Stackelberg Solution to
Two-Level Linear Programming Models of
Food Retailers and Brokerages Problems

Takeshi Matsui*, Masatoshi Sakawa, Ichiro Nishizaki and Kosuke Kato

Abstract—In Japan, farm products of fruits and vegetables are sent to consumers by the supply chain that manufactures pass through distributors, processing suppliers and retailers traditionally. The wholesale markets are of particular importance for the supply chain of the farm products' distribution. Under such a situation, it is necessary for retailers to take the sale policy which can support demand changes of consumers. In such cases, when retailers make a decision, brokerages as a transaction partner wield a very large influence over them. In this research, we focus on food retailers and brokerages problems, we formulate two-level programming problem maximizing both profits of a food retailer as an upper level decision maker and a brokerage as a lower level decision maker. And using an actual data, we derive a Stackelberg solution which is a reasonable solution in case that both decisions are made consecutively. Moreover we consider an order quantity and a purchase volume of each food maximizing both profits of a food retailer and a brokerage.

Keywords: two-level programming problem, Stackelberg solution, food retailer and brokerage problem

1 Introduction

In Japan, farm products of fruits and vegetables are sent to consumers by the supply chain that manufactures pass through distributors, processing suppliers and retailers traditionally. The wholesale markets are of particular importance for the supply chain of the farm products' distribution. The evidence that produces (about 80% in vegetables and about 60% in fruits [6]) are distributed through wholesale markets indicates that wholesale markets as an efficient brokerage system to close manufactures and consumers have worked for a long time.

For Asian food retailers except Japan, the existence of stalls and wet markets is important. Many consumers believe such a traditional market sells items at lower prices and fresher than a food supermarket. And they understand that food supermarkets are location purchasing processing foods instead of perishables. In addition, eating and drinking are prosperous at stalls and food courts in Asian various countries. This eating out is very popular since there are many households of working together in Asian Chinese community. Consumers purchase processing foods instead of perishables in food supermarkets [1].

On the other hand, in Japanese consumers, eating out is not so popular and they usually purchase several kinds freshness farm products by a small quantity at a time. Thus retailers have to prepare many products in order to respond to consumer demands at all times. For such a purchasing format of consumers, when retailers supply a large quantity of freshness farm products characterized by a small quantity at a time, if there's no wholesale market, each retailer has to do business with all producers. Since there is a system intermediating between transactions such as a wholesale market, retailers can reduce the number of transactions and the transaction cost becomes lower. Furthermore, for diversification of recent consumer needs, retailers have to prepare more many products over wide quality effectively since the present [3]. Thus, corresponding to purchasing behaviour of Japanese consumer, retailers stocking products from a producer or a distributor work toward improving consumers' satisfaction and with the help of a distributor, retailers supply necessary quantity when consumers feel necessary. In this way, retailers don't supply products only in own companies and they order products from a brokerage and supply, such a sale format is adopted in many retailers, and it makes possible to supply the proper quantity of the appropriate product in just in time.

Under such a situation, it is necessary for retailers to take the sale policy which can support demand changes of consumers. In such cases, when retailers make a decision, brokerages as a transaction partner wield a very large influence over them.

Thus, since interdependence between retailers and brokerages, to be concrete, there is a relation between a purchase (the volume of shipment) of brokerages and an order quantity (a quantity of supply) from retailers, we formulate as a two-level programming problem. Since

*Department of Artificial Complex Systems Engineering, Graduate School of Engineering, Hiroshima University, Email: tak-matsui@hiroshima-u.ac.jp
interdependence between retailers and brokers, to be
concrete, there is a relation between a purchase (the
volume of shipment) of brokers and an order quantity (a
quantity of supply) from retailers, we formulate as a two-
level programming problem. We consider the two-level
programming problem of food retailers and brokers
as a Stackelberg problem [4], [5] that both decisions are
made consecutively since retailers decide an order quan-
tity first and brokers decide a purchase.

In this research, we focus on food retailers and brokers
problems, we formulate two-level programming problem
maximizing both profits of a food retailer as an upper
level decision maker and a brokerage as a lower level de-
cision maker. And using an actual data, we derive a
Stackelberg solution which is a reasonable solution in case
that both decisions are made consecutively. Moreover we
consider an order quantity and a purchase volume of each
food maximizing both profits of a food retailer and a bro-
kerage.

2 Formulation

In the present life style, consumers buy the manufactur-
ing product and consume it. Therefore, if manufacturing
and consumption are divided, the process of distributing
products from manufacturing place to consuming place
is needed. In this way, if manufacturers’ place and con-
sumers’ place are far, it is necessary for products to dis-
tribute smoothly. In addition, it becomes important to
supply a necessary product to a consumer when a con-
sumer needs. Therefore, it is necessary to cover the dif-
ference of the distance or the hour between manufacturers
and consumers and to distribute smoothly. Thus, bro-
kerages purchase the product which a retailer needs from
each manufacturer in each manufacturing place (whole-
sale market) and transport to sale place of a retailer. And
a retailer purchases products from brokerages, and then
keeps products in a warehouse, and sells products to a
consumer when it is necessary. Such a selling form is
adopted in Japan.

In this research, for such a situation, we assume distribut-
ing from a producer to a consumer. There is a major
food retailer (upper level decision maker) in Tokyo (sale
place). And it sells fruits and vegetables for fruits and
vegetables branch of a supermarket. Here, we do model-
ing as follows:

Then a retailer purchases n kind foods (for example,
fruits, vegetables) through a brokerage (lower level deci-
sion maker) and sells. Here, a brokerage purchases n kind
foods in s wholesale markets in the whole country. Pur-
chased foods are transported to a warehouse of a retailer
by a brokerage. And a retailer pays this transportation
cost to a brokerage and supplies to a consumer. Then
we set decision variables of a retailer an order quantity
x_{ij} of food j, j = 1, 2, . . . , n. On the other hand, we
set decision variables of a brokerage a purchase quantity
x_{2qj} of food j, j = 1, 2, . . . , n in a wholesale market q,
q = 1, 2, . . . , s. If we assume warehouse capacity in a re-
tailer is w and unit volume of each food is v_j [cm^3/kg], a
constraint equation about volume of stack of a warehouse
is as follows:

\[ \sum_{j=1}^{n} v_j x_{ij} \leq W, \quad j = 1, 2, \ldots, n \] (1)

In addition, the smallest order quantity \( D^L_j \) and the
largest one \( D^U_j \) for each food j are settled. And the order
quantity \( x_{ij} \) decided is ordered in range of a bound con-
sidering a quantity of stock and constrained as follows:

\[ x_{ij} \geq D^L_j, \quad j = 1, 2, \ldots, n \] (2)

\[ x_{ij} \leq D^U_j, \quad j = 1, 2, \ldots, n \] (3)

On the other hand, a brokerage accepts orders from a
retailer and purchases foods. A brokerage has to purchase
the foods which can support orders and has constraint as
follows:

\[ \sum_{q=1}^{s} x_{2qj} \geq x_{ij}, \quad j = 1, 2, \ldots, n \] (4)

In addition, a brokerage has the fund constraint \( b_q \) pur-
chasing in each wholesale market as follows:

\[ \sum_{j=1}^{n} c_{2qj} x_{2qj} \leq b_q, \quad q = 1, 2, \ldots, s \] (5)

Under the above-mentioned constraints, we consider the
problem maximizing profits of both a retailer and a bro-
kerage. In this research, we assume parameters that for a
retailer, sale profit of food j is \( c_{11j} \), the transportation
cost from the wholesale market q for food j is \( c_{12qj} \), and
for a brokerage, shipping price from a brokerage to a re-
tailer for food j is \( c_{21j} \), purchase price in the wholesale
market q for food j is \( c_{22qj} \). As for the total sale profit of
a retailer, it is \( c_{11} x_1 \) and the transportation cost is \( c_{12} x_2 \).
In addition, as for the total shipping cost of a brokerage,
it is \( c_{21} x_2 \) and the purchasing cost is \( c_{22} x_2 \). Therefore,
the gross operating profit of a retailer is \( c_{11} x_1 - c_{12} x_2 \),
and the one of a brokerage is \( c_{21} x_2 - c_{22} x_2 \). Then, this
two-level linear programming problem maximizing both
profits of a retailer and a brokerage is formulated two-
level maximizing problem as follows:

maximize \( z_1(x_1, x_2) = c_{11} x_1 - c_{12} x_2 \)
subject to

\[ \sum_{j=1}^{n} v_j x_{ij} \leq W, \quad x_{ij} \geq D^L_j, \quad j = 1, 2, \ldots, n \]
\[ x_{ij} \leq D^U_j, \quad j = 1, 2, \ldots, n \]
\[ \sum_{q=1}^{s} c_{2qj} x_{2qj} \geq x_{ij}, \quad j = 1, 2, \ldots, n \]
\[ \sum_{q=1}^{s} c_{2qj} x_{2qj} \leq b_q, \quad q = 1, 2, \ldots, s \]
\[ x_1 \geq 0, \quad x_2 \geq 0 \] (6)
decision variable
\[ x_{1j} \]: order quantity for food \( j \) of a retailer (upper level decision maker)
\[ x_{2qj} \]: purchase quantity for food \( j \) in the wholesale market \( q \) of a brokerage (lower level decision maker)

parameters
\[ c_{1i} \]: sale profit of food \( j, j = 1, 2, \ldots, n \)
\[ c_{12qj} \]: transportation cost from the wholesale market \( q, q = 1, 2, \ldots, s \) for food \( j, j = 1, 2, \ldots, n \)
\[ c_{21j} \]: shipping price for food \( j, j = 1, 2, \ldots, n \)
\[ c_{22qj} \]: purchase cost for food \( j \) in the wholesale market \( q, q = 1, 2, \ldots, s \)
\[ W \]: warehouse capacity
\[ D^f_j \]: smallest order quantity for food \( j, j = 1, 2, \ldots, n \)
\[ D^l_j \]: largest order quantity for food \( j, j = 1, 2, \ldots, n \)
\[ b_q \]: the fund purchasing in each wholesale market \( q, q = 1, 2, \ldots, s \)

3 Application to actual data

3.1 data set

In this research, we assume that a retailer (upper level decision maker) sells 16 kinds of vegetables and fruits \((n = 16)\) for about 10000 households. The transportation cost of a retailer is calculated based on highway toll and light oil cost \((116[\text{yen/L}])\) that a brokerage transports from each wholesale market to Tokyo by 8t truck and shown in Table 1. From Table 2, we set food retail price from 50% to 75% that cost ratio of general fruits and vegetables and its mean cost ratio is 62%. And unit volume \( v_j \) \([\text{cm}^3/\text{kg}]\) of each food is estimate value. We assume that warehouse capacity \( W \) is 150 \([\text{m}^3] \times 2[\text{m}]\) for consumers to satisfy freshness demand and purchasing frequency. Based on past data of stocking quantities, the smallest order quantity \( D^f_j \) is estimate for 10000 households and the largest one \( D^l_j \) is that we multiply the smallest one by 1.1-1.4 (Table 4).

In addition, we assume that the wholesale markets of a brokerage is placed in Sapporo, Sendai, Niigata, Kanazawa, Tokyo, Osaka, Hiroshima and Miyazaki \((s = 8)\). And we set food shipping price \( c_{21j} \) \([\text{yen/kg}]\) from a brokerage to a retailer 95% of a wholesale price in Tokyo (Table 2). Although, we set purchase price of a brokerage in each wholesale market mean price in each Central Wholesale Markt at March, 2008 and it is shown in Table 5. Moreover, Table 6 shows the fund \( b_q \) purchasing in each wholesale market.

For the set two-level linear programming problem, we will derive a Stackelberg solution by HJS method [2].

4 Conclusion

In this research, we focus on food retailers and brokerage problems, formulated two-level linear programming mod-

References


Table 1: \( c_{12j} \): transportation cost from the wholesale market \( q \) for food \( j \)

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Table 2: \( c_{11j}, c_{21j}, c_{11j} \) : sale profit of food \( j \) [yen/kg] \( c_{21j} \) : shipping price of food \( j \) [yen/kg]

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Table 3: \( v_j \)

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Table 4: \( D_j^L, D_j^U \)

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