

RESEARCH PAPER

Facility Location Modeling in Multi-Echelon Distribution System: A Case Study of Indonesian Liquefied Petroleum Gas Supply Chain

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Abstract -This paper presents model of Indonesian LPG supply chain by opening new facilities (new echelon) taking into account the current facilities. The objective is to investigate the relation between distribution costs such as transportation, inventory cost and facility location in Indonesian multi-echelon LPG supply chain. Fixed-charged capacitated facility location problem is used to determine the optimal solution of the proposed model. In the sensitivity analysis, it is reported that the trade-offs between facility locations and distribution costs are exist. Results report that as the number of facility increases, total transportation and inventory cost also increase.

Keywords: LPG supply, location, inventory, transportation

Introduction

The Liquefied Petroleum Gas (LPG) supply chain in Indonesia can be divided into four echelons as shown in Figure 1. In the Indonesian LPG network, PERTAMINA manages the LPG supply chain from LPG procurement from the first echelon (refineries) to the fourth echelon (end-customers) of distribution system. It is also included the LPG transporters in each echelon, the storage facilities and the LPG stocks (Pertamina, 2007). Since the conversion program was ruled, the LPG demand between 2008 and 2010 in Indonesia has almost doubled from 2.6 million metric tonnes to 5.5 million metric tonnes (Potten and Partners, 2011). The current Indonesian LPG distribution system indicates that there is LPG shortage and scarcity at the consumers' end despite there is an excessive LPG production. Pertamina (2007) reported that it produces 0.4 million metric tonnes (annually) of LPG higher than the actual demand, however, in fact the shortage and scarcity still occurs. For example, the Indonesian Government reported that in September 2008, January 2009 and January 2012, the level of LPG's stocks were in a critical level which increase the price of LPG by 10 – 30% of normal price. Therefore, the current problem of satisfying demand is not on the level of production but on the efficient distribution system of LPG from the existing refineries to the end consumers. The purpose of this research are to develop and suggest efficient LPG distribution systems taking into account inventory and transportation decisions which will improve the customer service and minimise the overall distribution cost.

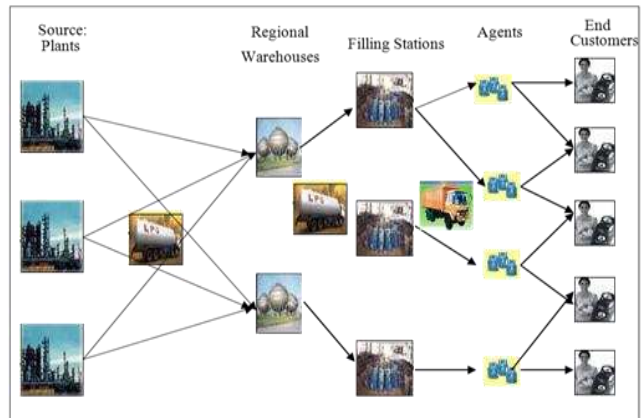


Figure 1. LPG distribution system (Pertamina, 2007)

In term of combining transportation and inventory decisions into location-allocation in multi echelon distribution system, previous research proved that these components need to be considered in modeling distribution facilities. The reason is due to high-dependency among facility location, inventory and transportation decisions (Sirisoponsilp, 1989; Nozick and Turnquist, 2001a; Shen and Qi, 2007). The implications of this involvement to the decisions in selecting facility locations are more significant when the structure of supply chain system and the hierarchy of physical distribution are multi-echelon and multi hierarchy system (Narulla, 1984).

Previous researchers considered facility location problems with transportation decisions or facility location problem with inventory decisions costs, however integration among them in a simultaneous multi-echelon and multi-hierarchy location-allocation models have not given much attention (Sahin and Sural, 2007). Melo (2009) noted that most of location-allocation problem discussed (alone or integrated) productions and inventory. Moreover, in term of the structures of the echelon, it is noted that more than 80% of location-

allocation research dealt with single echelon structure (Sahin and Süral, 2007). Also, other research was also generally assumed that the assignments of customers clearly follow the flow of hierarchical assignment flow.

In term of the application of multi-echelon facility location-allocation, it is noted that location-allocation was applied in various areas such as health care system (Rahman and Smith, 2000, Okabe *et al.*, 1997, Shen *et al.*, 2003) and manufacturing-distribution center (Ya Peng, 2011; Ya Peng and Yi Zhong, 2007b; Ya Peng and Yi Zhong, 2007a). However, there is a limited research in applications of multi echelon's location-allocation problem on LPG combining transportation and inventory decisions has been done previously. Prior LPG research has focused on efficient facility location based on transportation costs (Fölsz *et al.*, 1995; Van Roy, 1989).

This paper models facility location-allocation in multi-echelon considering transportation and inventory decisions taking into account the existing facilities and find the optimum facility locations and customer's allocations. In this research, the case study on LPG distribution system in Indonesia covers four echelons structures and considers intra echelon supply. The inventory model is developed based (Q, R) system with certain demand and service level, while transportation model is developed based on echelons involved find optimum solution based on the service level applied in the proposed distribution system. The sensitivity analysis is used to investigate the implications of the variables changes as facility locations, projected demand and service level on costs associated to developed location-allocation model.

Examining the problems of current distribution system and the literature in optimization location-allocation decisions in logistics system leads to design an optimal distribution system considering transportation and inventory decisions. This study has the objectives to model LPG's distribution system optimally to improve the customer service by locating optimally the location of new facilities (regional warehouses and feeder filling. Then it is followed by investigating the impacts of inventory and transportation decision to location decision in Indonesia LPG's distribution network.

Materials and Methods

Mixed Integer Linear Programming (MILP) is used to formulate the capacitated location-allocation model and Branch and Bound procedures is applied to solve the problem. The data is collected from the current Indonesian LPG distribution system which consists of 2 potential RWs, 52 potential FFSs and 52 FSs and 500 agents. LINGO package is used to solve the mathematical formulation in this model.

The idea is to develop the Feeder Filling Stations (FFS) located in the current Filling Stations (FS). Proposed FFS are supplied by the Regional Warehouses (RW) and will feed FS and Agents. The Capacitated Multi-Flows and Multi-Echelon Distribution Network (CMF-MEDN) is applied in the proposed distribution system. Given a distribution network with three distribution tiers in which tier 1 represents the LPG supply from RW (o) to FFS (i), tier 2 represents the flow from FFS (i) to FS (j) and the last tier represents the supply from FS (j) to Agent (k). In addition, FFS (i) may supply LPG directly to Agent (k).

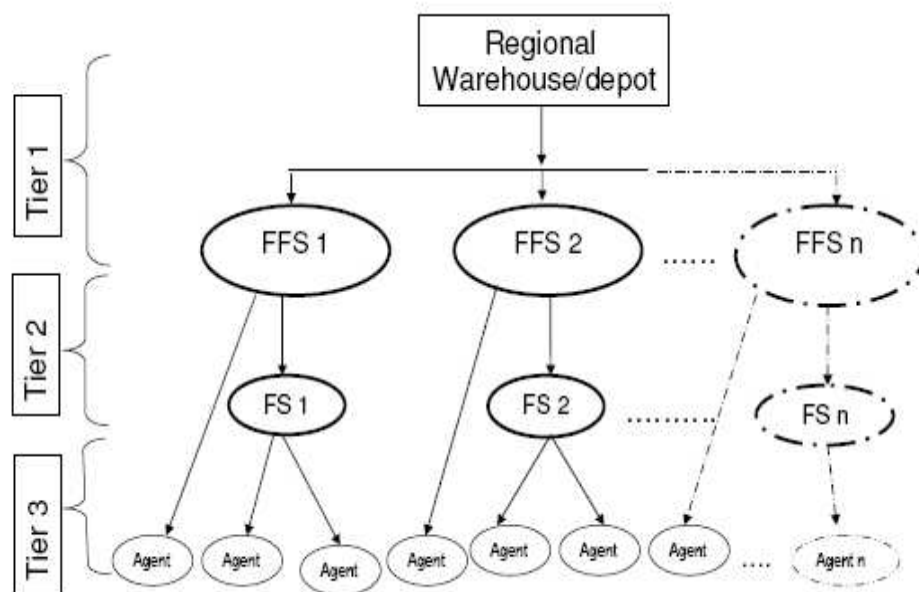


Figure 2. The proposed LPG hierarchical distribution system

The paper models four echelons of LPG distribution system from RW to agent. As shown in Figure 3, the inventory, transportation and fixed costs are modeled together to optimize RW and FFS locations simultaneously. The location-allocation model in this research as follows:

Index

O = sets of RW ($|O| = o, m \in O$)

I = sets of FFSs ($|I| = i, \ell \in I$)

J = sets of FSs ($|J| = j, k \in J$)

B = sets of agents ($|B| = b, p \in B$)

Decision Variables

$W_m = 1$ if the potential point of m for RW is located
= 0, otherwise

$V_\ell = 1$ if the potential point of l for FFS is located
= 0, otherwise

X_{kl} = allocation of FS k that is supplied by FFS l

Y_{lm} = allocation of FFS l that is supplied by RW m

Z_{lp} = allocation of agent p that is supplied by FFS l

Parameters

S_m = capacity of RW m

S_l = capacity of FFS l

C = transportation cost per unit

d_{kl} = distance between FFS l and FS k

d_{lm} = distance between FFS l and RW m

F_m = fixed cost for opened RW m

F_l = fixed cost for opened FFS l

D_{kl} = demand from FS k to FFS l

D_{lm} = demand from FFS l to RW m

$$\begin{aligned} \text{Min} Z = & \sum_{\ell=1}^i \sum_{k=1}^j C \cdot d_{k\ell} \cdot X_{k\ell} + \sum_{\ell=1}^i \sum_{m=1}^o C \cdot d_{\ell m} \cdot Y_{\ell m} + \sum_{\ell=1}^i F_{\ell} \cdot V_{\ell} + \sum_{m=1}^o F_m \cdot W_m + H \sum_{\ell=1}^i \left(\frac{Q_{\ell}}{2} + R_{\ell} - L_{\ell} \cdot X_{k\ell} \right) + \\ & H \sum_{m=1}^o \left(\frac{Q_m}{2} + R_m - L_m \cdot Y_{\ell m} \right) \end{aligned} \quad (1)$$

Subject to:

$$\sum_{k=1}^j \sum_{\ell=1}^i X_{kl} \geq D_{\ell} \quad \forall_{ij} \quad (2)$$

$$\sum_{\ell=1}^i \sum_{m=1}^o Y_{\ell m} \geq D_m \quad \forall_{io} \quad (3)$$

$$\sum_{p=1}^B \sum_{\ell=1}^i Z_{\ell p} \geq D_p \quad \forall_{ip} \quad (4)$$

$$\sum_{\ell=1}^i \sum_{m=1}^o Y_{\ell m} \leq S_m \cdot W_m \quad \forall_{\ell m} \quad (5)$$

$$\sum_{\ell=1}^i \sum_{k=1}^j \sum_{p=1}^B X_{k\ell} + Z_{\ell p} \leq S_{\ell} \cdot V_{\ell} \quad \forall_{k\ell p} \quad (6)$$

$$W_m \in \{0,1\} \quad \forall_m \quad (7)$$

$$V_{\ell} \in \{0,1\} \quad \forall_{\ell} \quad (8)$$

In equation (1), the first and second term represent transportation costs from RW to FFS and from FFSs to Agents. The third and fourth term is fixed operating cost in term of RW and FFS decisions. The fifth and sixth expressions represent inventory costs in the opened FFSs and RWs. Equation (2) represents FFS l demand constraint for allocation of FS k. Equation (3) represents RW l demand constraint for allocation of FFS l. Expression (4) represents FFS l demand constraint for allocation of agent p. Constraint (5) represent regional warehouse capacity. Expression (6) is represents a link between FFS, FS and agent and equation (7) and (8) are the integer constraints.

Results and Discussion

The optimum result shows that RW 1 should be opened to cover 20 potential FFSs, 52 FSs and 52 agents' cluster demand. The optimum objective is reached at iteration 83,769. The optimum results also found the locations of potential FFSs simultaneously as the extension of FS facilities. Figure 4 shows the potential FFSs

which are recommended to open as FFS and the LPG assignments from RW 1 to FFS candidates. It is reported that the proposed distribution system of 2 potential RWs, 52 potential FFSs and 52 agents recommends to open 20 FFS candidates.

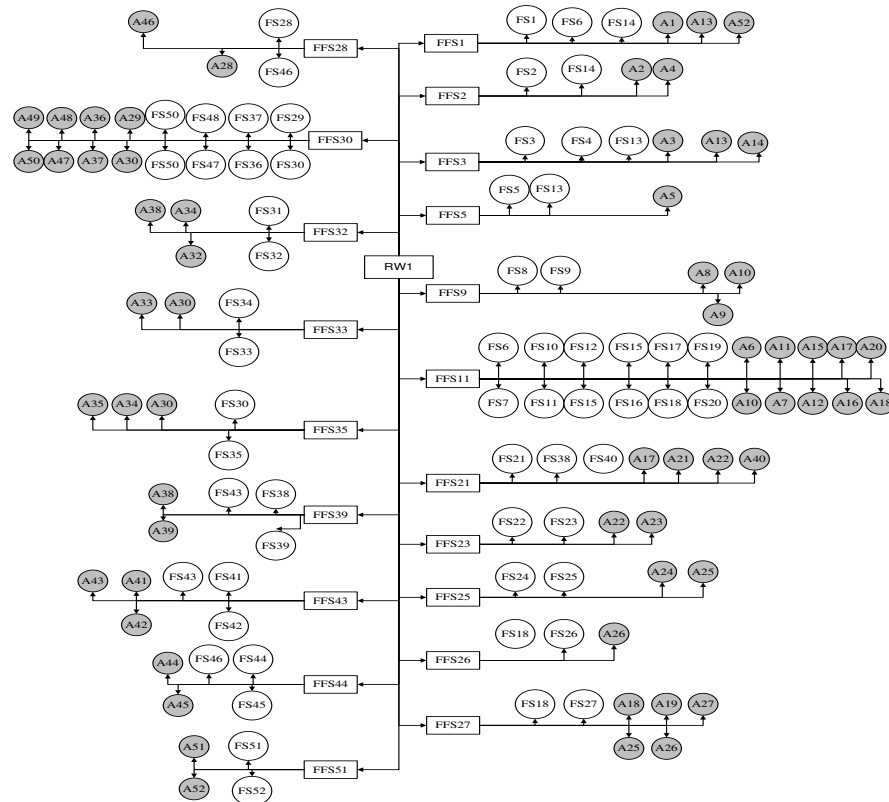


Figure 3. Recommended FFSs and LPG assignment

The locations of potential RW, FFSs, FSs and agent for the model of 2RW-52FS-52A in the optimal result can be shown in Figure 3. The figure shows the LPG distribution network from RW 1 to agent clusters. It is shown that the potential FFSs supply LPG to FSs and A. The LPG assignments indicate that some FSs could be supplied by more than one potential FFS. For instance, the LPG demand of FS 14 is supplied by both FFS 1 and 2. This also occurs in the agent level that some agent clusters are supplied by one or more facilities. The output of the optimal solution reported that the costs associated to the proposed distribution are lower than the associated costs in the existing distribution system. Table 1 presents the gap of the associated costs between the optimal outputs of the proposed the existing distribution system. It is noted that there is US\$ 106.57 million saving per year of total cost by applying the proposed distribution system. It is followed by inventory cost that reduces by 11 per cent per year.

Table 1. Associated distribution costs in optimal vs existing distribution system

Cost item	Existing distribution (US\$ million/year)	Optimal solution (US\$ million/year)	Gap (US\$ million/year)
Fixed cost	6.80	1.13	5.6
Inventory cost	201	178.3	22.7
Transportation cost	4,941	4,863	78
Total cost	5,149	5,042	106.57

The Implications of Facility Adjustment

Based on the results, the number of potential facility affects exponentially to total costs in different number of FFS candidates. It is indicated that the outputs of this research are consistent with previous research reported that there is a relationship between facility location decisions and inventory and transportation costs

(Nozick and Turnquist, 1998, 2001a). The location adjustment tries to compare the changes of FFSs' locations that impact on the LPG allocation from regional warehouse and their LPG allocations to FSs and agent clusters.

The implications of facility adjustment to associated costs of location-allocation model are shown in Figures 4a-4d. Figure 4a shows the trade-off between the adjusted number of FFSs and the number of LPG shortage (tonnes per year) occurs in echelon 3. It is shown that the number of opened facility impacts on the number of LPG shortage in the distribution system. The shortage is calculated by comparing total existing demand in echelon 3 and LPG allocation from opened FFSs to FSs. The figure indicates that the more facilities are recommended to open; the less number of shortages in FSs. For example, total LPG shortages in echelon 3 and 4 reach 0 tonnes of LPG per year with 20 FFSs and jumps to 14,404 tonnes of LPG shortage per year in 18 FFSs.

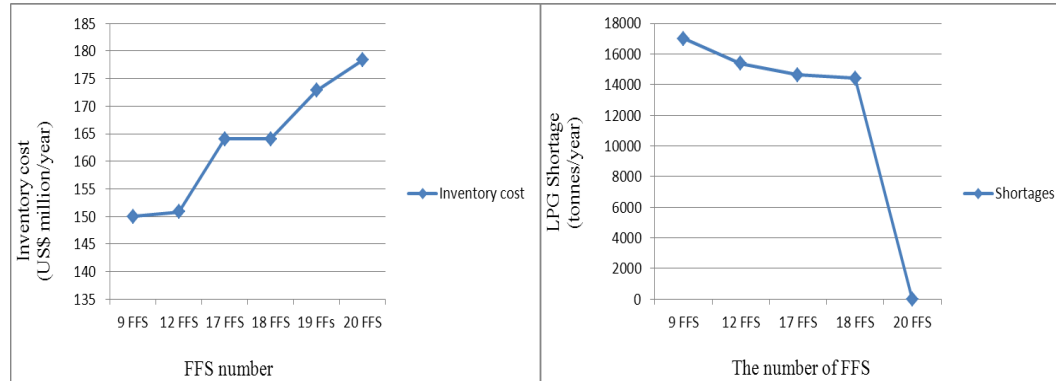


Figure 4a. Number of FFS vs. shortage

Figure 4b. Number of FFS vs. inventory cost

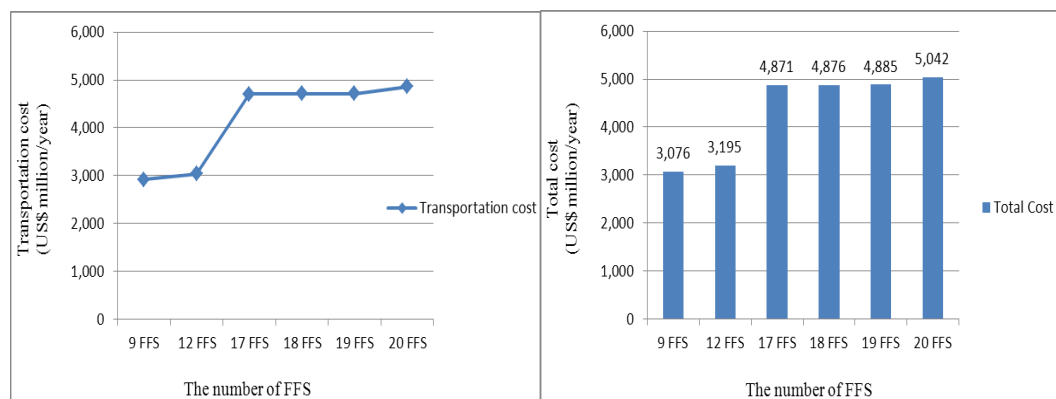


Figure 4c. number of FFS vs. transportation cost

Figure 4d. FFS number vs. total cost

The sensitivity analysis results show that there is a trade-off between inventory cost and the number of potential FFSs. In this study, holding inventory cost is assumed as a constant value which is US\$ 138 per tonne per year. Figure 4b presents the inventory cost based on the number of FFSs. It is reported that the inventory cost increase as the number of FFS increases. It means that more inventories are required as the more number of facilities are recommended to open. Conversely, the less number of facilities, the fewer inventories is required to serve demands.

The significant influence of transportation factors in making decisions about selecting facility location has been investigated by Escalante and Maier-Speredelozzi (2008) and Daskin *et al.* (2003). It is relevant with the results in the sensitivity analysis of this study which found that the trade-offs between the number of FFS and transportation cost is exist. Transportation cost is calculated along the echelons with different number of FFS opened in the distribution system. Total transportation costs tend to increase as the number of potential FFS increases. These costs are calculated based on the volume of LPG transported to echelon 2 and echelon 3 and distance between facilities. The final results revealed that the more FFSs operate in the system, the higher expenses for transportation costs. For instance, by opening 9 FFSs in the proposed distribution system, total transportation cost reach US\$ 3,076 million per year and increases significantly by 36.85 per cent to US\$ 4,871 million as the number of FFSs increase by 6 FFSs.

Total costs in this research is determined by totaling variable costs involved in the model such as fixed costs, inventory and transportation costs. The output of the model indicates that total costs in the model increase significantly as the number of potential FFS increases (see Figure 4d). For instance, total cost of the proposed

distribution system reach US\$ 3,076 million when 9 FFSs are opened and top up to US\$ 5,042 million as 20 FFS are recommended to open in the proposed distribution system.

Service level

The uses of the service level are common in production-distribution and location-allocation problems. Prior research using different levels of service in the location-allocation problem was carried out by Jeffery, Butler and Malone (2008) and Miranda and Garrido (2009). In this sensitivity analysis, an investigation of the changes of service level at echelon 4 is made to explore the implication to the proposed distribution model. The changes of demand fulfillment rate are modified from constraint number 4:

$$\sum_{p=1}^B \sum_{\ell=1}^I Z_{\ell p} \geq dr.D_p$$

dr = demand fulfillment rate for echelon 4

The results show that there are significant implications of the service level changes on the global optimal, the potential facility locations and LPG allocations from the potential regional warehouse to agents. Consequently, the costs involved in the model such as fixed cost, transportation and inventory also changes. The following sections explore the implications of LPG allocation rate (service level) adjustment in echelon 4 on associated distribution costs. The adjustment of the proportion of LPG allocation to echelon 4 has the implications on total shortages in the distribution system.

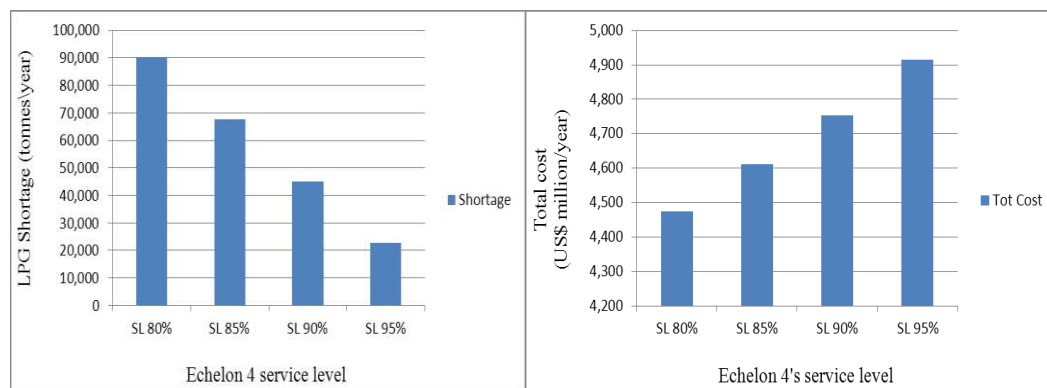


Figure 5a. service level vs. shortages

Figure 5b. Service level vs. total cost

There is trade-off between the changes of echelon's service level and total shortage in the distribution system. It is noted that the increasing service level in the echelon 4 lead to increase total shortage in the distribution system (Figure 5a). The implication of the allocation adjustments also occurred on total cost. This implication is caused by the changes of the LPG allocation from the potential FFS to FS and agent. Figure 5b describes the implication of service level on total distribution costs. It is noted that the higher reduction of service level at echelon 4 results a higher total distribution costs. For instance, in 80 per cent service level in echelon 4, total distribution costs reach US\$ 4,474 million per year.

Conclusions

A new distribution system with direct and indirect LPG supplies from the potential FFS candidates to FSs and agents clusters has been proposed. A capacitated four echelons location-allocation model has been presented by integrating fixed, inventory and transportation costs. The proposed location-allocation model has been developed as mixed-integer programming with the objective to minimize total distribution costs and constrained by capacity, demand in each facility and supply-demand link between facilities at each echelon. Our conclusion is that the integration of transportation and inventory costs has a significant implication on total costs which is the objective of this location-allocation problem. The result shows that a regional warehouse and 20 potential FFSs need to be opened for the proposed distribution system for the optimal solution. Comparing to the existing distribution system, it provides better customer service level with the lower distribution cost.

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