Chapter 6

Optimal Future Petroleum Supply Chain

February 2022

This chapter should be cited as

ERIA Study Team (2022), 'Optimal Future Petroleum Supply Chain', in ERIA and General Department of Petroleum, Ministry of Mines and Energy of Cambodia (eds.), *Cambodia Petroleum Master Plan 2022-2040.* ERIA Research Project Report FY2021 No. 21, Jakarta: ERIA, pp.96-116.

Chapter 6

Optimal Future Petroleum Supply Chain

Based on the demand for petroleum, which consists of gasoline and diesel oil per province in 2030 and 2040, we examined the optimal future petroleum supply chains from primary terminals to each province's capital by using the logistics optimisation with minimum cost approach model. Chapter 5 clarified that the total demand for gasoline and diesel oil would increase from 2,457,261 kilolitres (kl) in 2018 to 4,580,455 kl in 2030, and 7,798,740 kl in 2040. The Phnom Penh area, which includes nine provinces, is the largest demand area, accounting for 56.5% of the total demand in 2030 and 55.5% in 2040. The West area, which includes five provinces, accounting for 22.8% of the total demand in 2030 and 23.8% in 2040, is the second demand area. The logistics optimisation model aims to find the optimal supply chain in the whole of Cambodia. The model assumes 13 supply routes, with three transportation means (tank-truck, railway, and pipeline).

Two primary terminals are assumed: one for the Sihanoukville terminals, including Kampot and others on the seaside, and the other, for terminals along the Mekong River in Phnom Penh and Kandal. These are the primary terminals used to import petroleum products from Singapore, Thailand, and Viet Nam. The Phnom Penh and Battambang hub terminals are assumed to be secondary terminals. Gasoline and diesel oil will be transferred from primary terminals, mainly Sihanoukville, to these hub terminals. The objective function of the logistics optimisation model minimises total transport costs to move petroleum products from the primary terminals to the province's capitals. However, the model does not represent each oil company, only the nationwide petroleum logistics.

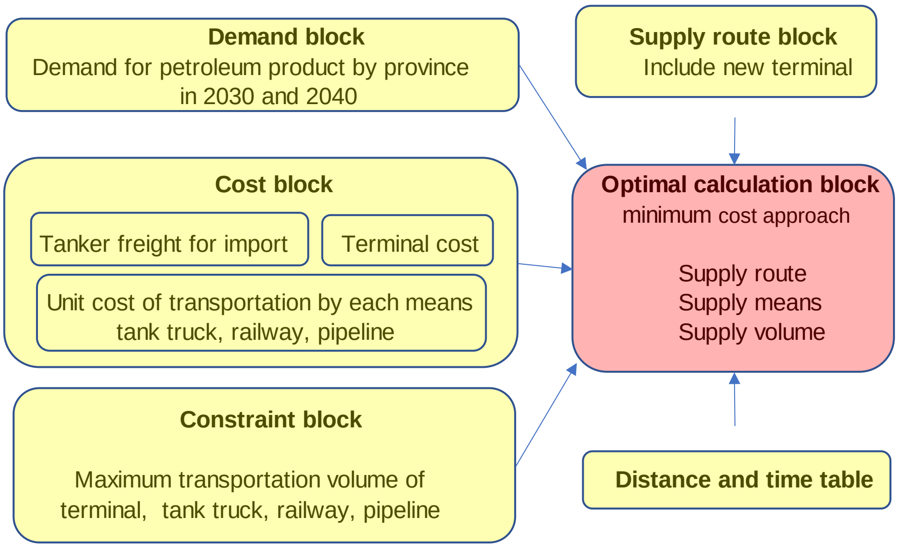
1. Structure of the Logistics Optimisation Model

The logistics optimisation model consists of the following blocks:

- Demand block: demand for gasoline and diesel oil by each province in 2030 and 2040
- Supply route block: 13 supply routes, including new terminals, are assumed.

- Cost block: import freight, terminal cost, transfer cost, final delivery cost, and unit transport cost of tank-trucks, railways, and pipelines
- Constraint block: maximum transportation volume from the primary terminals, by tank-truck, railway, and pipeline
- Optimal calculation block: minimum cost approach

Figure 6.1 Structure of Logistics Optimisation Model for Cambodia



Source: Author.

1.1 Demand block

Table 6.1 is shows gasoline and diesel oil demand by province in 2030 and 2040.

Table 6.1. Demand for Gasoline and Diesel Oil by Province in 2030 and 2040 (kl)

Demand by province	Gasoline + Diesel Oil			2040 Gasoline + Diesel	
	2018	2030	2040	%	2018–2040
Banteay Meanchey	129,522	253,343	455,261	5.8	5.9
Battambang	215,042	314,843	559,018	7.2	4.4
Kampong Cham	127,409	199,215	334,100	4.3	4.5
Kampong Chhnang	68,183	120,381	208,699	2.7	5.2
Kampong Speu	52,902	101,502	174,750	2.2	5.6
Kampong Thom	75,939	127,445	225,422	2.9	5.1
Kampot	30,875	49,723	84,898	1.1	4.7
Kandal	176,039	313,542	520,499	6.7	5.1
Kohkong	9,335	15,503	26,971	0.3	4.9
Kratie	79,511	147,736	252,724	3.2	5.4
Mondolkiri	48,968	106,612	183,546	2.4	6.2
Phnom Penh	566,751	1,226,439	2,006,053	25.7	5.9
Preah Vihear	54,709	119,745	209,883	2.7	6.3
Prey Veng	89,728	160,305	273,086	3.5	5.2
Pursat	94,187	153,590	267,816	3.4	4.9
Ratanakiri	49,260	103,739	169,798	2.2	5.8
Siem Reap	196,334	348,007	608,139	7.8	5.3
Preah Sihanouk	61,264	128,625	219,457	2.8	6.0
Stung Treng	34,682	74,555	130,909	1.7	6.2
Svay Rieng	68,403	118,940	202,952	2.6	5.1
Takeo	55,167	95,382	158,936	2.0	4.9
Oddar Meanchey	44,235	93,814	167,202	2.1	6.2
Kep	2,105	3,980	6,561	0.1	5.3
Pailin	22,548	35,108	63,047	0.8	4.8
Tbong Khmum	104,164	168,380	289,014	3.7	4.7
Cambodia total	**2,457,262**	**4,580,455**	**7,798,740**	**100.0**	**5.4**

kl = kilolitres.

Source: This project.

Table 6.2 shows petroleum demand in four areas in Cambodia.

Table 6.2. Demand for Gasoline and Diesel Oil by Area in 2030 and 2040

	2018		2030		2040		2018–2040
	1,000 kl	%	1,000 kl	%	1,000 kl	%	AGR %
Around PP	1,370,803	55.8	2,588,237	56.5	4,327,640	55.5	5.4
West area	607,681	24.7	1,045,116	22.8	1,852,666	23.8	5.2
Northeast	267,129	10.9	552,387	12.1	946,861	12.1	5.9
SV direct	211,648	8.6	394,714	8.6	671,573	8.6	5.4
Total	**2,457,262**	**100.0**	**4,580,455**	**100.0**	**7,798,740**	**100.0**	**5.4**

kl = kilolitres.

Source: This project.

The Phnom Penh area, which includes nine provinces, is the largest demand area; the Mekong River terminals are the nearest supply base but far from the Sihanoukville terminals, which is the largest base. The West area, which includes five provinces, is the second demand area. It is 200 km–300 km from the Mekong River terminals. On the other hand, it is about 500 km away from the Sihanoukville terminals, and the role of the Battambang hub is great.

The Mekong River terminals are nearest supply base to the Northeast area. Gasoline and diesel oil can be delivered directly to the Sihanoukville area from the Sihanoukville terminals.

1.2 Supply route block

The logistics optimisation model assumes 13 supply routes. A supply route means a supply chain from a primary terminal to each provincial capital using a transportation means via a secondary terminal, if necessary. The following are the 13 supply routes.

1) Direct delivery of petroleum product by tank-truck from the Mekong River terminals
2) Transfer petroleum product from the Mekong River terminals to the Battambang hub terminal by tank-truck, and final delivery by tank-truck
3) Direct delivery by tank-truck from the Sihanoukville terminals
4) Transfer from the Sihanoukville terminals to the Phnom Penh hub terminal by railway, and final delivery by tank-truck

5) Transfer from the Sihanoukville terminals to the Phnom Penh hub terminal by tank-truck, and final delivery by tank-truck.
6) Transfer from the Sihanoukville terminals to the Phnom Penh hub terminal by tank-truck using the highway, and final delivery by tank-truck
7) Transfer from the Sihanoukville terminals to the Phnom Penh hub terminal by pipeline, and final delivery by tank-truck
8) Transfer from the Sihanoukville terminals to the Phnom Penh hub terminal by pipeline, and transfer to the Battambang hub terminal by tank-truck and final delivery by tank-truck
9) Transfer from the Sihanoukville terminals to the Battambang hub terminal directly by railway, and final delivery by tank-truck
10) Import from the Rayon refinery in Thailand to the Battambang hub terminal by pipeline and final delivery by tank-truck
11) Import from Vung Tau in Viet Nam to the Phnom Penh hub terminal by pipeline and final delivery by tank-truck
12) Transfer from the Phnom Penh hub terminal to the Battambang hub terminal by pipeline, and final delivery by tank-truck
13) Transfer from the Phnom Penh hub terminal to the Northeast hub terminal by pipeline, and final delivery by tank-truck.

For each supply route, the total transportation cost is calculated as follows, import freight + primary terminal cost + transfer cost + second terminal cost + final transportation cost represented by US$/kl. These cost elements are shown in the cost block.

1.3 Cost block

1) Import freight

Since the river is shallow, small tankers of 500–2,000 tonnes (deadweight tonne) carry imports at the Mekong River terminals. This is more expensive than the Sihanoukville terminal in terms of unit cost, which tankers of 5,000–10,000 tonnes can carry.

The difference in freight due to tanker size is about five times, but the actual difference is double because many imports are from Viet Nam via the Mekong River, which is nearer than Singapore and Thailand. Based on this information, the import freight to the Mekong River terminals is assumed to be charged U$30/kilolitre (kl), and the import freight to the Sihanoukville terminal is U$17/kl for the logistics optimisation model.

2) Terminal cost

As for the terminal cost, the larger the capacity, the smaller the cost per kilolitre. Table 6.3 shows the costs by capacity category, based on the data of Japanese oil companies.

Table 6.3 Terminal Cost ($/kl)

Category	Size	Terminal cost ($/kl)
Ultra Large	100,000 kl or more	1.5
Large	50,000 kl–100,000 kl	3.0
Medium	10,000 kl–50,000 kl	5.0
Small	10,000 kl or less	8.0

kl = kilolitres.

Source: Author.

3) Unit cost of tank-truck

Oil companies own tank-trucks and transport petroleum products by themselves. So, it is necessary to estimate the daily cost as the unit cost of tank-trucks.

The average cost per year of a tank-truck is estimated from the market price of the tank-truck and the service life of a new and used tank-truck in Asia. The price of a new truck includes import costs. The price of a used truck includes overhaul costs and import costs, and its service life is shorter than a new one. The average cost per year is estimated at $7,630 which is about $8,000 (in case of 20 kl tank-truck).

In addition, tank-truck transport costs include the driver’s labour costs, the tank-truck’s fuel, maintenance, and overhead costs. The composition ratio of tank-truck costs is about 20% of the total cost. Thus, the yearly expenses of tank-truck transport total about $40,000 ($8,000/0.2).

For example, if the number of working days per year is 200, the tank-truck transport cost per day is $200 (40,000/200). Since the capacity of the tank-truck is 20 kl, the cost/day is about $10/kl per day.

On the logistics optimisation model, the delivery for over 200 km takes 2 days for a round trip, such as Sihanoukville to Phnom Penh and vice versa. So, the cost/kl is calculated at $20 for 230 km. The delivery for 50–200 km takes 1 day. So, the cost/kl is $10 for less than 200 km. The delivery for less than 50 km takes half a day. So, the cost/kl is $5/kl. Based on this idea, tank-truck transport cost was calculated proportionally based on the distance from each primary and secondary terminal to each provincial capital. In principle, we assumed the transportation distance of tank-trucks per day to be 350 km or less.

These are almost the same as the result of the interview with oil companies in Cambodia.

4) Unit cost of railway

Currently, the railway transport of petroleum products has two routes: from Sihanoukville to Phnom Penh and Sihanoukville to Battambang.

The transportation cost of railway is about half that of a tank-truck, so it is effective, but the speed is slow due to the poor condition of the railway, so that the maximum capacity of each route is around 90,000 kl per year (1,800kl/trip, 50 trips). According to informal information, the railway condition will improve in the future, and total transportation capacity will increase to 600,000 kl/y and 1,200,000 kl/y in 2040. The increase of railway fees due to the improvement is assumed to be 3$/kl (in case of all to Battambang). The investment amount for improvement is unclear. However, based on the recent investment of new railway construction in Tanzania, the investment cost is $5.7–$5.8 million/km. If the ratio of oil transportation revenue is assumed to be 10% of total passenger and freight transportation revenue of Cambodia railway company, the total revenue for 30 years will be 2.23 MM$/km. This is about 40% of new railway investment costs in Tanzania, so 3$/kl increase of transport fee seems appropriate.

Tanzania Project 1: Investment amount is $1.2 billion, 207 km, $5.8 million/km

Tanzania Project 2: Investment amount is $1.9 billion, 336 km, $5.7 million/km

Cambodia railway company's revenue for 30 years from petroleum products.

3$ × 1,200,000 kl × 30 years/0.1/ 522 km => $2.23 million/km

Distance from Sihanoukville to Battambang is 522 km.

5) Unit cost of pipeline

According to the World Onshore Pipelines Market Forecast 2019–2023,[4] the total construction cost of a pipeline is 0.6 MM$/km–0.8 MM$/km on average worldwide.

On the other hand, India and Nepal officially opened South Asia's first cross-border oil pipeline. India funded a US$45-million pipeline project with an annual capacity of 2 million metric tonnes and a 69 km length . The unit construction cost of the India and Nepal pipeline was calculated at 0.7 MM$/km.

According to the above information, the construction cost of the Sihanoukville to Phnom Penh pipeline was about 150 MM$. On the other hand, there is also information that the investment amount would be 240 MM$.

If a third-party company constructs the pipeline and sets the fee, adding the project management cost and margin to the calculation is necessary. However, this study based the calculation on the assumption that the oil company constructed and used the pipeline.

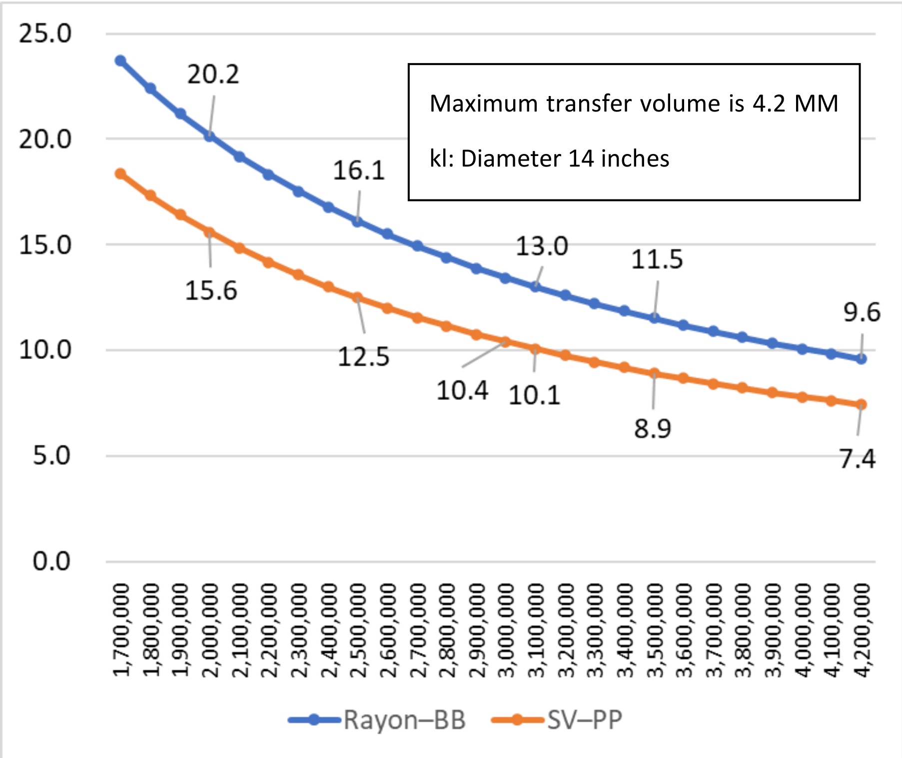
Assumption of calculation for unit cost of pipeline	
Construction cost:	: 240 MM$
Period of use	: 20 years
Operation cost/year	: 1% of construction cost
Maintenance cost/year:	: 2% of construction cost
Interest cost/year:	: 5% of construction cost
Total annual cost	: 31.2 MM$

[4] https://www.westwoodenergy.com/reports/world-onshore-pipelines-market-forecast-2019-2023 (accessed 9 May 2020)

The unit cost of a pipeline depends on the transfer volume. Therefore, a larger transfer volume reduces unit cost. Figure 6.2 shows the relationship between transfer volume and unit cost.

Figure 6.2 Unit Cost of Pipeline

$/kl



Source: This project.

Figure 6.2 shows the unit costs of the Sihanoukville–Phnom Penh (SV-PP) and the Rayon–Battambang (Rayon-BB) hub terminals. We calculated the unit cost of the Rayon pipeline assuming that the investment amount of the Rayon pipeline increases with distance. Considering the expected demand scale and relative cost competitiveness, the transportation volume of the pipeline is calculated by iteratively calculating the logistics optimisation model. The unit cost of the pipeline from Viet Nam is same as the Rayon pipeline.

6) Unit cost of highway use

If the highway is used to transfer petroleum products from Sihanoukville to the Phnom Penh hub terminal by tank-truck, transportation that takes 2 days for a round trip will be possible in 1 day; that is, the cost is $10/kl instead of $20/kl. However, highway tolls will be added.

The highway fare is $0.4/km for vehicles over 20 tonnes and $0.32/km for those under 20 tonnes. Since a tank-truck loaded with fuel weighs 20 tonnes or more, the highway toll will be $0.4 × 190 km[5] = $76, and the 20 kl tank-truck will be $3.8/kl. On the other hand, since an empty tank-truck weighs less than 20 tonnes, the highway toll is $0.32 × 190 km = $60.8, and the 20 kl tank-truck is $3.0/kl. So then, transportation via the highway costs $16.8/kl ($10 + $3.8 + $3.0) for a round trip. If the transportation volume of the SV-PP pipeline exceeds 2.0 MM kl/y, the unit price of the pipeline will be less than 15.6$/kl and the use of the highway will be infeasible.

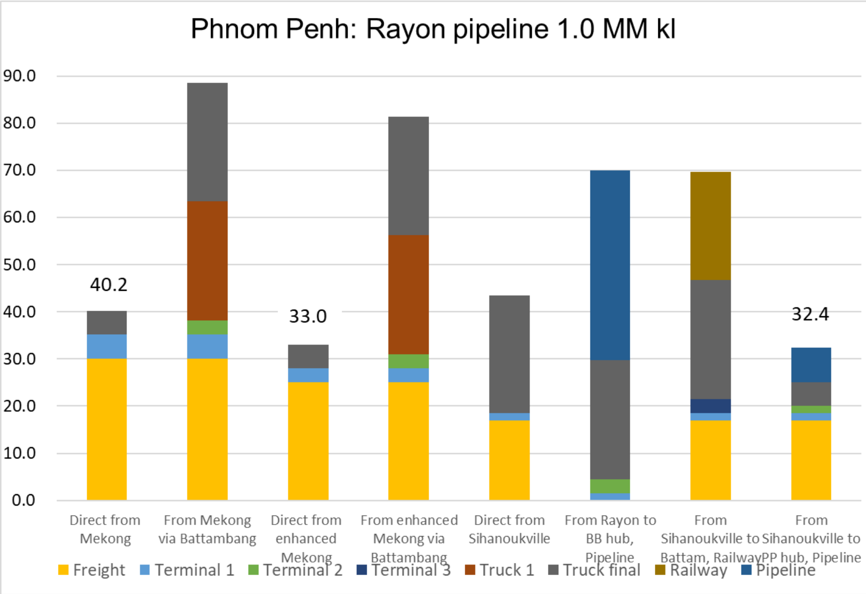
In addition, the maximum amount of tank-trucks that can be received at the hub terminal is 100 units per day due to the unloading work time.

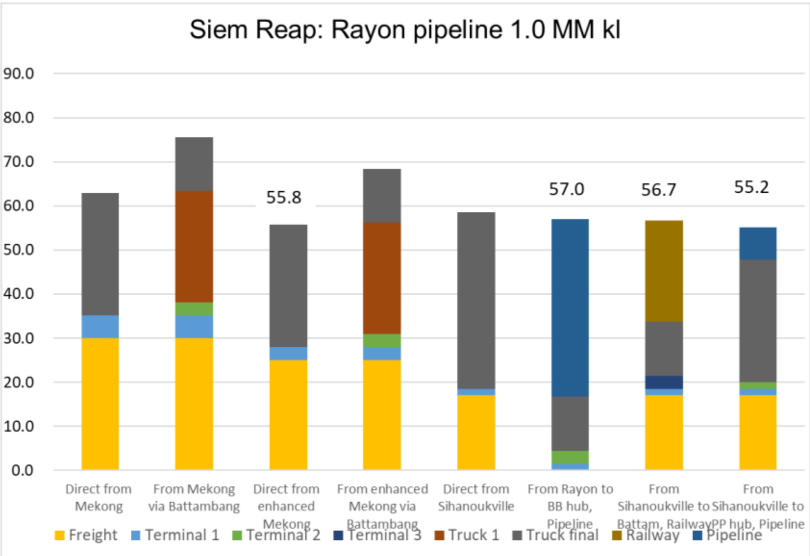
7) Transportation costs to major provincial capitals in 2040

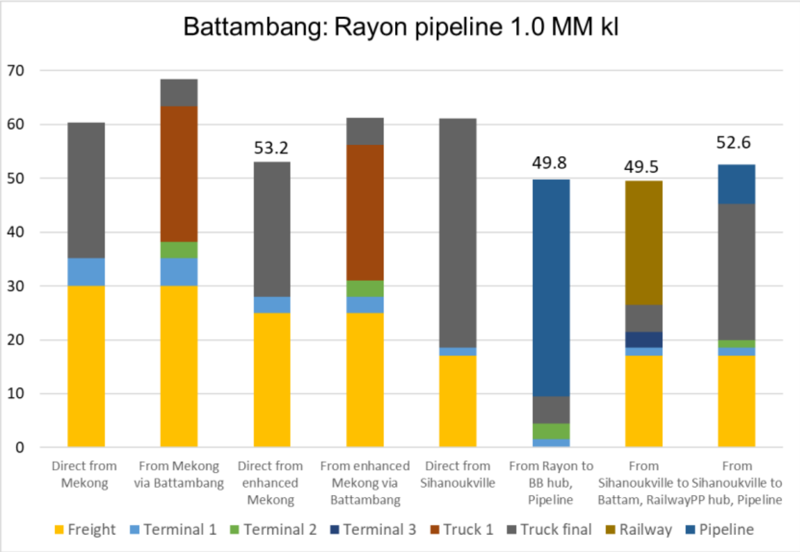
Figure 6.3 shows the total transportation costs – import freight, primary terminal cost, transport cost, second terminal cost, and final delivery cost – to major provincial capitals by supply routes in 2040.

[5] From the entrance to the highway is 190 km.

Figure 6.3. Total Transportation Costs to Major Provincial Capitals, by Supply Route







Source: This project.

The graph above shows when the SV-PP pipeline transport volume is max and Rayon pipeline is 1.0 MM kl case.

1.4 Optimal calculation block

The basic formula for calculating the minimum cost is as follows. And find x^{ij} that minimizes this with the linear programming model (hereinafter LP model). $\sum_{i=1}^{n}, \sum_{j=1}^{n} x^{ij} c^{ij}$

x^{ij} .... Delivery volume to j via supply route i (kl/y)

j is 25 province capitals, i is 11 supply routes

c^{ij} .... Transportation cost to j via supply route i (\$/kl)

$\sum_{j=1}^{n} x^{ij}$ =< max supply volume of supply route i

$\sum_{i=1}^{n} x^{ij}$ = demand of province j

1.5 Constraint block

1) The maximum mileage of a tank-truck

The delivery distance of a tank-truck is assumed to be within 350 km. However, for the three provinces over 350 km, petroleum products are transported by tank-trucks from the nearest Mekong River terminal to Ratana Kiri (531 km), Mondolkiri (366 km), and Stung Treng (379 km) because there are no other means of delivery.

2) The maximum delivery volume from the Mekong River

The Mekong River terminals almost have no vacant land and are difficult to expand.

It is also difficult to accept large tankers because the river is shallow at this time.

In addition, the frequency of delivery is limited due to traffic jams. Therefore, the maximum delivery volume from the Mekong River terminals is assumed to be 1.3 million kl/year. However, this will only increase by about 30% from the current delivery volume, estimated at 0.9–1.0 million kl/y. For the LP model, we assumed an enhanced Mekong River terminal with an additional storage tank that can accommodate large tankers in the future, and calculated cases where cost reduction is also attempted.

3) The maximum delivery volume by railway

The maximum delivery volume by railway is limited to 600,000 kl/y in 2030, and 1,200,000 kl/y in 2040 on the LP model. And the railway transportation volume in 2030 was calculated as 480,000 kl/y for Phnom Penh and 120,000 kl/y for Battambang, but the total transportation cost was lower if the total volume is allocated for Battambang. Therefore, in 2040, all transportation volume by railway was allocated for Battambang.

4) Importable volume from Thailand (Rayon refinery)

According to the Energy Balance 2019 of Thailand's Ministry of Energy, the total export volume of gasoline and diesel oil in Thailand is about 5 million kl in 2019 (Table 6.4). There are seven refineries in Thailand with a total capacity of 1,234,500 barrels/day. The Rayon refinery accounts for 17.4% of the total in 215,000 barrels/day. Therefore, the export volume of the Rayon refinery in 2019 was calculated at 870,000 kl/y. So, on the LP model, we set 1,000,000 kl/y as importable volume.

Table 6.4. Supply and Demand of Gasoline and Diesel Oil in Thailand

Unit: 1,000 kl		Gasoline	Diesel Oil	Total
2019	production	1,747	25,775	27,522
	Import	28	2,374	2,402
	Export	1,223	3,776	4,999
	Consumption	389	24,579	24,968
2018	production	2,278	28,219	30,497
	Import	0	582	582
	Export	1,707	5,533	7,240
	Consumption	437	23,587	24,024
2017	production	2,126	28,258	30,384
	Import	0	813	813
	Export	1,599	5,245	6,844
	Consumption	508	23,223	23,731

kl = kilolitres.

Source: The Ministry of Energy in Thailand

2. Case Study

We conducted several case studies using the logistics optimisation model to find the optimal supply chain in 2030 and 2040. These case studies were based on the premise that one ideal oil company would supply petroleum products nationwide. The case studies were on the following:

- BAU case in 2030 (business-as-usual scenario), where the current supply method continues
- All candidate supply routes are sequentially applied to the LP model to find the optimal solution in 2030.

- BAU case in 2040, where the supply method in the optimal solution in 2030 continues
- All candidate supply routes are sequentially applied to the LP model to find the optimal solution in 2040.

2.1 Case studies in 2030

1) BAU case in 2030

The BAU case in 2030 reflects the existing petroleum supply chain applied by oil companies in Cambodia. It means that there will be no railway improvement, no highway use, no pipeline, no pipeline import from Thailand or Viet Nam. Due to the limited capacity of the Mekong River terminal route, delivery volume from Sihanoukville will increase significantly (2,330,455 kl+1,000,000 kl). As a result, direct delivery from Sihanoukville will be accounted for at 50.9%, followed by from Sihanoukville to the Phnom Penh hub at 21.8%. The storage capacity of the Sihanoukville terminals is enough, but shipping lanes and shipping frequency must be increased. On the other hand, direct delivery from the Mekong River terminals will be at 14.2% (9.2%+5.0%) (Table 6.5). In 2030, the major transport mode for transporting petroleum products to each provincial capital will still be tank-trucks.

Table 6.5. BAU Case in 2030

kl/year	%	Supply Route
422,843	9.2	Direct from Mekong
227,157	5.0	From Mekong via Battambang hub
2,330,455	50.9	Direct from Sihanoukville
480,000	10.5	From Sihanoukville to PP hub, Railway
120,000	2.6	From Sihanoukville to BB hub, Railway
1,000,000	21.8	From Sihanoukville to PP hub, Tank truck
4,580,455	100.0	Cost: US$ 234,329,081 $

Supply Volume to Each Area by Supply Route

Supply Route	Around PP	West Area	Northeast	SV Direct	Total
Direct from Mekong	0	168,495	254,348	0	422,843
From Mekong via Battambang hub	0	227,157	0	0	227,157
Direct from Sihanoukville	1,935,740	0	0	394,714	2,330,455
From Sihanoukville to PP hub, Railway	365,177	114,823	0	0	480,000
From Sihanoukville to BB hub, Railway	0	120,000	0	0	120,000
From Sihanoukville to PP hub, Tank truck	287,320	414,641	298,039	0	1,000,000
Total	2,588,237	1,045,116	552,387	394,714	4,580,455

kl = kilolitres.

Source: Author.

2) SV-PP pipeline case in 2030

This case study reflects a pipeline system between SV and PP. Transfer volume via the SV-PP pipeline is over 3.0 MM kl and unit cost is 10.4$/kl. Since the SV-PP pipeline has strong cost competitiveness if the transporting amount is large such as more than 2 million kl, transfer from SV to PP by tank-trucks will be zero and direct delivery from SV by tank-trucks will decrease. And the total transportation cost as the objective function is –9.7% compared with the BAU case.

Table 6.6. SV-PP Pipeline Case in 2030

kl/year	%	Supply Route
422,843	9.2	Direct from Mekong
227,157	5.0	From Mekong via Battambang hub
293,212	6.4	Direct from Sihanoukville
480,000	10.5	From Sihanoukville to PP hub, Railway
120,000	2.6	From Sihanoukville to BB hub, Railway
3,037,243	66.3	From Sihanoukville to PP hub, Pipeline
4,580,455	100.0	Cost: US$ 211,617,923 $

Supply Volume to Each Area, by Supply Route

Supply Route	Around PP	West Area	Northeast	SV Direct	Total
Direct from Mekong	118,940	229,347	74,555	0	422,843
From Mekong via Battambang hub	0	227,157	0	0	227,157
Direct from Sihanoukville	0	0	0	293,212	293,212
From Sihanoukville to PP hub, Railway	480,000	0	0	0	480,000
From Sihanoukville to BB hub, Railway	0	120,000	0	0	120,000
From Sihanoukville to PP hub, Pipeline	1,989,297	468,612	477,832	101,502	3,037,243
Total	2,588,237	1,045,116	552,387	394,714	4,580,455

kl = kilolitres.

Source: Author.

3) Optimal solution case in 2030

This case study reflects that all of the railway capacity would be allocated to the BB hub terminal. Railway is cost-competitive for transportation to the west area. When 600,000 kl of petroleum products would be transferred from the SV to the BB hub, the transport cost from the Mekong River terminal to the BB hub terminal will decrease to zero, and the decreased volume will be transferred to direct delivery from the Mekong River terminal for a total of 650,000 kl. And the total transportation cost will be –12.5% compared with BAU case. This is optimal case in 2030.

Table 6.7. Optimal Solution Case in 2030

kl/year	%	Supply Route
650,000	14.2	Direct from Mekong
0	0.0	From Mekong via Battambang
293,212	6.4	Direct from Sihanoukville
0	0.0	From Sihanoukville to PP hub, Railway
600,000	13.1	From Sihanoukville to BB hub, Railway
3,037,243	66.3	From Sihanoukville to PP hub, Pipeline
4,580,455	100.0	Cost: US$ 205,456,148 $

Supply Volume to Each Area, by Supply Route

Supply Route	Around PP	West Area	Northeast	SV Direct	Total
Direct from Mekong	438,537	211,463	0	0	650,000
From Mekong via Battambang hub	0	0	0	0	0
Direct from Sihanoukville	0	0	0	293,212	293,212
From Sihanoukville to PP hub, Railway	0	0	0	0	0
From Sihanoukville to BB hub, Railway	0	600,000	0	0	600,000
From Sihanoukville to PP hub, Pipeline	2,149,701	233,652	552,387	101,502	3,037,243
Total	2,588,237	1,045,116	552,387	394,714	4,580,455

kl = kilolitres.

Source: Author.

2.2 Case studies in 2040

1) BAU case in 2040

The demand for gasoline and diesel oil will increase 1.7 times from 2030 to 7.8 MM kl.

BAU case in 2040, when the supply means of optimal solution case in 2030 will continue, the SV-PP pipeline will reach 4.2 MM kl (max capacity) and direct delivery from SV will be over 2.3 MM kl, which will be big volume.

Table 6.8. BAU Case in 2040

kl/year	%	Supply Route
627,537	8.0	Direct from Mekong
22,463	0.3	From Mekong via Battambang
2,348,740	30.1	Direct from Sihanoukville
0	0.0	From Rayon to BB hub, Pipeline
600,000	7.7	From Sihanoukville to BB hub, Railway
4,200,000	53.9	From Sihanoukville to PP hub, Pipeline
7,798,740	100.0	Cost: US$ 350,555,051 $

Supply Volume to Each Area, by Supply Route

Supply Route	Around PP	West Area	Northeast	SV Direct	Total
Direct from Mekong	0	627,537	0	0	627,537
From Mekong via Battambang	0	22,463	0	0	22,463
Direct from Sihanoukville	1,677,167	0	0	671,573	2,348,740
From Rayon to BB hub, Pipeline	0	0	0	0	0
From Sihanoukville to BB hub, Railway	0	600,000	0	0	600,000
From Sihanoukville to PP hub, Pipeline	2,650,473	602,666	946,861	0	4,200,000
Total	4,327,640	1,852,666	946,861	671,573	7,798,740

kl = kilolitres.

Source: Author.

2) Enhanced Mekong River terminal and enhanced railway case in 2040

An enhanced Mekong terminal means expanded storage capacity and receiving large oil tankers with 5,000 tonnes; the maximum supply amount will be 1.3 MM kl. And we assumed US$7 cost down from the existing Mekong River terminal. An enhanced railway can transport 1.2 MM kl/y due to improvement, and contribute to the West area demand by allocating all the capacity to the BB hub. So then, the direct delivery volume will decrease to 1.1 MM kl. As a result, the total transportation cost will be 4.7% compared with the BAU case. This is the optimal case in 2040.

Table 6.9. Enhanced Mekong River Terminal and Railway Case in 2040

kl/year	%	Supply Route	
1,300,000	16.7	Direct from enhanced Mekong	
0	0.0	From enhanced Mekong via Battambang	
1,098,740	14.1	Direct from Sihanoukville	
1,200,000	15.4	From Sihanoukville to BB hub, Railway	
4,200,000	53.9	From Sihanoukville to PP hub, Pipeline	
7,798,740	100.0	Cost: US$	334,078,729

Supply Volume to Each Area, by Supply Route

Supply Route	Around PP	West Area	Northeast	SV Direct	Total
Direct from enhanced Mekong	819,202	44,527	436,271	0	1,300,000
From enhanced Mekong via Battambang	0	0	0	0	0
Direct from Sihanoukville	427,167	0	0	671,573	1,098,740
From Sihanoukville to BB hub, Railway	0	1,200,000	0	0	1,200,000
From Sihanoukville to PP hub, Pipeline	3,081,271	608,139	510,590	0	4,200,000
Total	4,327,640	1,852,666	946,861	671,573	7,798,740

kl = kilolitres.

Source: Author.

3) Possibility of import from Rayong refinery (in Thailand)

The importation by tank-trucks from the Rayong refinery (in Thailand) cannot rule out the possibility of illegal imports, so we excluded it from consideration. On the other hand, the Rayon-BB hub pipeline is cost-competitive because it does not require tanker freight, and it would be effective for the West area. However, we assumed the importable volume from the Rayon refinery would be limited to 1.0 MM kl/y, so the unit cost will increase, and the transport cost will be larger than other means of supply. Therefore, the import from the Rayon refinery by pipeline cannot be feasible.

4) Other result of case studies in 2040

- SV-PP double pipelines

When the enhanced Mekong River terminal and enhanced railway would not be realised, an additional SV-PP pipeline was considered.

The transfer volume of SV-PP double pipelines was 5.1 MM kl; it is a small volume and the total transportation cost was +4.3% compared with the BAU case.

- PP-BB pipeline

Since the demand for the West area is 1.9 MM kl, the transfer volume of PP-BB pipeline is small and the unit cost is high. The LP model cannot select PP–BB pipeline because the cost of direct delivery by tank-truck from the PP hub is lower than pipeline.

The above two may be effective when the demand further increases.

- Viet Nam-PP pipeline

We considered of pipeline imports from the Ho Chi Minh or Vung Tau oil terminals in Viet Nam. But the LP model did not select the Viet Nam pipeline because the distance required for the pipeline is more than 300 km, and the cost is higher than the SV-PP pipeline.

3. Conclusions

- The optimal solution for 2030 is the SV-PP pipeline case (Table 6.7).

By allocating all rail transportation to BB in addition to the SV-PP pipeline, the transportation cost to the west area will be reduced and the total transportation cost will be –12.5% compared with the BAU case.

- The optimal solution for 2040 is the SV-PP pipeline, enhanced Mekong River terminal, and enhanced railway case (Table 6.9). And the total transportation cost will be –4.7% compared with the BAU case.

In addition, in this case, all transportation method is domestic.