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EVALUATION OF THE DECENTRALIZED PLANT DISTRIBUTION SYSTEM IN THE LOGISTICS OF THAI CEMENT

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Abstract: Siam Cement Public Company Limited (SCC) faced stiff competition after the economic crisis in 1997, decided to close most of their warehouses for the change of logistics system. SCC presently operates five cement plants located whole regions in Thailand with except of the northeast region where three warehouses are still operated. This plant distribution system can be called the decentralized plant distribution system. Which plant distribution system is more efficient for SCC as the logistics strategy between centralized and decentralized? Based on this background, total logistics costs of both systems are formulated and calculated. In addition, the locations of a single warehouse without plant operation are evaluated using linear programming to minimize total logistics costs, which calculated with and without environmental cost. The results of calculation showed that transportation cost was the most significant cost of the plant distribution system and a decentralized plant distribution system is more efficient.

Key Words: Total logistics costs, Decentralization, Plant distribution system, Warehouse location, Environmental cost

1. INTRODUCTION

Siam Cement Public Company Limited (SCC) was the first cement manufacturer in Thailand established in 1913 and produced cement for more than 40 years (TDRI, 2003). Cement business takes full responsibility for cement and ready-mixed concrete products. It operates five grey cement manufacturing plants throughout Thailand both domestically and internationally. Due to increasing domestic cement demand during 1992 to 1996, many cement manufacturers invested more to increase capacity of cement producing. However, as SCC faced stiff competition after the economic crisis in 1997, they decided to close 39 of their total 42 warehouses to compete with other cement companies for reducing logistics cost. SCC produced cement only 54 and 68 percent of their ability in 2001 and 2003, respectively, which affected to production cost in terms of economy of scale.

SCC ioperates three left warehouses only in the Northeast region of Thailand to store and distribute cement from plants to dealers because there are no manufacturing plants in this region. However, in other regions of Thailand, SCC distributes cement directly from local manufacturing plants to their dealers as shown in Figure 1, because they consider local manufacturing plants are possible to cover whole regions for distributions of cement. This can be called decentralized plant distribution system. In this system, local plants will function as warehouses and controlling production level using historical information and e-Technology, but operating local plants is also required to spend the cost. We think that SCC might have an alternative to close these local plants and concentrate on using three central manufacturing plants for reducing logistics cost. Which plant distribution system is more efficient for SCC as the logistics strategy? This question is the primary purpose of this study.

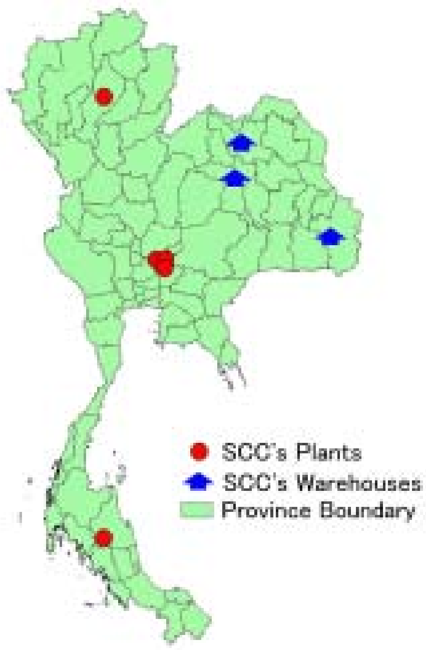

Figure 1. The Warehouse and Plant Locations of SCC (SCG, 2003)

Table 1. Comparison between Decentralized and Centralized Distribution System

System	Advantage	Disadvantage
Centralized distribution system	- High Economy of scale (lower total overhead cost) - Global optimization logistics cost - Low safety stock levels	- High transportation cost from plant to warehouse - High lead time
Decentralized distribution system	- Low transportation cost from plant to warehouse - Low lead time - Local optimization logistics cost	- Few economy of scale (higher total overhead cost) - High safety stock levels

Source: Simchi-Levi *et al*. (2000)

Simchi-Levi *et al*. (2000) compared between the impacts of centralized and decentralized distribution system. The trade-offs between them are summarized as Table 1.

Logistics cost should include social cost regarding accident cost and environmental cost as well as direct cost. Even though logistics cost usually deals with only direct cost, the logistics industry in general is a long way from being considered as an environmental friendly logistics (Brewer *et al*., 2001). To create a long-term sustainable society with the least possible negative environmental impact, environmental issue is very significant.

The purpose of this study is to develop a model that can evaluate optimum solution considering total logistics costs between two plant distribution systems. We also evaluate environmental cost of both plant distribution systems. In case of centralized distribution system, the best location of new single warehouse to minimize total logistics costs is calculated. A case study focuses the south region of Thailand because there are some alternative modes taking cement to implement the different logistics strategies.

2. DEVELOPMENT OF THE EVALUATION METHODOLOGY OF THE PLANT DISTRIBUTION SYSTEM

2.1 Formulation of Logistics Cost

In this section, the methodology of the logistics system is developed to evaluate the total logistics costs of both decentralized and centralized plant distribution system. It is assumed that inventory carrying cost, customer service cost, order-processing cost and lot quantity cost of both distribution systems are approximately the same. These four costs, therefore, are not considered. We conduct the data from annual report of SCC, data from Internet, logistics magazine in Thailand, interview and some questionnaires.

2.1.1 Total Logistics Costs

The existing plant distribution system of SCC is the decentralized system which cement at the south region of Thailand is distributed from local plants to the dealers by trucks. New system is the centralized system. Total logistics costs between decentralized and centralized system are compared due to four major components in this paper. Since characteristics of four costs have to convert to be the same-based year, annual cost is used as based characteristic as follows:

$$TC = Pl + Tr + Wa \tag{1}$$

where: TC, PL, Tr and Wa are total an annual logistics costs, an annual plant cost, an annual transportation cost and an annual warehousing or hubs cost, respectively.

2.1.2 Plant Cost

Plant cost consists of two components regarding operation cost of cement producing and annual depreciation cost. Plant operation cost is calculated as a percentage of selling prices (assumed to be 30 percent of selling price). Depreciation is calculated by straight-line method as follow:

$$Pl_d = \frac{\text{Investment - Salvage}}{n} \tag{2}$$

Since some required data is unknown, three assumptions related to depreciation cost are as follows:

- Life of plant (n) is 10 years
- Salvage value at the last year is 10 percent of investment cost
- Investment cost is obtained from website of Department of Industry Works.

2.1.3 Warehousing Cost

The warehousing cost consists of handling cost, fixed cost and storage cost. The assumptions of a fixed ordering cost are as follows:

- Minimum order is a half of trailer (a maximum load of a trailer is 28 tons).
- The service level specified by the distributor (assumed to be 95 percent).

The formulations of calculation are as follows:

$$\text{Warehousing cost} = \text{Storage cost} + \text{Fixed cost} \tag{3}$$

$$\text{Storage cost} = [K+(W\times h_w \times Inv)]\times 52 \tag{4}$$

$$h_w = \frac{h_a}{52} \tag{5}$$

$$W = \left(\frac{Inv}{AVG_w}\right) \tag{6}$$

$$AVG_w = \frac{AVG_m}{4.3} \tag{7}$$

$$Inv = \left(\frac{Q}{2}\right) + \left(z \times STD_w \times \sqrt{L}\right) \tag{8}$$

$$STD_w = \frac{STD_m}{\sqrt{4.3}} \tag{9}$$

$$Q = \sqrt{\frac{2K \times AVG}{h_w}} \tag{10}$$

$$S = Q + s \tag{11}$$

$$s = (L \times AVG) + \left(z \times STD \times \sqrt{L}\right) \tag{12}$$

$$\text{Inventory turnover Ratio} = \frac{\text{Annual Sale}}{\text{Average inventory level}} \tag{13}$$

where, W: the warehouse keeps stocks (weeks)
h_w: weekly inventory holding cost (baht/week)
h_a: annual inventory holding cost (baht/year)
Inv: the average inventory level (tons)
AVG_w: average weekly demand (tons/week)
AVG_m: average monthly demand (tons/month)
Q: the order quantity (ton)
z: safety factor, z equals 1.65 at service level 95%
L: replenishment lead-time from the supplier to the warehouse (week)
STD_w: standard deviation of weekly demand (tons/week)
STD_m: monthly standard deviation (tons/month)
K: fixed ordering cost (baht)
s: reorder point (tons)
S: the order up to level (tons)
$L \times AVG$: average demand during lead-time (tons/week)
$z \times STD \times \sqrt{L}$: safety stock (tons/week)

Investment cost of new warehouse (5,500 baht/m^2) is calculated according to Thai Appraisal Foundation (TAF, 2003). The size of cement is approximately 0.40x0.60x0.10 m. or 0.024 m^3. The required area to keep cement one bag is multiplied by 1.20 (additional 20 percent) for bagged cement area and operation area such as operation by folk lift or manpower. Finally, in order to calculate the required area of warehouse and fixed cost, 5 meters is assumed to be the height of warehouse. The formulations, therefore, are as follows:

$$\text{Warehouse\_size} = S \times \left(\frac{1{,}000}{50}\right) \times \left(\frac{0.024 \times 1.20}{5}\right) = 0.1152 \times S \tag{14}$$

$$\text{Fixed cost} = \text{Warehouse\_size x } 5{,}500 \tag{15}$$

where, Warehouse_size: the required size of warehouse (m^2)

2.1.4 Transportation Cost

Transportation cost is varied with respect to volume of shipment, weight of shipment, distance of distribution, and points of origin and destination. The surveyed data includes the transportation rate of each vehicle. Simchi-Levi, *et al*. (2000) mentioned that transportation cost could be calculated using transportation rate. Two major modes consisting of freight and ship are related in this paper. Freight is conceived as two types with regard to trailer and truck for distribution from plants to warehouses and from warehouses to dealers, respectively. The transportation cost of freight and ship researched by MOT (2001) are depicted as Table 2 and Table 3, respectively.

Table 2. Relationship between Average Transportation Cost and Distance by Freight

Freight distance (Hauls)	10-wheel truck	18-wheel truck (Trailer)
Short haul	3.04	1.93
Medium haul	1.18	1.22
Long haul	1.15	0.93

Note: Short haul = 1-100 km., Medium haul = 101-400 km. and Long haul = distance is greater than 400 km; Source: MOT (2001)

Table3. Service Cost of Transportation by Ship

Characteristics	Thai Transportation by Water Company Limited	Thai Ship Transportation and Service Company Limited
Weigh of transportation (ton)	200-1,600	500-1,500
Distance (km)	25	250
Transportation cost (baht/ton-km)	0.20	0.23

Source: MOT (2001)

Transportation cost is based on the distance of transportation, load factor of shipment and mode of transportation calculated with and without environmental impact as follows:

$$Tr_{ij}^{m} = \sum_{m}^{M}\left(t_{ij}^{m} \cdot l_{ij}^{m} \cdot w_{ij}^{m} \cdot c_{ij}^{m}\right) + \sum_{k}^{K}\left(t_{jk} \cdot l_{jk} \cdot w_{jk} \cdot c_{jk}\right) + \sum_{m}^{M}\left(t_{ij}^{m} \cdot l_{ij}^{m} \cdot w_{ij}^{m} \cdot e_{ij}^{m} \cdot \varepsilon\right) + \sum_{k}^{K}\left(t_{jk} \cdot l_{jk} \cdot w_{jk} \cdot e_{jk} \cdot \varepsilon\right) \tag{16}$$

where, Tr_{ij}^{m}: transportation cost depended on mode of transport; truck, rail or ship

m: transportation mode

i: plant

j: potential warehouse site

k, K: dealer k to dealer K

m, M: transportation mode m to mode M

c_{ij}^{m}, c_{jk}: unit cost of delivering d_{ij} and d_{jk} units on mode m (baht/km/ton)

d_{ij}, d_{jk}: demand between i, j and k (ton)

w_{ij}^{m}, w_{jk}: net weight of delivering cement on mode m between i, j and k (ton/trip)

l_{ij}^{m}, l_{jk} : distance of delivering on mode m between i, j and k (km)
t_{ij}^{m}, t_{jk} : a number of vehicles or ships delivering cement between i, j and k (trip)
e_{ij}^{m}, e_{jk} : CO_2 emission rate on mode m (g-C/km/ton)
ε: unit cost of CO_2 (baht/g-C) in case of environmental cost calculation; otherwise ε equals zero

Four terms of right hand side of equation (16) are explained as follows:

- The first term is cost of cement distribution which means that cement products are distributed from the plant in the central region to the warehouse in the south by one mode or inter modal.
- The second term is cost of cement distributed by trucks from warehouse to dealers.
- The third term and fourth term is environmental cost of distribution which is similar to the first term.

2.2 Environmental Cost

CO_2 from both cement manufacturing process at plant and transportation are considered to be the main source of air environment of cement business. This paper, therefore, considers CO_2 emission, which conversion factor of CO_2 is 49.1 g-C/baht according to PCD (2003) based on year 2000.

2.2.1 Environmental Impacts from Plant

CO_2 is a by-product of a chemical conversion process used in the production of clinker. CO_2 is not emitted during cement production (Gibbs *et al*., 2003). CO_2 emission resulting from plant operation can be obtained from two ways. Firstly, raw data is obtained from plants. Secondly, data is estimated as recommend by Gibbs *et al*. (2003) that equal 0.507 tons of CO_2/ton of clinker. As a result, the IPCC Guidelines provided a general approach to estimate CO_2 emissions from clinker production, in which the amount of clinker produced, is multiplied by an emission factor.

2.2.2 Environmental Impacts from Transportation

CO_2 emissions associated with fuel consumption are estimated using formulation from Ooishi (1996) considering speed and type of vehicles as follows:

For large truck $$f_c = \frac{539.0}{V} - 11.03V + 0.0758V^2 + 587.6 \tag{17}$$

For small truck $$f_c = \frac{544.2}{V} - 1.194V + 0.0117V^2 + 81.2 \tag{18}$$

where, f_c: fuel consumption (cm^3/km)
V: average travel speed of vehicles (km/h)

Then, the CO_2 emissions can be calculated as follow:

$$E_c = f_c \cdot U_c \tag{19}$$

where, E_c: CO_2 emissions (g-C/km)
U_c: CO_2 emissions per unit fuel consumption (g-C/cm^3)

Taniguchi *et al*. (2001) indicated that the typical value of U_c are given as 0.623 and 0.730 g-C/cm^3 for gasoline and diesel, respectively.

2.3 Formulation of New Single Warehouse Location

The new warehouse location can be considered as the centralized plant distribution system. In the case of new single warehouse location, it needs to find suitable location of new single warehouse with the lowest cost. Thus, there are mainly two objective functions in this section. Firstly, in order to minimize total direct costs, three major costs are calculated. Next objective function is to minimize total logistics costs considering environmental cost. The total cost is calculated using linear programming. The assumptions are as follows:

- Every customer can only be served by exactly one warehouse or plant.
- The location of existing plants, the potential warehouse sites and the existing customers (dealers) are known.
- The supply capacities of plant, the capacities of new single warehouse site and the demand of the dealers are also known.
- The summation of the dealer demands does not exceed plant and warehouse capacity.
- The capacity of the potential warehouse site is not less than the total demand.
- The demand of the dealers are produced and transported in the same period.
- Transportation cost depends on distance, amount of transported bagged cement and mode of transport.
- The warehousing cost and the plant cost are constant at every potential warehouse site.

The cost components calculated in this model are as follows:

- The plant cost including operation cost and depreciation cost.
- The transportation cost from plants to warehouse, and from warehouse to dealers
- The warehousing cost including storage cost and fixed cost at the potential warehouse site.

The formulations are as follows:

$$\text{Min} \quad TC_{ij} = Pl_i + Tr_{ij}^m + Wa_j \tag{20}$$

subject to

$$d_{ij} = \sum_{k=1}^{K} d_{jk} \qquad \forall i, j \tag{21}$$

$$t_{ij}^m = \frac{d_{ij}}{f_{ij}^m \cdot w_{ij}^m} \qquad \forall i, j \tag{22}$$

$$t_{jk} = \frac{d_{jk}}{f_{jk} \cdot w_{jk}} \qquad \forall j, k \tag{23}$$

$$d_{ij} \le s_i \qquad \forall i, j \tag{24}$$

$$\sum_{k=1}^{K} d_{jk} \le s_j \qquad \forall j \tag{25}$$

$$f_{ij}^m \le 1 \qquad \forall i, j \tag{26}$$

$$f_{jk} \le 1 \qquad \forall j, k \tag{27}$$

$$m \in M, \quad k \in K \tag{28}$$

where: TC_{ij}: total transportation cost of the distribution system (baht)
f_{ij}^{m}, f_{jk} : load factor of delivering on mode m between i, j and k
s_i, s_j: capacity of plant and warehouse (ton)

Trailers or ships are normally the main mode of cement distribution from plant to warehouse. Trucks are the primary mode to deliver cement from warehouse to each dealer. Constraints (21) to (23) mean demand conservation, a number of trailers or ships, and a number of trucks, respectively. Next, demands are always less than or equal to capacity of plants and warehouse, which are constraints (24) and (25), respectively. Both constraints (26) and (27) mean load factors delivering cement that are always less than or equal one. Finally, the last constraint consisting of m, M, k and K variables represent the first mode of delivery, the maximum number of mode, the first dealer and the last dealer, respectively.

3. EVALUATION OF PLANT DISTRIBUTION SYSTEM OF THAI CEMENT

3.1 Evaluation of Logistics Costs

At the southern region of Thailand, Thungsong plant is the main manufacturing plant satisfied with the demand of this region. Cement is distributed directly from the plant to dealers as illustrated in Figure 2.

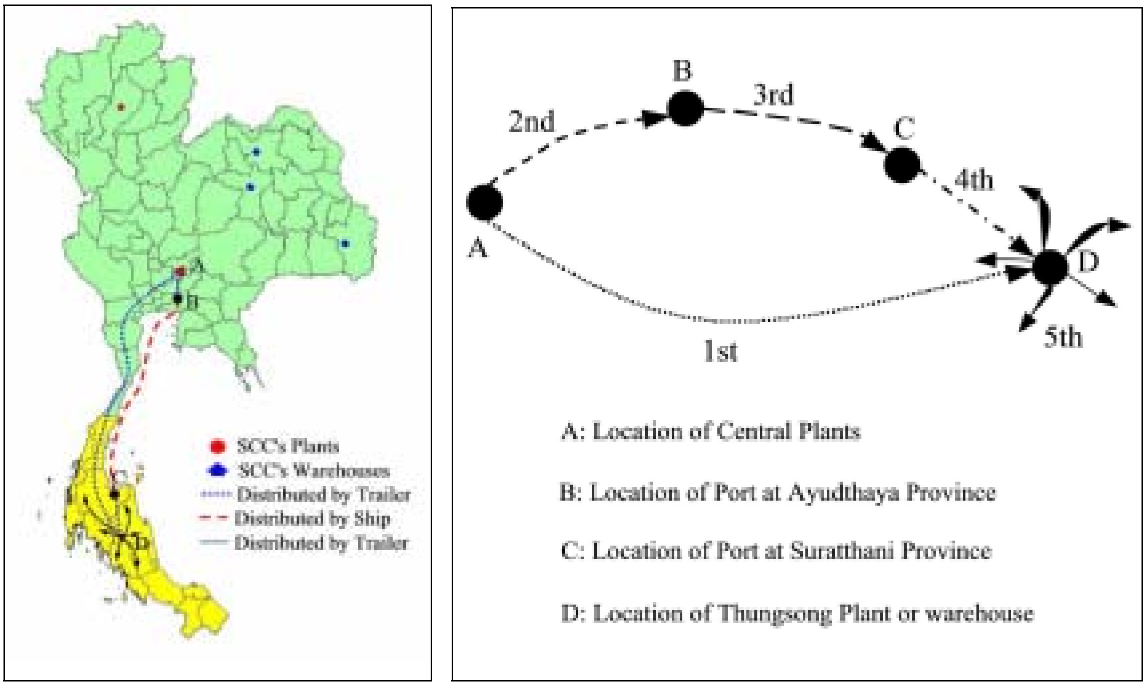

Figure 2. Distribution Routes

Distribution routes in the right hand side of Figure 2 are classified with 5 types as follows:

- The first and the second routes are distributed by trailer from plant to warehouse,
- The first and the second routes are distributed by trailer from plant to port at Ayudthaya Province.
- The third route is distributed by ship from port at Ayudthaya province to Suratthani province.
- The fourth route is distributed by trailer from plant to warehouse.

- The fifth route is distributed by truck from warehouse to dealers.

Four cases are evaluated in this paper. The conditions and assumptions are shown in Table 4 and Table 5, respectively.

Table 4. Conditions of Four Cases

Conditions	Case 1	Case 2	Case 3	Case 4
1. Plant				
- System	Decentralized	Centralized	Centralized	Centralized
- Location	Thungsong (Existing)	Central	Central	Central
- Thungsong plant	Operate	Close	Close	Close
2.Warehouse				
- Location	-	at Thungsong plant	New Location	New Location
3.Transportation				
- Mode	Truck	Trailer and Truck	Trailer and Truck	Trailer, Truck and Ship
- Route	5	1 and 5	1 and 5	2,3, 4 and 5

Table 5. Some Assumptions Related to Four Cases

Assumption	Case 1	Case 2	Case 3	Case 4
1. Plant				
- Operation cost	30% of selling price	25% of selling price	25% of selling price	25% of selling price
- Depreciation cost	Calculate	0	0	0
2.Warehouse				
- Depreciation cost	0	Calculate	Calculate	Calculate
3.Transportation				
- Lead-time	0.5 day	1.5 days	1.5 days	5.0 days

Calculation is based on some assumptions as follows:

- The depreciation cost is calculated by straight-line method.
- Life of plant and warehouse are 10 years.
- The operation cost is 30% of cement products, which is the same value for all strategies. On the other hand, the operation cost is decreased from 30% to 25% of cement price respected to economy of scale concept.
- Lead-time of decentralized plant distribution system is a half-day, 1.5 days and 5 days for truck, trailer and ship, respectively.
- A 10-wheel truck is the main mode for cement distribution from warehouse to dealers and load factor was 0.7.
- Trailers and ships are the main mode for cement distribution from plant to warehouse and their load factor are one.

3.2 Evaluation of Environmental Cost

The additional assumptions on the evaluation of environment cost are as follows:

- Average speed of both trailer and 10-wheel truck for the first and the fifth, respectively, is 60 km/hr. Thus, fuel consumption of 10-wheel truck and trailer are 60.75 and 207.66 cm^3/km, respectively.
- CO_2 emission of diesel is 0.730 g-C/cm^3. CO_2 emission of 10-wheel truck and trailer, therefore, is equal 44.35 and 151.59 g-C/ton/km, respectively. However, these values are bias in case of using in Thailand since these values followed the research in Japan.

CO_2 emission from ship is 10 g-C/ton/km used to calculate environmental cost (MOT, 2002).

CO_2 emission of cement product during manufacturing process is 640.4 kg per cement one ton (SCG, 2003).

3.3 Results

The different operation cost is changed to compare the affect of economy of scale of cement producing. The calculations of direct cost of the same and different operation cost are shown in Table 6. According to Table 6, the new single warehouse locations of all cases are illustrated as Figure 3. The results of calculation of difference operation cost from all cases, which considered CO_2 emission, are shown in Table 7.

Table 6. Total Direct Cost of the Same and Different Operation
(unit: million baht)

Table 6a. The Same Operation Cost

Cost components	Case 1	Case 2	Case 3	Case 4
1.Plant cost				
- Depreciation cost	182.2	-	-	-
- Operation cost	356.95	356.95	356.95	356.95
- Sub total	539.13	356.95	356.95	356.95
2.Transportation cost				
- The first route	-	626.35	514.58	-
- The second route	-	-	-	117.2
- The third route	-	-	-	121
- The forth route	-	-	-	1.94
- The fifth route	228.31	228.31	232.94	230.76
- Sub total	228.31	854.66	747.52	470.88
3.Warehousing cost				
- Storage cost	2.22	2.43	2.43	2.43
- Depreciation cost	-	0.83	0.83	0.83
- Sub total	2.22	3.26	3.26	3.26
Total logistics costs	769.66	1,214.87	1,107.73	831.09

Table 6b. Different Operation Cost

Cost components	Case 1	Case 2	Case 3	Case 4
1.Plant cost				
- Depreciation cost	182.2	-	-	-
- Operation cost	356.95	297.46	297.46	297.46
- Sub total	539.13	297.46	297.46	297.46
2.Transportation cost				
- The first route	-	626.35	514.58	-
- The second route	-	-	-	117.2
- The third route	-	-	-	121
- The forth route	-	-	-	1.94
- The fifth route	228.31	228.31	232.94	230.76
- Sub total	228.31	854.66	747.52	470.88
3.Warehousing cost				
- Storage cost	2.22	2.43	2.43	2.43
- Depreciation cost	-	0.83	0.83	0.83
- Sub total	2.22	3.26	3.26	3.26
Total logistics costs	769.66	1,155.38	1,048.24	771.60

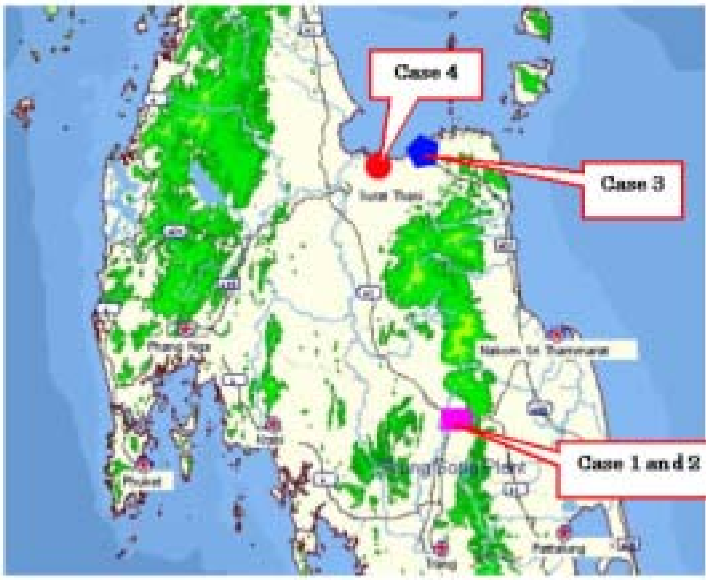

Figure 3. Warehouse Location of All Cases Without Considering Environmental Cost

Table 7. Total Logistics Costs Including Environmental Cost of Different Operation Cost (unit: million baht)

Cost components	Case 1	Case 2	Case 3	Case 4
1.Plant cost				
- Depreciation cost	182.18	-	-	-
- Operation cost	356.95	297.46	297.46	297.46
- CO_2 Cost	8,621.53	8,621.53	8,621.53	8,621.53
- Sub total	9,160.66	8,918.99	8,918.99	8,918.99
2.Transportation cost				
- The first route	-	626.35	252.09	-
- The second route	-	-	-	117.23
- The third route	-	-	-	120.95
- The forth route	-	-	-	1.94
- The fifth route	228.31	228.31	612.85	230.76
- CO_2 Cost	144.72	2,231.17	1,316.90	387.05
- Sub total	373.03	3,085.83	2,181.84	857.93
3.Warehousing cost				
- Storage cost	2.22	2.43	2.43	2.43
- Depreciation cost	-	0.83	0.83	0.83
- Sub total	2.22	3.26	3.26	3.26
Total logistics costs	9,535.91	12,008.08	11,104.09	9,780.18

Table 8. Total CO_2 Emission of Each Activity (unit: million kg-C)

Location	Case 1	Case 2	Case 3	Case 4
1. Plant	423.32	423.32	423.32	423.32
2.Transportation				
- The first route	-	102.10	41.09	-
- The second route	-	-	-	5.26
- The third route	-	-	-	5.26
- The forth route	-	-	-	0.15
- The fifth route	7.11	7.11	23.57	8.33
- Sub total	7.11	109.21	64.66	19.00
Total	430.43	532.53	487.98	442.32

The assumptions calculated in Table 7 are the same as calculation only direct cost. Although economy of scale of cement producing calculated previously is from labor cost, CO_2 emission from cement producing is not affected by economy of scale. CO_2 emissions for all cases, therefore, are the same. Table 8 is illustrated the CO_2 emission of each activity related to cement producing and cement delivering. Figure 4 shows the new single warehouse location of all cases from the results of Table 7.

3.4 Summary and Discussion of the Results

The centralized plants system or case 2 of Table 6a is viewed as reducing depreciation cost from plants investment. Depreciation cost of case 1 is neglected or it is zero that the plant cost

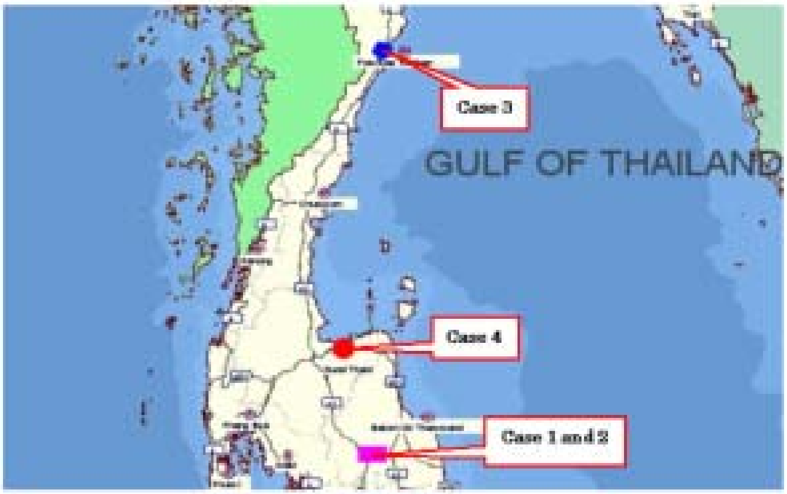

Figure 4. Warehouse Location of All Cases With Considering Environmental Cost

is reduced by 182,182,000 baht. However, the transportation cost is increased by 626,354,000 baht, which is approximately 3.5 times of depreciation cost. As a result, the decentralized plant system acquires advantages from cutting down this transportation cost.

Comparing between case 2 and case 3 of Table 6a, the transportation cost of the new single warehouse is less than that of warehouse located at the same location with plant by 107,140,800 baht or 12 percent of the transportation cost of case 2. However, a total logistics cost of case 3 is greater than case 1 by 338,070,000 baht or 44 percent.

Although the transportation cost of case 4 of Table 6a is less than case 2 by 383,776,000 baht or 45 percent of transportation cost of case 2, total logistics cost of case 4 is greater than case 1 by 61,436,000 baht or 8 percent. Distribution system of case 4, therefore, can reduce much transportation cost.

Considering the economy of scale of case 4 of Table 6a, although its operation cost is decreased due to economy of scale, the total cost of case 4 is greater than case 1 by 1,944,000 baht or 0.3 percent of case 1.

Total logistics costs can be mainly minimized by transportation cost, while other costs of case 3 are not changed. Transportation cost consists of two parts as transportation from plant to warehouse and from warehouse to dealers. The former is constant as 0.93 baht/km/ton. In contrast, the latter varied by distance as 3.04, 1.18 and 1.15 baht/km/ton, is more significant than the former. Thus, the new single warehouse location without environmental cost as Figure 3 is valid since its location is the center of all dealers.

The cost concept of the case 4 is as same as the case 3. The new single warehouse location calculated only direct cost as Figure 3 is valid since its location is the center of all dealers and near port at Suratthani province in order to minimize transportation cost.

To minimize direct cost including environmental cost, the best location of new single warehouse must minimize distance of distribution too. Obviously, CO_2 emission from trailer is much higher than truck. Decreasing distance by trailer is more significant than truck. The warehouse location of case 3 as Figure 4 is near the first boundary and valid, since the more transportation is the more CO_2 emission.

Finally, the warehouse location of case 4 is also located near the port as Figure 4, since cement is distributed to port at Suratthani province before delivering to warehouse. In order to minimize environmental cost and logistics cost, warehouse location should be the center of dealers and near port. Thus, based on the same conceptual thinking as case 3, this warehouse location was valid.

4. CONCLUSION

This paper evaluated both centralized and decentralized plant distribution system of SCC. The system changing from decentralized to centralized plant distribution is not recommended since total logistics costs of centralized system and CO_2 cost are higher than that of the decentralized system. The decentralized plants system takes advantages from cutting down transportation cost. Although the economy of scale of cement producing is taken account in logistics cost by decreasing operation cost of cement five percent of selling price each ton, it is negligible compared with higher transportation cost.

The concept of decentralized or centralized plants system might be used to view the overall logistics cost of companies for decision making whether they should change the system.

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