1. Introduction

In this paper, we study the impact of pricing decisions and demand management on logistics network design. We consider a two-echelon network that consists of a hub and multiple warehouses. We assume the demand at each customer location is known and we can segment the customers into two demand classes, based on their delivery lead time (LT) requirements. Customers requiring a short delivery LT must be served from the local warehouse; customers requiring long delivery LT can be served from the hub, usually located further away. Due to substantial savings in the logistics costs by serving customers directly from the hub, we offer price discounts to entice customers to accept a long (rather than short) delivery LT.

We use a single-location model with one hub and one warehouse as a building block for larger networks. For the single-location model, we compare the net profit from three potential logistics network designs. We apply the model to a chemical industry case study.

Previous research on location problems with price-sensitive demand mainly deals with a single demand value that is dependent on the pre-defined pricing policy, and the network is thus designed to serve the resulting demand. Examples of such research include Wagner and Falkson (1975), Hansen and Thisse (1977), Erlenkotter (1977), Hanjoul et al. (1990). In terms of price-sensitive stochastic demand, interested readers can refer to Logendran and Terrell (1988, 1991). Other relevant papers include Hill and Khosla (1992), So and Song (1998), Palaka et al. (1998), So (2000), Rao et al. (2000) and Ray and Jewkes (2004).

Our work differs from previous work. First, we assume that the total demand value at each demand location is known and exogenously given, and can be segmented into two demand classes according to their delivery lead time requirements. Second, we employ price discount to entice some or all of this total demand at each location to accept the long LT class. Third, we
treat this price discount as a decision variable and obtain the optimal network design by comparing the net profit of three potential network designs.

2. Analysis

We consider a single-location model with one hub, and one warehouse that serves one corresponding customer region (Figure 1).

Figure 1: Single-Location Model

We consider three possible network designs (Figure 2) and the optimal network design will be the one that gives the highest net profit.

Figure 2: Three Possible Network Designs

- No-Discount – there is no price discount and all demand is served from the local warehouse.
- WH-Open – we find the optimal price discount that segments the customers into two classes; the hub serves the long LT customers and the local warehouse serves the short LT customers.
• WH-Closed – we close the warehouse and offer a price discount to entice some customers to accept the long delivery LT from the hub. Any remaining short LT demand is lost at cost \( L_S \).

For each of the three possible network designs, we model the net profit equations.

**No-Discount:** Net Profit, \( G_0 = \text{Revenue} - \text{Cost} = (P_S - Q_S)D - (Z_k + Z_i) \) \hspace{1cm} (1)

**WH-Open:** Net Profit, \( G_1 = (P_S - Q_S)D_S + (P_L - Q_L)D_L - (Z_k + Z_i) \) \hspace{1cm} (2)

**WH-Closed:** Net Profit, \( G_2 = (P_L - Q_L)D_L - Z_k - (D - D_L) L_S \) \hspace{1cm} (3)

To determine the optimal network design, we need to establish conditions on the demand function that relates the price discount \( P_L \) to the long LT demand \( D_L \). Given the original price \( P_S \) and demand \( D \), we denote this demand function as \( D_L = f(P_L) \). We assume that this demand function is non-increasing and concave.

For the **WH-Open** network design, to maximize the net profit (2), we solve for the first order condition and find the optimal price discount as the solution to

\[
\frac{df(P_L)}{dP_L} = \frac{-f(P_L)}{[(Q_S - Q_L) - (P_S - P_L)]}.
\] \hspace{1cm} (4)

From the second-order conditions we know a solution to (4) that maximizes (2). A necessary condition for equation (4) to have a solution is that \( P_L > P_S - (Q_S - Q_L) \). Thus, for the WH-Open network design, we set the price discount \( P_L \) to the solution of (4), if a solution exists; otherwise, we set \( P_L = P_S \), and there is no discount and all customers will get short LT delivery.

Similarly, for the **WH-Closed** network design, to maximize the net profit (3), we solve for the first order condition and obtain the optimal price discount from solving

\[
\frac{df(P_L)}{dP_L} = \frac{-f(P_L)}{[P_L - Q_L + L_S]}.
\] \hspace{1cm} (5)

A necessary condition to have a solution is \( P_L > Q_L - L_S \). Thus, for the WH-Closed network design, we set the price discount according to the solution of (5), if a solution exists; otherwise, we set \( P_L = P_S \) and all customer demand is lost for this region.

We extend the single-location model to larger networks with one hub, I customer locations and I warehouses. The parameters and decision variables are the same as before, except with a subscript \( i \) to denote location \( i \). The original network profit before price discount is,

\[
G_{\text{original}} = \sum_{i=1}^{I} (P_{Si} - Q_{Si})D_i - \sum_{i=1}^{I} Z_i - Z_k
\]
With the possibility to use price discounts to segment demand, each location chooses its optimal network design. We obtain the improved network profit by summing up the net profits for each location in the three different categories (No-Discount, WH-Open and WH-Closed),

\[
G_{\text{improved}} = \sum_{i \in \text{No-Discount}} \left[ (P_{Si} - Q_{Si}) D_i - Z_i \right] \\
+ \sum_{i \in \text{WH-Open}} \left[ (P_{Si} - Q_{Si}) D_{Si} + (P_{Li} - Q_{Li}) D_{Li} - Z_i \right] \\
+ \sum_{i \in \text{WH-Closed}} \left[ (P_{Li} - Q_{Li}) D_{Li} - L_{Si} D_{Si} \right] - Z_k
\]

The improvement in the network profit equals the sum of improvement due to demand segmentation for the individual locations that choose WH-Open and WH-Closed network designs. Thus, we can determine the optimal network design for larger networks by solving the model for each customer location independently and combining the individual optimal solutions.

3. Chemical Industry Case Study

TextDye is a world leader in supplying textile mills with textile dyes that are responsible for coloring the fabrics for the production of fashion wear. It has its headquarters in Europe and three regional distribution centers (RDCs) or hubs located in Europe, Asia and United States. Asia’s distribution network consists of ten local warehouses (Singapore, India, Indonesia, Korea, Taiwan, Thailand, two locations in Japan and two locations in China) and the Singapore hub.

We illustrate the benefits of employing price discount on network design for TextDye. We consider three different demand functions [A], [B] and [C] shown in Figure 3. For each demand function, we apply the analyses from prior section to obtain the overall optimal network design for the entire Asian distribution network of the firm.

For demand function [A]: The WH-Open network design is the optimal strategy for each location. The percentage of long LT demand ranged from 17% to 82%, with most locations around 30% to 60%. The overall increase in net profit is 3.06%.

For demand function [B]: Nine locations selected WH-Closed network design and only one location (China1) selected WH-Open network design. For the nine locations, 100% of the short LT demand is moved to long LT, with the price set at 9.5. For the single location (China1), 61% of its short LT demand is moved. The overall increase in net profit is 6.35%.

For demand function [C]: Nine locations selected WH-Open network design, and only one loca-
tion (Japan1) selected WH-Closed network design. For the nine locations, percentage of short LT demand moved ranges from 59% to 87%. For Japan1, 99.6% of the short LT demand is converted to long LT, while 0.4% is lost. The overall increase in net profit is 5.37%.

From these results, we conclude that there are real benefits from using price discount as a mechanism to segment the demand and to entice short LT demand to accept longer delivery lead time. The size of these benefits depends on the demand function faced by the market, which influences the optimal network design for each location. This analysis can help a logistics manager to decide how to set the discounted price to maximize the net profit in operating the network, and whether a local warehouse is needed at the customer locations. We refer the interested reader to Cheong (2005) and Cheong et al. (2005) for more details on this research.

Acknowledgments

The authors would like to thank the Singapore-MIT Alliance for funding the PhD research scholarship, and the Singapore Management University for funding the conference trip.

References


