	M	M	
Storage capacity (CBM)	30,000	30,000	30,000	
Storage capacity (kiloton)	13.8	13.8	13.8	41.4
①Initial value of storage (kilotons)	9.2	9.2	9.2	27.6
②Unloading weight (kiloton/year)	248.4	184.7	231.8	664.9
Tanker unloading volumes (kiloton/time)	8.28	8.28	8.28	
Level of calling a tanker (kiloton)	6.9	6.9	6.9	
Number of unloading (times)	33	33	33	99
Maximum level of storage (kiloton)	10.54	11.08	9.53	
Minimum level of storage (kiloton)	1.04	5.32	2.69	
Average level of storage (kiloton)	5.9	8.2	6.1	
Maximum level/Storage capacity	0.76	0.80	0.69	
③Stock at end of period (kiloton)	8.5	6.49	5.96	21.0
④Total supply (kiloton) ①＋②－③	249.1	187.4	235.1	671.6
⑤Annual consumption （kiloton）	247.5	191.8	229.6	668.9
⑥Comparison ④/⑤	1.01	0.98	1.02	1.00

Source: Author.

3) Operating status of tanker

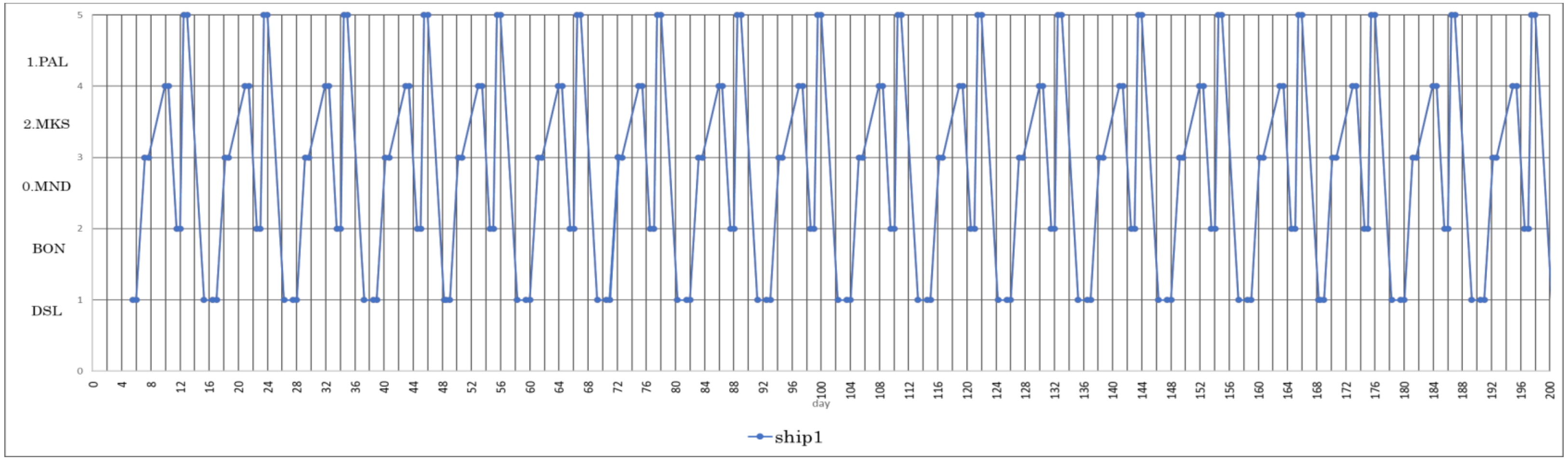
Figure 7.12 is a diagram of case 3. It shows one LNG tanker picking up LNG at two LNG origins (Donggi and Bontang) and transporting it to three LNG destinations (Manado, Makassar, and Palu), ensuring that no LNG shortage happens in 365 days. Table 7.14 shows that the operation rate of the LNG tanker is 88% and its idling time is 12%. Case 3 is a feasible solution, and only one tanker is enough to deliver LNG from the origins to the destinations. One concern is how to assess 12% as contingency. Expert views are needed to assess the contingency rate.

Figure 7.11: Storage Level of Onshore Storage. BON–DSL (Case 3)



Source: Author's analysis.

Figure 7.12: Diagram of Tanker Operations, BON–DSL (Case 3)



Source: Author's analysis.

4) Key findings

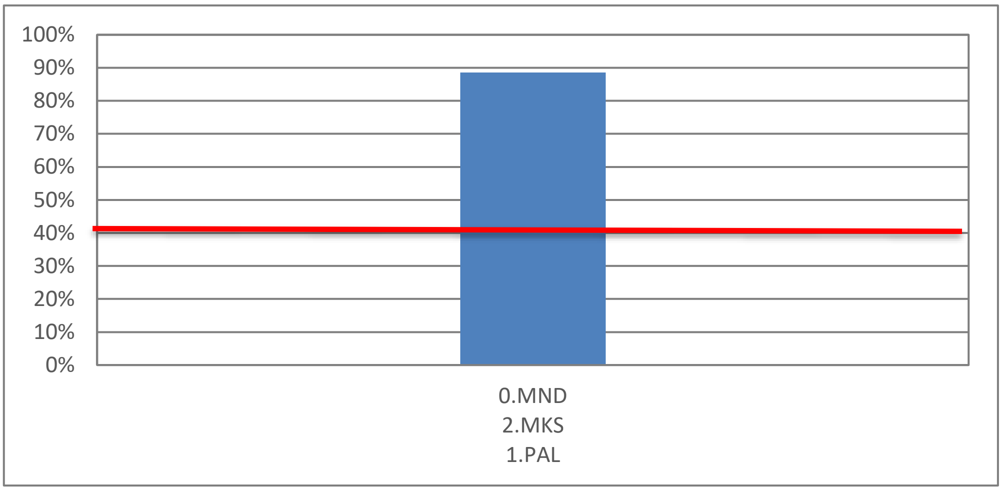
The operating rate of the LNG tanker to cover the three destinations rises to around 90%. Case 3 is an economically feasible solution if around 10% as contingency rate would be acceptable (Table 7.14).

Table 7.14: Results of Tanker Operations, BON–DSL, Milk-Run Method (Case 3)

Home port terminal	Destination	Tanker number	Waiting time for shipment (hour)	Loading time (hour)	Transport time (hour)	Unloading time (hour)	Operating time (hour)	Total time (hour)	Rate of operation	Number of loading (times)	Number of unloading (times)
DSL BON	0.MND 2.MKS 1.PAL	1	1,007	792	5,750	1,188	7,730	8,737	88%	66	99

Source: Author.

Figure 7.13: Rate of Tanker Operations, BON–DSL (Case 3)



Source: Author.

The operation cost of case 3 is much higher than cases 1 and 2 due to longer cruising distance, defined as 72,105 – 52,138 = 19,967 miles. Distances between Makassar–Bontang and Palu–Donggi are newly added. Distance between Manado–Makassar is much farther than Donggi–Makassar. However, case 3 uses only one medium-sized LNG tanker in this group.

Table 7.15: Tanker Cruising Distance and OPEX, BON–DSL, Milk-Run Method (Case 3)

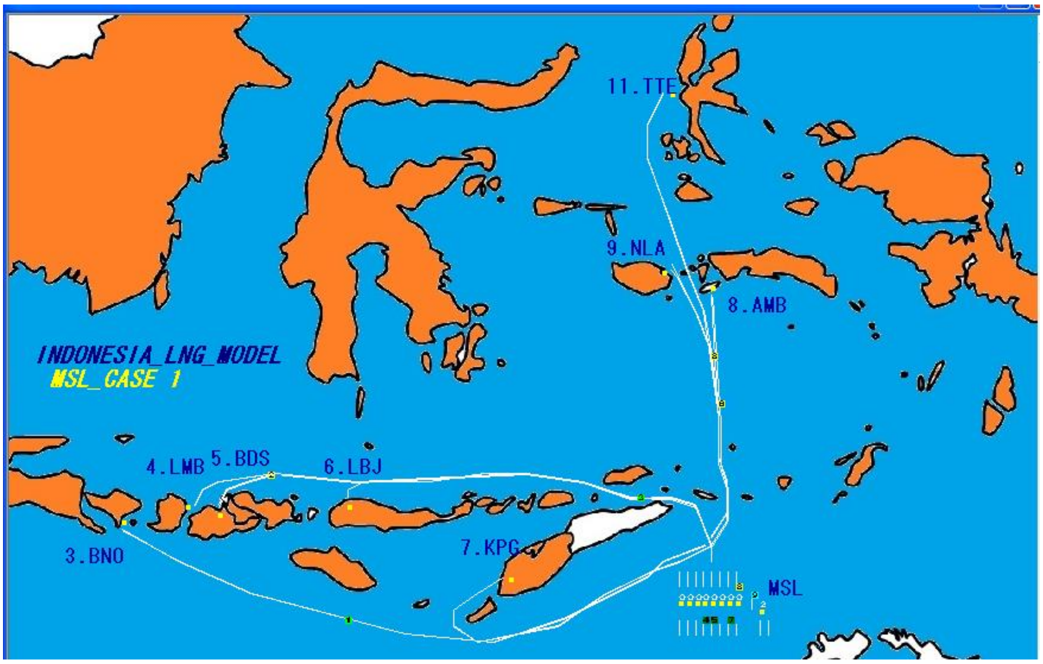
						Tanker OPEX	
Home port terminal	Destination	Tanker Size	Cruise distance (round-trip miles)	Unloading weight (kiloton)	Ton miles (1,000 tonne miles)	Unit price (US$/1,000 tonne miles)	Ship operating costs (Million US$/ year)
DSL BON	0.MND 2.MKS 1.PAL	M	72,105	665	305,630	5.9	1.80

Source: Author.

2.2. Masela Group

The Masela group consists of one LNG origin (Masela LNG) and eight LNG destinations such as Bali, Lombok, and Ambon. The distances from Masela to the eight LNG destinations are much farther than the Bontang–Donggi group (Figure 7.14).

Figure 7.14: Image of the Simulation on PC Screen (Masela Group)



Source: Author.

Conditions of LNG shipping and receiving ports, LNG onshore storages, and LNG tankers

Table 7.16 shows the water depth, annual LNG consumption, capacity of LNG onshore storage of each LNG receiving terminal, and size of LNG tanker to be initially assigned to each delivery route.

Table 7.16: Input Conditions for Simulation

Production base	No.	Port abbreviation	Port water depth	Annual consumption (kiloton)	Onshore storage			Tanker storage			
					Type	Capacity (m^3)	Weight (kiloton)	Water depth (m)	Type	Capacity (m^3)	Weight (kiloton)
MSL	3	BNO	9	519	L	50,000	23.00	10.08	L	35,000	16.10
	4	LMB	7	454	L	50,000	23.00	8.8	M	27,500	12.65
	5	BDS	7	258	M	30,000	13.80	6.05	S	18,000	8.28
	6	LBJ	10	104	S	20,000	9.20	6.05	S	18,000	8.28
	7	KPG	17	99	S	20,000	9.20	6.05	S	18,000	8.28
	8	AMB	26	90	S	20,000	9.20	5.28	SS	5,000	2.30
	9	NLA	8	75	S	20,000	9.20	5.28	SS	5,000	2.30
	11	TTE	12	444	L	50,000	23.00	8.8	M	27,500	12.65

Source: Author.

Number and size of LNG tankers

Case 1 assumes that eight LNG tankers are assigned to eight LNG delivery routes; therefore, eight LNG tankers are needed. Case 2 applies an LNG tanker sharing method where one LNG tanker covers two destinations: Masela–Labuan Bajo/Kupang and Masela–Ambon/Namlea. Case 3 is more ambitious as one LNG tanker covers three destinations applying the milk-run method: one is Masela–Badas/Labuan Bajo/Kupang and other is Masela–Ambon/Namlea/Ternate. Table 7.17 summarises the number and size of LNG tankers in each case.

Table 7.17: Number and Size of Tankers in Each Case

	MSL							
	3.BNO	**4.LMB**	**5.BDS**	**6.LBJ**	**7.KPG**	**8.AMB**	**9.NLA**	**11.TTE**
Case 1	L	M	S	S	S	SS	SS	M
Case 2	L	M	S	S		SS		M
Case 3	L	M	M			M		

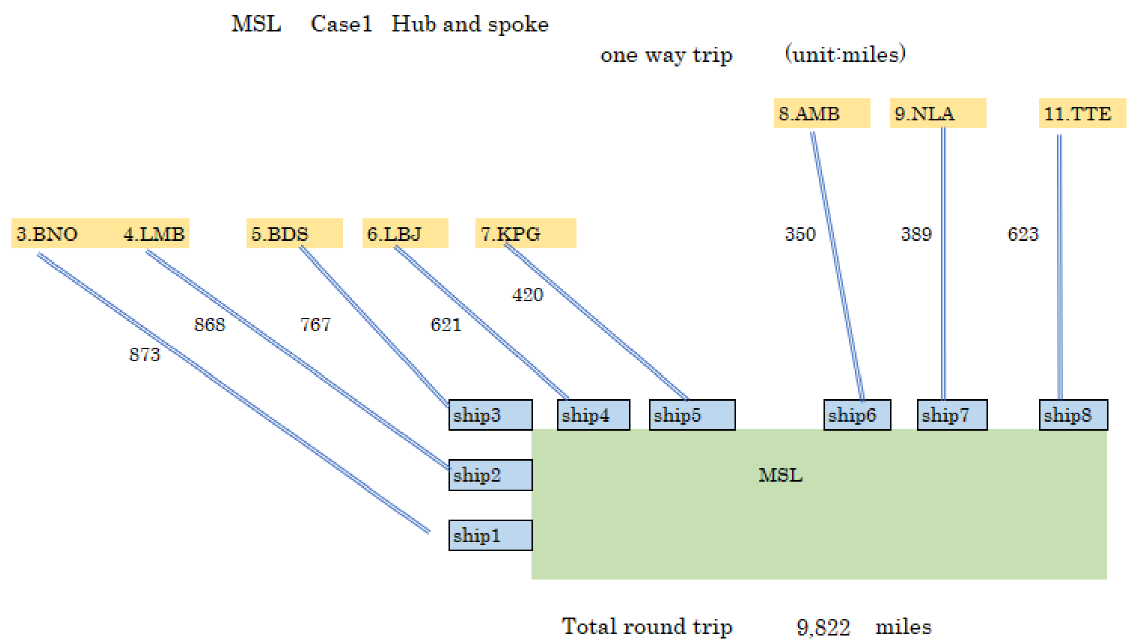
Source: Author.

a. Case 1: hub & spoke method

2) Image of LNG tanker operation

Case 1 allocates eight LNG tankers to deliver LNG to eight destinations from Masela. Figure 7.15 shows the LNG delivery of case 1 from Masela.

Figure 7.15: LNG Delivery, MSL, Hub & Spoke Method (Case 1)



Source: Author.

3) Operational status of storage

Table 7.17 shows the simulation results of LNG onshore storage at eight receiving ports. This table indicates the following:

- The initial volume of each LNG onshore storage is assumed to be half of its capacity, but no shortage has happened at the eight receiving ports.
- The LNG storage capacity at Labuan Bajo and Kupang, which is 20,000 CBM, is appropriate due to the simulation results of three indicators: maximum, minimum, and average level of LNG storage.
- On the other hand, the LNG storage capacity of Ambon and Namlea, which is also 20,000 CBM, is oversized because it is less than 50% of the ratio defined as the maximum storage level per storage capacity due to the small LNG demand.

Figure 7.16 shows the LNG storage level of the eight LNG receiving ports. Based on Figure 7.16 and Table 7.18, the LNG storage capacity of Ambon and Namlea can be reduced largely. However, the LNG storage capacity of Benoa, Lembar, Badas, and Ternate seems to be a bit oversized.

4) Operational status of tankers

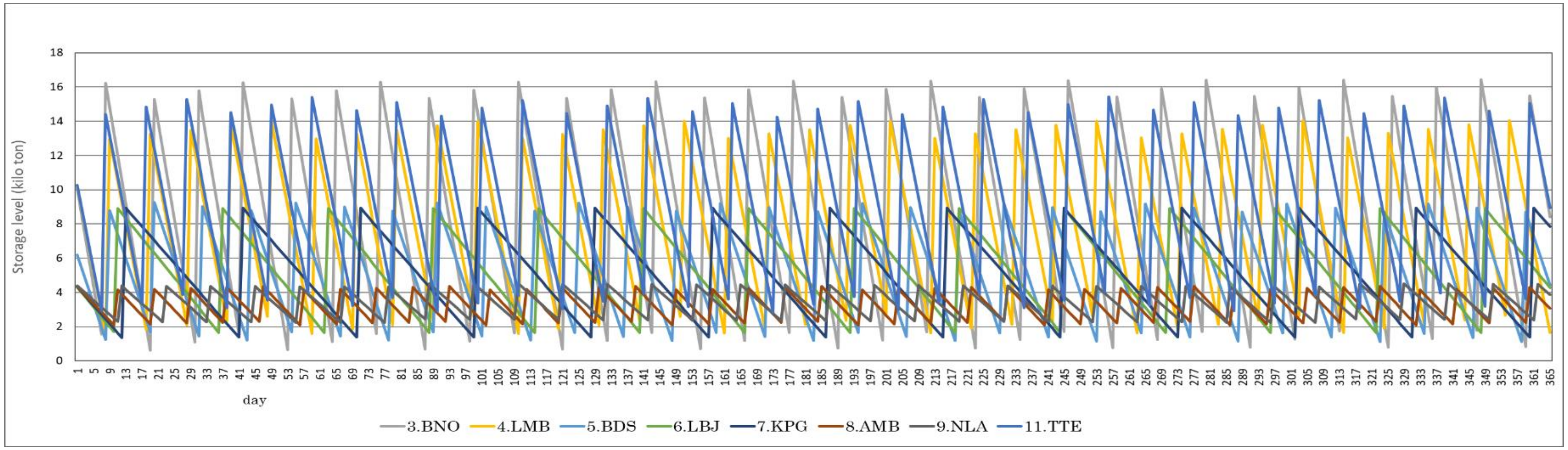
Figure 7.17 clearly shows that the operation of eight LNG tankers in case 1 is feasible. Several LNG tankers also show remarkable idling time due to many LNG tankers. Table 7.19 and Figure 7.18 show the operation status of an LNG tanker per each route. The operation rate of LNG tankers on the four routes of Labuan Bajo, Kupang, Ambon, and Namlea is less than 50%. This result suggests that the number of LNG tankers can be reduced.

Table 7.18: Operational Status of Onshore Storage, MSL (Case 1)

Operational Status of Storage	3.BNO	4.LMB	5.BDS	6.LBJ	7.KPG	8.AMB	9.NLA	11.TTE	Total
Storage size	L	L	M	S	S	S	S	L	
Storage capacity (CBM)	50,000	50,000	30,000	20,000	20,000	20,000	20,000	50,000	
Storage capacity (kiloton)	23.0	23.0	13.8	9.2	9.2	9.2	9.2	23.0	119.6
①Initial value of storage (kilotons)	11.5	11.5	6.9	4.6	4.6	4.6	4.6	11.5	59.8
②Unloading weight (kiloton/year)	515.2	442.8	256.7	105.5	101.8	89.7	75.9	442.8	2030.3
Tanker unloading volumes (kiloton/time)	16.1	12.7	8.3	8.3	8.3	2.3	2.3	12.7	
Level of calling a tanker (kiloton)	7.67	7.67	4.60	3.07	2.30	3.07	3.07	7.67	
Number of unloading (times)	32	35	31	14	13	39	33	35	232
Maximum level of storage (kiloton)	16.44	14.05	9.26	8.91	8.93	4.35	4.52	15.43	
Minimum level of storage (kiloton)	0.62	1.58	1.12	1.66	1.36	2.1	2.23	2.84	
Average level of storage (kiloton)	8.5	7.8	5.2	5.3	5.1	3.2	3.4	9.1	
Maximum level/Storage capacity	0.71	0.61	0.67	0.97	0.97	0.47	0.49	0.67	
③Stock at end of period (kiloton)	8.4	1.65	6.73	4.85	3.26	4.58	5.38	8.95	43.8
④Total supply (kiloton) ①＋②－③	518.3	452.6	256.9	105.3	103.1	89.7	75.1	445.3	2,046.3
⑤Annual consumption (kiloton)	518.9	454.4	257.9	104.4	98.8	90.1	75.3	444.2	2,044.1
⑥Comparison ④/⑤	1.00	1.00	1.00	1.01	1.04	1.00	1.00	1.00	1.00

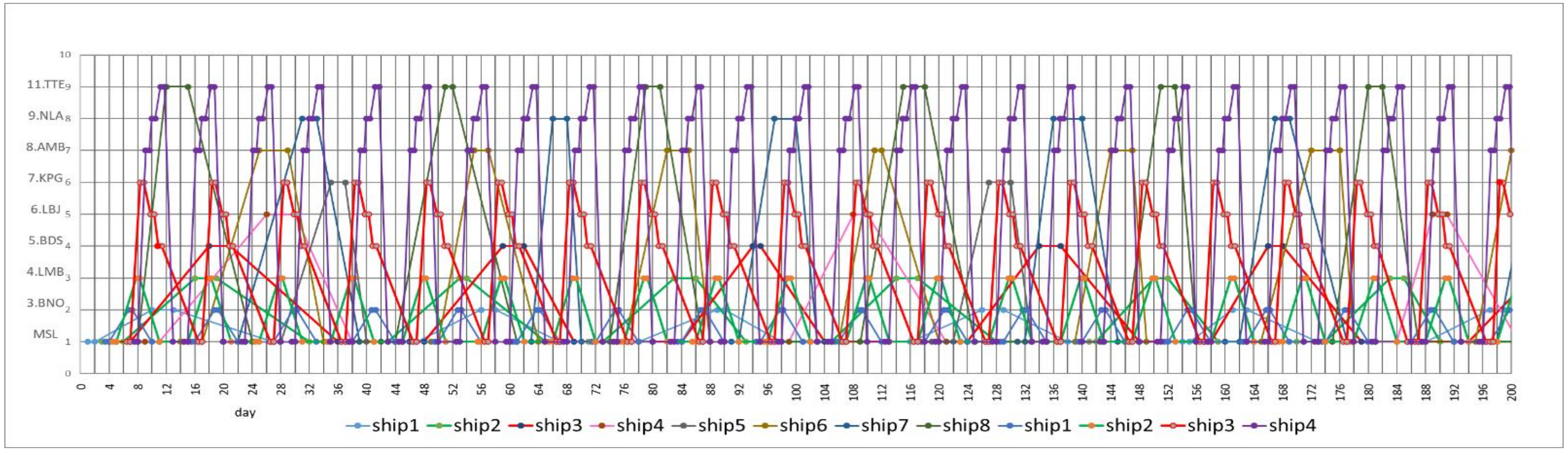
Source: Author.

Figure 7.16: Storage Level of Onshore Storage, MSL (Case 1)



Source: Author's analysis.

Figure 7.17: Diagram of Tanker Operations, MSL (Case 1)



Source: Author's analysis.

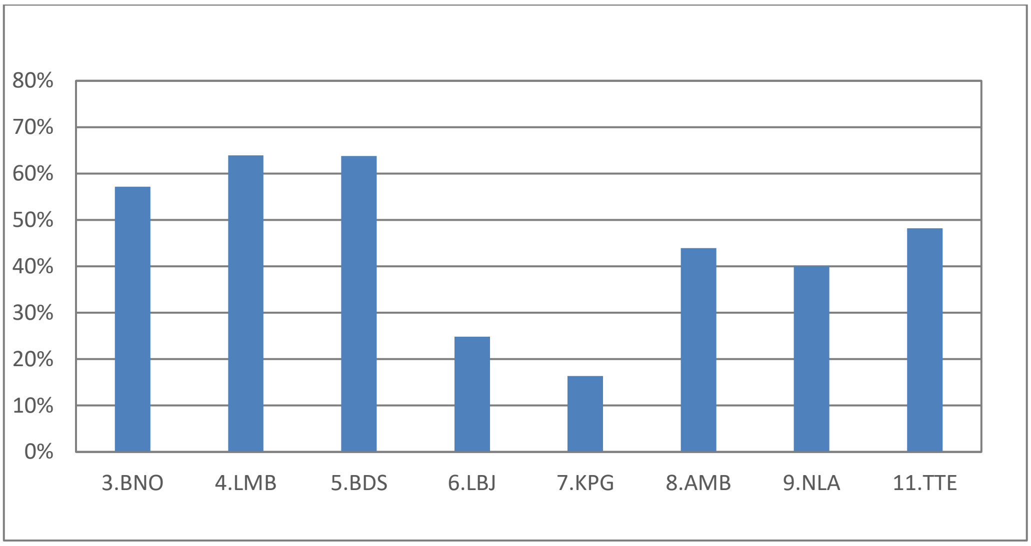
5) Amount of statistics

Table 7.19: Results of Tanker Operations, MSL, Hub & Spoke Method (Case 1)

Home Port Terminal	Destination	Tanker Number	Waiting Time for Shipment (hour)	Loading Time (hour)	Transport Time (hour)	Unloading Time (hour)	Operating Time (hour)	Total Time (hour)	Rate of Operation	Number of Loading (times)	Number of Unloading (times)
MSL	3.BNO	1	3,719	384	4,201	384	4,969	8,687	57%	32	32
	4.LMB	2	3,091	420	4,638	420	5,478	8,569	64%	35	35
	5.BDS	3	3,147	372	4,795	372	5,539	8,686	64%	31	31
	6.LBJ	4	6,325	168	1,756	168	2,092	8,417	25%	14	14
	7.KPG	5	7,270	156	1,107	156	1,419	8,689	16%	13	13
	8.AMB	6	4,852	468	2,866	468	3,802	8,654	44%	39	39
	9.NLA	7	5,220	396	2,698	396	3,490	8,709	40%	33	33
	11.TTE	8	4,493	420	3,343	420	4,183	8,675	48%	35	35
Total			**38,116**	**2,784**	**25,403**	**2,784**	**30,971**	**69,087**		**232**	**232**

Source: Author.

Figure 7.18: Rate of Tanker Operations, MSL (Case 1)



Source: Author.

In addition, the operating cost of an LNG tanker per each route is estimated based on cruising distances, unloading volumes, and assumed unit of OPEX. The operation costs of two routes, which are Benoa (Bali) and Lembar (Lombok), are highest based on the long distance from Masala and the high LNG demand due to popular tourist places. On the other hand, the operation costs of Labuan Bajo, Kupang, Ambon, and Namlea are too low due to the shorter distance and smaller LNG demand.

Table 7.20: Cruising Distance and OPEX of Tanker, MSL, Hub & Spoke (Case 1)

						Tanker OPEX	
Home Port Terminal	Destination	Tanker Size	Cruise Distance (round-trip miles)	Unloading Weight (kiloton)	Tonne Miles (1,000 tonne miles)	Unit Price (US$/1,000 tonne miles)	Ship Operating Costs (million US$/year)
MSL	3.BNO	L	55,872	515	449,770	5.9	2.65
	4.LMB	M	60,760	443	384,307	5.9	2.27
	5.BDS	S	47,554	257	196,874	5.9	1.16
	6.LBJ	S	17,388	106	65,528	5.9	0.39
	7.KPG	S	10,920	102	42,756	5.9	0.25
	8.AMB	SS	27,300	90	31,395	5.9	0.19
	9.NLA	SS	25,674	76	29,525	5.9	0.17
	11.TTE	M	43,610	443	275,833	5.9	1.63
Total			**289,078**	**2,030**	**1,475,988**		**8.71**

Source: Author.

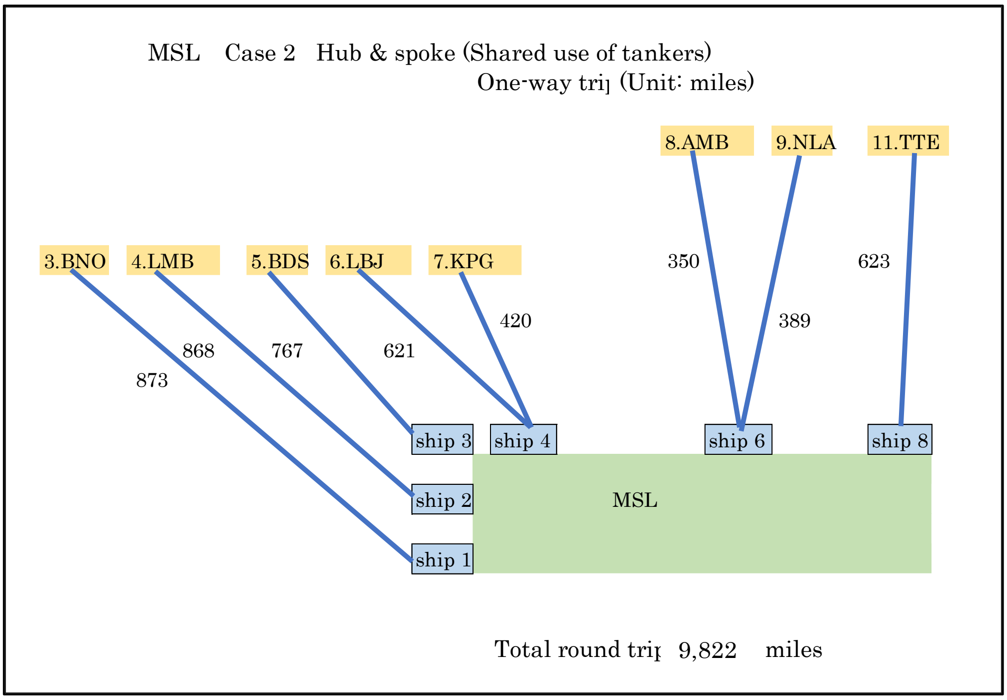
b. Case 2: LNG tanker sharing method (partly executed)

Table 7.17 shows the number and size of LNG tankers in case 2. Per Table 7.19 of case 1, the operation rate of LNG tankers assigned to Labuan Bajo and Kupang, which are adjacent to each other, is less than 30%. The operating rate of LNG tankers at Ambon and Namlea, which are also close to each other, is less than 50%. Therefore, case 2 was conducted to assess the possibility of reducing the LNG tankers from two to one to cover the four destinations: Labuan Bajo, Kupang, Ambon, and Namlea.

1) Image of tanker operation

Case 2 allocates six LNG tankers to deliver LNG from Masala to eight destination ports (Figure 7.19).

Figure 7.19: Delivery from LNG Terminal, MSL, Hub & Spoke Method (Case 2)



Source: Author.

2) Operational status of storage

Table 7.21 and Figure 7.20 show the simulation results of LNG onshore storages at each port. The table and figure suggest the following:

- Due to the application of the hub & spoke method to one LNG tanker to Labuan Bajo & Kupang and Ambon & Namlea, the initial volume of four LNG onshore storages at Labuan Bajo & Kupang and Ambon & Namlea is on two thirds of its capacity. However, no shortage has happened at the four receiving ports.
- The LNG storage capacity at the four ports where the hub & spoke method was applied to one LNG tanker is appropriate due to the simulation results of three indicators, which are maximum, minimum, and average levels of storage.

Table 7.21: Operational Status of Onshore Storage, MSL (Case 2)

Operational Status of storage	3.BNO	4.LMB	5.BDS	6.LBJ	7.KPG	8.AMB	9.NLA	11.TTE	Total
Storage size	L	L	M	S	S	S	S	L	
Storage capacity (CBM)	50,000	50,000	30,000	20,000	20,000	20,000	20,000	50,000	
Storage capacity (kiloton)	23.0	23.0	13.8	9.2	9.2	9.2	9.2	23.0	119.6
①Initial value of storage (kilotons)	11.5	11.5	9.2	6.1	4.6	6.1	6.1	11.5	66.7
②Unloading weight (kiloton/year)	515.2	442.8	253.7	105.5	101.8	89.7	75.9	442.8	2027.3
Tanker unloading volumes (kiloton/time)	16.1	12.7	8.3	8.3	8.3	2.3	2.3	12.7	
Level of calling a tanker (kiloton)	7.67	7.67	6.90	4.60	2.30	4.60	4.60	7.67	
Number of unloading (times)	32	35	32	14	13	39	33	35	233
Maximum level of storage (kiloton)	16.44	14.05	11.55	8.91	8.93	5.88	6.05	15.43	
Minimum level of storage (kiloton)	0.62	1.58	1.78	1.78	1.36	2.88	2.99	2.84	
Average level of storage (kiloton)	8.5	7.8	6.7	5.6	5.1	4.6	4.7	9.1	
Maximum level/Storage capacity	0.71	0.61	0.84	0.97	0.97	0.64	0.66	0.67	
③Stock at end of period (kiloton)	8.4	1.65	6.73	4.85	3.26	4.58	5.38	8.95	43.8
④Total supply (kiloton) ①+②−③	518.3	452.6	256.2	106.8	103.1	91.3	76.7	445.3	2,050.2
⑤Annual consumption (kiloton)	518.9	454.4	257.9	104.4	98.8	90.1	75.3	444.2	2,044.1
⑥Comparison ④/⑤	1.00	1.00	0.99	1.02	1.04	1.01	1.02	1.00	1.00

Source: Author.

3) Operational status of tankers

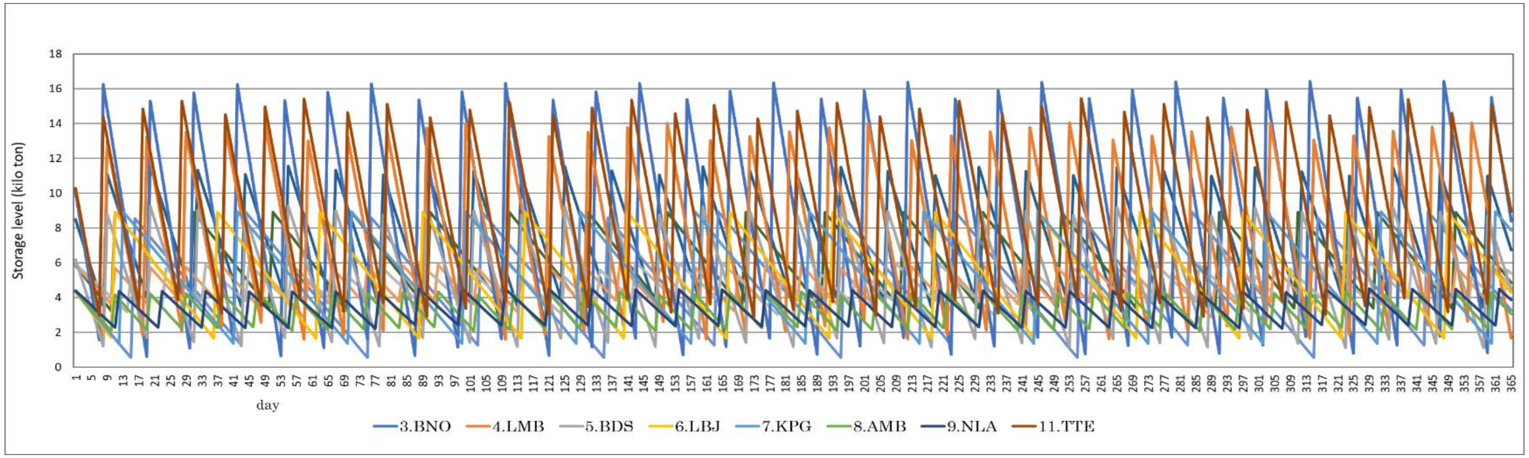
LNG tanker 4 (ship 4) transports LNG to Labuan Bajo & Kupang and LNG tanker 6 (ship 6) delivers LNG to Ambon & Namlea (Figure 7.21) . Due to different LNG demand of the four destinations, the frequency of LNG delivery of ship 4 is higher than ship 6. The operating rate of an LNG tanker for Ambon and Namlea exceeds 80%; however, for Labuan Bajo and Kupang, it is still below 50%.

Table 7.22: Results of Tanker Operation, MSL (Case 2)

Home Port Terminal	Destination	Tanker Number	Waiting Time for Shipment (hour)	Loading Time (hour)	Transport Time (hour)	Unloading Time (hour)	Operating Time (hour)	Total Time (hour)	Rate of Operation	Number of Loading (times)	Number of Unloading (times)
MSL	3.BNO	1	3,719	384	4,201	384	4,969	8,687	57%	32	32
	4.LMB	2	3,091	420	4,638	420	5,478	8,569	64%	35	35
	5.BDS	3	3,152	372	4,791	372	5,535	8,686	64%	31	31
	6.LBJ 7.KPG	4	4,469	360	3,277	360	3,997	8,466	47%	30	30
	8.AMB 9.NLA	6	1,491	864	5,540	864	7,268	8,759	83%	72	72
	11.TTE	8	4,495	420	3,340	420	4,180	8,675	48%	35	35
Total			**20,416**	**2,820**	**25,786**	**2,820**	**31,426**	**51,842**		**235**	**235**

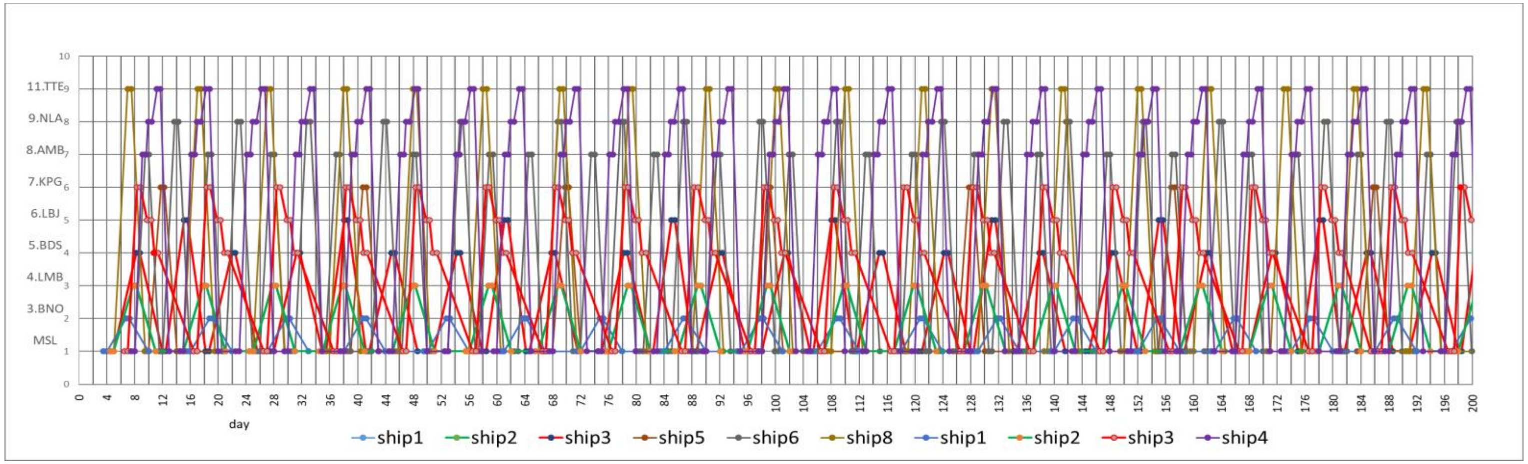
Source: Author.

Figure 7.20: LNG Storage Level of Onshore Storage, MSL (Case 2)



Source: Author's analysis.

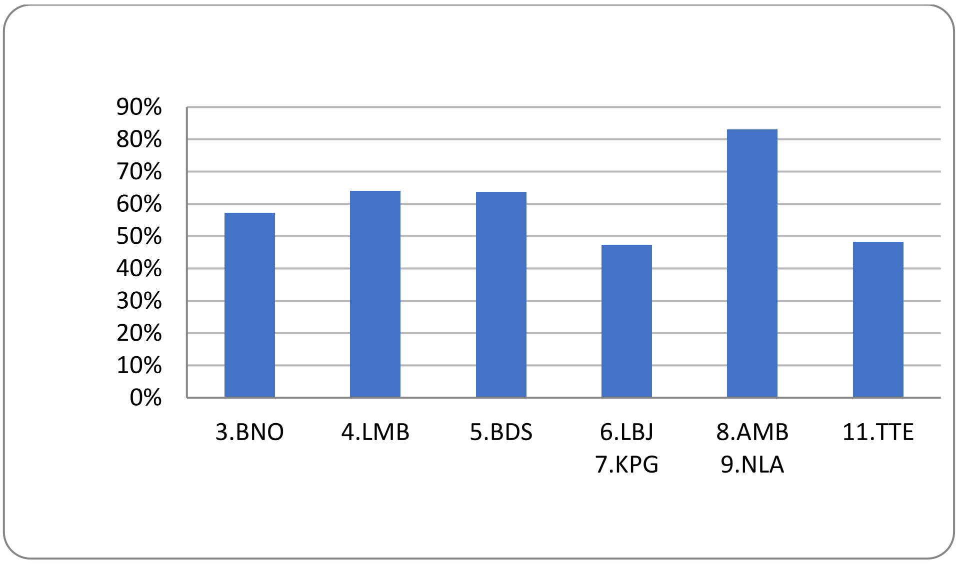
Figure 7.21: Diagram of LNG Tanker Operations, MSK (Case 2)



Source: Author's analysis.

4) Other information

Figure 7.22: Rate of Tanker Operations, MSL (Case 2)



Source: Author.

The total operation cost of case 2 is a little bit higher than case 1 because only one LNG tanker delivers LNG to Labuan Bajo and Namlea. The number of unloading in Labuan Bajo and Namlea in case 1 is 14 + 13 = 27. On the other hand, the number of unloading in case 2 is 30 (Tables 7.19 and 7.22). Therefore, the cruising distance x LNG delivery volume of case 2 is bigger than case 1. This is why the operating cost of case 2 is higher than case 1. But the number of LNG tankers of case 2 decreases from eight to six.

Table 7.23 Cruising Distance and OPEX of LNG Tankers, MSL (Case 2)

						Tanker OPEX	
Home Port Terminal	**Destination**	**Tanker Size**	**Cruise Distance (ound-trip miles)**	**Unloading Weight (kiloton)**	**Tonne Miles (1,000 tonne miles)**	**Unit Price (US$/1,000 tonne miles)**	**Ship Operating Costs (million US$/year)**
MSL	3.BNO	L	55,872	515	449,770	5.9	2.65
	4.LMB	M	60,760	443	384,307	5.9	2.27
	5.BDS	S	47,554	257	196,874	5.9	1.16
	6.LBJ 7.KPG	S	40,764	202	118,479	5.9	0.70
	8.AMB 9.NLA	SS	52,974	166	60,920	5.9	0.36
	11.TTE	M	43,610	443	275,833	5.9	1.63
Total			**301,534**	**2,025**	**1,486,183**		**8.77**

Source: Author.

c. Case 3: milk-run method partly applied

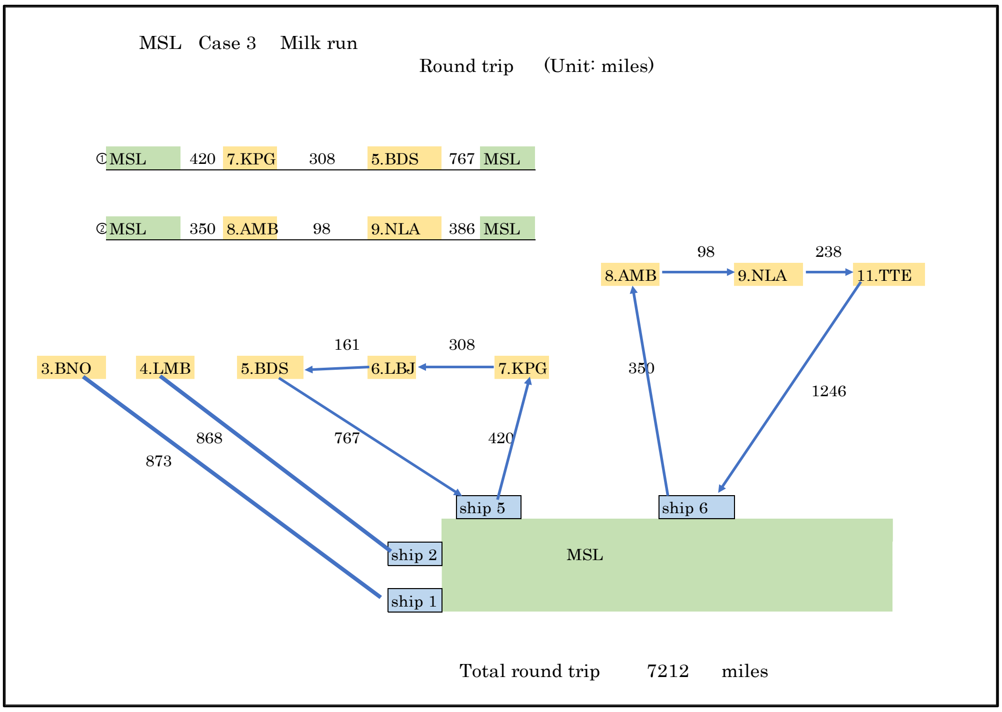
Table 7.17 shows the number and size of LNG tankers of case 3.

1) Operation of LNG tankers

Since the operation rate of the LNG tanker to deliver LNG to Labuan Bajo and Kupang of case 2 is less than 50%, Badas is added to the subgroup of Labuan Bajo and Kupang. Therefore, the milk-run method is applied to a new subgroup to include Kupang, Labuan Bajo, and Badas by one LNG tanker. In addition, the operation rate of Ternate is less than 50% in case 2, so that Ternate is also added to the subgroup of Ambon and Namlea. Then the milk-run method with one LNG tanker is applied to the new subgroup of Ambon, Namlea, and Ternate.

- ✔ Masela–Kupang–Labuan Bajo–Badas–Masela to use M type LNG tanker
- ✔ Masela–Ambon–Namlea–Ternate–Masela to use M type LNG tanker.

Figure 7.23: LNG Delivery, MSL, Milk-Run Method (Case 3)



Source: Author.

The total cruising distance of case 1 is 9,822 miles; that of case 3 is 7,212 miles. Thus, occasionally, the milk-run method contributes to shortening the cruising distance. However, destinations should be close to each other.

Table 7.24: Comparison of Cruising Distance between Hub & Spoke (Case 1) and Milk-Run Methods (Case 3)

MSL Group	City Name	Hub & Spoke	Milk-Run
		Round Trip	
MSL	3.BNO	1,746	1,746
	4.LMB	1,736	1,736
	5.BDS	1,534	
	6.LBJ	1,242	1,656
	7.KPG	840	
	8.AMB	700	828
	9.NLA	778	
	11.TTE	1,246	1,246
	Total	9,822	7,212

Milk-run area

Source: Author.

2) Operational status of storage

Due to the application of the milk-run method, the initial volume of the two LNG onshore storages at Badas and Ternate are assumed to be two thirds of its capacity. However, no shortage has occurred. In addition, looking at the ratio defined as 'maximum level/capacity of LNG onshore storage', the ratios of the eight sites are lying about 0.6–0.7 and they look good. But the difference between the maximum and the minimum levels of LNG onshore storage at Labuan Bajo, Kupang, Ambon, and Namlea seem to be narrow. Therefore, the LNG storage capacity might be too big. The SS type of LNG storage could be available (Table 7.25).

Table 7.25: Operational Status of Onshore Storage, MSL (Case 3)

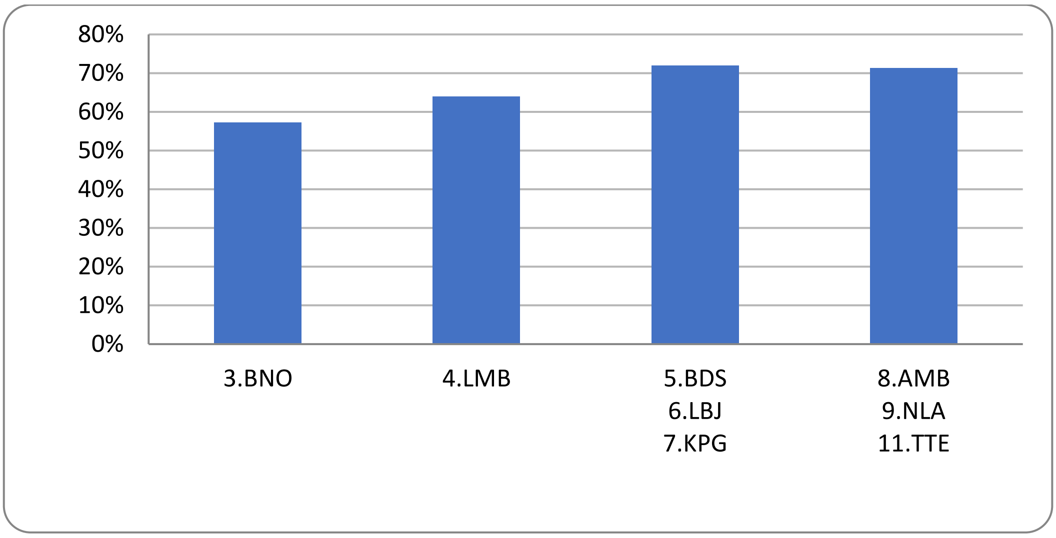
Operational Status of Storage	3.BNO	4.LMB	5.BDS	6.LBJ	7.KPG	8.AMB	9.NLA	11.TTE	Total
Storage size	L	L	M	S	S	S	S	L	
Storage capacity (CBM)	50,000	50,000	30,000	20,000	20,000	20,000	20,000	50,000	
Storage capacity (kiloton)	23.0	23.0	13.8	9.2	9.2	9.2	9.2	23.0	119.6
①Initial value of storage (kilotons)	11.5	11.5	9.2	6.1	6.1	6.1	6.1	15.3	72.1
②Unloading weight (kiloton/year)	515.2	442.8	253.7	98.8	101.8	89.7	75.9	442.8	2020.6
Tanker unloading volumes (kiloton/time)	16.1	12.7	8.3	8.3	8.3	2.3	2.3	12.7	
Level of calling a tanker (kiloton)	7.67	7.67	6.90	4.60	4.60	4.60	4.60	11.50	
Number of unloading (times)	32	35	36	36	36	48	48	48	319
Maximum level of storage (kiloton)	16.44	14.05	8.49	5.84	6.4	5.88	5.92	14.11	
Minimum level of storage (kiloton)	0.62	1.58	0.34	3.23	3.97	3.85	4.02	1.91	
Average level of storage (kiloton)	8.5	7.8	4.4	4.5	5.2	4.8	4.8	6.8	
Maximum level/Storage capacity	0.71	0.61	0.62	0.63	0.70	0.64	0.64	0.61	
③Stock at end of period (kiloton)	8.4	1.65	4.55	4.68	4.78	5.12	5.32	11.15	45.65
④Total supply (kiloton) ①＋②－③	518.3	452.6	258.4	100.3	103.2	90.7	76.7	446.9	2,047.0
⑤Annual consumption (kiloton)	518.9	454.4	257.9	104.4	98.8	90.1	75.3	444.2	2,044.1
⑥Comparison ④/⑤	1.00	1.00	1.00	0.96	1.04	1.01	1.02	1.01	1.00

Source: Author.

3) Operational status of LNG tankers

Figure 7.25 shows the operation of four LNG tankers of case 3. The figure also shows the busy situation of LNG tankers or ships 3 and 4, whilst ships 1 and 2 have plenty of idle time. Ship 3 transports LNG from Masela to Badas, Labuan Bajo, and Kupang by the milk-run method. Ship 4 also delivers LNG to Ambon, Namlea, and Ternate by the same method. Thus, the operation rates of both ships increase to 72% and 71%, respectively (Table 7.26).

Figure 7.24: Rate of LNG Tanker Operations, MSL (Case 3)



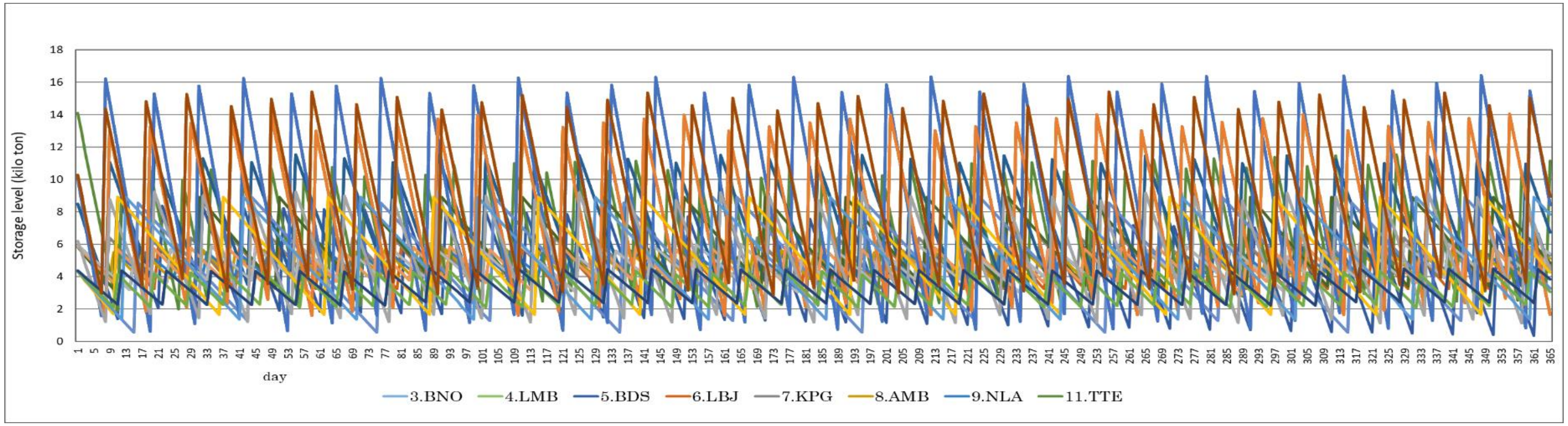
Source: Author.

Table 7.26: Results of Tanker Operations, MSL, Milk-Run Method (Case 3)

Home Port Terminal	Destination	Tanker Number	Waiting Time for Shipment (hour)	Loading Time (hour)	Transport Time (hour)	Unloading Time (hour)	Operating Time (hour)	Total Time (hour)	Rate of Operation	Number of Loading (times)	Number of Unloading (times)
MSL	3.BNO	1	3,719	384	4,201	384	4,969	8,687	57%	32	32
	4.LMB	2	3,091	420	4,638	420	5,478	8,569	64%	35	35
	5.BDS 6.LBJ 7.KPG	5	2,453	432	4,549	1,296	6,277	8,730	72%	36	108
	8.AMB 9.NLA 11.TTE	6	2,525	576	3,953	1,728	6,257	8,782	71%	48	144
Total			**11,788**	**1,812**	**17,341**	**3,828**	**22,981**	**34,768**		**151**	**227**

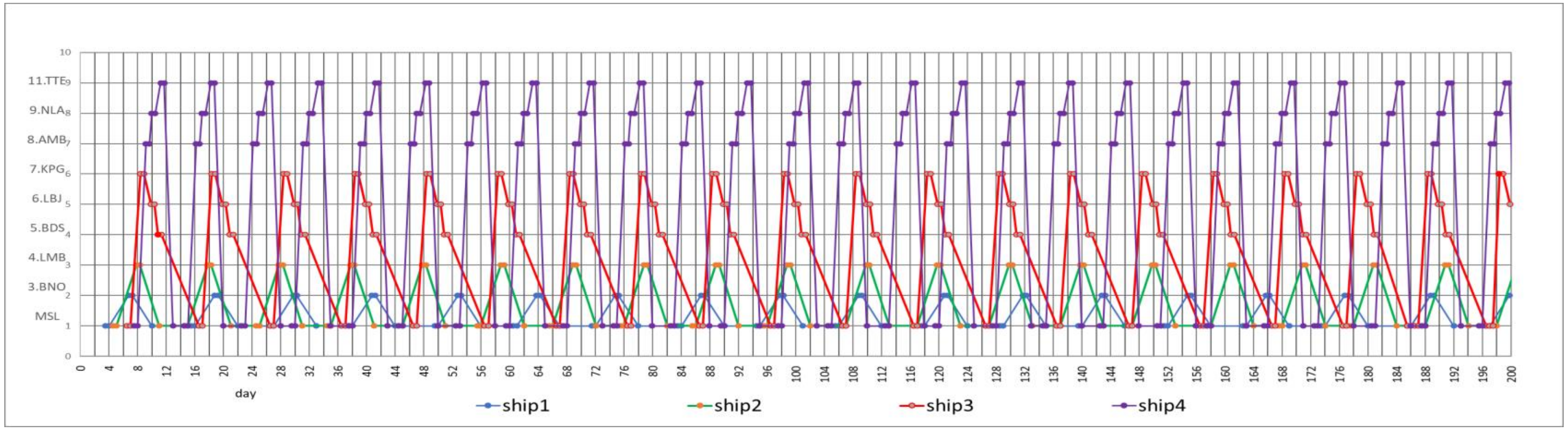
Source: Author.

Figure 7.25: LNG Storage Level of Each Site, MSL (Case 3)



Source: Author's analysis.

Figure 7.26: LNG Tanker Operations, MSL (Case 3)



Source: Author's analysis.

4) Key findings

The total operation cost of case 3 is higher than case 2. But the cruising distance of case 3 is shorter than case 2. Operation cost is defined as tonne mile (distance x unloading of LNG) x unit operation cost of LNG tanker (US$/1,000 tonne miles). Therefore, the tonne miles of case 3 should be bigger than case 2 because the LNG tanker leaving Masela should load roughly three times the LNG amount compared to case 2. But for case 3, LNG tankers are reduced from six to four.

Table 7.27: Cruising Distance and OPEX of LNG Tankers, MSL, Milk-Run Method (Case 3)

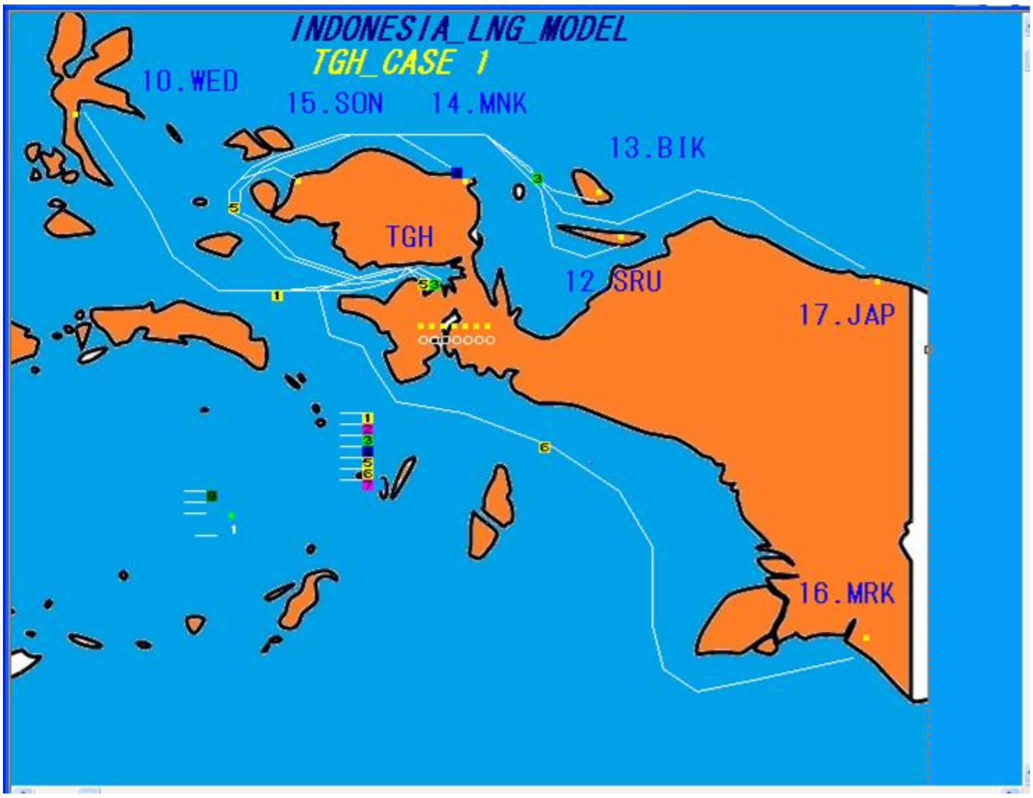
						Tanker OPEX	
Home Port Terminal	**Destination**	**Tanker Size**	**Cruise Distance (round-trip miles)**	**Unloading Weight (kiloton)**	**Tonne Miles (1,000 tonne miles)**	**Unit Price (US$/1,000 tonne miles)**	**Ship Operating Costs (million US$/year)**
MSL	3.BNO	L	55,872	515	449,770	5.9	2.65
	4.LMB	M	60,760	443	384,307	5.9	2.27
	5.BDS 6.LBJ 7.KPG	M	59,616	455	342,455	5.9	2.02
	8.AMB 9.NLA 11.TTE	M	59,388	607	405,223	5.9	2.39
Total			**235,636**	**2,021**	**1,581,755**		**9.33**

Source: Author.

2.3. Tangguh group

The Tangguh group consists of one LNG shipping site (Tangguh) and seven LNG receiving sites: Weda, Yapen Island (Serui), Biak, Manokwari, Sorong city, Merauke, and Jayapura city. These are around South Halmahera to Papua province. Figure 7.27 shows the simulation image of LNG delivery from Tangguh to seven LNG receiving sites in the Tangguh group.

Figure 7.27: Simulation of LNG Delivery on PC Screen, TGH, Milk-Run Method (Case 3)



Source: Author.

Ports of LNG receiving terminal, LNG onshore facility, and LNG tankers

Table 7.28 summarises the water depth at each receiving port, annual LNG consumption, LNG onshore storage capacity, and type of LNG tanker to be initially deployed.

Table 7.28: Input Conditions for Simulation

Production Base	No.	Port Abbreviation	Port Water Depth	Annual Consumption (kiloton)	Onshore Storage			Tanker Storage			
					Type	Capacity (CBM)	Weight (kiloton)	Water Depth (m)	Type	Capacity (CBM)	Weight (kiloton)
TGH	10	WED	—	454	L	50,000	23.00	6.05	S	18,000	8.28
	12	SRU	10	23	SS	5,000	2.30	5.28	SS	5,000	2.30
	13	BIK	9	36	SS	5,000	2.30	5.28	SS	5,000	2.30
	14	MNK	12	154	S	20,000	9.20	6.05	S	18,000	8.28
	15	SON	15	247	M	30,000	13.80	6.05	S	18,000	8.28
	16	MRK	7	51	SS	5,000	2.30	5.28	SS	5,000	2.30
	17	JAP	9	23	SS	5,000	2.30	5.28	SS	5,000	2.30

Source: Author.

Table 7.29 shows the number and types of LNG tankers deployed for each case. Four SS-type LNG tankers and three S-type LNG tankers are assigned to case 1. Case 2 reduces the number of LNG tankers from seven to five. These are three SS-type and two S-type LNG tankers. Case 3 assigns only three LNG tankers consisting of SS, S, and M types.

Table 7.29: Number and Size of Tanker (Cases 1–3)

	TGH						
	10.WED	12.SRU	13.BIK	14.MNK	15.SON	17.JAP	16.MRK
Case 1	S	SS	SS	S	S	SS	SS
Case 2	S	SS		S		SS	SS
Case 3	S	M					SS

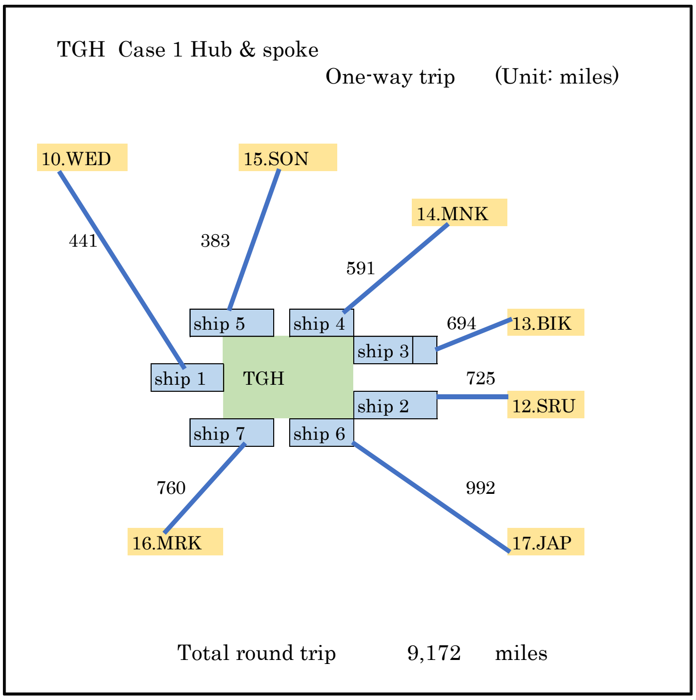
Source: Author.

a. Case 1: Hub & spoke method

1) Image of LNG tanker operation

Case 1 allocates seven ships to seven routes for delivering LNG from Tangguh to seven destination ports. Figure 7.28 shows the image of case 1.

Figure 7.28: Image of LNG Delivery from TGH, Hub & Spoke Method (Case 1)



Source: Author.

2) Operational status of LNG onshore storage

The simulation results of LNG onshore storages at seven LNG receiving ports are shown in Table 7.30 and Figure 7.29, indicating the following:

- The initial volume of each onshore storage is assumed half of its capacity, but no shortage has happened at the seven receiving ports.
- The storage capacity at Serui and Biak with 5,000 CBM, Manokwari with 20,000 CBM, Merauke and Jayapura with 5,000 CBM is appropriate, as indicated by 'maximum level/LNG storage capacity'. The indicators of the four LNG receiving sites are more than 90%.
- On the other hand, the storage capacity of Weda with 50,000 CBM and Sorong with 30,000 CBM is oversized due to lower indicators defined as 'maximum level/LNG storage capacity'.
- Considering the 'minimum level of LNG storage' of the three sites – Weda, Manokwari, and Sorong city – and considering these to be less than a few days, increasing the initial volume of the LNG storage is recommended.

Table 7.30: Operational Status of Onshore Storage, TGH (Case 1)

Operational Status of Storage	10.WED	12.SRU	13.BIK	14.MNK	15.SON	16.MRK	17.JAP	Total
Storage size	L	SS	SS	S	M	SS	SS	
Storage capacity (CBM)	50,000	5,000	5,000	20,000	30,000	5,000	5,000	
Storage capacity (kiloton)	23.0	2.3	2.3	9.2	13.8	2.3	2.3	55.2
①Initial value of storage (kilotons)	11.5	1.2	1.2	4.6	6.9	1.2	1.2	27.6
②Unloading weight (kiloton/year)	447.1	21.8	37.4	157.1	248.4	50.4	22.5	984.6
Tanker unloading volumes (kiloton/time)	8.3	2.3	2.3	8.3	8.3	2.3	2.3	
Level of calling a tanker (kiloton)	5.75	0.58	0.58	2.30	3.45	0.77	0.58	
Number of unloading (times)	54	11	17	19	30	24	11	166
Maximum level of	10.26	2.24	2.2	8.78	8.98	2.16	2.24	

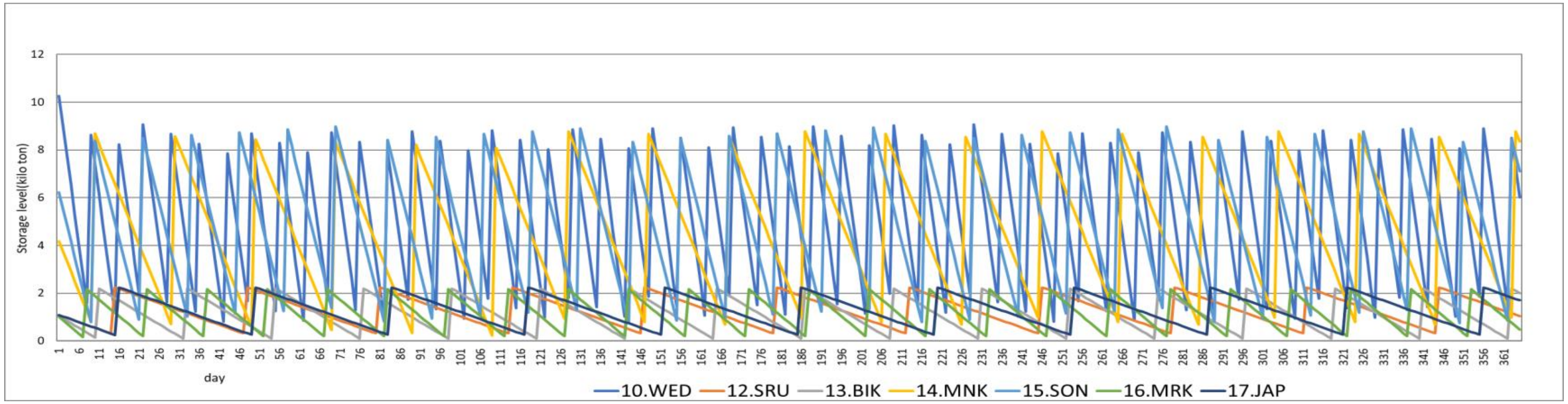
storage (kiloton)								
Minimum level of storage (kiloton)	0.82	0.31	0.1	0.22	0.74	0.17	0.25	
Average level of storage (kiloton)	5.0	1.3	1.1	4.6	4.8	1.2	1.2	
Maximum level/Storage capacity	0.45	0.97	0.96	0.95	0.65	0.94	0.97	
③Stock at end of period (kiloton)	6.02	1.04	2	8.36	7.1	0.48	1.7	26.7
④Total supply (kiloton) ①＋②－③	452.6	21.9	36.5	153.3	248.2	51.1	21.9	985.5
⑤Annual consumption （kiloton）	454.0	23.4	35.6	154.1	247.1	51.2	22.9	988.3
⑥Comparison ④/⑤	1.00	0.94	1.03	0.99	1.00	1.00	0.96	1.00

Source: Author.

3) Operational status of tankers

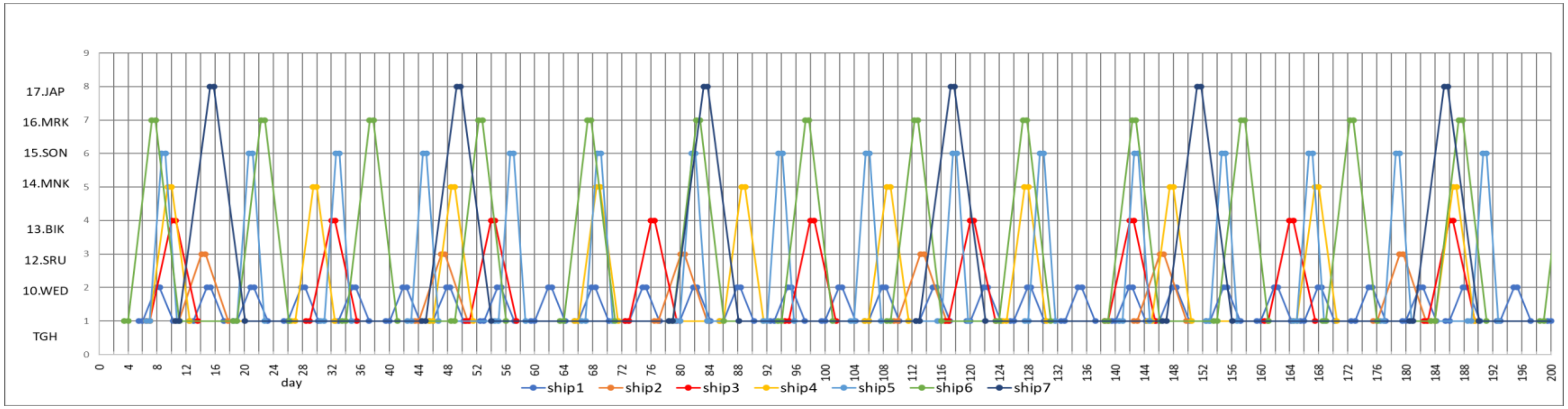
Figure 7.29 shows the operation of seven tankers. Table 7.31 shows the operation status of LNG tanker per each route, including waiting time, loading time, transporting time, unloading time, operating time, total time, operating rate, and number of loading and unloading of LNG. The operation rate of LNG tankers on five routes – Serui, Biak, Monokwari, Sorong, and Jayapura – is quite low. This suggests improving the operation rate through the application of other methods.

Figure 7.29: **LNG Storage Level of Each Site, TGH (Case 1)**



Source: Author's analysis.

Figure 7.30: LNG Tanker Operations, TGH (Case 1)



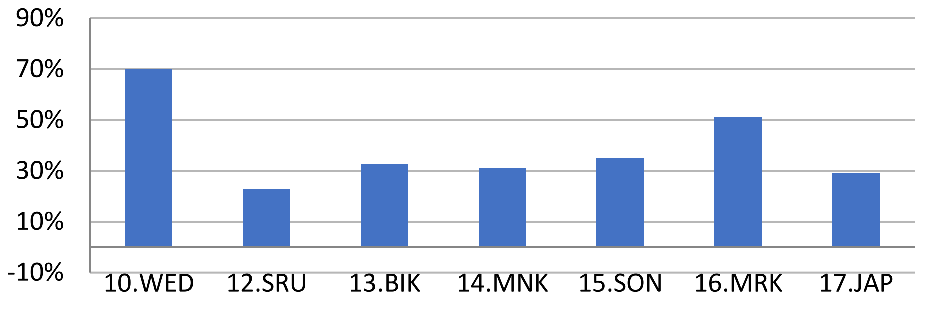
Source: Author's analysis.

Table 7.31: Results of Tanker Operations, TGH, Hub & Spoke Method (Case 1)

Home Port Terminal	Destination	Tanker Number	Waiting Time for Shipment (hour)	Loading Time (hour)	Transport Time (hour)	Unloading Time (hour)	Operating Time (hour)	Total Time (hour)	Rate of Operation	Number of Loading (times)	Number of Unloading (times)
TGH	10.WED	1	2,628	648	4,817	648	6,113	8,741	70%	54	54
	12.SRU	2	6,427	132	1,655	132	1,919	8,346	23%	11	11
	13.BIK	3	5,911	204	2,453	204	2,861	8,772	33%	17	17
	14.MNK	4	6,070	228	2,269	228	2,725	8,795	31%	19	19
	15.SON	5	5,675	360	2,336	360	3,056	8,731	35%	30	30
	16.MRK	6	4,179	288	3,791	288	4,367	8,546	51%	24	24
	17.JAP	7	6,112	132	2,266	132	2,530	8,642	29%	11	11
Total			**37,002**	**1,992**	**19,587**	**1,992**	**23,571**	**60,573**	**39%**	**166**	**166**

Source: Author.

Figure 7.31: Rate of Tanker Operation, TGH (Case 1)



Source: Author.

4) Key findings

The operation cost of LNG delivery to Weda is more than US$1 million per year. That of other ports is less than US$1 million due to shorter cruising distances and smaller LNG amounts.

Table 7.32: Cruising Distance and OPEX of LNG Tanker, TGH, Hub & Spoke Method (Case 1)

						Tanker OPEX	
Home Port Terminal	**Destination**	**Tanker Size**	**Cruise Distance (round-trip miles)**	**Unloading Weight (kiloton)**	**Tonne Miles (1,000 tonne miles)**	**Unit Price (US$/1,000 tonne miles)**	**Ship Operating Costs (million US$/year)**
TGH	10.WED	S	47,628	447	197,180	5.9	1.16
	12.SRU	SS	15,950	22	15,798	5.9	0.09
	13.BIK	SS	23,596	37	25,921	5.9	0.15
	14.MNK	S	22,458	157	92,822	5.9	0.55
	15.SON	S	22,980	248	95,137	5.9	0.56
	16.MRK	SS	36,480	50	38,327	5.9	0.23
	17.JAP	SS	21,824	22	22,270	5.9	0.13
Total			**190,916**	**985**	**487,455**		**2.88**

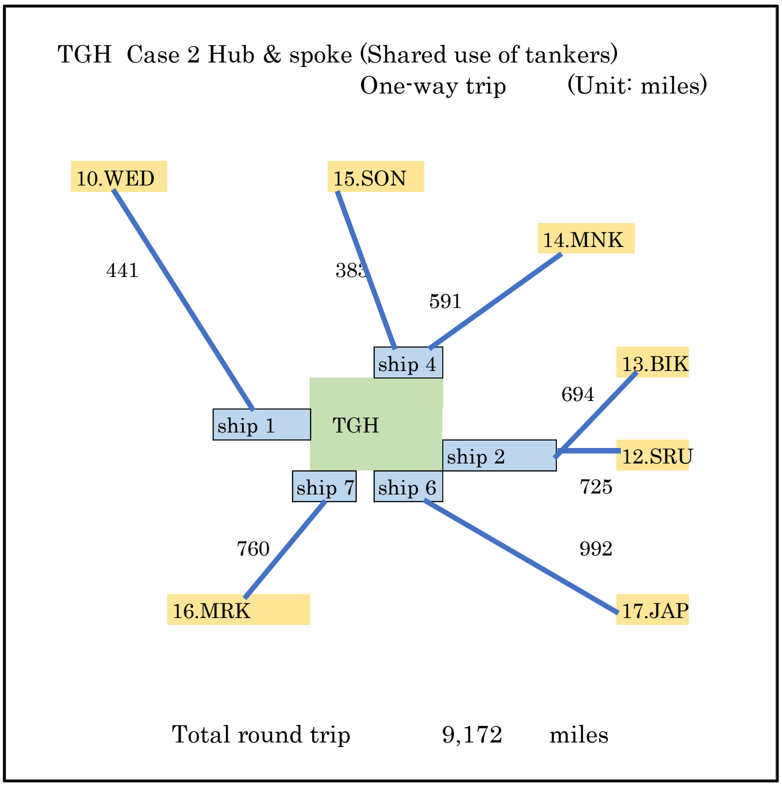
Source: Author.

b. Case 2: LNG tanker sharing method (partly applied)

1) Image of LNG tanker operation

Figure 7.32 shows the operation of LNG tankers of case 2. LNG tanker ship 2 covers two LNG demand sites, Serui and Biak. Another LNG tanker, ship 4, delivers LNG to Manokwari and Sorong city. As a result, the number of LNG tankers decreased from seven to five.

Figure 7.32: Delivery from LNG Terminal, TGH, Hub & Spoke (Case 2)



Source: Author.

2) Operational status of LNG onshore storage

The initial volume of the four ports (Serui, Biak, Manokwari, and Sorong) increases from one half to two thirds due to the operation of one LNG tanker. The capacities of the ports do not change because no LNG shortage occurs. In addition, the LNG storage capacity at Weda and Manokwari seems to be bigger compared to the actual storage level, defined as the difference between the maximum and the minimum levels. Weda has a 23-kiloton capacity less 10 kilotons as minimum level. Manokwari's capacity is 9.2 kilotons less 6.7 kilotons minimum level (Table 7.33 and Figure 7.33).

Table 7.33: Operational Status of Onshore Storage, TGH (Case 2)

Operational Status of Storage	10.WED	12.SRU	13.BIK	14.MNK	15.SON	16.MRK	17.JAP	Total
Storage size	L	SS	SS	S	M	SS	SS	
Storage capacity (CBM)	50,000	5,000	5,000	20,000	30,000	5,000	5,000	
Storage capacity (kiloton)	23.0	2.3	2.3	9.2	13.8	2.3	2.3	55.2
①Initial value of storage (kilotons)	11.5	1.5	1.5	6.1	9.2	1.2	1.2	32.2
②Unloading weight (kiloton/year)	447.1	21.7	37.3	152.5	248.4	50.4	22.5	979.9
Tanker unloading volumes (kiloton/time)	8.3	2.3	2.3	8.3	8.3	2.3	2.3	
Level of calling a tanker (kiloton)	5.75	1.15	1.15	4.60	6.90	0.77	0.58	
Number of unloading (times)	54	14	20	25	30	24	11	178
Maximum level of storage (kiloton)	10.26	2.24	2.2	8.78	12.44	2.16	2.24	
Minimum level of storage (kiloton)	0.82	0.5	0.1	2.06	0.36	0.17	0.25	
Average level of storage (kiloton)	5.0	1.4	1.3	5.9	6.9	1.2	1.2	
Maximum level/Storage capacity	0.45	0.97	0.96	0.95	0.90	0.94	0.97	
③Stock at end of period (kiloton)	6.02	2.18	0.6	6.26	9.4	0.48	1.7	26.64
④Total supply (kiloton) ①＋②－③	452.6	21.1	38.2	152.4	248.2	51.1	22.0	985.5
⑤Annual consumption (kiloton)	454.0	23.4	35.6	154.1	247.1	51.2	22.9	988.3
⑥Comparison ④/⑤	1.00	0.90	1.07	0.99	1.00	1.00	0.96	1.00

Source: Author.

3) Operational status of tankers

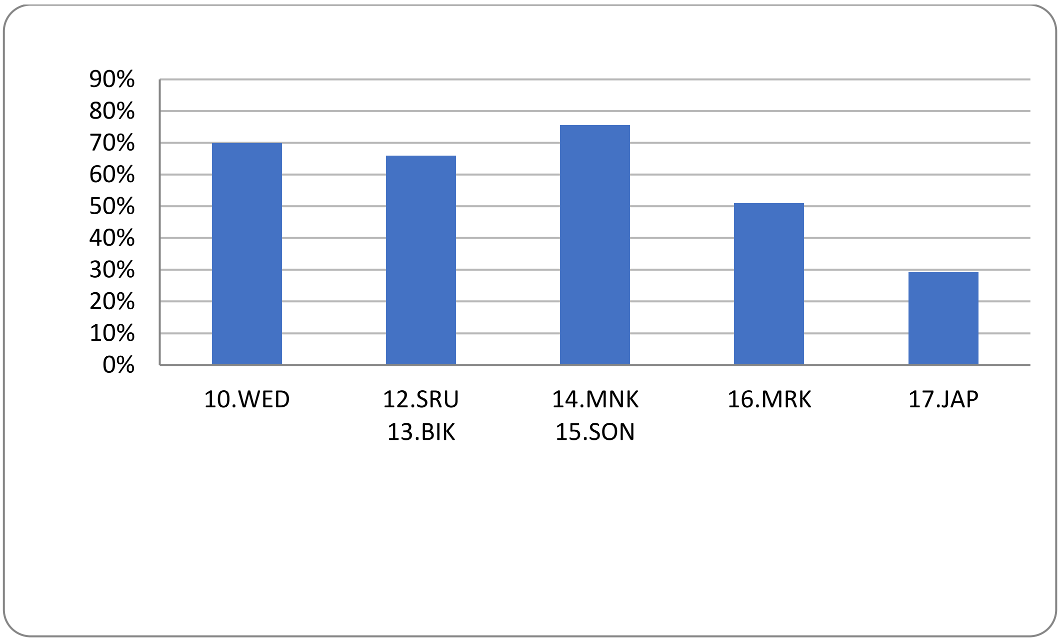
The operation rate of LNG tankers, ships 2 and 4, improves largely due to LNG delivery by one tanker to two LNG demand sites.

Table 7.34: Results of LNG Tanker Operations, Hub & Spoke (Case 2)

Home Port Terminal	Destination	Tanker Number	Waiting Time for Shipment (hour)	Loading Time (hour)	Transport Time (hour)	Unloading Time (hour)	Operating Time (hour)	Total Time (hour)	Rate of Operation	Number of Loading (times)	Number of Unloading (times)
TGH	10.WED	1	2,628	648	4,817	648	6,113	8,741	70%	54	54
	12.SRU 13.BIK	2	2,994	408	4,994	408	5,810	8,803	66%	34	34
	14.MNK 15.SON	4	2,148	660	5,309	660	6,629	8,777	76%	55	55
	16.MRK	6	4,182	288	3,788	288	4,364	8,546	51%	24	24
	17.JAP	7	6,113	132	2,265	132	2,529	8,642	29%	11	11
Total			**18,064**	**2,136**	**21,172**	**2,136**	**25,444**	**43,509**	**58%**	**178**	**178**

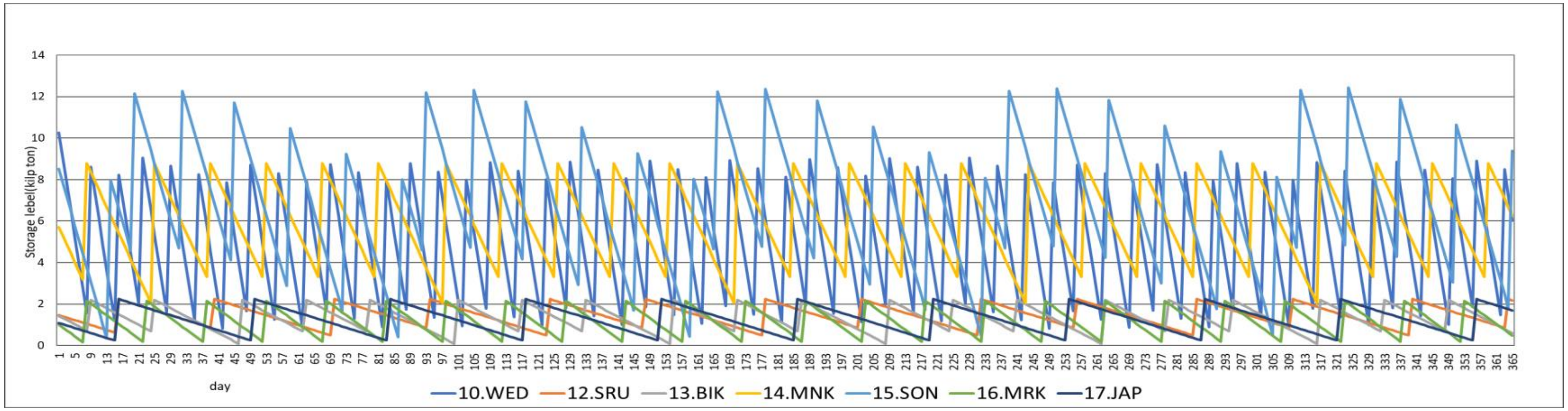
Source: Author.

Figure 7.33: Rate of LNG Tanker Operation, TGH (Case 2)



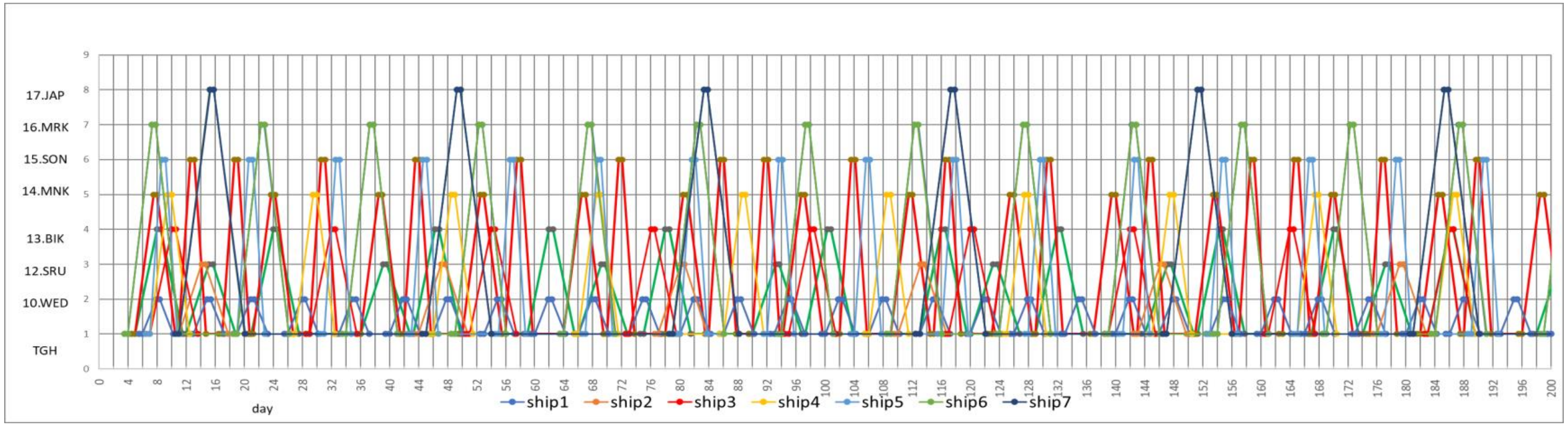
Source: Author.

Figure 7.34: LNG Storage Level of Each Site, TGH (Case 2)



Source: Author's analysis.

Figure 7.35: LNG Tanker Operation, TGH (Case 2)



Source: Author's analysis.

4) Key findings

The total operation cost of LNG tankers of case 2 is similar to case 1 due to the application of the same delivery method, which is hub & spoke. But cases 1 and 2 have different assumptions, which are the initial volume at LNG storages and LNG tanker calling level. Thus, the unloading amount of LNG to Manokwari is smaller than case 1. This is why the operation costs between cases 1 and 2 are different.

Table 7.35: Cruising Distance and OPEX of LNG Tanker, TGH (Case 2)

						Tanker OPEX	
Home Port Terminal	**Destination**	**Tanker Size**	**Cruise Distance (round-trip miles)**	**Unloading Weight (kiloton)**	**Tonne Miles (1,000 tonne miles)**	**Unit Price (US$/1,000 tonne miles)**	**Ship Operating Costs (million US$/year)**
TGH	10.WED	S	47,628	447	197,180	5.9	1.16
	12.SRU 13.BIK	SS	48,060	58	41,034	5.9	0.24
	14.MNK 15.SON	S	52,530	402	185,814	5.9	1.10
	16.MRK	SS	36,480	50	38,327	5.9	0.23
	17.JAP	SS	21,824	22	22,270	5.9	0.13
Total			**206,522**	**980**	**484,626**		**2.86**

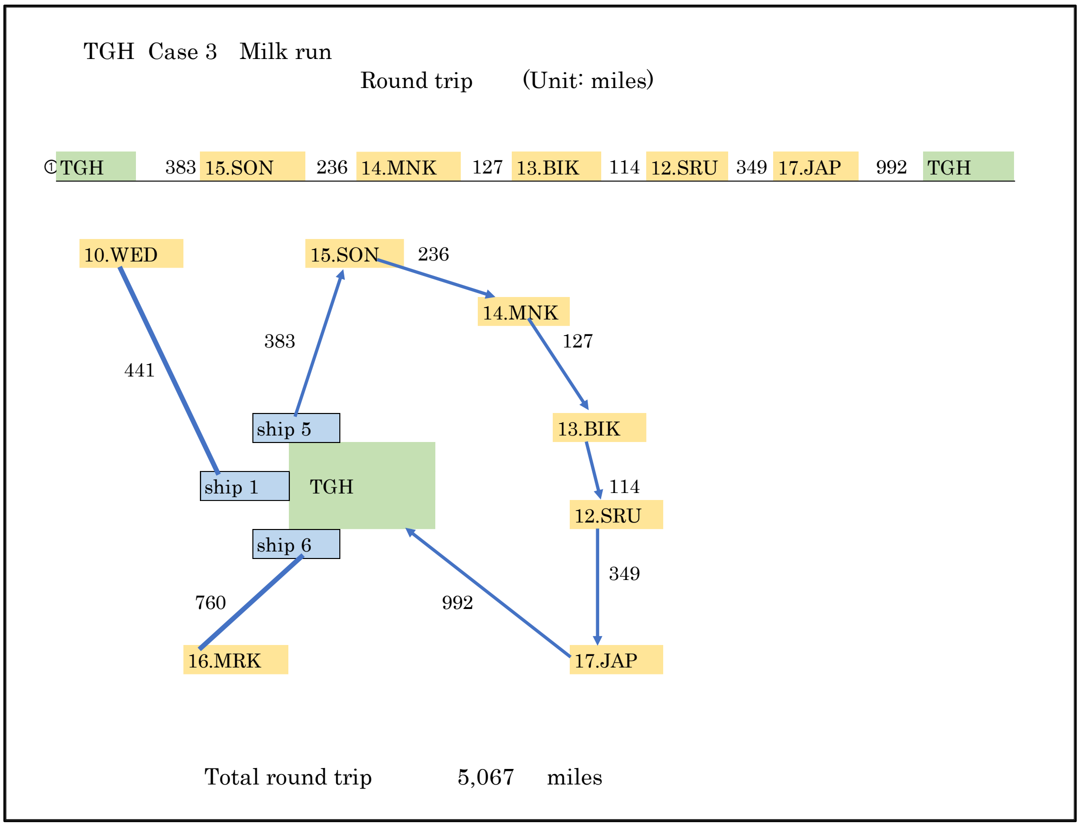
Source: Author.

c. Case 3: Milk-run method (partly applied)

1) Image of tanker operation

The milk-run method is applied to LNG delivery for Tangguh Sorong Manokwari Biak Serui Jayapura Tangguh (Figure 7.36).

Figure 7.36: Image of LNG Delivery, TGH, Milk-Run Method (Case 3)



Source: Author.

In the hub & spoke method, the cruising distance is 9,172 miles (case 1). On the other hand, it is 4,603 miles in the milk-run method (case 3).

Table 7.36: Comparison of Distance of Hub & Spoke and Milk-Run Methods

TGH Group	City Name	Hub & Spoke	Milk-Run
		Round Trip	
	10.WED	882	882
	12.SRU	1,450	
	13.BIK	1,388	
TGH	14.MNK	1,182	2,201
	15.SON	766	
	17.JAP	1,984	
	16.MRK	1,520	1,520
	Total	9,172	4,603

Milk-run area

Source: Author.

2) Operational status of storage

The initial volume of seven receiving terminals are the same as case 2, except for Jayapura whose volume increased from 1.2 kilotons to 1.5 kilotons due to one of the target ports of the milk-run method. In case 3, one M-type LNG tanker covers five LNG receiving terminals, so that the LNG unloading volume per time is also smaller than case 2 except for Sorong. Due to reduced unloading LNG amount, the number of unloading times increases to 30 times in each port; it is the same for Sorong in case 2. The capacity of LNG onshore storage at Weda, Merauke, and Sorong is oversized, referring to the difference between the maximum and the minimum levels, and can be further reduced.

Table 7.37: Operational Status of Onshore Storage, TGH (Case 3)

Operational Status of Storage	10.WED	12.SRU	13.BIK	14.MNK	15.SON	16.MRK	17.JAP	Total
Storage size	L	SS	SS	S	M	SS	SS	
Storage capacity (CBM)	50,000	5,000	5,000	20,000	30,000	5,000	5,000	
Storage capacity (kiloton)	23.0	2.3	2.3	9.2	13.8	2.3	2.3	55.2
①Initial value of storage (kilotons)	11.5	1.5	1.5	6.1	9.2	1.2	1.5	32.6
②Unloading weight (kiloton/year)	447.1	21.7	37.3	152.5	248.1	50.4	22.5	979.7
Tanker unloading volumes (kiloton/time)	8.3	0.7	1.2	5.1	8.3	2.3	0.7	
Level of calling a tanker (kiloton)	5.75	1.15	1.15	4.60	6.90	0.77	1.15	
Number of unloading (times)	54	30	30	30	30	24	30	228
Maximum level of storage (kiloton)	10.26	1.69	1.91	8.13	13.12	2.16	1.57	
Minimum level of storage (kiloton)	0.82	0.92	0.71	2.99	4.96	0.17	0.8	
Average level of storage (kiloton)	5.0	1.3	1.3	5.6	9.0	1.2	1.2	
Maximum level/Storage capacity	0.45	0.73	0.83	0.88	0.95	0.94	0.68	
③Stock at end of period (kiloton)	6.02	1.53	1.63	6.43	9.86	0.48	0.8	26.75

④Total supply (kiloton) ①＋②－③	452.6	21.7	37.2	152.2	247.5	51.1	23.2	985.5
⑤Annual consumption (kiloton)	454.0	23.4	35.6	154.1	247.1	51.2	22.9	988.3
⑥Comparison ④/⑤	1.00	0.93	1.05	0.99	1.00	1.00	1.01	1.00

Source: Author.

3) Operational status of LNG tankers

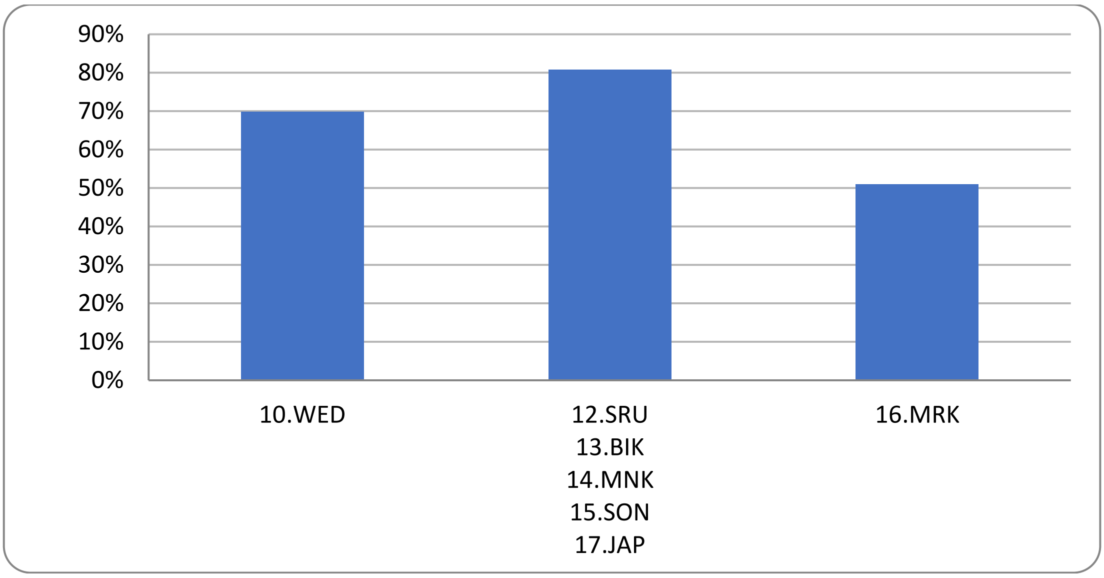
The operational status of LNG tankers is shown in Table 7.38 and the diagram of the operation of the three LNG tankers in the Tangguh Group is shown in Figure 7.38. The occupancy rate increased to 81% due to the application of the milk-run method in five LNG receiving sites. Therefore, one M-sized tanker operation is feasible because of the absence of LNG shortage.

Table 7.38: Results of LNG Tanker Operations, TGH, Milk-Run Method (Case 3)

Home Port Terminal	Destination	Tanker Number	Waiting Time for Shipment (hour)	Loading Time (hour)	Transport Time (hour)	Unloading Time (hour)	Operating Time (hour)	Total Time (hour)	Rate of Operation	Number of Loading (times)	Number of Unloading (times)
TGH	10.WED	1	2,640	648	4,805	648	6,101	8,741	70%	54	54
	12.SRU 13.BIK 14.MNK 15.SON 17.JAP	5	1,683	360	4,899	1,788	7,047	8,730	81%	30	149
	16.MRK	6	4,189	288	3,781	288	4,357	8,545	51%	24	24
Total			**8,512**	**1,296**	**13,485**	**2,724**	**17,505**	**26,016**	**67%**	**108**	**227**

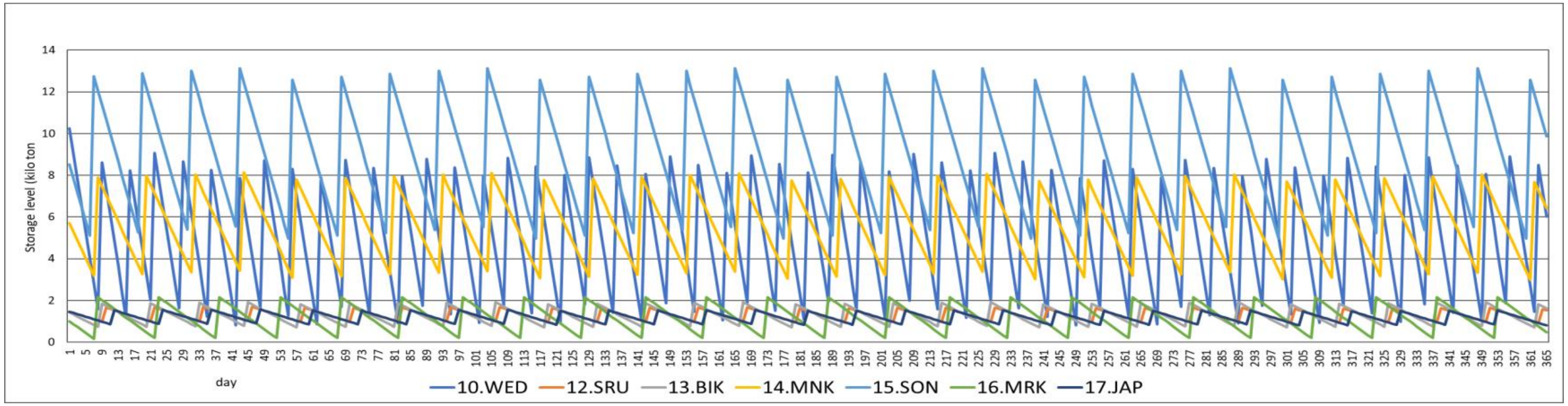
Source: Author.

Figure 7.37: Rate of Tanker Operation, TGH (Case 3)



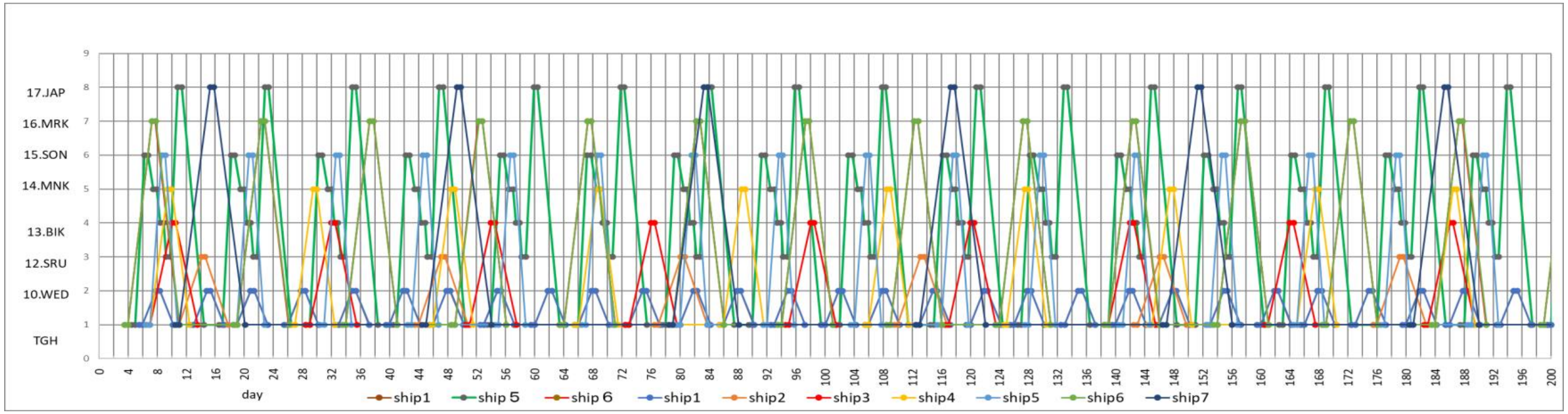
Source: Author.

Figure 7.38: LNG Storage Level of Each Site, TGH (Case 3)



Source: Author's analysis.

Figure 7.39: LNG Tanker Operation, TGH (Case 3)



Source: Author's analysis.

4) Key findings

The operation cost of case 3 is higher than cases 1 and 2. The cruising distance of the ship is shorter than cases 1 and 2, but the tonne miles are more than cases 1 and 2 because one ship has to load a bigger LNG amount than cases 1 and 2 to deliver LNG to five ports. But the increase of operation costs is only 2% from case 1.

Table 7.39: Cruising Distance and OPEX of Tanker, TGH, Milk-Run Method (Case 3)

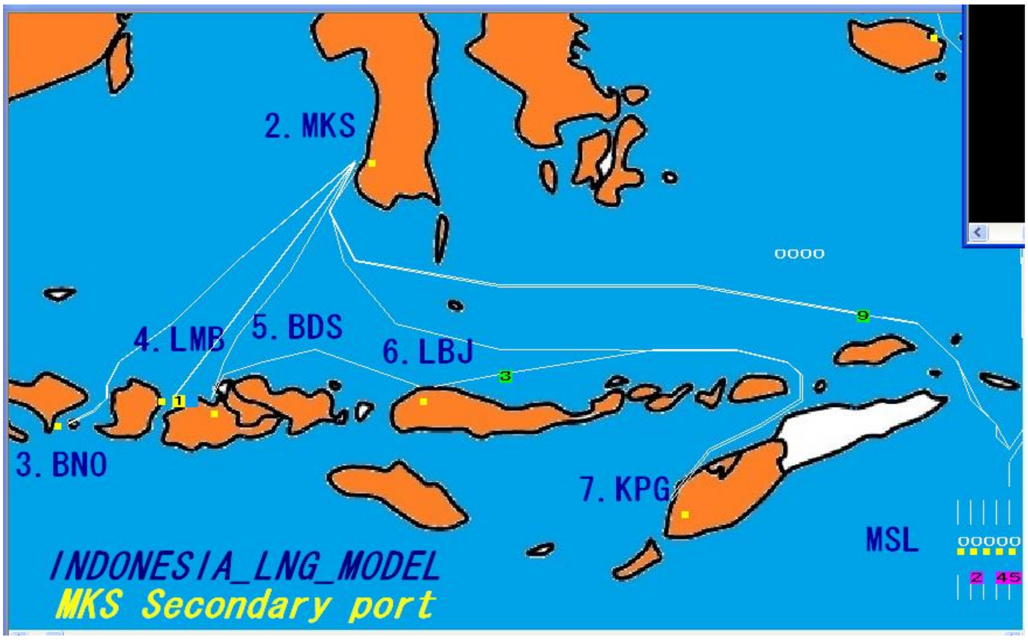
						Tanker OPEX	
Home Port Terminal	**Destination**	**Tanker Size**	**Cruise Distance (round-trip miles)**	**Unloading Weight (kiloton)**	**Tonne Miles (1,000 tonne miles)**	**Unit Price (US$/1,000 tonne miles)**	**Ship Operating Costs (million US$/year)**
TGH	10.WED	S	48,227	447	197,180	5.9	1.16
	12.SRU 13.BIK 14.MNK 15.SON 17.JAP	M	65,368	482	262,921	5.9	1.55
	16.MRK	SS	36,983	50	38,327	5.9	0.23
Total			**150,578**	**980**	**498,428**		**2.94**

Source: Author.

3. Application of a Secondary Terminal

This section analyses the technical and economic impacts brought about by the application of a secondary terminal system. We assume the secondary port at Makassar in the Masela group covers the following five LNG receiving ports: Bali (Benoa), Lombok (Lembar), Sumbawa (Badas), Flores (Labuan Bajo), and Kupang. Figure 7.40 shows the simulation execution screen on a PC screen.

Figure 7.40: Simulation of LNG Delivery on PC Screen (Secondary Terminal)



Source: Author.

a. Necessary additional data

1) Distance table

For this analysis, data on two distances are needed: (i) between Masela and Makassar and (ii) between Makassar and the five LNG receiving sites. The distance from Masela and Makassar for each port is less than one half except for Kupang. This surely reduces the operation cost of the LNG tankers. At Makassar, an LL-sized secondary LNG storage is assumed; it covers the LNG consumption at Makassar and the five receiving sites. Makassar never receives LNG from Donggi Senoro.

Table 7.40: Distance from Masera to Makassar and Makassar to the Five Ports

	2	3	4	5	6	7
Base	2.MKS	3.BNO	4.LMB	5.BDS	6.LBJ	7.KPG
MSL	695	873	868	767	621	420
2. MKS	—	324	311	298	207	441

Source: Author.

2) Capacity of a new secondary storage at Makassar

The secondary terminal covers five LNG receiving terminals, which are Bali to Kupang and Makassar. LNG demand and annual LNG delivery amount is 1,624 kilotons. This simulation assumes a 180,000 CBM capacity.

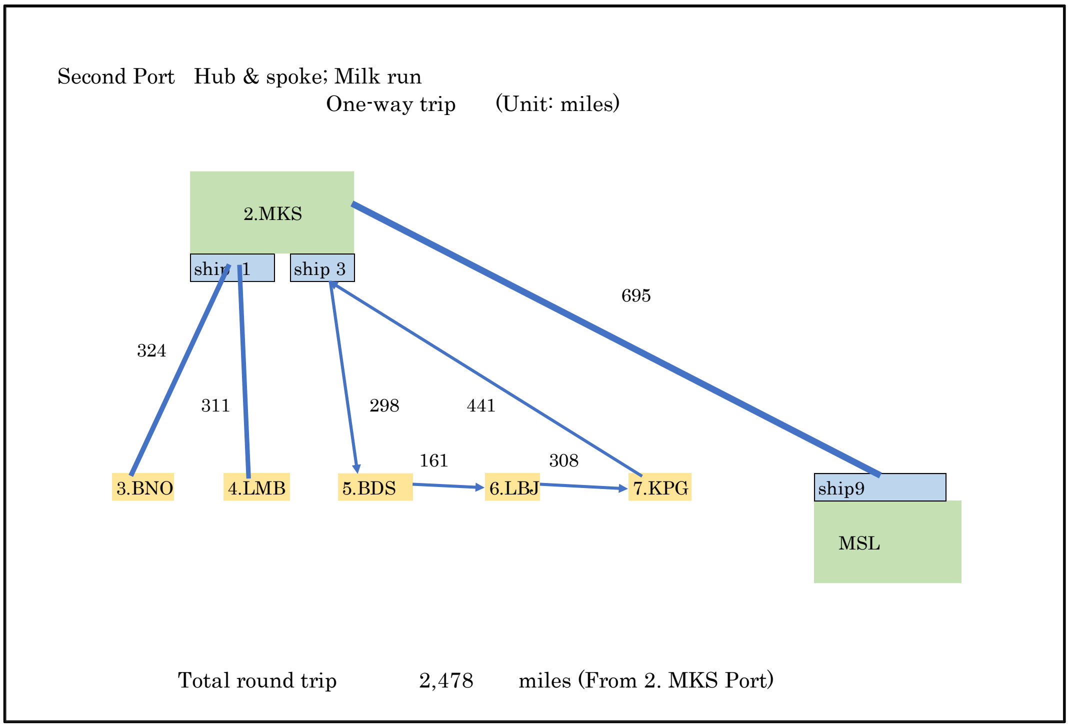
3) Additional LNG tanker between Masela - Makassar

We assume a 70,000 CBM capacity of the secondary super L-type LNG tanker.

b. Operation of the LNG tankers

Figure 7.41 shows the operation of LNG tankers. One super large LNG tanker transports LNG from Masala to the secondary terminal at Makassar. One L-type LNG tanker is assigned to deliver LNG from the secondary terminal at Makassar to Bali and Lombok applying the hub & spoke method, respectively. On the other hand, one M-type LNG tanker covers three ports – Badas, Labuan Bajo, and Kupang – applying the milk-run method. The milk-run method contributes to the reduction of the cruising distance of around 700 miles compared to the hub & spoke method (Table 7.41).

Figure 7.41: LNG Delivery, Secondary Port (Milk-Run Method Partially Applied)



Source: Author.

Table 7.41: Comparison of Distance of Hub & Spoke and Milk-Run Methods

Secondary Port	City Name	H&S	Milk-Run
		round-trip	
2. MKS	3.BNO	648	648
	4.LMB	622	622
	5.BDS	596	
	6.LBJ	414	1,208
	7.KPG	882	
	Total	**3,162**	**2,478**

H&S = hub & spoke.
Source: Author.

c. **Simulation results**

1) **Operational status of the storages**

- The initial volume of each LNG receiving site is assumed to be two thirds of its storage capacity. But the initial volume of the secondary terminal is assumed to be three fourths of its capacity due to the long-distance cruise of the LNG tanker.
- The storage capacity of each port is appropriate because the ratio defined as maximum level divided by storage capacity at the ports is high.
- Figure 7.42 shows each LNG storage, including the secondary LNG storage. No shortage has happened and remarkable spare capacities of Bali, Lombok, and the secondary terminal are recognised.

Table 7.42: Operational Status of LNG Onshore Storage (Secondary Terminal)

Operational Status of Storage	3.BNO	4.LMB	5.BDS	6.LBJ	7.KPG	2.MKS
Storage size	L	L	M	S	S	LL
Storage capacity (CBM)	50,000	50,000	30,000	20,000	20,000	150,000
Storage capacity (kiloton)	23.0	23.0	13.8	9.2	9.2	69.0
①Initial value of storage (kilotons)	15.3	15.3	9.2	6.1	6.1	51.8
②Unloading weight (kiloton/year)	518.7	442.8	260.9	107.3	97.2	1642.2
Tanker unloading volumes (kiloton/time)	12.65	12.65	7.05	2.90	2.70	32.20
Level of calling a tanker (kiloton)	11.5	11.5	6.9	4.6	4.6	46.0
Number of unloading (times)	41	35	37	37	36	51
Maximum level of storage (kiloton)	19.84	20.36	11.81	7.58	7.21	68.1
Minimum level of storage (kiloton)	4.48	4.21	4.79	4.1	3.97	9.51
Average level of storage (kiloton)	13.1	13.3	8.3	5.8	5.6	42.9
Maximum level / Storage capacity	0.86	0.89	0.86	0.82	0.78	0.99
③Stock at end of period (kiloton)	15.68	5.48	10.9	7.58	4.78	22.65
④Total supply (kiloton) ①＋②－③	518.3	452.6	259.2	105.9	98.6	1,671.4
⑤Annual consumption (kiloton)	518.9	454.4	257.9	104.4	98.8	1,664.4
⑥Comparison ④/⑤	1.00	1.00	1.00	1.01	1.00	1.00

Source: Author.

2) **LNG tanker operational status**

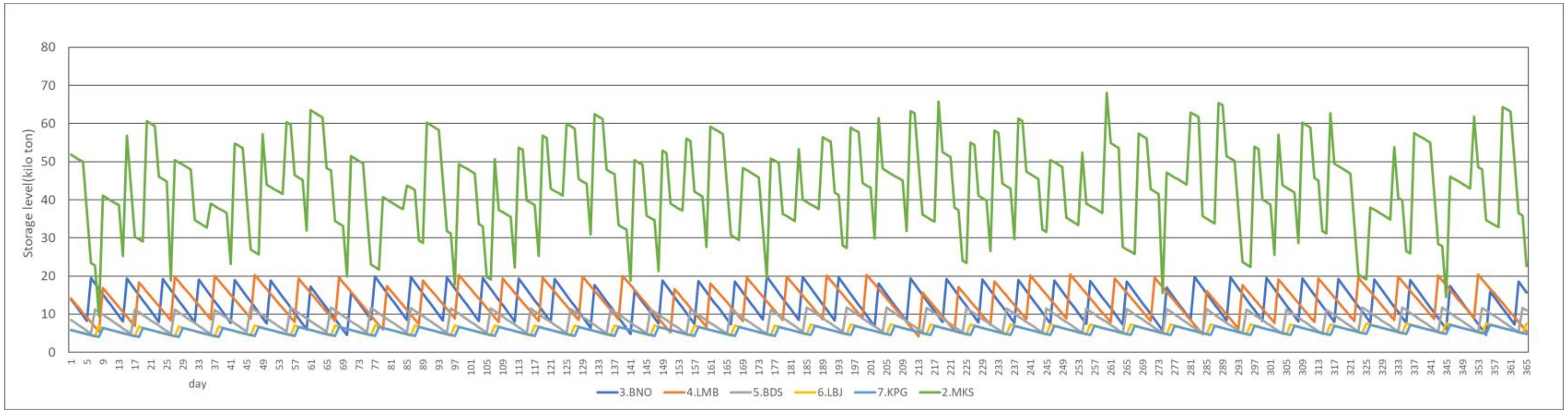
Table 7.43 shows that the operation rates of the two LNG tankers are not significant: 64% for Bali, Lombok and 59% for Badas, Labuan Bajo, and Kupang. In addition, Figure 7.42 indicates no LNG shortage. This is a statistical value regarding the operation of LNG tankers for each route. The waiting time, loading time, transportation time, unloading time, operating time, total time, operating rate, number of times of loading, number of times of unloading are shown.

Table 7.43: Results of Tanker Operations (Secondary Terminal)

Home Port Terminal	Destination	Tanker Number	Waiting Time for Shipment (hour)	Loading Time (hour)	Transport Time (hour)	Unloading Time (hour)	Operating Time (hour)	Total Time (hour)	Rate of Operation	Number of Loading (times)	Number of Unloading (times)
2.MKS	3.BNO 4.LMB	1	3,162	912	3,740	912	5,564	8,726	64%	76	76
	5.BDS 6.LBJ 7.KPG	3	3,512	432	3,328	1,296	5,056	8,568	59%	36	108
Total			**6,673**	**1,344**	**7,068**	**2,208**	**10,620**	**17,294**	**61%**	**112**	**184**
Secondary port transportation											
MSL	2.MKS	9	2,099	612	5,289	612	6,513	8,612	76%	51	51

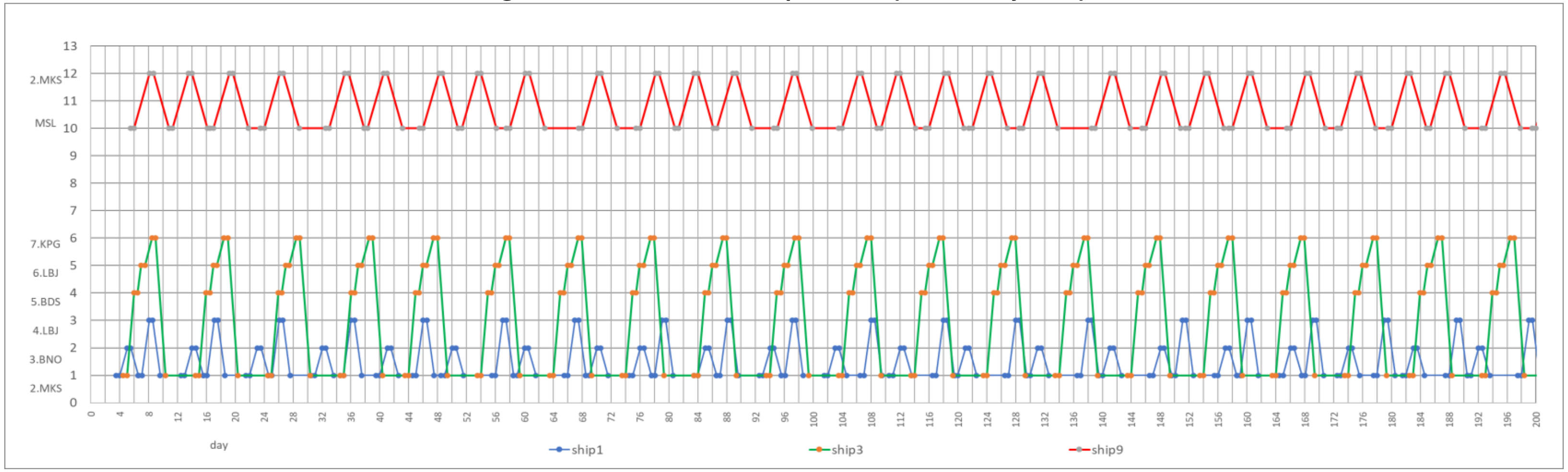
Source: Author.

Figure 7.42: LNG Storage Level of Each Site (Secondary Port)



Source: Author's analysis.

Figure 7.43: LNG Tanker Operation (Secondary Port)



Source: Author's analysis.

3) Key findings

The total operation cost is US$9.70 million, which is much higher than directly delivering LNG from Masela (US$6.94 million). The operation cost from Masela to Makassar of US$6.73 million is high due to the long cruising distance and big volume of loaded LNG. LNG demand in Makassar is 225 kilotons whilst that of five other cities is 1,417 kilotons, so that the share of Makassar is only 14%. Most LNG transported from Masela to Makassar is delivered to the five LNG receiving sites.

Table 7.44: Cruising Distance and OPEX of Tanker (Secondary Terminal)

						Tanker OPEX	
Home Port Terminal	**Destination**	**Tanker Size**	**Cruise Distance (round-trip miles)**	**Unloading Weight (kiloton)**	**Tonne Miles (1,000 tonne miles)**	**Unit Price (US$/1,000 tonne miles)**	**Ship Operating Costs (million US$/year)**
2.MKS	3.BNO 4.LMB	1	—	961	305,738	5.9	1.80
	5.BDS 6.LBJ 7.KPG	3	—	455	198,104	5.9	1.17
Total				**1,417**	**503,842**		**2.97**
Secondary port transportation							
MSL	2.MKS	9	35,445	1,642	1,141,329	5.9	6.73

Source: Author.

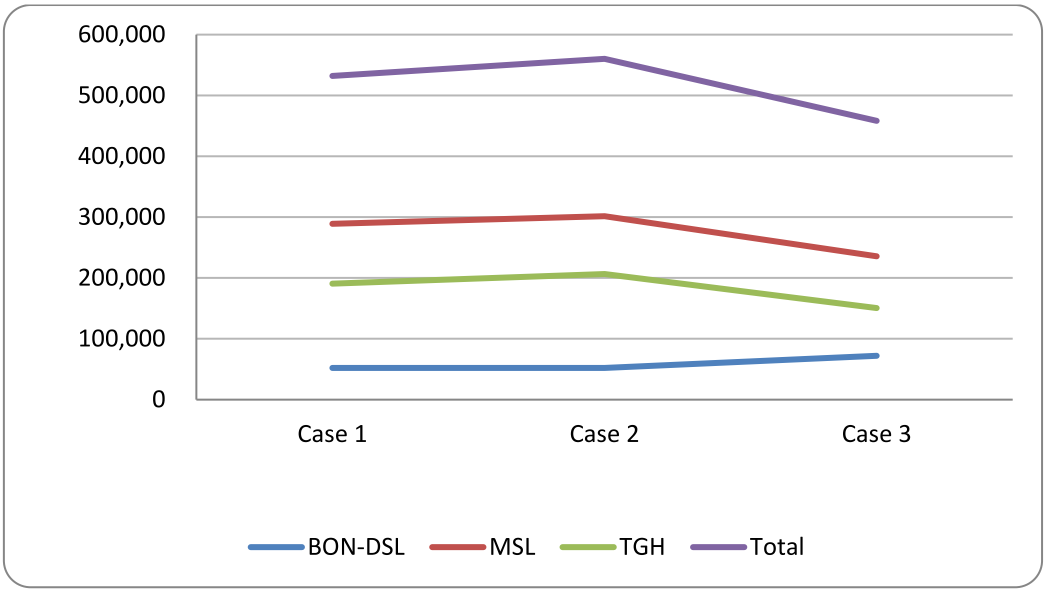
4. Dynamic Simulation Results vs Linear Programming Results

This section compares the DS results with LP results. The unit of LP results is shown by volume x distance, so that the simulation results are also converted to volume x distance. Before that, the cruising distances of cases 1–3 are compared.

4.1. Cruising distance of cases 1–3 (DS)

The cruising distance between cases 1 and 2 are the same or almost the same because the hub & spoke method is applied. But case 3 applies the milk-run method, so that the cruising distance of case 3 is generally shorter than cases 1 and 2, except for the Bontang–Donggi group. For the Masela and Tangguh groups, the milk-run method contributes to the reduction of the number of cruises returning to the LNG production port compared to hub & spoke method. But in the case of the Bontang–Donggi group, the milk-run method reduces returned cruises to Donggi and Bontang, whilst new cruises of Manado–Makassar, Makassar–Bontang, and Palu–Donggi are added. As a result, the cruising distance of case 3 becomes longer than cases 1 and 2 in the Bontang–Donggi group.

Figure 7.44: Cruise Distance, by Case and Group (Round-trip Miles)

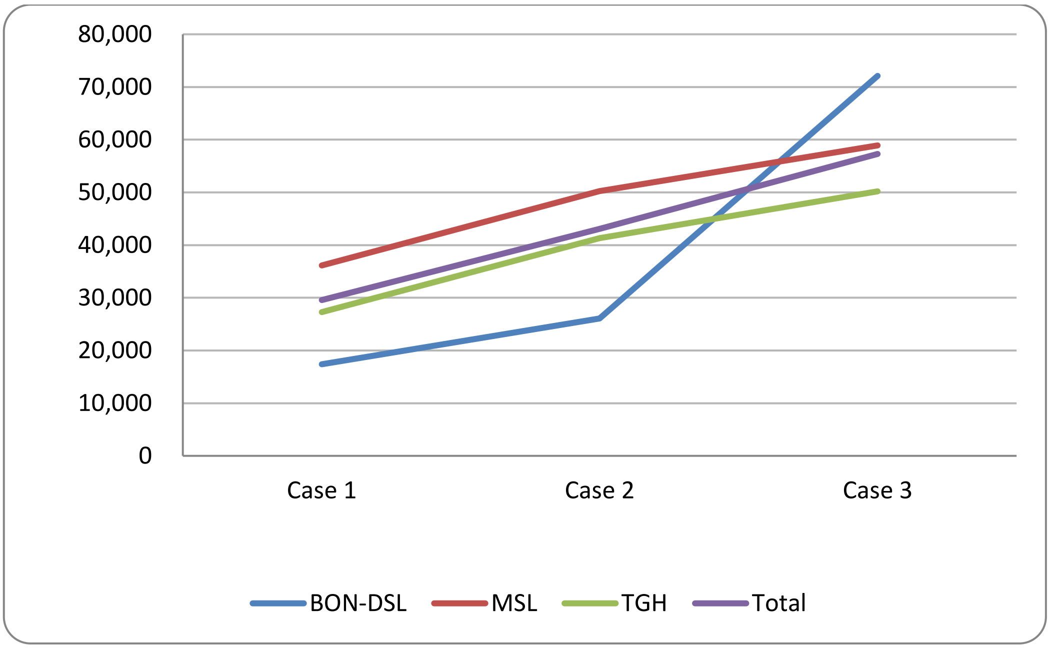


Source: Author.

4.2. Cruising distance per LNG tanker of the dynamic simulation

Depending on the number of LNG tankers and their operation rates, cruising distance per LNG tanker of case 3 is longest, followed by cases 2 and 1. The Bontang–Donggi group is a small area but, in case 3, only one tanker goes around two LNG production sites and three LNG demand sites. Therefore, case 3 of the Bontang–Donggi group shows a longer cruising distance than Masela and Tangguh.

Figure 7.45: Cruising Distance per Tanker



Source: Author.

4.3. LP vs DS results based on tonne miles

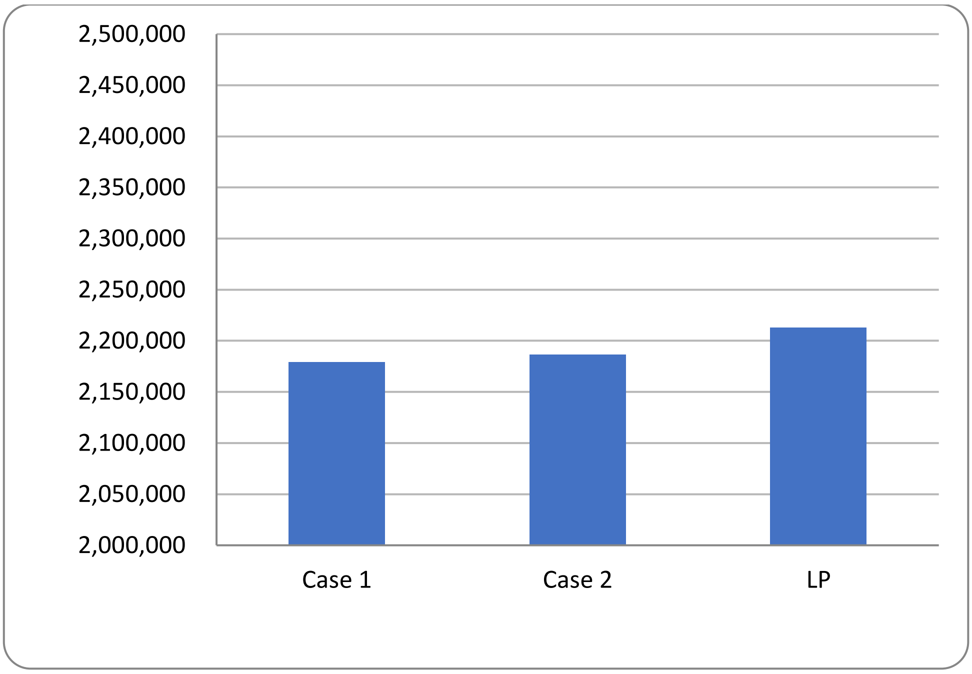
Theoretically, the tonne miles of cases 1 and 2 should be the same as the LP model. But in the DS study, each storage has its initial stock (basically one-half or two-thirds capacity of storage) and this stock is not reflected in tonne miles. In Table 7.45, a ratio defined as DP divided by LP in terms of total tonne miles are close at 0.98. Needless to say, case 3 of the dynamic simulation is much lower than the LP in terms of tonne miles.

Table 7.45: Comparison of Distance of Cases 1–2 and Linear Programming (tonne miles)

Dynamic Simulation		
	Case 1	**Case 2**
BON–DSL	215,851	215,851
MSL	1,475,988	1,486,183
TGH	487,455	484,626
Total	2,179,295	2,186,660
DS/LP	0.985	0.988
LP		
2,213,109		

DS = dynamic simulation, LP = linear programming.
Source: Author.

Figure 7.46: Comparison of Tonne Miles of Cases 1–2 of Dynamic Simulation and Linear Programming (tonne miles)



Source: Author.

5. Economic Evaluation based on the Simulation Results

5.1. Estimation of CAPEX and OPEX

a. Bontang–Donggi Senoro group

The estimation results of CAPEX and OPEX of LNG onshore storages and LNG tankers are shown in Table 7.46 based on the cost assumptions specified in Section 7.2 and the simulation results of the Bontang–Donggi group. The CAPEX is converted into annual cost such as depreciation using the construction costs of LNG onshore storages and LNG tankers depending on their sizes, SS–L, and on the duration, which is 20 years. The annual total cost consisting of CAPEX and OPEX is shown in Table 7.47. Due to one LNG tanker's operation, the CAPEX and OPEX of case 3 are much lower than cases 1 and 2. Thus, the milk-run method supported by one LNG tanker is recommended to deliver LNG in the Bontang–Donggi group.

Table 7.46: CAPEX and OPEX of Cases 1–3, BON–DSL

Onshore Storage		Abbreviation	1.PAL	0.MND	2.MKS	Total	Unit
		Size	M	M	M		
		①CAPEX	139.5	139.5	139.5	417.0	Million US$
		a. OPEX	3.5	3.5	3.5	10.5	Million US$/year
Case 1 Hub & Spoke	Tanker	Size	S	S	S	3	Tankers
		②CAPEX	48.66	48.66	48.66	145.98	Million US$
		b. OPEX (Management costs)	4.20	4.20	4.20	12.60	Million US$/year
		c. OPEX (Operating costs)	0.21	0.29	0.77	1.27	Million US$/year
	Total	OPEX (b+c)	**4.41**	**4.49**	**4.97**	**13.88**	Million US$/year
Case 2 Multiple Locations	Tanker	Size	S	S		2	Tankers
		②CAPEX	48.66	48.66		97.32	Million US$
		b. OPEX (Management costs)	4.20	4.20		8.40	Million US$/year
		c. OPEX (Operating costs)	0.21	1.06		1.27	Million US$/year
	Total	OPEX (b+c)	**4.41**	**5.26**		**9.67**	Million US$/year
Case 3 Milk-Run	Tanker	Size	M			1	Tankers
		②CAPEX	52.50			52.50	Million US$
		b. OPEX (Management costs)	4.80			4.80	Million US$/year
		c. OPEX (Operating costs)	1.80			1.80	Million US$/year
	Total	OPEX (b+c)	**6.60**			**6.60**	Million US$/year

Source: Author.

Table 7.47: CAPEX and OPEX of LNG Storages and Tankers (Cases 1–3)

BON-DSL Million US$/year

BON-DSL	Case 1	Case 2	Case 3
Storage CAPEX	20.9	20.9	20.9
Storage OPEX	10.5	10.5	10.5
Tanker CAPEX	7.3	4.9	2.6
Tanker OPEX	13.9	9.7	6.6
Total	**52.5**	**45.9**	**40.5**

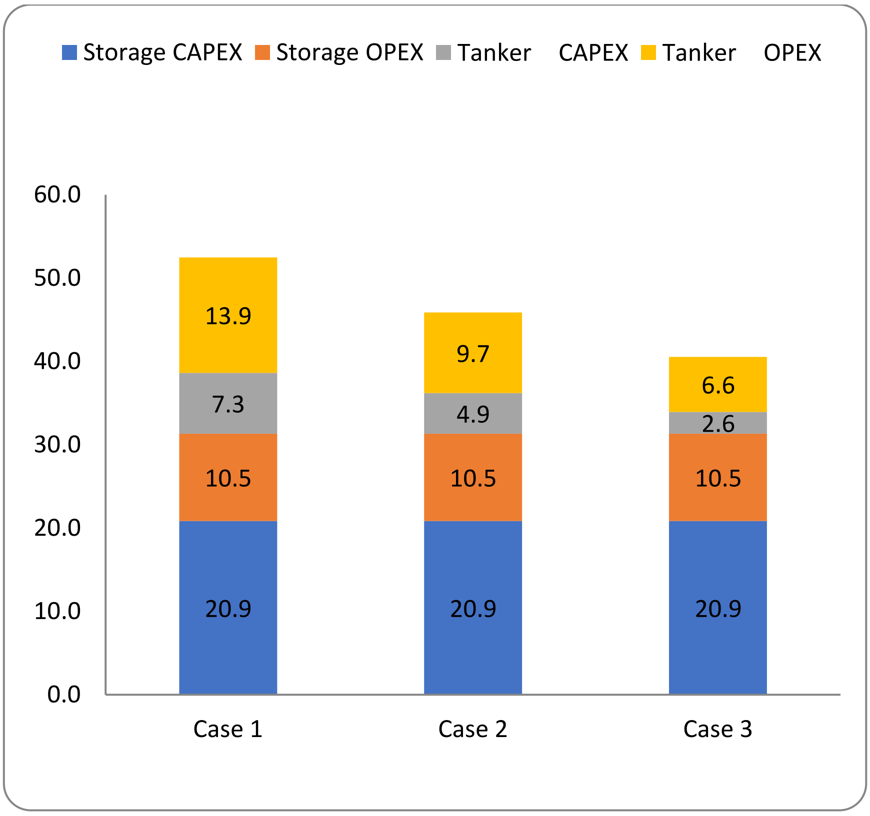
〇〇

Total CAPEX+OPEX (Case 3) Million US$/year

	BON–DSL	MSL	TGH	Total
Storage CAPEX	20.9	48.8	36.9	106.5
Storage OPEX	10.5	24.4	18.4	53.3
Tanker CAPEX	2.6	10.6	6.9	20.2
Tanker OPEX	6.6	28.8	14.3	49.7
Total	**40.5**	**112.6**	**76.5**	**229.7**

Source: Author.

Figure 7.47: CAPEX and OPEX in LNG Onshore Storages and Tankers, BON–DSL



Source: Author.

b. Masela group

Table 7.48 shows the estimation results of CAPEX and OPEX of LNG onshore storages and tankers based on the cost assumptions specified in Section 7.2 and the simulation results of the Masela group. Similar to the Bontang–Donggi group, CAPEX is converted into annual cost, such as depreciation, using the construction costs of LNG onshore storages and tankers depending on their sizes, SS to L, and on the duration which is 20 years. The annual total cost of each case consisting of CAPEX and OPEX is shown in Table 7.49. Due to the operation of four LNG tankers, the CAPEX and OPEX of case 3 are much lower than cases 1 and 2. Thus, the milk-run method supported by four LNG tankers is recommended to deliver LNG in the Masela group. Since eight LNG onshore storages and more than four LNG tankers are needed, the total costs of Masela are much higher than the Bontang–Donggi group.

Table 7.48: CAPEX and OPEX, MSL (Cases 1–3)

Onshore Storage		Abbreviation	3.BNO	4.LMB	5.BDS	6.LBJ	7.KPG	8.AMB	9.NLA	11.TTE	Total	Unit
		Size	L	L	M	S	S	S	S	L		
		①CAPEX	177.2	177.2	139.5	120.6	120.6	120.6	120.6	177.2	975.9	Million US$
		a. OPEX	4.43	4.43	3.49	3.02	3.02	3.02	3.02	4.43	24.41	Million US$/year
Case 1 Hub & Spoke	Tanker	Size	L	M	S	S	S	SS	SS	M	7	Tankers
		②CAPEX	54.8	52.5	48.7	48.7	48.7	36.9	36.9	52.5	324.9	Million US$
		b. OPEX Management costs	5.1	4.8	4.2	4.2	4.2	2.4	2.4	4.8	32.0	Million US$/year
		c. OPEX (operating costs)	2.65	2.27	1.16	0.39	0.25	0.19	0.17	1.63	8.71	Million US$/year
	Total	OPEX (b+c)	7.8	7.0	5.4	4.6	4.5	2.6	2.6	6.4	40.8	Million US$/year
Case 2 Hub & Spoke (Shared use of tankers)	**Tanker**	Size	L	M	S		S	SS		M	5	Tankers
		②CAPEX	54.8	52.5	48.7		48.7	36.9		52.5	262.9	Million US$
		b. OPEX Management costs	5.12	4.78	4.20		4.20	2.38		4.78	25.46	Million US$/year
		c. OPEX (operating costs)	2.65	2.27	1.16		0.70	0.36		1.63	8.77	Million US$/year
	Total	OPEX (b+c)	7.77	7.05	5.36		4.90	2.74		6.41	34.23	Million US$/year
Case 3 Milk-run	**Tanker**	Size	L	M	M			M			4	Tankers
		②CAPEX	54.8	52.5	52.5			52.5			212.4	Million US$
		b. OPEX Management costs	5.12	4.78	4.78			4.78			19.46	Million US$/year
		c. OPEX (operating costs)	2.65	2.27	2.02			2.39			9.33	Million US$/year
	Total	**OPEX (b+c)**	**7.77**	**7.05**	**6.80**			**7.17**			**28.79**	**Million US$/year**

Source: Author.

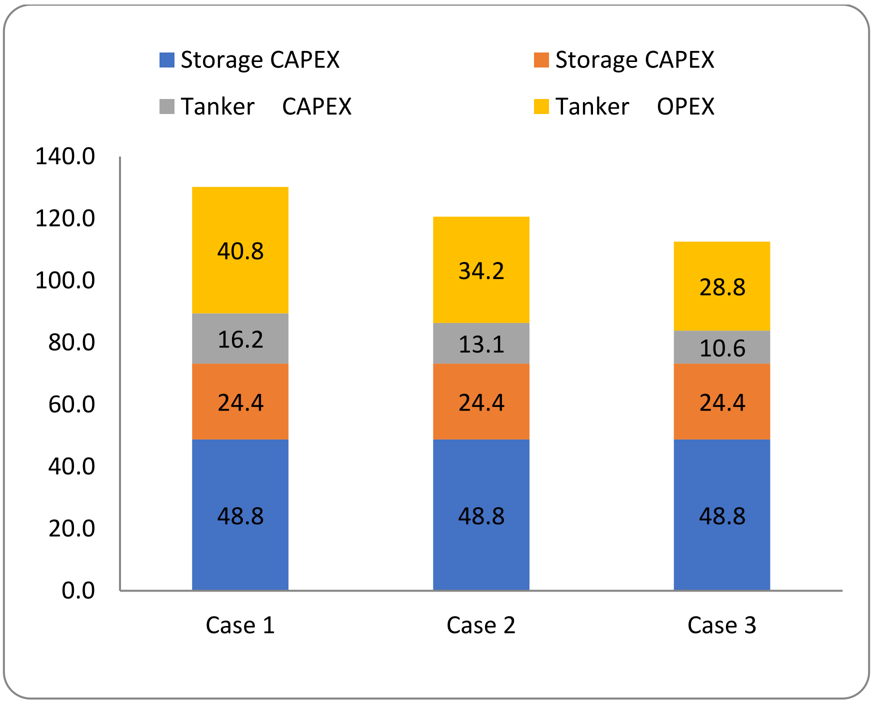
Table 7.49: Comparison of CAPEX and OPEX, MSL (Cases 1–3)

MSL Million US$/year

MSL	Case 1	Case 2	Case 3
Storage CAPEX	48.8	48.8	48.8
Storage CAPEX	24.4	24.4	24.4
Tanker CAPEX	16.2	13.1	10.6
Tanker OPEX	40.8	34.2	28.8
Total	**130.2**	**120.6**	**112.6**

Source: Author.

Figure 7.48: Comparison of CAPEX and OPEX, MSL (Cases 1–3)



Source: Author.

c. Tangguh group

The estimates of CAPEX and OPEX of LNG onshore storages and tankers are shown in Table 7.50 based on the cost assumptions specified in Section 7.2 and the simulation results of the Tangguh group. As in the Masela group, CAPEX is converted into annual cost, such as depreciation, using the construction costs of LNG onshore storages and tankers depending on their sizes, SS to L, and on the duration, which is 20 years. The annual total cost of each case consisting of CAPEX and OPEX is shown in Table 7.51. Due to the operation of three LNG tankers, the CAPEX and OPEX of case 3 are much lower than cases 1 and 2. Thus, the milk-run method supported by three tankers is recommended for LNG delivery in the Tangguh group. Even though seven LNG onshore storages and three LNG tankers are needed, the total costs of Tangguh are much lower than the Masela group. The reasons are shorter cruising distances and smaller LNG delivery amounts than Masela.

Table 7.50: CAPEX and OPEX, TGH, by Case

Onshore Storage		Abbreviation	10.WED	12.SRU	13.BIK	14.MNK	15.SON	17.JAP	16.MRK	Total	Unit
		Size	L	SS	SS	S	M	SS	SS		
		①CAPEX	177.2	75.0	75.0	120.6	139.5	75.0	75.0	737.3	Million US$
		a. OPEX	4.4	1.9	1.9	3.0	3.5	1.9	1.9	18.4	Million US$/year
Case 1	Tanker	Size	S	SS	SS	S	S	SS	SS	7	Tankers
Hub & Spoke		②CAPEX	48.7	36.9	36.9	48.7	48.7	36.9	36.9	297.6	Million US$
		b. OPEX Management costs	4.2	2.4	2.4	4.2	4.2	2.4	2.4	22.1	Million US$/year
		c. OPEX （operating costs ）	1.16	0.09	0.15	0.55	0.56	0.13	0.23	2.88	Million US$/year
	Total	OPEX (b+c)	5.4	2.5	2.5	4.7	4.8	2.5	2.6	25.0	Million US$/year
Case 2	Tanker	Size	S	SS		S		SS	SS	5	Tankers
Hub & Spoke (Shared use of tankers)		②CAPEX	48.7	36.9		52.5		36.9	36.9	212.0	Million US$
		b. OPEX Management costs	4.2	2.4		4.2		2.4	2.4	15.6	Million US$/year
		c. OPEX (operating costs)	1.16	0.24		1.10		0.13	0.23	2.86	Million US$/year
	Total	OPEX (b+c)	5.4	2.6		5.3		2.5	2.6	18.4	Million US$/year
Case 3	Tanker	Size	S	M					SS	3	Tankers
Milk-run		②CAPEX	48.7	52.5					36.9	138.1	Million US$
		b. OPEX Management costs	4.2	4.8					2.4	11.4	Million US$/year
		c. OPEX (operating costs)	1.16	1.55					0.23	2.94	Million US$/year
	Total	**OPEX (b+c)**	**5.4**	**6.4**					**2.6**	**14.3**	**Million US$/year**

Source: Author.

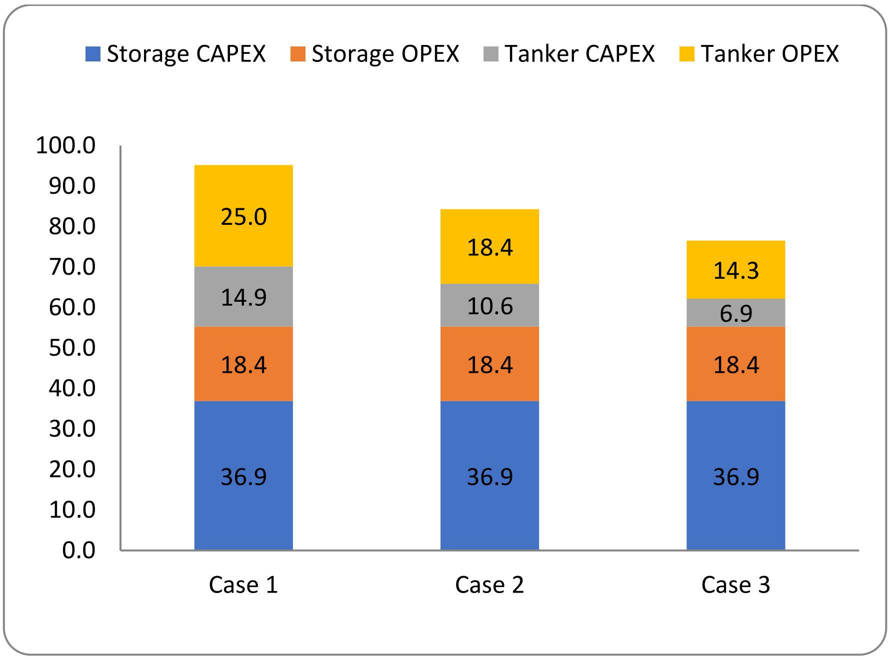
Table 7.51: Comparison of CAPEX and OPEX, TGH (Cases 1–3)

TGH Million US$/year

	Case 1	Case 2	Case 3
Storage CAPEX	36.9	36.9	36.9
Storage OPEX	18.4	18.4	18.4
Tanker CAPEX	14.9	10.6	6.9
Tanker OPEX	25.0	18.4	14.3
Total	**95.2**	**84.3**	**76.5**

Source: Author.

Figure 7.49: Comparison of CAPEX and OPEX, TGH (Cases 1–3)



Source: Author.

d. Application of a secondary terminal between Masela and five destinations

1) CAPEX and OPEX estimates with a secondary terminal

One more simulation applies a secondary terminal at Makassar and five LNG receiving islands, which are Bali, Lombok, Sumbawa, Flores, and Kupang. Estimates of CAPEX and OPEX of LNG onshore storages and tankers are shown in Table 7.52 based on the cost assumptions specified in Section 7.2 and the simulation results of the secondary terminal scenario.

As the Tangguh group, CAPEX is converted into annual cost, such as depreciation, using the construction costs of LNG onshore storages and tankers depending on their sizes, SS to L, and on the duration, which is 20 years. The annual total cost of this scenario consisting of CAPEX and OPEX is shown in Table 7.54. Due to the large LNG onshore storage and tanker operation, the total cost of this scenario is much higher than case 3 of the Masela group.

Table 7.52: CAPEX and OPEX for Application of Secondary LNG Terminal

Secondary Port

Onshore Storage		**Abbreviation**	**3.BNO**	**4.LMB**	**5.BDS**	**6.LBJ**	**7.KPG**	**Total**	**Unit**
		Size	**L**	**L**	**M**	**S**	**S**		
		①CAPEX	177.2	177.2	139.5	120.6	120.6	735.2	Million US$
		a.OPEX	4.43	4.43	3.49	3.02	3.02	18.38	Million US$/year
Multiple locations Milk-run	Tanker	Size	M		M			2	Tankers
		②CAPEX	52.5		52.5			105.0	Million US$
		b.OPEX Management costs	4.78		4.80			9.58	Million US$/year
		c.OPEX （operating costs）	1.80		1.17			2.97	Million US$/year
	Total	**OPEX （b+c）**	**6.58**		**5.97**			**12.55**	**Million US$/year**

Secondary port	
2.MKS	Unit
LL	
366.0	Million US$
9.150	Million US$/year
LL 1	Tanker
81.10	Million US$
9.30	Million US$/year
6.73	Million US$/year
16.03	Million US$/year

Source: Author.

Table 7.53: CAPEX and OPEX for Direct Delivery from MSL to the Five LNG Receiving Sites

3.BNO~7.KPG		Abbreviation	3.BNO	4.LMB	5.BDS	6.LBJ	7.KPG	Total	Unit
Onshore Storage		Size	L	L	M	S	S		
		①CAPEX	177.2	177.2	139.5	120.6	120.6	735.2	Million US$
		a. OPEX	4.43	4.43	3.49	3.02	3.02	18.4	Million US$/year
Case 1	Tanker	Size	L	M	S	S	S	5	Tankers
Hub & Spoke		②CAPEX	54.8	52.5	48.7	48.7	48.7	253.3	Million US$
		b. OPEX Management costs	5.1	4.8	4.2	4.2	4.2	22.5	Million US$/year
		c. OPEX (operating costs)	2.65	2.27	1.16	0.39	0.25	6.7	Million US$/year
	Total	OPEX (b+c)	7.8	7.0	5.4	4.6	4.5	29.2	Million US$/year
Case 2	Tanker	Size	L	M	S		S	4	Tankers
Hub & Spoke (Shared use of tankers)		②CAPEX	54.8	52.5	48.7		48.7	204.7	Million US$
		b. OPEX management costs	5.12	4.78	4.20		4.20	18.3	Million US$/year
		c. OPEX (operating costs)	2.65	2.27	1.16		0.70	6.8	Million US$/year
	Total	OPEX (b+c)	7.77	7.05	5.36		4.90	25.1	Million US$/year
Case 3	Tanker	Size	L	M	M			3	Tankers
Milk-run		②CAPEX	54.8	52.5	52.5			159.8	Million US$
		b. OPEX management costs	5.12	4.78	4.78			14.7	Million US$/year
		c. OPEX (operating costs)	2.65	2.27	2.02			6.9	Million US$/year
	Total	**OPEX (b+c)**	**7.77**	**7.05**	**6.80**			**21.6**	**Million US$/year**

Source: Author.

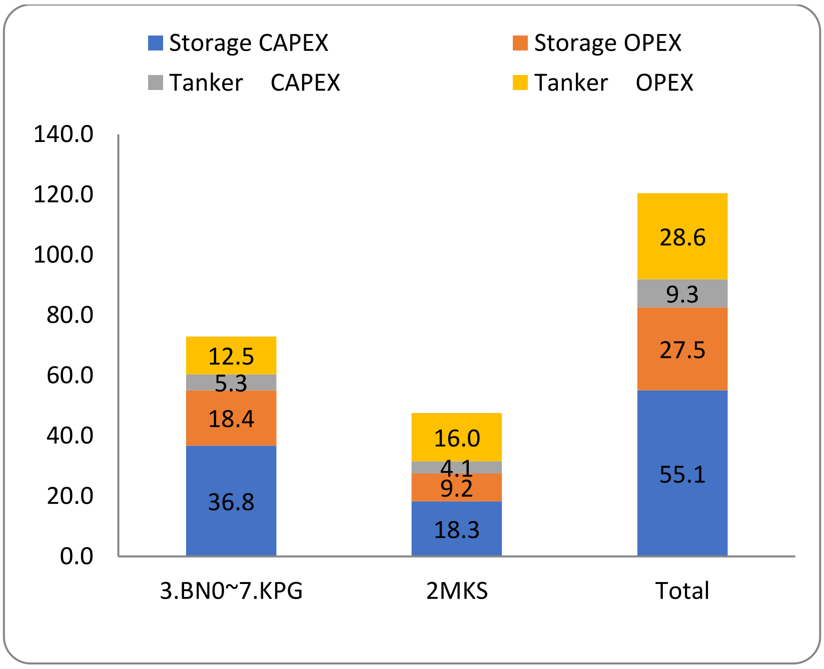
Table 7.54: Total CAPEX and OPEX for Application of Secondary LNG Terminal

Secondary port Million US$/year

	3.BN0~7.KPG	2MKS	Total
Storage CAPEX	36.8	18.3	55.1
Storage OPEX	18.4	9.2	27.5
Tanker CAPEX	5.3	4.1	9.3
Tanker OPEX	12.5	16.0	28.6
Total	**72.9**	**47.5**	**120.5**

Source: Author.

Figure 7.50: Total CAPEX and OPEX for Application of Secondary LNG Terminal



Source: Author.

e. Cost comparison between direct delivery of LNG and via a secondary terminal

Table 7.55 compares the cost between direct LNG delivery from Masela to the five LNG receiving sites and via the secondary terminal at Makassar. The left-hand table shows the CAPEX and OPEX of LNG storages and tankers under the secondary terminal scenario, which is the same as Table 7.54. On the other hand, the right-hand table shows the CAPEX and OPEX of LNG storages and tankers of direct LNG deliveries from Masela. ③ indicates the CAPEX and OPEX at Makassar, which is case 1 of Table 7.46. ④ means the CAPEX and OPEX of case 3 of Table 7.48. As a result, the total cost of applying the secondary terminal is US$18 million higher than the direct LNG delivery from Masela. The reason is a significant CAPEX of super L-sized LNG storage at Makassar and L-sized LNG tanker to cruise between Masela and Makassar.

Table 7.55: Cost Comparison between Direct Delivery of LNG and Via a Secondary Terminal

Million US$/year

Million US$/year

Secondary port (Delivery from secondary port)				Directly from base		Newly increasing investment ①＋②－③－④
	① 3.BN0~7.KPG	② 2.MKS	Total	③ 2.MKS	④ 3.BNO~7.KPG	
Storage CAPEX	36.8	18.3	55.1	7.0	36.8	11.3
Storage OPEX	18.4	9.2	27.5	3.5	18.4	5.7
Tanker CAPEX	5.3	4.1	9.3	2.4	8.0	-1.1
Tanker OPEX	12.5	16.0	28.6	5.0	21.6	2.0
Total	**72.9**	**47.5**	**120.5**	17.9	84.8	17.9
	Newly increasing costs			Cost of disappearing		

Source: Author.

f. Comparison of CAPEX in each group

1) CAPEX

Table 7.56 summarises CAPEX of LNG onshore storages and tankers of case 3 (lowest cost amongst cases 1–3) in each group. A US$2,533 million–worth of investment will be needed to facilitate the LNG delivery chain in Eastern Indonesia and more than 80% of the investment will go to the construction of LNG onshore storages.

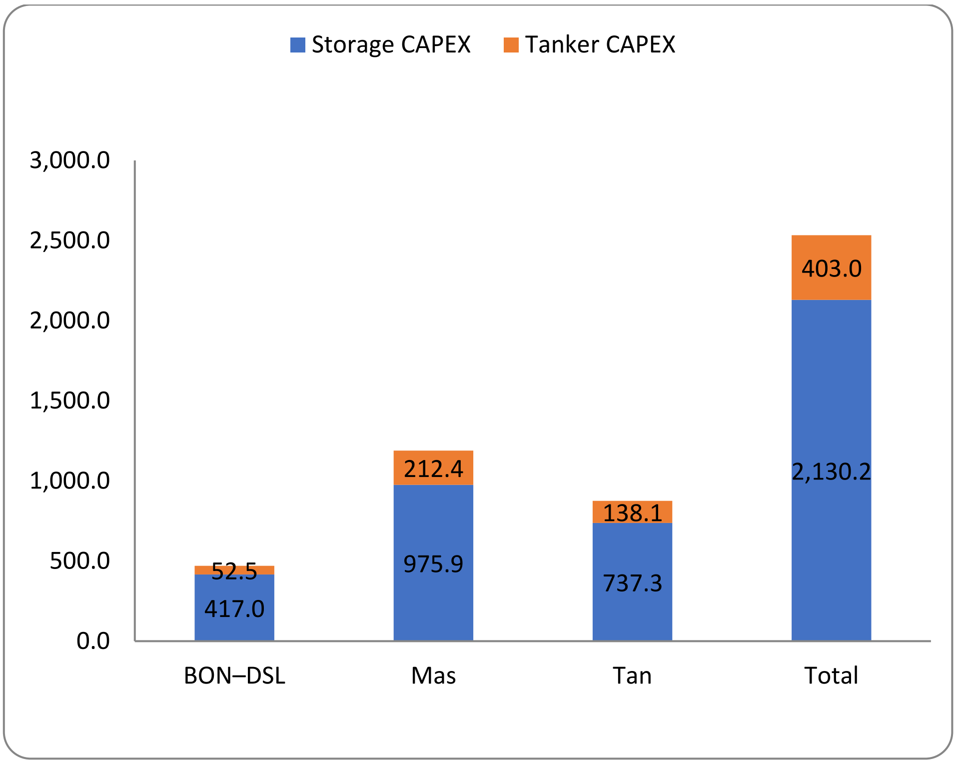
Table 7.56: CAPEX of Each Group (Case 3)

Total CAPEX (Case 3) Million US$

	BON–DSL	Mas	Tan	Total
Storage CAPEX	417.0	975.9	737.3	2,130.2
Tanker CAPEX	52.5	212.4	138.1	403.0
Total	**469.5**	**1,188.3**	**875.4**	**2,533.2**

Source: Author.

Figure 7.51: CAPEX of Each Group (Case 3)



Source: Author.

How about CAPEX of cases 1 and 2? Table 7.57 clearly shows that CAPEX of case 3 is the lowest amongst cases 1–3. This is because CAPEX of LNG storages amongst the cases shows no change. However, CAPEX of LNG tankers depends on the number of LNG tankers.

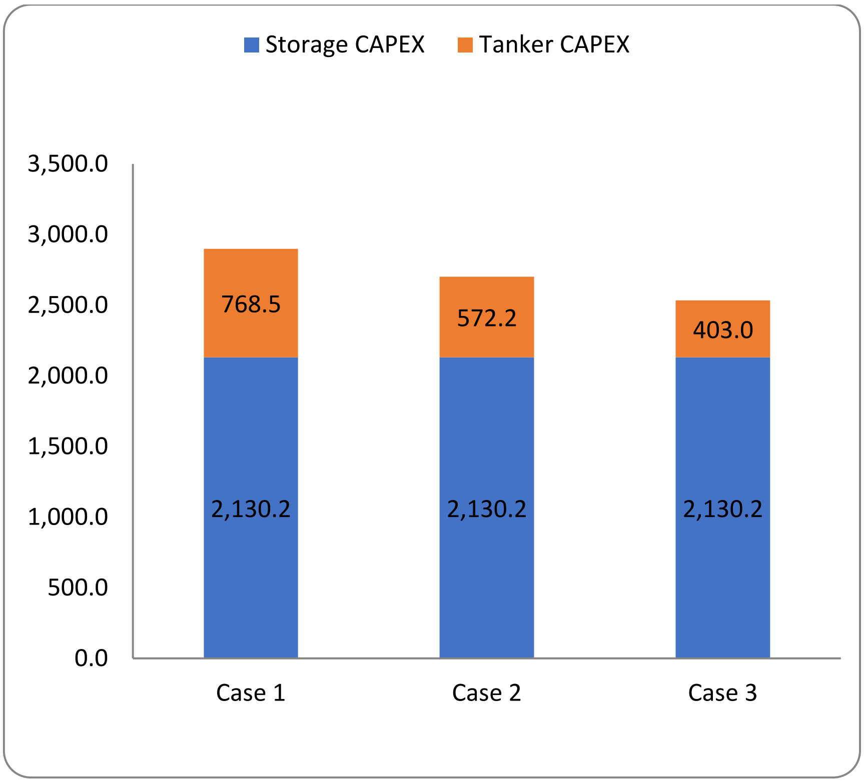
Table 7.57: Total CAPEX of Each Case

Total CAPEX — Million US$

	Case 1	Case 2	Case 3
Storage CAPEX	2,130.2	2,130.2	2,130.2
Tanker CAPEX	768.5	572.2	403.0
Total	**2,898.7**	**2,702.4**	**2,533.2**

Source: Author.

Figure 7.52 Total CAPEX, by Group (Cases 1–3)



Source: Author.

2) Annual expenses

Comparing the total cost of each group, Table 7.58 summarises the total costs (CAPEX + OPEX) of LNG onshore storages and tankers of case 3 (which has the lowest cost amongst cases 1–3 [refer to Table 7.59 and Figure 7.54]) per each group. CAPEX is converted into annual basis. A total of US$229.7 million per year of total operation costs will be needed to facilitate the LNG delivery chain in Eastern Indonesia. Using the LNG delivery amounts per each group – 669 kilotons for Bontang–Donggi; 2,047 kilotons for Masela; and 988 kilotons for Tangguh – the unit costs of LNG are calculated at US$60/tonne, US$55/tonne, and US$77/tonne, respectively. These costs do not include LNG production costs. Thus, the unit costs are high compared to Japan's LNG CIF (cost, insurance, and freight), which was US$50–US$70/tonne in the last 2 years.

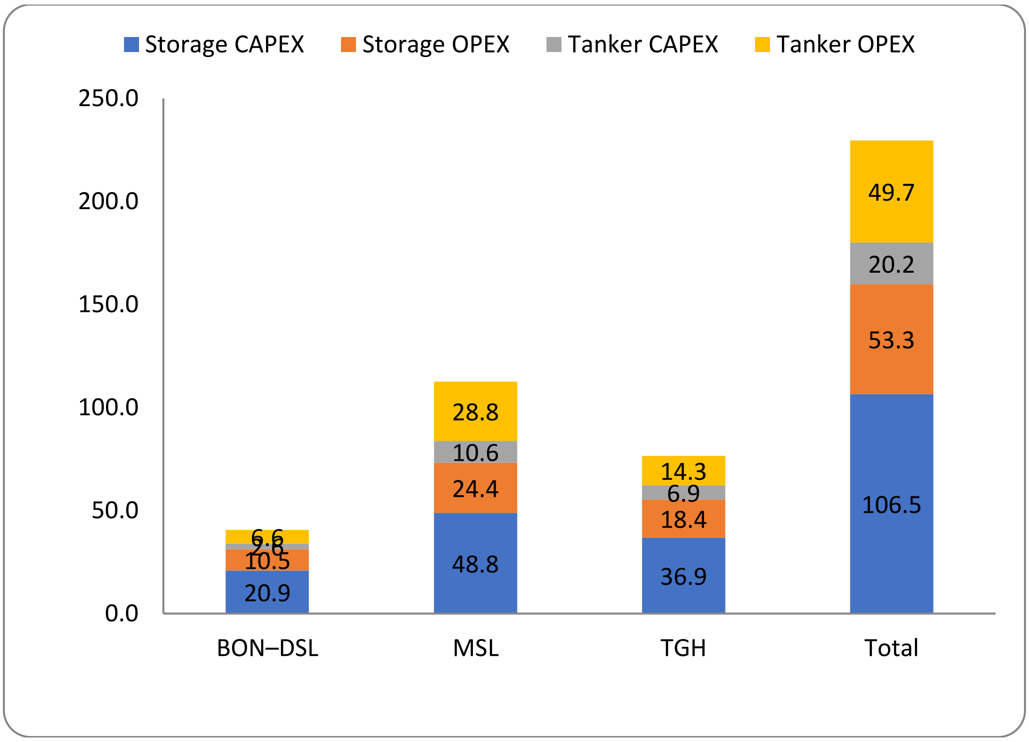
Table 7.58: CAPEX and OPEX of Each Group (Case 3)

Total CAPEX+OPEX (Case 3) Million US$/year

	BON–DSL	MSL	TGH	Total
Storage CAPEX	20.9	48.8	36.9	106.5
Storage OPEX	10.5	24.4	18.4	53.3
Tanker CAPEX	2.6	10.6	6.9	20.2
Tanker OPEX	6.6	28.8	14.3	49.7
Total	**40.5**	**112.6**	**76.5**	**229.7**

Source: Author.

Figure 7.53: CAPEX and OPEX, by Group (Case 3)



Source: Author.

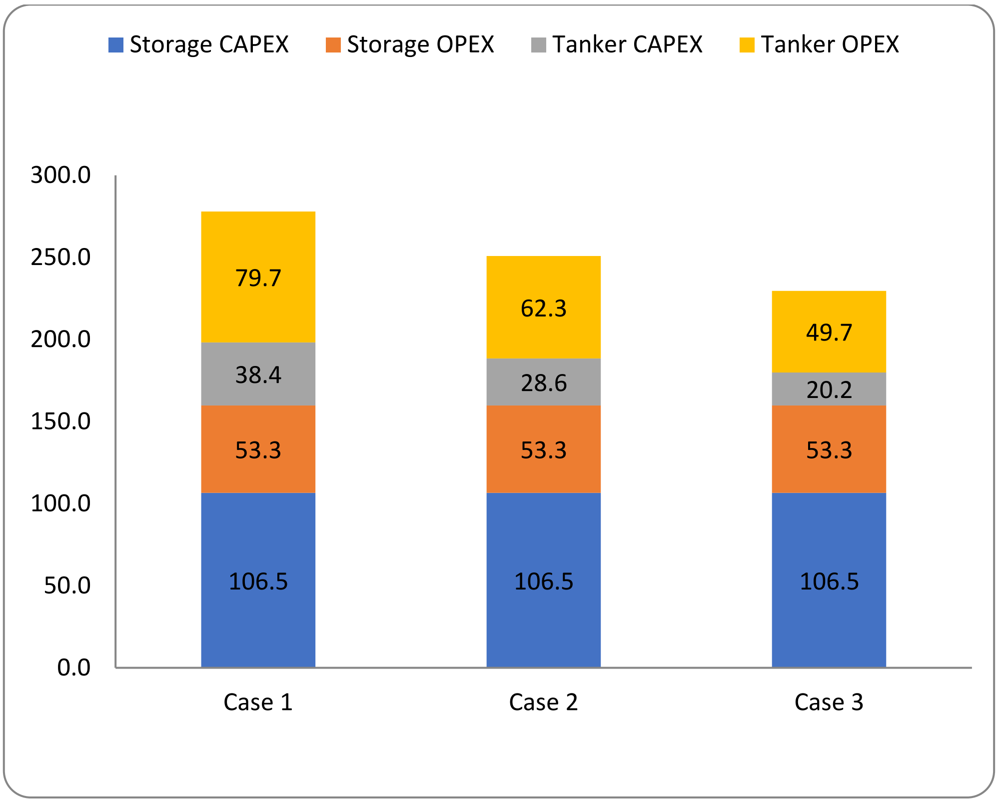
Table 7.59: CAPEX and OPEX (Cases 1–3)

Total CAPEX+OPEX Million US$/year

	Case 1	Case 2	Case 3
Storage CAPEX	106.5	106.5	106.5
Storage OPEX	53.3	53.3	53.3
Tanker CAPEX	38.4	28.6	20.2
Tanker OPEX	79.7	62.3	49.7
Total	**277.9**	**250.8**	**229.7**

Source: Author.

Figure 7.54: CAPEX and OPEX (Cases 1–3)



Source: Author.

5.2. Summary of DS results

Since Eastern Indonesia (surrounded by Kalimantan, Sulawesi, Papua, and Nusa Tenggara islands) covers a wide area, this study applied the LP model (optimisation approach) to seek basic LNG delivery routes from four LNG production sites (Bontang, Donggi, Masela, and Tangguh) to 18 LNG demand sites. The LP model extracts three LNG delivery groups: (i) the Bontang–Donggi group to cover three cities in the north-west; (ii) Masela group to cover eight cities in the south and north-central part; (iii) Tangguh group to cover seven cities in the east.

DS was applied to seek for the appropriate capacity of onshore storages at each LNG demand site and the number of LNG tankers and tanker size through three case studies. Case 1 assigns one tanker to one LNG demand site with hub & spoke as the delivery method. Thus, case 1 needs the same number of LNG tankers as the number of LNG demand sites. Case 2 reduces the number of LNG tankers, assuming that one ship covers two LNG demand cities; thus, case 2 shows a higher operation rate of LNG tankers than case 1. Case 2 applies the hub & spoke method. Case 3, which applies the milk-run method, also reduces the number of LNG tankers from case 2. Due to appropriate setting of assumed parameters which are capacity, initial volume and calling time of an LNG tanker of the LNG onshore storages, and capacity of LNG tankers, all three cases in the three groups are feasible.

Basically, the capacity of onshore storage per each demand site is assumed to be appropriate considering the annual LNG demand volume of and the distance between the cities and an LNG production site. Cases 2 and 3 indicate efficient use of the LNG onshore storages because the ratios defined as maximum level capacity are more than 0.6, except for Weda (0.45). If the number of LNG tankers are reduced, the maximum level of the storages has to be higher than case 1 because the transport of LNG takes time compared to case 1.

The necessary number of LNG tankers depends on the size of LNG onshore storages and LNG delivery methods, which are hub & spoke and milk-run. The number of LNG tankers of all cases shown in this report is feasible. Looking at the economic analysis results, case 3 is recommended due to its lowest cost. But case 3 applies the milk-run method whose operation is complicated; an emergency disruption might affect normal operations. Thus, a contingency plan is also recommended if the milk-run method will be applied.

5.3. Policy Implications

a. Issues and challenges

The dynamic simulations are successful under appropriate assumptions such as several parameters of LNG onshore storages at the demand sites and LNG tankers in the groups. As a result, the simulation study contributes to extracting the appropriate size of LNG onshore storage per each demand site and the size and operation method of LNG tankers per each group. But the simulation study does not consider natural disasters, accidents, and preventive maintenance. Therefore, more thorough simulation studies to include the negative conditions mentioned earlier will be needed. One more issue is that smaller LNG tankers are main vessels due to the shallow water depth of ports at the LNG demand sites. But if the simulation assumes the construction of dolphin structures between a pier on land and a berth at a deeper place in the water, the simulation can use large LNG tankers to engage the milk-run method.

b. Secondary terminal scenario

Application of a secondary LNG storage between LNG production sites and LNG demand sites is expected. This is to reduce LNG delivery costs due to shorter distance from the secondary terminal to the demand sites and have economic advantage to achieve bulk LNG transport using a large LNG tanker from LNG production site to the secondary terminal. But the results of the simulation studies do not recommend this scenario due to significant costs of the secondary terminal.

c. Milk-run method

The milk-run method contributes to reducing the number of LNG tankers. Therefore, the total operation cost of the LNG tankers become lower than the hub & spoke method due to the lower CAPEX of the LNG tankers. Thus, appropriate assumptions of LNG storages, such as initial volume and scheduling of the LNG tankers, are extremely important in case the milk-run method is applied.

d. Power development policy

As mentioned before, the LNG delivery cost in Eastern Indonesia, which consists of four LNG production sites and 18 LNG demand sites, is too high according to the simulation study. It will be US$55–US$77 per tonne without LNG production cost. One reason is that LNG demand at more than half of the 18 demand sites is not significant due to smaller electricity demand. Thus, gas power generation can be applied for higher electricity demand sites such as Bali, Lombok, Halmahera, and Ternate. Other power generation systems such as the hybrid system of diesel and solar PV with microgrid can be applied in small and midsized electricity demand sites.