Chapter 4

Necessary Liquefied Natural Gas Delivery System: Dynamic Simulation to Identify Necessary Liquefied Natural Gas Shipping and Storage Capacity

In this chapter, we analyse the cost of LNG delivery by ship using dynamic simulation. First, we discuss the assumptions and conditions of dynamic simulation with reference to the results in Chapter 3. Then, we simulate LNG delivery using a dynamic simulation model. Scenarios are developed in which factors such as the number of ships and the storage capacity of the LNG terminal are changed, and their costs are evaluated. The scenarios include the case of typhoon strikes.

4.1 Outline of the Analysis

4.1.1 Basic concepts of dynamic simulation

The Luzon grid is excluded from the model because, as indicated in Chapter 2, LNG terminals in Luzon are large enough to become LNG import terminals and dedicated gas supply terminals for connected GPPs. Therefore, the study targets only the Visayas and Mindanao grids. The delivery of LNG is executed with LNG barges. New LNG storage facilities are prepared for both at the primary terminal ports, which store LNG for bulk breaking, and subordinate terminal ports where GPPs are located.

LNG for bulk breaking is supplied to primary terminals that receive imported LNG directly from outside the Philippines.

Using simulation techniques, this chapter analyses the delivery plan from the primary terminals to the subordinate (secondary and tertiary) terminals at each port where GPPs are located.

4.1.2 Simulation procedures

Simulation procedures are as follows.

- ✓ Select the location of primary and subordinate LNG terminals.
- ✓ Refer to the minimum-cost distribution plan from the linear programming model analysis.
- ✓ Seek a feasible distribution plan using the dynamic simulation model.
- ✓ Estimate total costs of LNG bulk breaking.

4.2 General Assumptions

4.2.1 Liquefied natural gas distribution ports in the study

The LNG distribution ports in this study are Cebu, Tagbilaran, Tacloban, Zamboanga, Iligan, Bislig, Surigao, and General Santos. Figure 3.1, in Chapter 3, shows their locations.

4.2.2 Ports for delivery

Classification of ports. Ports are divided into primary and subordinate terminals. A primary LNG terminal is one where LNG is imported from outside the Philippines directly to the terminal for storage and continuous reshipment to subordinate LNG terminals. A subordinate LNG terminal one where LNG is delivered from a primary LNG terminal to store LNG, regasify LNG, and supply regasified natural gas to GPPs. The classification of ports is in Table 4.1.

Water depth. Bislig, Surigao, and General Santos have a water depth of 9 metres. The five other ports each have a depth of 8 metres (Table 3.4)

Classification of barges. There are two types of LNG barges – large and small. Large barges require ports with a water depth of 9 metres. Table 4.2 shows barge tank capacity.

Capital expenditure and operational expenditure assumptions. Table 3.2, in Chapter 3, shows the CAPEX and OPEX assumptions for the cost calculation.

Table 4.1. Classification of Ports

Port	Primary Terminal	Subordinate Terminal
1. Cebu	✓	
2. Zamboanga	✓	
3. Tagbilaran		✓
4. Tacloban		✓
5. Iligan		✓
6. Bislig		✓
7. Surigao		✓
8. General Santos		✓

Source: Author.

Table 4.2. Barge Tank Capacity

Barge Type	Tank Capacity	
	cubic metres	tonnes
Large barge	30,000	13,500
Small barge	12,000	5,400

Source: Author.

4.3 Evaluation of Result from Linear Programming Model Analysis

Chapter 3 identified the optimum cost delivery plan using a static approach linear programming model.

4.3.1 Assessment of the result

Selection of delivery method. The two methods of delivering LNG from primary terminal to subordinate terminals are the hub-and-spoke method and the milk-run method (Figures 3.3 and 3.4). Chapter 3 identified the hub-and-spoke model as the cheaper option for LNG delivery.

Section of primary terminal. As discussed in Chapter 3, Cebu and Zamboanga are selected as primary LNG terminals. Scenarios for the location of secondary terminals are listed in Table 4.3 and the expenditure breakdown of Scenario 5 is in Table 4.4.

Table 4.3. List of Scenarios

Scenario	Operation Model	Location of Secondary Terminal
Scenario 1	Hub-and-spoke	Cebu
Scenario 2	Hub-and-spoke	Bislig
Scenario 3	Hub-and-spoke	Zamboanga
Scenario 4	Hub-and-spoke	General Santos
Scenario 5	Hub-and-spoke	Cebu and General Santos

Source: Author.

Table 4.4. Decomposed Capital Expenditure and Operational Expenditure in Scenario 5

($ million)

Scenario	CAPEX: Offshore FSRU	CAPEX: Tertiary Terminal	CAPEX: LNG Barges	OPEX: Onshore Terminal and FSRU	OPEX: LNG Barges
Scenario 5 (Hub-and-spoke)	624 × 2	127.2 × 6	0.3 × 3 + 0.18 × 9	66.56	13.18

CAPEX = capital expenditure, FSRU = floating storage and regasification unit, LNG = liquefied natural gas, OPEX = operational expenditure.

Source: Author.

4.3.2 Barge allocation schedule

The distribution of LNG delivery between primary and subordinate terminals is shown in Table 4.5. Nine small barges and three large barges (12 in total) are required.

- ✓ LNG is delivered from Cebu to Tagbilaran, Tacloban, Bislig, and Surigao. Small barges are used for delivery to Tagbilaran and Tacloban. Large barges are used for delivery to Bislig and Surigao.
- ✓ LNG is delivered from Zamboanga to Iligan and General Santos. Small barges are used for delivery to Iligan. Large barges are used for delivery to General Santos.

Table 4.5. Primary Terminals, Subordinate Terminals, and Barges in Linear Programming Model Analysis

Primary Terminal	Subordinate Terminal	Size of Barge	Remarks
Ceb	Tag	Small	Small barges are distributed at two ports, which causes no shared use of multiple barges and is less effective.
Ceb	Tac	Small	
Ceb	Bis	Large	
Ceb	Sur	Large	
Zam	Ili	Small	Each barge delivers liquefied natural gas only to the designated port (one for one).
Zam	San	Large	

Bis = Bislig, Ceb = Cebu, Ili = Iligan, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

4.4 Dynamic Simulation

4.4.1 Assumptions

Gas consumption and storage capacity of terminals. Table 4.6 shows the LNG consumption and storage capacity of the terminals.

Table 4.6. Liquefied Natural Gas Consumption and Storage Capacity of Terminals

LNG Terminal	LNG Consumption		Storage Capacity		Duration of Operational at Full Load
	Annual	Daily			
	(kton)	(kton)	(m^3)	(kton)	(days)
Cebu	1,159	3.17	172,000	77.4	
Zamboanga	597	1.63	172,000	77.4	
Tagbilaran	772	2.11	30,000	13.5	6.4
Tacloban	772	2.11	30,000	13.5	6.4
Iligan	597	1.63	30,000	13.5	8.3
Bislig	597	1.63	30,000	13.5	8.3
Surigao	597	1.63	30,000	13.5	8.3
General Santos	597	1.63	30,000	13.5	8.3

kton = kiloton, LNG = liquefied natural gas, m^3 = cubic metre.

Source: Author.

Navigation distances. Table 4.7 shows the navigation distances between the ports in nautical miles.

Table 4.7. Navigation Distances between Ports

(nautical miles)

	Ceb	Zam	Tag	Tac	Ili	Bis	Sur	San
Ceb		279	53	190	148	214	107	475
Zam	279		238	422	261	434	315	220
Tag	53	238		202	89	238	119	469
Tac	190	422	202		208	214	95	475
Ili	148	261	89	208		249	137	487
Bis	214	434	238	214	249		119	255

Sur	107	315	119	95	137	119		350
San	475	220	469	475	487	255	350	

Bis = Bislig, Ceb = Cebu, Ili = Iligan, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Note: 1 nautical mile = 1,852 metre.

Source: Author.

4.4.2 Developing simulation models

Distribution of barges. In the simulation models, barges are distributed according to the water depth of the ports. LNG is delivered from a primary terminal to a subordinate terminal under the following rules (Table 4.8).

- ✓ LNG is delivered by small barges from Cebu to Tagbilaran, Tacloban, and Iligan. Large barges are used for delivery from Cebu to Surigao.
- ✓ LNG is delivered by large barges from Zamboanga to Bislig and General Santos.

Table 4.8. Primary Terminals, Subordinate Terminals, and Barges in Scenarios

Primary Terminal	Subordinate Terminal	Barge Size	Remarks
Ceb	Tag	Small	Small barges are operated in a group. LNG-loaded barges leave sequentially.
Ceb	Tac	Small	
Ceb	Ili	Small	
Ceb	Sur	Large	Each large barge delivers LNG only to the designated port (one for one).
Zam	Bis	Large	
Zam	San	Large	

Bis = Bislig, Ceb = Cebu, Ili = Iligan, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

Operation rules of barges from Cebu. It is not known how many small barges are required for operations at Cebu. Nine small barges and one large barge are deployed at the initial stage, referring to the result of the linear programming model analysis in Chapter 3. In the dynamic simulation, three small barges make up one group, which covers three subordinate terminals. The relationship of barges to ports is not one-to-one. The operation of three small barges loaded with LNG is as follows. Barges leave port for delivery in sequence (first, second, and third), depending on the LNG delivery requirements of the three ports (i.e. the amount of LNG remaining in their storage tanks). If the first barge returns after finishing the delivery before second and third barges leave port, the first barge might leave port again. As a result, the third barge has almost no chance of leaving the port.

Operation rules for barges from Zamboanga. Two large barges are deployed at Zamboanga. Deliveries to Bislig and General Santos are made on a one-to-one basis, with one barge allocated to deliver to Bislig and the other to General Santos.

Initial storage volume in tanks. All the tanks at subordinate terminals are full of LNG at the beginning of the simulation time.

Voyage speed of barges. Voyage speed is assumed to be 13.3 knots for both small and large barges.[3]

Movement of barges. The initial state of a barge is that LNG is loaded up. When a subordinate terminal orders a delivery, a barge goes into service. LNG is unloaded at the subordinate terminal within 12 hours. After returning to a primary terminal, LNG is loaded onto a barge within 12 hours and the barge waits for a delivery order. The loading facility at a primary terminal is prepared for only one barge. There is a virtual waiting position at a subordinate terminal. If there is no order for delivery, a barge waits in a virtual waiting position.

Term and time resolution of dynamic simulation. The term resolution of the dynamic simulation is 365 days; the time resolution is 1 minute.

[3] Referring to the example of Japanese small barges.

4.4.3 Simulation scenario

Six cases are developed in the simulation. Simulation starts from the scenario equivalent to the linear programming model analysis in Chapter 3, as Case 1.

As summarised in the previous subsections, ports are classified as primary terminals or subordinate terminals. Small barges are deployed at one primary terminal at Cebu. The actual required number of barges is analysed in Case 1.

The simulation results of Case 1 are reflected in cases 2 to 6, which aim to identify better shipping and tank operation to ensure LNG supply. Small barges are used for cases 1 to 3. Large barges are used for all cases.

As the Philippines is hit by many typhoons, LNG supply must be resilient to such natural disasters. Cases 3 and 6 analyse the impact of typhoons. They include provisions for idle barges, and thus require larger tank capacity to meet natural gas demand. Table 4.9 compares case 1 to 6.

Table 4.9. Comparison of Cases

Description	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Transportation system	Hub-and-spoke					
LNG consumption	Refer to Table 4.7					
Storage capacity at primary terminal	172,000 m^3 (= 77.4 kton)					
Storage capacity at subordinate terminal	30,000 m^3 (= 13.5 kton)			60,000 m^3 (= 27.0 kton)		
Number of large barges available	3			6		
Number of small barges available	9			0		
Navigation distances between Ports	Refer to Table 4.8					
Barge voyage speed	13.3 knots					
Loading hours at secondary terminal	12 hours					

Unloading hours at tertiary terminal	12 hours					
Typhoon			Typhoon			Typhoon
Remarks	LP model equiv.	Modified Case 1	Lack of storage capacity	Modified Case 2	Modified Case 4	Typhoon response : Yes

kton = kilotonne, LP = linear programming, m^3 = cubic metres.

Source: Author.

4.5 Simulation Results

4.5.1 Simulation rules of trial case

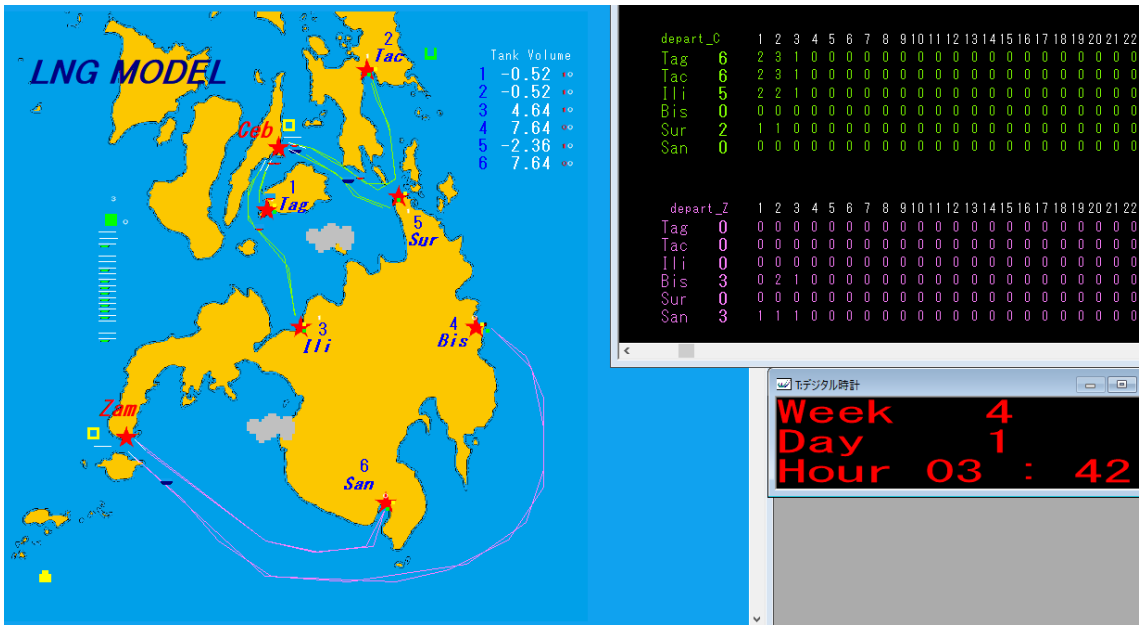
This simulation seeks to compare LNG delivery systems in terms of how barges move over time while maintaining natural gas supply to GPPs. The locations of primary and subordinate terminals are the result of linear programming model analysis in Chapter 3, i.e. they are an exogenous condition. The simulation sets out to review variables such as the combination of primary and subordinate terminals (origin and destination ports), barge operating rules, number of barges, and unit volume of LNG delivery. Before running the cases, a trial simulation was conducted to confirm the delivery rules. The trial simulation tested

- whether barges should be operated as a group (i.e. with flexibility in destination) or one-to-one (i.e. designated a certain destination),
- the thresholds for the remaining LNG tank volume and for the LNG delivery order,
- the unit volume of LNG delivery, and
- the calculation method for the remaining LNG tank volume.

These rules were confirmed and the tuning of the model was repeated.

Figure 4.1 shows the result of the most important elements of the simulation operation – rules of barge group, remaining storage volume, and loading and unloading volumes.

Figure 4.1. Image of Simulation



Source: Author.

Simulation rules

Rule for barge allocation: One large barge and nine small barges are deployed in Cebu. From Cebu, LNG is delivered to Tagbilaran, Tacloban, Iligan, and Surigao (Table 4.10). Two large barges are deployed in Zamboanga. From Zamboanga, LNG is delivered to Bislig and General Santos.

Table 4.10. Terminal and Barge Allocation: Trial Case

Primary Terminal	Subordinate Terminal			
Cebu (Barge)	Tagbilaran (Small)	Tacloban (Small)	Iligan (Small)	Surigao (Large)
Zamboanga (Barge)	Bislig (Large)	General Santos (Large)		

Source: Author.

Rule for LNG delivery orders (calls for LNG delivery):

- Subordinate ports delivered by small barge
  - ✓ Unit volume of LNG delivery: 5.4 kilotonnes (kton) (= capacity of small barge)
  - ✓ Call point: Tank capacity – unit volume of LNG delivery (13.5 – 5.4 = 8.1 kton)
- Subordinate ports delivered by large barge
  - ✓ Unit volume of LNG delivery: 10.0 kton[4]
  - ✓ Call point: Tank capacity – unit volume of LNG delivery (13.5 – 10.0 = 3.5 kton)

Simulation result

In Cebu, nine small barges are deployed and dispatched loaded with LNG, in order (first barge, second barge, etc.). The trial analysis confirmed that the dispatch method will work but that four small barges, rather than nine, would be enough (Table 4.11).

Figure 4.2 shows the daily change in the LNG volume remaining in the subordinate terminal storages. Although the capacity of the large barges (13.5 kton) is underutilised (10.0 kton), all terminals show that no shortage will occur.

[4] 10 kton is smaller than capacity of a large barge (13.5 kton) since 13.5 kton of LNG cannot be received by a tank with a maximum storage capacity of 13.5 kton considering the minimum LNG storage left in the tank.

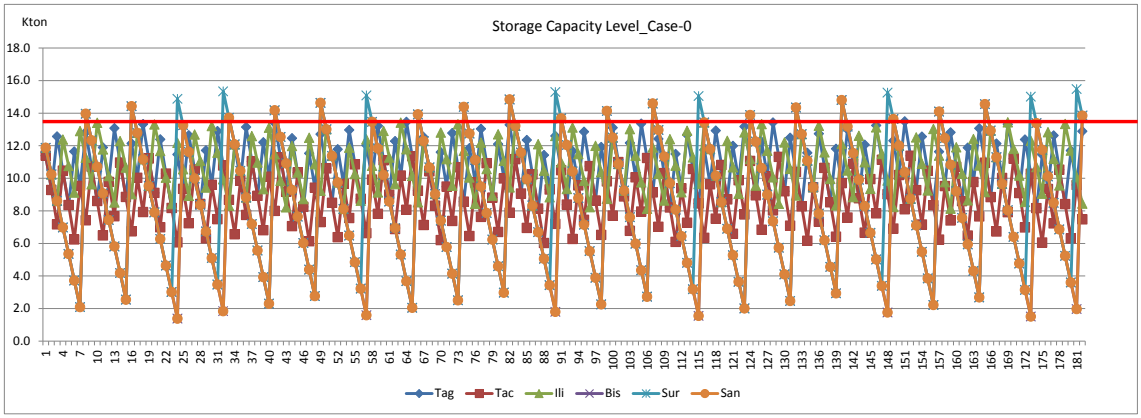
Table 4.11. Results of Dynamic Simulation: Trial Case

Barge Number	Idle (%)	Orders (%)	Load/ Unload (%)	Transport (%)	Stoppage (%)	Block (%)	Navigation Distance	Number of Loadings
1	42.9	8.5	38.9	9.7	0.0	0.9	20,229	142
2	35.9	14.7	30.3	19.1	0.0	4.2	34,571	111
3	42.0	14.5	27.5	16.0	0.0	1.4	34,008	101
4	76.8	5.9	11.0	6.4	0.0	0.5	13,809	40
5	100.0	0	0	0	0	0	0	0
6	100.0	0	0	0	0	0	0	0
7	100.0	0	0	0	0	0	0	0
8	100.0	0	0	0	0	0	0	0
9	100.0	0	0	0	0	0	0	0
11	78.4	4.0	12.1	5.6	0.0	1.4	9,549	44
12	55.3	16.4	11.9	16.4	0.0	0.0	38,248	44
13	71.3	8.3	12.1	8.4	0.0	0.0	19,493	44

Note: Barge numbers 1–9 = small barge, barge numbers 11–13 = large barge.

Source: Author.

Figure 4.2. Remaining Liquefied Natural Gas Volume in Terminal Storages: Trial Case



Source: Author.

4.5.2 Simulation of Case 1

This case has been simulated under conditions equivalent to the optimised solution of the linear programming model analysis.

Simulation rules

Rule for barge allocation: Three large barges and nine small barges are allocated to Cebu and Zamboanga. Cebu has two large barges that deliver LNG to Surigao and Bislig, and eight small barges that deliver LNG to Tagbilaran and Tacloban. Zamboanga has one large barge for General Santos and one small barge for Iligan (Table 4.12).

Table 4.12. Terminal and Barge Allocation: Case 1

Primary terminal	Subordinate Terminals			
Cebu (Barge)	Tagbilaran and Tacloban (Eight small barges)		Bislig (Large)	Surigao (Large)
Zamboanga (Barge)	Iligan (Small)	General Santos (Large)		

Source: Author.

Rule for LNG delivery orders:

- Subordinate ports delivered by small barge
  - ✓ Unit volume of LNG delivery: 5.4 kton (capacity of small barge)
  - ✓ Call point: Tank capacity – unit volume of LNG delivery (13.5 – 5.4 = 8.1 kton)
- Subordinate ports delivered by large barge
  - ✓ Unit volume of LNG delivery: 10.0 kton (footnote 4)
  - ✓ Call point: Tank capacity – unit volume of LNG delivery (13.5 – 10.0 = 3.5 kton)

Simulation result

Large barges that load 10 kton of LNG leave a port. It has been proven that it does not exceed the tank storage capacity even if 10 kton of LNG is unloaded.

Three small barges are required at Cebu and one small barge at Zamboanga to deliver LNG, but operational flexibility is not available. If we try to operate barges more efficiently, all small barges need to be placed at the same port.

Table 4.13 shows the results of the simulation. It has been proven that three small barges in Cebu can cover delivery to both Tagbilaran and Tacloban. A small barge from Zamboanga to Iligan is operated independently, with a low idle ratio and a high operation rate at 80%. This means the small barge operation is tight. Three large barges are required for three ports because of their independent operation. In all, seven barges are required.

Table 4.13. Results of Dynamic Simulation: Case 1

Barge Number	Idle (%)	Order (%)	Load/ Unload (%)	Transport (%)	Stoppage (%)	Block (%)	Navigation Distance	Number of Loadings
1	47.9	6.5	38.9	6.8	0.0	0.1	15,479	142
2	51.0	13.1	21.9	14.1	0.0	0.9	30,640	80
3	61.8	10.1	17.0	11.2	0.0	0.9	23,747	62
5	100.0	0	0	0	0	0	0	0
6	100.0	0	0	0	0	0	0	0
7	100.0	0	0	0	0	0	0	0
8	100.0	0	0	0	0	0	0	0
9	100.0	0	0	0	0	0	0	0
11	56.0	10.8	16.2	17.0	0.0	6.1	25,430	59
12	71.6	5.4	16.2	6.8	0.0	1.3	12,804	59
4	19.7	24.6	29.9	25.8	0.0	1.2	57,487	110
13	61.5	11.1	16.2	11.2	0.0	0.0	26,138	59

Note: Barge numbers 1–9 = small barge, barge numbers 11–13 = large barge.

Source: Author.

Table 4.14 shows the detailed operation times of each barge.

Table 4.14. Detailed Operation Time by Barge: Case 1

Primary Terminal	Barge Number	Waiting Time for Shipment a	Loading Time b	Transport Time c	Unloading Time d	Operating Time e=a+b+c	Total Time f=a+e	Rate of Operation g=e/f	Travel Times
		(minute)	(minute)	(minute)	(minute)	(minute)	(minute)	(%)	(No.)
Ceb	1	353,939	102,240	67,739	102,240	272,219	626,158	43	142
Ceb	2	325,743	56,880	135,331	56,880	249,091	574,834	43	79
Ceb	3	369,985	44,640	106,209	44,640	195,489	565,474	35	62
Ceb	11	366,143	42,480	113,868	42,480	198,828	564,971	35	59
Ceb	12	422,165	42,480	56,880	42,480	141,840	564,005	25	59
Zam	4	187,851	78,480	256,584	78,480	413,544	601,395	69	110
Zam	15	363,009	42,480	117,056	42,480	202,016	565,025	36	59
Total		**2,388,834**	**409,680**	**853,668**	**409,680**	**1,673,028**	**4,061,862**	**41**	**570**

Ceb = Cebu, Zam = Zamboanga.

Note: Barge numbers 1–4 = small barge; barge numbers 11, 12, 15 = large barge.

Source: Author.

Table 4.15 shows the OPEX for barges in Case 1.

Table 4.15. Barge Operational Expenditure: Case 1

Item	Unit	Navigation Route (From/To)						
		Ceb/ Tag	Ceb/ Tac	Ceb/ Bis	Ceb/ Sur	Zam/ Ili	Zam/ San	**Total**
Number of loadings	times	142	142	59	59	110	59	**571**
Point-to-point (one way)	mile	53	190	214	107	261	220	

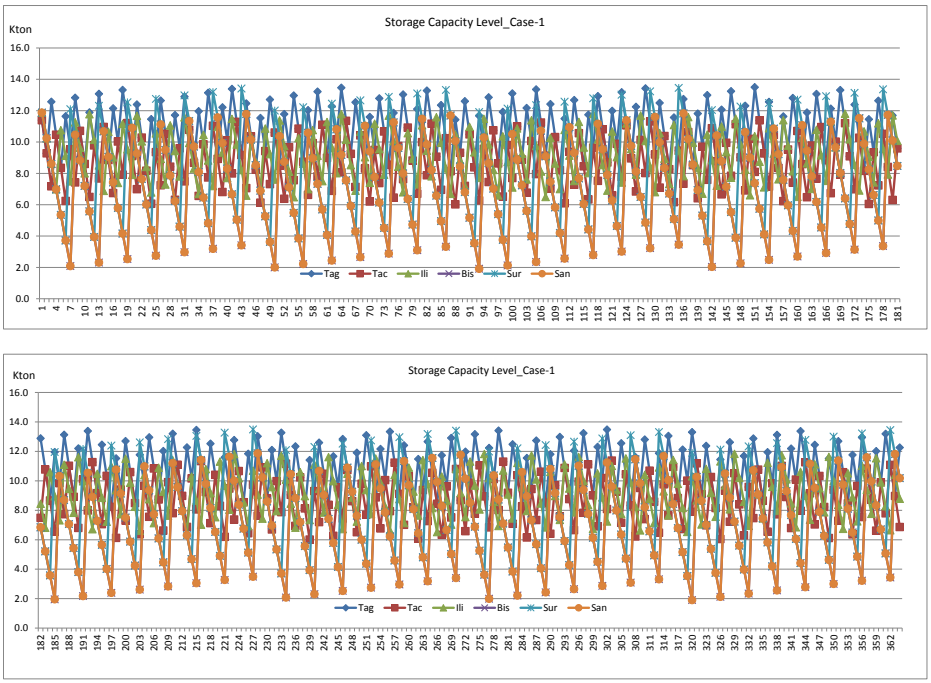
Total navigation distance (one way)	mile	7,526	26,980	12,626	6,313	28,710	12,980	**95,135**
Loading volume	kton/times	5.4	5.4	10.0	10.0	5.4	10.0	
Total transport volume	kton	767	767	590	590	594	590	**3,898**
Travelling unit price of barge	$/tonne/mile	0.083	0.083	0.059	0.059	0.083	0.059	
Total	**$'000/year**	**479**	**1,717**	**440**	**220**	**1,415**	**452**	**4,723**

Bis = Bislig, Ceb = Cebu, Ili = Iligan, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

Figure 4.3 shows the daily change in the LNG volume remaining in the subordinate terminal storages. All terminals show that no shortage will occur.

Figure 4.3. Remaining Liquefied Natural Gas Volume in Terminal Storages: Case 1



Note: Upper graph = days 1–181; lower graph = days 182–365.

Source: Author.

4.5.3 Simulation of Case 2

This case has been simulated under the modified conditions of Case 1.

Simulation rules

Allocation of barges: There are three large barges and four small barges, all of which are allocated to Cebu and Zamboanga. Cebu has one large barge to deliver LNG to Surigao and four small barges to deliver to Tagbilaran, Tacloban, and Iligan. Zamboanga has two large barges for deliveries to Iligan and General Santos (Table 4.16).

Table 4.16. Terminal and Barge Allocation: Case 2

Primary Terminal	Subordinate Terminals		
Cebu (Barge)	Tagbilaran, Tacloban, and Iligan (Four small barges)		Surigao (Large)
Zamboanga (Barge)	Bislig (Large)	General Santos (Large)	

Source: Author.

Rules for LNG delivery orders: Same as in Case 1.

Simulation result

Large barges loading 10 kton of LNG leave port. It has been proven that it does not exceed the storage capacity even if 10 ktoe of LNG is unloaded.

Four small barges are capable of delivering LNG from Cebu to three ports: Tagbilaran, Tacloban, and Iligan.

Table 4.17 shows the results of the simulation. The simulation proves that four small barges are sufficient to deliver LNG. However, as the idle ratio of the fourth barge is high, the travel plans should be reviewed. As large barges are operated independently, three large barges are required. In all, seven barges are required.

Table 4.17. Results of Dynamic Simulation: Case 2

Barge Number	Idle (%)	Order (%)	Load/ Unload (%)	Transport (%)	Stoppage (%)	Block (%)	Navigation Distance	Number of Loadings
1	42.8	8.5	38.9	9.8	0.0	1.0	20,229	142
2	35.4	14.7	30.4	19.6	0.0	4.7	34,571	111
3	42.4	14.4	27.3	16.0	0.0	1.6	33,625	100
4	76.1	6.0	11.2	6.7	0.0	0.6	14,192	41
11	71.0	5.4	16.2	7.4	0.0	1.9	12,804	59
12	39.8	22.0	16.2	22.1	0.0	0.0	51,390	59
13	61.5	11.1	16.2	11.2	0.0	0.0	26,138	59

Note: Barge numbers 1–4 = small barge; barge numbers 11–13 = large barge.

Source: Author.

Table 4.18 shows the detailed operation times of each barge.

Table 4.18. Detailed Operation Time by Barge: Case 2

Primary Terminal	Barge Number	Waiting Time for Shipment a (minute)	Loading Time b (minute)	Transport Time c (minute)	Unloading Time d (minute)	Operating Time e=a+b+c (minute)	Total Time f=a+e (minute)	Rate of Operation g=e/f (%)	Travel Times (No.)
Ceb	1	332,514	102,240	89,164	102,240	293,644	626,158	47	142
Ceb	2	289,025	79,200	152,609	79,200	311,009	600,034	52	110
Ceb	3	301,109	71,280	149,506	71,280	292,066	593,175	49	99
Ceb	4	420,701	29,520	63,413	29,520	122,453	543,154	23	41
Ceb	11	422,165	42,480	56,880	42,480	141,840	564,005	25	59
Zam	12	247,008	41,760	227,068	41,760	312,992	560,000	56	58
Zam	15	363,009	42,480	117,056	42,480	202,016	565,025	36	59
Total		**2,375,531**	**408,960**	**855,696**	**408,960**	**1,676,020**	**4,051,551**	**41**	**568**

Ceb = Cebu, Zam = Zamboanga.

Note: Barge numbers 1–4 = small barge; barge numbers 11, 12, 15 = large barge.

Source: Author.

Table 4.19 shows OPEX for barges in Case 2.

Table 4.19. Barge Operational Expenditure: Case 2

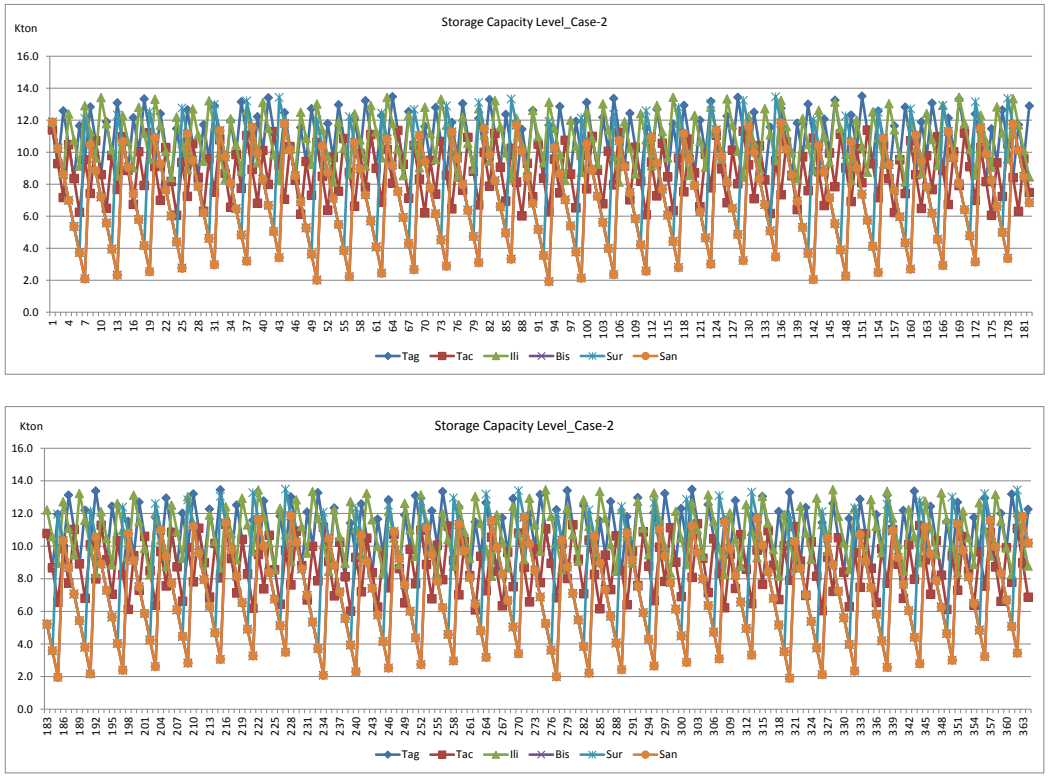
Item	Unit	Navigation Route (From/To)						
		Ceb/ Tag	Ceb/ Tac	Ceb/ Bis	Ceb/ Sur	Zam/ Ili	Zam/ San	**Total**
Number of loadings	times	142	142	109	59	59	59	**570**
Point-to-point (one way)	mile	53	190	148	214	315	220	
Total navigation distance (one way)	mile	7,526	26,980	16,132	12,626	18,585	12,980	**94,829**
Loading volume	kton/times	5.4	5.4	5.4	10.0	10.0	10.0	
Total transport volume	kton	767	767	589	590	590	590	**3,892**
Travelling unit price of barge	$/tonne/ mile	0.083	0.083	0.083	0.059	0.059	0.059	
Total	**$'000/year**	**479**	**1,717**	**788**	**440**	**647**	**452**	**4,523**

Bis = Bislig, Ceb = Cebu, Ili = Iligan, kton = kilotonne, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

Figure 4.4 shows the daily change in the LNG volume remaining in the subordinate terminal storages. All terminals show that no shortage will occur.

Figure 4.4. Remaining Liquefied Natural Gas Volume in Terminal Storages: Case 2



Note: Upper graph = days 1–181; lower graph = days 182–365.

Source: Author.

4.5.4 Simulation of Case 3

This case assumes typhoon strikes.

Rules for typhoon strike

Initially, the annual average frequency of typhoon strikes in each region – Luzon, Visayas, and Mindanao – was calculated and the result was less than 1. However, to minimise risk, we decided to employ data from a single year when the Philippines hit by a historically high number of typhoons. This was 2006 for Luzon and 2013 for Visayas and Mindanao.

A typhoon in Visayas will affect the operation of ships departing from Cebu port, and a typhoon in Mindanao will affect shipping in and around Zamboanga port.

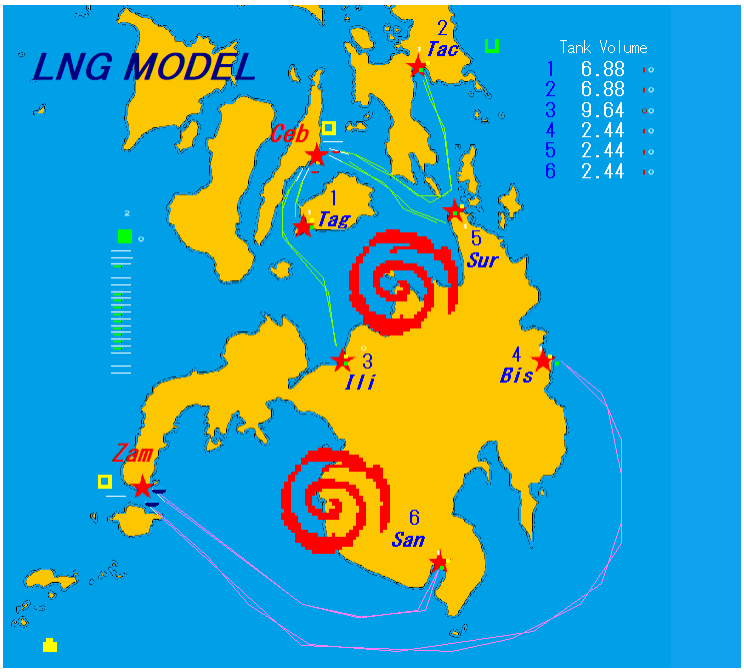
Table 4.20. Dates of Typhoon Strikes, 2006 and 2013

Year	Grid	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	Luzon					9-15	10-14 21-25	28-2	5-9	25-29	10-12 27-30	28-1	
2013	Visayas		30-1	21-25			13-17	18-23		12-15 17-22		26-28	4-10
2013	Mindanao	17-20	30-1	21-25								26-28	4-10

Source: Government of the Philippines, Department of Energy.

Figure 4.5 shows an image from the simulation. Barge operations of are stopped for the duration of the typhoon.

Figure 4.5. Typhoon Strike Simulation Image



Source: Author.

Simulation rules

Rules for allocation of barges: To prepare for typhoon strikes, eight small barges have been deployed at Cebu in a group and the operation rule is that LNG-loaded barges leave port for delivery in sequence (first, second, third, etc.). Eight small barges are assigned to deliver to Tagbilaran, Tacloban, and Iligan, and one large barge is allocated for deliveries to Surigao. Zamboanga has two large barges, which deliver to Bislig and General Santos (Table 4.21).

Table 4.21. Terminal and Barge Allocation: Case 3

Primary terminal	Subordinate terminal		
Cebu (Barge)	Tagbilaran, Tacloban, and Iligan (Eight small barges)		Surigao (Large)
Zamboanga (Barge)	Bislig (Large)	General Santos (Large)	

Source: Author.

Rules for LNG delivery orders: Same as in Case 1.

Simulation result

Table 4.22 shows the results of the simulation. It indicates a very low rate of dispatch of orders for barge numbers 5 to 8. As delivery is suspended during the typhoon, the blocking ratio is high compared with Case 2.

Table 4.22. Results of Dynamic Simulation: Case 3

Barge Number	Idle (%)	Order (%)	Load/ Unload (%)	Transport (%)	Stoppage (%)	Block (%)	Navigation Distance	Number of Loading
1	36.1	16	34.52	13.24	0	12.36	19,915	126
2	32.5	18	27.89	21.62	0	13.96	29,962	102
3	37.7	17	26.44	19.19	0	9.18	31,133	97
4	65.7	9	13.42	11.59	0	7.75	15,347	49
5	90.6	3	2.74	3.91	0	3.86	3,315	10
6	94.9	1	1.92	2.23	0	1.26	2,269	7
7	99.0	0	0.27	0.57	0	0.4	385	1
8	99.1	0	0.27	0.47	0	0.34	301	1
11	64.3	10	16.2	9.4	0	8.5	12,863	59
12	35.8	23	16.2	24.6	0	3.9	51,449	59
13	57.1	13	16.2	14.2	0	4.3	26,197	59

Note: Barge numbers 1–8 = small barge; barge numbers 11–13 = large barge.

Source: Author.

Table 4.23 shows the detailed operation times of each barge.

Table 4.23. Detailed Operation Time by Barge: Case 3

Primary Terminal	Barge Number	Waiting Time for Shipment a (minute)	Loading Time b (minute)	Transport Time c (minute)	Unloading Time d (minute)	Operating Time e=a+b+c (minute)	Total Time f=a+e (minute)	Rate of Operation g=e/f (%)	Travel Times (No.)
Ceb	1	820,807	90,720	128,915	90,720	310,355	1,131,162	27	126
Ceb	2	787,262	73,440	175,216	73,440	322,096	1,109,358	29	102
Ceb	3	770,536	69,120	164,198	69,120	302,438	1,072,974	28	96
Ceb	4	883,986	35,280	89,974	35,280	160,534	1,044,520	15	49
Ceb	5	853,243	7,200	22,451	7,200	36,851	890,094	4	10
Ceb	6	483,689	5,040	10,131	5,040	20,211	503,900	4	7
Ceb	7	385,921	720	1,718	720	3,158	389,079	1	1
Ceb	8	385,921	720	1,665	720	3,105	389,026	1	1
Ceb	11	397,266	42,480	81,784	42,480	166,744	564,010	30	59
Zam	12	230,168	42,480	256,192	42,480	341,152	571,320	60	59
Zam	13	339,721	42,480	140,348	42,480	225,308	565,029	40	59
Total		**6,338,521**	**409,680**	**1,072,591**	**409,680**	**1,891,951**	**8,230,472**	**23**	**569**

Ceb = Cebu, Zam = Zamboanga.

Note: Barge numbers 1–4 = small barge; barge numbers 11–13 = large barge.

Source: Author.

Table 4.24 shows the OPEX for barges in Case 3.

Table 4.24. Barge Operational Expenditure: Case 3

Item	Unit	Navigation Route (From/To)						
		Ceb/ Tag	Ceb/ Tac	Ceb/ Bis	Ceb/ Sur	Zam/ Ili	Zam/ San	**Total**
Number of loadings	times	142	141	110	59	59	59	**570**
Point-to-point (one way)	mile	53	190	148	214	315	220	
Total navigation distance (one way)	mile	7,526	26,790	16,280	12,626	18,585	12,980	**94,787**
Loading volume	kton/times	5.4	5.4	5.4	10.0	10.0	10.0	
Total transport volume	kton	767	761	594	590	590	590	**3,892**
Travelling unit price of barge	$ tonne/ mile	0.083	0.083	0.083	0.059	0.059	0.059	
Total	**$'000/ year**	**479**	**1,693**	**803**	**440**	**647**	**452**	**4,513**

Bis = Bislig, Ceb = Cebu, Ili = Iligan, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

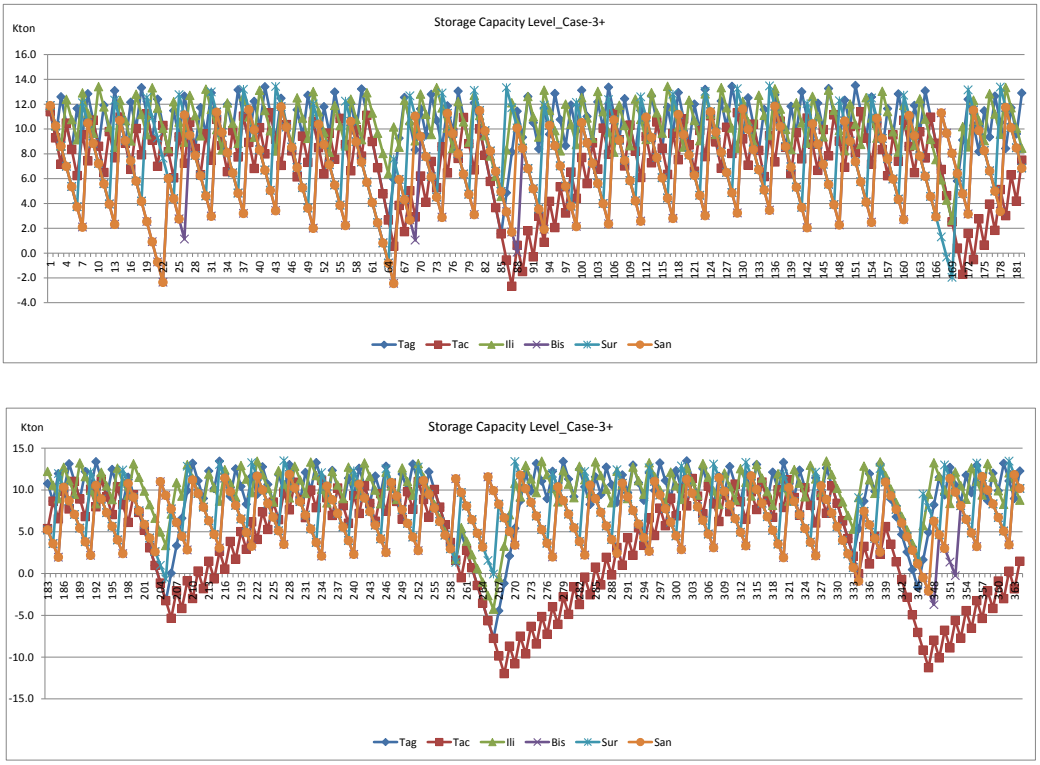
Figure 4.6 shows the daily change in the remaining LNG volume in the subordinate terminal storages.

In Tacloban, which consumes a lot of LNG, the remaining LNG volume in the storage tank becomes a negative value for a long period, meaning Tacloban cannot sustain a natural gas supply to the GPP under the assumed storage capacity and ship operation parameters.

In Tagbilaran, which also consumes a lot of LNG, the LNG volume remaining in the storage tank becomes negative as well. However, the period of LNG shortage is shorter in Tagbilaran than it is in Tacloban because Tagbilaran is the first port in the sequence of LNG delivery.

Bislig and General Santos, in Mindanao, are hit by fewer typhoons.

Figure 4.6. Remaining Liquefied Natural Gas Volume in Terminal Storages: Case 3



Note: Upper graph = days 1–181; lower graph = days 182–365.

Source: Author.

4.5.5 Simulation of Case 4

This case is based on and modified from Case 2. In cases 4 to 6, we assumed that LNG is delivered only by large barges and that terminal storage capacity is increased.

Simulation rules

Terminal storage capacity: The terminal storage capacity of subordinate terminals is doubled (Table 4.25).

Table 4.25. Terminal Storage Capacity by Case

Classification of Terminal	Terminal	Cases 1–3		Cases 4–6	
		m^3	kton	m^3	kton
Primary	Cebu	188,000	85.0	188,000	85.0
	Zamboanga	188,000	85.0	188,000	85.0
Suboridnate	Tagbilaran	30,000	13.5	60,000	27.0
	Tacloban	30,000	13.5	60,000	27.0
	Iligan	30,000	13.5	60,000	27.0
	Bislig	30,000	13.5	60,000	27.0
	Surigao	30,000	13.5	60,000	27.0
	General Santos	30,000	13.5	60,000	27.0

kton = kiloton, m^3 = cubic metre.

Source: Author.

Allocation of barges: Only large barges are deployed. Three large barges are deployed at Cebu in a group to deliver LNG to Tagbilaran, Tacloban, Iligan, and Surigao. Two large barges are deployed at Zamboanga in a group to deliver LNG to Bislig and General Santos (Table 4.26).

Table 4.26. Terminal and Barge Allocation: Case 4

Primary Terminal	Subordinate Terminal
Cebu (Barge)	Tagbilaran, Tacloban, Iligan, and Surigao (Three large barges)
Zamboanga (Barge)	Bislig and General Santos (Two large barges)

Source: Author.

Rule for LNG delivery orders:

- ✓ Unit volume of LNG delivery: 13.5 kton
- ✓ Call point: Tank capacity – unit volume of LNG delivery (27.0 – 13.5 = 13.5)

Simulation result

In Case 2, four small barges and one large barge are deployed at Cebu, while Case 4 assumes three large barges instead.

Table 4.27 shows the results of the simulation. It has been proven that three large barges are sufficient to deliver LNG from Cebu to the four islands.

Table 4.27. Results of Dynamic Simulation: Case 4

Barge Number	Idle (%)	Order (%)	Load/ Unload (%)	Transport (%)	Stoppage (%)	Block (%)	Navigation Distance	Number of Loading
11	61	7	23	10	0	2	16,424	84
12	55	11	23	11	0	0	25,089	82
13	83	4	9	4	0	1	8,687	34
14	56	16	12	16	0	0	37,771	43
15	72	8	12	8	0	0	19,270	43

Note: Barge numbers 11–15 = large barge.

Source: Author.

Table 4.28 shows the detailed operation times of each barge.

Table 4.29 shows the OPEX for barges in Case 4. Because the storage capacity of the subordinate terminals was doubled, the number of loadings and navigation time, and consequently their cost, are reduced compared with Case 2.

Table 4.28. Detailed Operation Time by Barge: Case 4

Primary Terminal	Barge Number	Waiting Time for Shipment a (minute)	Loading Time b (minute)	Transport Time c (minute)	Unloading Time d (minute)	Operating Time e=a+b+c (minute)	Total Time f=a+e (minute)	Rate of Operation g=e/f (%)	Travel Times (No.)
Ceb	11	380,018	59,760	74,917	59,760	194,437	574,455	34	83
Ceb	12	342,857	59,040	114,821	59,040	232,901	575,758	40	82
Ceb	13	456,214	23,760	37,980	23,760	85,500	541,714	16	33
Zam	14	317,973	30,960	168,343	30,960	230,263	548,236	42	43
Zam	15	399,073	30,960	85,312	30,960	147,232	546,305	27	43
Total		**1,896,135**	**204,480**	**481,373**	**204,480**	**890,333**	**2,786,468**	**32**	**284**

Ceb = Cebu, Zam =Zamboanga.

Note: Barge numbers 11–15 = large barge.

Source: Author.

Table 4.29. Barge Operational Expenditure: Case 4

Item	Unit	Navigation Route (From/To) Ceb/ Tag	Ceb/ Tac	Ceb/ Bis	Ceb/ Sur	Zam/ Ili	Zam/ San	Total
Number of loadings	times	57	57	44	43	43	44	**288**
Point-to-point (one way)	mile	53	190	148	214	315	220	
Total navigation distance (one way)	mile	3,021	10,830	6,512	9,202	13,545	9,680	**52,790**
Loading volume	kton/times	13.5	13.5	13.5	13.5	13.5	13.5	
Total transport volume	kton	770	770	594	581	581	594	**3,888**

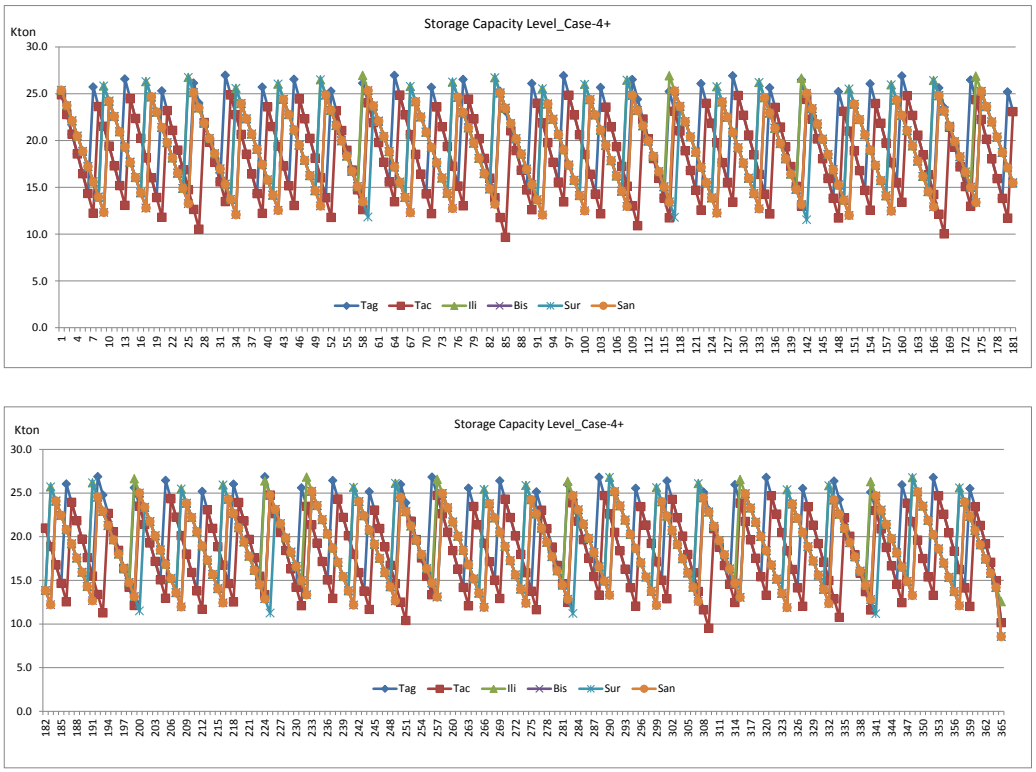
Travelling unit price of barge	$/tonne/mile	0.059	0.059	0.059	0.059	0.059	0.059	
Total	**$'000/year**	**137**	**492**	**228**	**315**	**464**	**339**	**1,975**

Bis = Bislig, Ceb = Cebu, Ili = Iligan, kton = kilotonne, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

Figure 4.7 shows the daily change in the LNG volume remaining in the subordinate terminal storages. All terminals show that no shortage will occur.

Figure 4.7. Remaining Liquefied Natural Gas Volume in Terminal Storages: Case 4



Note: Upper graph = days 1–181; lower graph = days 182–365.

Source: Author.

4.5.6 Simulation of Case 5

This case is based on and modified from Case 4.

Simulation rules

Initial condition of remaining storage volume: From Case 1 to Case 4, the initial condition of all storage tanks is set as full. The barge dispatch order is signalled when the amount of LNG left in the tank hits the lower limit after regasified gas is consumed by the GPP. If the subordinate terminals' LNG consumption are the same (Table 4.6), the remaining LNG storage would reach the limit level at the same time. It means that barge dispatch orders for different subordinate terminals would be signalled about the same timing and more barges would be required. To avoid this situation, the remaining LNG storage volume in each subordinate terminal is differentiated. This adjustment is expected to reduce the congestion of dispatch orders and improve the operation of barges.

Allocation of barges: Only large barges are deployed. Two large barges are deployed at Cebu in a group to deliver LNG to Tagbilaran, Tacloban, Iligan, and Surigao. One large barge is deployed at Zamboanga to deliver LNG to Bislig and General Santos (Table 4.30).

Table 4.30. Terminal and Barge Allocation: Case 5

Primary Terminal	Subordinate Terminal
Cebu (Barge)	Tagbilaran, Tacloban, Iligan, and Surigao (two large barges)
Zamboanga (Barge)	Bislig and General Santos (one large barge)

Source: Author.

Rule of LNG delivery order: Same as in Case 4.

Simulation result

By changing the size of the barge fleet and the initial condition of the remaining LNG storage volume in subordinate terminal tanks, the total number of barges can be reduced from five to three.

Table 4.31 shows the results of the simulation. It has been proven that two large barges are satisfactory to deliver LNG from Cebu and one large barge is enough for deliveries from Zamboanga.

Table 4.31. Results of Dynamic Simulation: Case 5

Barge number	Idle (%)	Order (%)	Load/ Unload (%)	Transport (%)	Stoppage (%)	Block (%)	Navigation distance	Number of loading
11	41.3	13.0	32.2	13.5	0.0	0.5	30,502	117
12	58.7	8.6	23.4	9.3	0.0	0.6	20,241	86
13	25.9	25.0	24.1	25.0	0.0	0.0	58,329	88

Note: Barge number 11-13: large barge

Source: Author.

Table 4.32 shows the detailed operation times of each barge. The operating rate of barge allocated to Cebu is improved compared with Case 4.

Table 4.32. Detailed Operation Time by Barge: Case 5

Primary Terminal	Barge Number	Waiting Time for Shipment a (minute)	Loading Time b (minute)	Transport Time c (minute)	Unloading Time d (minute)	Operating Time e=a+b+c (minute)	Total Time f=a+e (minute)	Rate of Operation g=e/f (%)	Travel Times (No.)
Ceb	11	302,264	84,240	135,021	84,240	303,501	605,765	50	117
Ceb	12	444,557	61,200	89,336	61,200	211,736	656,293	32	85
Zam	13	405,951	63,360	320,999	63,360	447,719	853,670	52	88
Total		**1,152,773**	**208,800**	**545,356**	**208,800**	**962,956**	**2,115,728**	**46**	**290**

Ceb = Cebu, Zam = Zamboanga.

Note: Barge numbers 11–13 = large barge.

Source: Author.

Table 4.33 shows the OPEX for barges in Case 5.

Table 4.33. Barge Operational Expenditure: Case 5

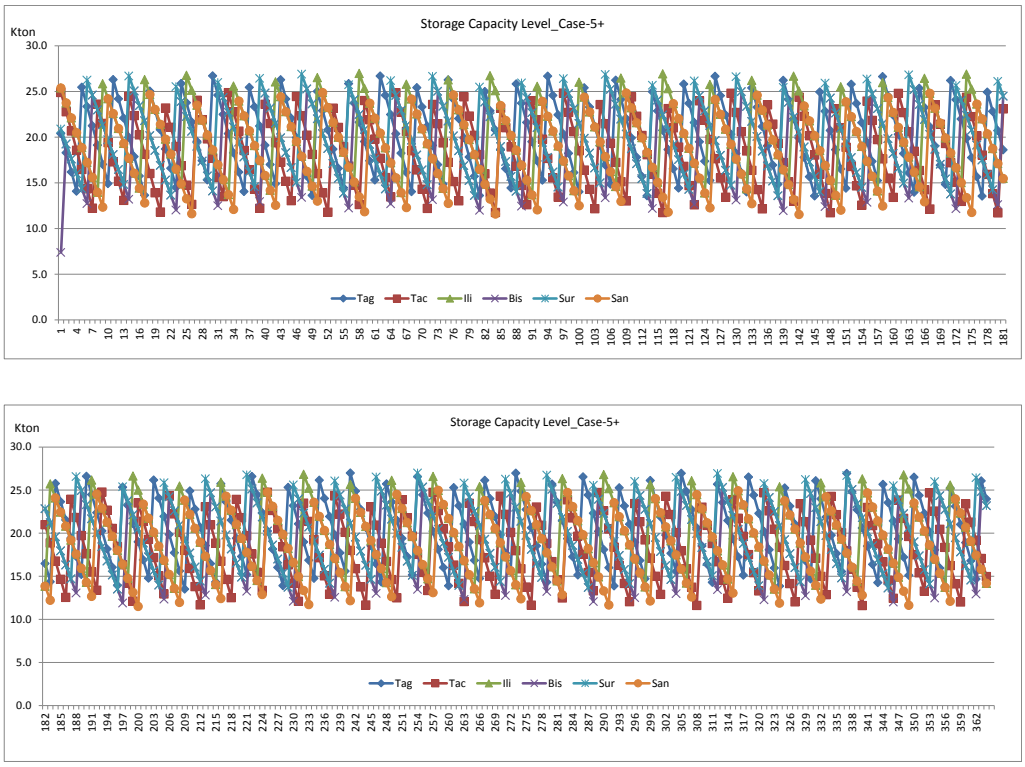
Item	Unit	Navigation Route (From/To)						
		Ceb/ Tag	Ceb/ Tac	Ceb/ Bis	Ceb/ Sur	Zam/ Ili	Zam/ San	**Total**
Number of loadings	times	58	57	44	45	45	43	**292**
Point-to-point (one way)	mile	53	190	148	214	315	220	
Total navigation distance (one way)	mile	3,074	10,830	6,512	9,630	14,175	9,460	**53,681**
Loading volume	kton/times	13.5	13.5	13.5	13.5	13.5	13.5	
Total transport volume	kton	783	770	594	608	608	581	**3,942**
Travelling unit price of barge	$/tonne/mile	0.059	0.059	0.059	0.059	0.059	0.059	
Total	**$'000/year**	**142**	**492**	**228**	**345**	**508**	**324**	**2,039**

Bis = Bislig, Ceb = Cebu, Ili = Iligan, kton = kilotonne, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

Figure 4.8 shows the daily change in the LNG volume remaining in the subordinate terminal storages. All terminals show that no shortage will occur.

Figure 4.8. Remaining Liquefied Natural Gas Volume in Terminal Storages: Case 5



Note: Upper graph = days 1–181; lower graph = days 182–365.

Source: Author.

4.5.7 Simulation of Case 6

This case assumes typhoon strikes.

Rule of typhoon strike: Same as in Case 3.

Simulation rules

Allocation of barges: To prepare for typhoon strikes, four large barges have been deployed at Cebu in a group operation in which LNG-loaded barges leave port for delivery in sequence (first, second, third, etc.). Zamboanga has two large barges in a group operation, which deliver LNG to Bislig and General Santos (Table 4.34).

Table 4.34. Terminal and Barge Allocation: Case 6

Primary Terminal	Subordinate Terminal
Cebu (Barge)	Tagbilaran, Tacloban, Iligan, and Surigao (Four large barges)
Zamboanga (Barge)	Bislig and General Santos (Two large barges)

Source: Author.

Rule of LNG delivery order: Same as in Case 1

Simulation result

Table 4.35 shows the results of the simulation.

Table 4.35. Results of Dynamic Simulation: Case 6

Barge Number	Idle (%)	Order (%)	Load/ Unload (%)	Transport (%)	Stoppage (%)	Block (%)	Navigation Distance	Number of Loadings
11	36.2	18.8	29.7	15.4	0.0	10.3	27,820	108
12	53.2	15.3	22.3	9.2	0.0	7.7	19,619	82
13	91.4	5.0	2.2	1.4	0.0	4.6	2,109	8
14	96.3	1.1	1.4	1.2	0.0	1.2	1,397	5
15	52.4	18.5	12.3	16.8	0.0	1.6	39,241	45
16	68.6	11.4	11.9	8.2	0.0	3.0	19,314	43

Note: Barge numbers 11–16 = large barge.

Source: Author.

Table 4.36 shows the detailed operation times of each barge.

Table 4.36. Detailed Operation Time by Barge: Case 6

Primary Terminal	Barge Number	Waiting Time for Shipment a (minute)	Loading Time b (minute)	Transport Time c (minute)	Unloading Time d (minute)	Operating Time e=a+b+c (minute)	Total Time f=a+e (minute)	Rate of Operation g=e/f (%)	Travel Times (No.)
Ceb	11	786,534	77,760	175,195	77,760	330,715	1,117,249	30	108
Ceb	12	856,268	58,320	122,595	58,320	239,235	1,095,503	22	81
Ceb	13	459,275	6,480	32,492	6,480	45,452	503,038	9	9
Ceb	14	485,789	3,600	9,101	3,600	16,301	502,090	3	5
Zam	15	307,071	33,840	188,352	33,840	256,032	563,103	45	45
Zam	16	384,513	30,960	99,876	30,960	161,796	546,309	30	43
Total		**3,279,450**	**210,240**	**635,274**	**210,240**	**1,055,754**	**3,293,913**	**32**	**291**

Ceb = Cebu, Zam = Zamboanga.

Note: Barge numbers 11–16 = large barge.

Source: Author.

Table 4.37 shows OPEX for barges in Case 6.

Table 4.37. Barge Operational Expenditure: Case 6

Item	Unit	Navigation Route (From/To)						Total
		Ceb/ Tag	Ceb/ Tac	Ceb/ Bis	Ceb/ Sur	Zam/ Ili	Zam/ San	
Number of loadings	times	58	57	44	45	45	44	**293**
Point-to-point (one way)	mile	53	190	148	214	315	220	
Total navigation distance	mile	3,074	10,830	6,512	9,630	14,175	9,680	**53,901**

(one way)								
Loading volume	kton/ times	13.5	13.5	13.5	13.5	13.5	13.5	
Total transport volume	kton	783	770	594	608	608	594	**3,956**
Travelling unit price of barge	$/ tonne/ mile	0.059	0.059	0.059	0.059	0.059	0.059	
Total	**$'000/ year**	**142**	**492**	**228**	**345**	**508**	**339**	**2,054**

Bis = Bislig, Ceb = Cebu, Ili = Iligan, kton – kilotonne, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

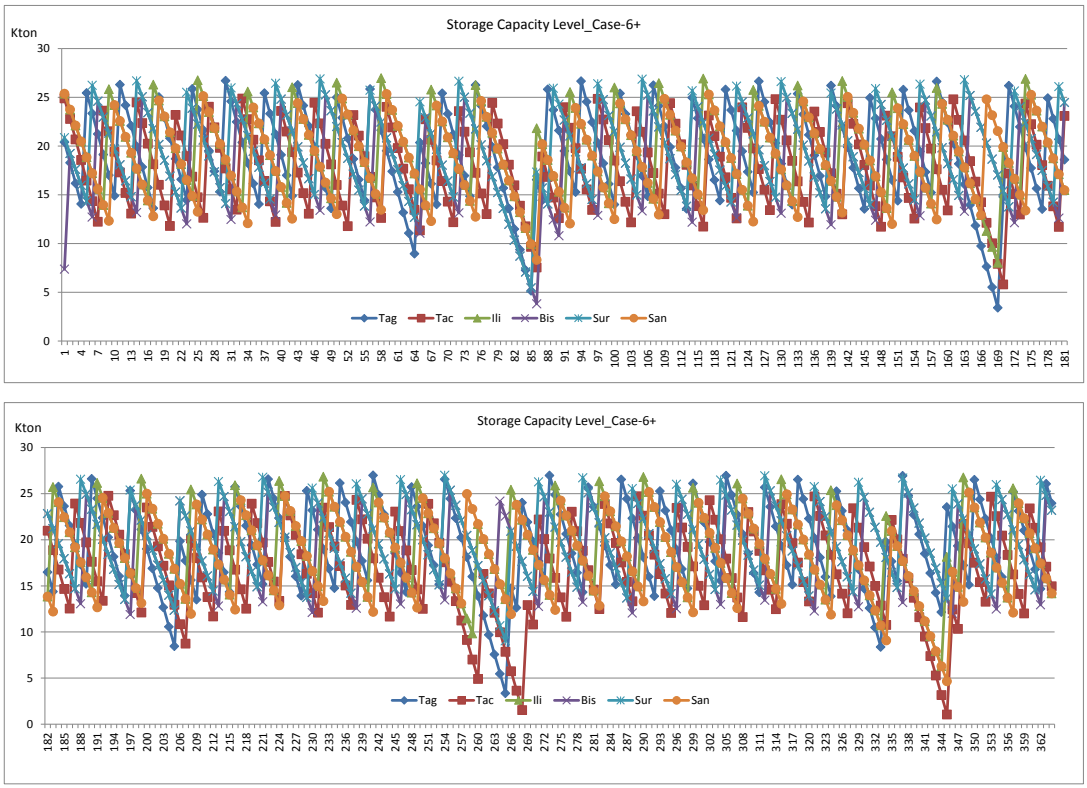
Source: Author.

Figure 4.9 shows the daily change in LNG volume remaining in the subordinate terminal storages.

By doubling the storage capacity in the subordinate terminals, the remaining LNG storage volume avoided falling to zero, although it sometimes almost dropped to this level. Delivery of LNG from Cebu to the subordinate terminals in Tagbilaran, Tacloban, Iligan, and Surigao is manageable with four large barges even in the event of a typhoon.

However, Tacloban and Tagbilaran (which consume a lot of LNG) and Bislig (which requires long-distance navigation) experienced critically low storage levels of less than 5 ktons on six occasions. Even though the result shows that the natural gas supply to GPPs will be sustained under the assumed typhoon hit, it also indicates that LNG receiving tanks in subordinate terminals could become empty if the frequency of typhoon is higher and their duration is longer.

Figure 4.9. Remaining Liquefied Natural Gas Volume in Terminal Storages: Case 6



Note: Upper graph = days 1–181; lower graph = days 182–365.

Source: Author.

4.5.8 Summary

Table 4.38 summarises the simulation results.

Because of the lower operating cost of large barges, the cases that assume the use of large barges only are cheaper than those that use small barges. Case 4 is the cheapest operation. However, the share of OPEX against annual total cost is very low – less than 3%. CAPEX and fixed costs are dominant in the total cost. Considering the total cost, Case 2 is the cheapest operation. When considering preparedness for typhoons, Case 6 is the only viable choice.

Table 4.38. Summary of Simulation Results

	Case 1 (LP Model)	Case 2	Case 3 (Typhoon)	Case 4	Case 5	Case 6 (Typhoon)
Main Features of Cases						
Storage capacity (Primary terminal)	77.4 kton	<--	<--	<--	<--	<--
Storage capacity (Subordinate terminal)	13.5 kton	<--	<--	27.0 kton	<--	<--
Number of Small barge	9	4	8			
Number of Large barge	3	3	3	5	3	6
CAPEX + Fixed cost						(Thousand USD)
(i) Primary terminal	1,248,000	1,248,000	1,248,000	1,248,000	1,248,000	1,248,000
(ii) Subordinate terminal	765,600	765,600	765,600	1,531,200	1,531,200	1,531,200
(iii) Small barge	32,400	14,400	28,800			
(iv) Large barge	18,000	18,000	18,000	30,000	18,000	36,000
(v) Total CAPEX (20 years)	2,064,000	2,046,000	2,060,400	2,809,200	2,797,200	2,815,200
(vi)=(i):(v) Total CAPEX (per year)	103,200	102,300	103,020	140,460	139,860	140,760
(vii) Fixed cost (FSRU OPEX)	47,840	47,840	47,840	47,840	47,840	47,840
(x) Fixed cost (Subordinate terminal OPEX)	18,720	18,720	18,720	28,080	28,080	28,080
(ix)=(vii)+(x) Total Fixed cost per year	66,560	66,560	66,560	75,920	75,920	75,920
(ix)=((vi)+(vii) CAPEX + Fixed cost (per year)	169,760	168,860	169,580	216,380	215,780	216,680
OPEX						(Thousand USD)
(iix) Barges	4,723	4,523	4,513	1,975	2,039	2,054
Total cost (per year)						(Thousand USD)
(iiix)=(ix)+(iix)	174,483	173,383	174,093	218,355	217,819	218,734
Evaluation						
Without Typhoon	Yes	Yes	Yes	Yes	Yes	Yes
Typhoon response	No	No	No	No	No	**Yes**

<-- = same value as the left cell, CAPEX = capital expenditure, FSRU = floating storage and regasification unit, kton = kilotonne, LP = linear programming, OPEX = operational expenditure,

Note: The operation cost of doubled storage capacity in subordinate terminal is assumed to be 1.5 times of unit cost of daily storage operation.

Source: Author.