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Development of An Optimal Routes Selection Model Considering Price Characteristics of Agricultural Products

농산물의 가격특성을 고려한 최적경로 선정모델 개발

Suh, Kyo* · Lee, Jeong-Jae · Huh, Yoo-Man*** · Kim, Han-Joong* · Yi, Ho-Jae***

서 교 · 이 정 재 · 허 유 만 · 김 한 중 · 이 호 재

Abstract

Transportation and logistics of agricultural products have been one of the major interests of many researches. Most of researches have been limited to presuming these as a first dimensional process or considering only economic value of agricultural products at each stage of logistics. However, the particular characteristics of agricultural products, such as quality change during transportation or extensively scattered origins, require examining these problems as a whole system. Network model has been adopted to represent nodes, which stand for spatial location of demand and supply of agricultural products, and communication between these nodes. Based on network theory and advanced marketing potential function, an optimal routes selection model is developed. The model employed network simplex method for routes optimization. The application of the model focused on transportation network organization to reflect different market prices for different locations and resulted in optimum routes and profit improvement of the applied agricultural product.

Keywords : Optimization, Route selection, Logistics, Agricultural products, Network model

I. Introduction

According to development of economy and industry, producers and consumers of agricultural products have been separated so agricultural products transported from cultivated fields are distributed by wholesaler and retailer, or commercially exchanged in markets.

However, agricultural products have different characteristics from other products manufactured in factories due to multiple factors such

* Dept. of Agricultural Eng., Seoul National University, Seoul, Korea
** Prof. of Agricultural Eng., Seoul National University, Seoul, Korea
*** Rural Research Institute, Korea Agricultrual & Rural Infrastructure Corporation
Tel.: +82-2-880-4592
Fax: +82-2-873-2087
E-mail address: skyo@skypond.snu.ac.kr

as seasonal change of production quantity, difficulties of storage and packaging, long period of production, severe weather effects of production, etc. So we should handle logistics of agricultural products differently from other products.

The logistics cost of products manufactured in factories is studied through network model, but agricultural products have only studied on first dimension process or logistics margin aspect at each stage because agricultural products have different characteristics from general logistics model. Generally manufactured products have fixed and concentrated location for production, regular production quantity can be controlled, and the marketprice is almost the same in all the regions. However, locations and production of agricultural products are always changing due to weather condition and different market situation. The market price is different among wholesale markets in South Korea.

Network model for agricultural products mainly have two kinds of different modules from general business logistics model. Origin nodes for supply can be reflected all the changing characteristics such as node condition, irregular production quantity, etc. Destination nodes for demand can presume the daily market price using analysis of accumulated data for several years and updated new information.

In this study, we proposed how to develop network model for reflecting characteristics of agricultural products. An optimal routes selection model was developed as the network model for agricultural products, and then this model was applied to an agricultural product.

The objectives of an optimal routes selection model are to develop logistics of agricultural products and to find the optimal routes for maximizing gross earnings excluding transportation cost. An optimal routes selection model was evaluated through comparing the gross earnings excluding transportation cost of general business logistics model with that of an optimal routes selection model for agricultural products.

Ⅱ. Literature Review

1. Logistics Research of Agricultural Products

As it is gradually hard to reduce production costs and increase production quantity, logistics cost is the target of improving profit. Logistics cost comparatively has big margin for reduction. Han (1997) suggested direct transaction of agricultural products between producers (farmers) and consumers. According to his theory direct transaction can reduce the logistics cost and eliminate the inefficiency of multi-staged logistics. Moreover, confidence will be improved by direct transaction.

Sim (1992) studied calculation of logistics cost for agricultural products. He insisted reduction of logistics cost is consistent with service improvement.

2. Network Simplex Method for Optimization

The main object of this model is to find minimum cost routes from specified origin nodes to specified destination nodes. Although the network problems can be solved using the regular simplex method, the special structure of network simplex method offers a more convenient procedure for solving this type of problems.

Golden and Magnanti (1978) used NSM in preparation of travel time and distance charts. Christofieds, Ningozzia and Toth (1981) applied NSM to vehicle routing and scheduling. Schwartz and Stern(1980) solved design and expansion of transportation and communication network problem.

Network simplex method has been proved to be an useful solution of network flow, multi-commodity flow, and discrete optimization. In discrete location problems, optimum facility locations are chosen from a finite set of candidate facilities (Francis, 1983). The principle that any facility can satisfy all demands was applied to the incapacitated facility location problems (Mirchadani and Francis, 1990)

3. Transportation Network Model

Activities of Logistics are classified into two categories. One is main activity such as customer service standards, transportation, inventory management, and order processing. The other is support activity such as warehousing, material handling, purchasing, protective packaging, cooperation with producers, and information maintenance.

E. Brown (1996) developed a model for locating and allocating a fixed number of market sites of equal capacity while minimizing transportation cost.

Generally product flow network is organized for handling these complex activities in most business logistics. Choi (1997) developed the logistics network model using GIS. However, we can't apply this model to logistics of agricultural products because the target of this model is the individual firm.

The main differences are production location and market price. General goods are usually manufactured at a few fixed factories and the price of these goods is the same in all the regions. Agricultural products are produced scattered and unfixed fields and the price is different according to markets.

Ⅲ. Optimal Market Selection Model for Agricultural Products

1. Network Simplex Method for Logisics Network Model

The assignment and transportation problems are single commodity with minimum cost flow problems on pure bipartite networks. The methods and algorithms for network models are Hugarian Method, Primal-Dual Method, Network Simplex Method, Relaxation Method, Signature Method etc. These methods have been applied to balanced transportation problems, assignment problems, and minimum cost flow problems.

The procedure of network simplex method is based on the same theory of the simplex method, but it makes use of some shortcuts that yield a simpler computational scheme.

Suppose that there are m origins $R_1, R_2, \ldots, R_m$ (e.g., warehouses) and n destinations $D_1, D_2, \ldots, D_n$ (e.g. markets). Let a_i be the amount of a commodity available at origin i (i = 1, 2, , m) and b_j be the amount required at destination j (j = 1, 2, , n). Let c_{ij} be the cost per unit of transporting the commodity from the origin i to the destination j. The objective is to determine the amount of commodity transported from the origin i to the destination j such that the total transportation costs are minimized. Transportation network problem can be formulated mathematically as:

$$Minimize\ f = \sum_{i=0}^{m} \sum_{j=0}^{n} x_{ij} \ \cdots\cdots\cdots\cdots (1)$$

subject to, $x_{ij} \geq 0, i = 1,2,\ldots, m, \ j = 1, 2, \ldots, n$

$$\sum_{j=1}^{n} x_{ij} = a_i \quad (i = 1, 2, \ldots, m) \cdots\cdots\cdots\cdots (2),$$

$$\sum_{i=1}^{m} x_{ij} = b_i \quad (j = 1, 2, \ldots, n) \cdots\cdots\cdots\cdots (3)$$

Equation (2) states that the total amount of the commodity transported from the origin i to various destinations must be equal to the amount available at origin i ($i = 1, 2, \ldots, m$), while equation (3) states that the total amount of the commodity received by the destination j from all the sources must be equal to the amount required at the destination j ($j = 1, 2, \ldots, n$).

The basic steps involved in the solution of a transportation network problem are:

1. Determine a starting basic feasible solution.
2. Test the current basic feasible solution for optimality. If the current solution is optimal, stop the interactive process; otherwise, go to step 3.
3. Select a variable to enter the basis among the current non-basic variables.
4. Select a variable to leave the basis among the current basic variables (using the feasibility condition).
5. Find a new basic feasibility condition.

2. Model Organization

가. Production

Generally two methods are used for forecasting production quantity of agricultural products. First one is the dynamic method which is a physiological method based on growing processes. The other is the empirical method which is a statistical method based on classical data. The dynamic method is very difficult to organize a function because of many unstable natural conditions and artificial factors, so the function for production is composed by the empirical method.

$$P_i = d_i[R_i D_i + I_i] \cdots\cdots\cdots\cdots (4)$$

where, P_i: Production of the region i, d_i: Reduction rate of movement and storage at the region i, D_i: Shipping amount of the region i, I_i: Import amount of the region i, R_i: Delayed coefficient of forwarding at the region i

나. Consumption

Total consumption of a certain region can be calculated through population and personal consumption.

$$C_i = u(1 + r_i)b_i N_i f_i + E_i \cdots\cdots\cdots\cdots (5)$$

where, C_i: Consumption of the region i, u: Monthly demand index, r_i: Fluctuation coefficient of population at the region ., b_i: Seasonal distribution coefficient of the region , N_i: Population of the region , f_i: Daily consumption of one person, E_i: Export amount of the region

다. Logistics

Logistics of the region i is the difference between production and consumption including storage.

$$\Phi_i = P_i - C_i + S_i \quad \cdots\cdots (6)$$

where, Φ_i: Logistics of the region i, P_i: Production of the region i, C_i: Consumption of the region i, S_i: Storage of the region i

3. Comparison Objective Functions of Each Model

In case of general business logistics model, the objective function minimizes logistics. This model optimizes the logistics without different market prices.

Minimize

$$f = \sum_{i=1}^{n}\sum_{j=1, i\neq j}^{n} f_{ij} = \sum_{i=1}^{n}\sum_{j=1, i\neq j}^{n} \Phi_{ij}\cdot t_{ij} = \sum_{i=1}^{n}\sum_{j=1, i\neq j}^{n} (P_i - C_i + S_i)\cdot t_{ij} \quad \cdots\cdots (7)$$

subject to, $P_i, C_i \geq 0$, $\sum_{i=1}^{n} S_i \leq \sum_{i=1}^{n} P_i$, $\sum_{i=1}^{n} S_i \geq \left|\sum_{i=1}^{n} P_i - \sum_{i=1}^{n} C_i\right|$, $\Phi_i \geq 0$, $t_{ij} \geq 0$, $l_{ij} \geq 0$,

$t = l \times c_v$, l: Distance between nodes, c_v: Effect coefficient of limit speed

In case of an optimal routes selection model for agricultural products, the objective function maximizes the gross earnings excluding transportation cost. The different market price is considered in an optimal routes selection model.

Maximize

$$f = \sum_{i=1}^{n}\sum_{j=1, i\neq j}^{n} [(P_i - C_i + S_i)\cdot sp_j - \left\{{(P_i - C_i + S_i)}/{u}\right\}\cdot l_{ij}\cdot tc_{ij}] \quad \cdots\cdots (8)$$

subject to, $P_i, C_i \geq 0$, $\sum_{i=1}^{n} S_i \leq \sum_{i=1}^{n} P_i$, $\sum_{i=1}^{n} S_i \geq \left|\sum_{i=1}^{n} P_i - \sum_{i=1}^{n} C_i\right|$ $P_i - C_i + S_i$: Shipping amount of i the orgin, sp_j: Market price in j destination, l_{ij}: Distance between the orgin i and the destination j, u : Transportation unit, tc_{ij}: Transportation cost per kilometer

4. Implementation of an Optimal Routes Selection Model

Transportation network was constructed with data of regions and roads. Functions variables were extracted through analysis of logistics and unit factors are investigated in the real market situation.

The optimal routes of each supply node were selected among all the routing network simplex method. Optimization performed for maximizing the gross earnings excluding transportation cost and the result of an optimal routes selection model was compared with that of general business logistics model.

가. Characteristics of Agricultural Products

Agricultural products have several differences from manufactured goods. Agricultural products have big seasonal changes of production quantity and their production fields are broadly distributed over the country. Moreover production quantity is very unstable because it is easily affected by weather condition and most of agricultural products are very difficult to store and package while requiring long period of production compare to manufactured goods. Freshness is also easily affected by duration of transport time and it directly influences products quality and price in most cases. Moreover, every market has different price about the same product.

나. Logistics Environment of Agricultural Products

The target of logistics is the activities for acquisition of the right goods or services to the right place at the right time and in desired condition. Time for movement and communication has been reduced due to development of telecommunication and transportation. Advanced agricultural technologies allow to changing harvesting season and storage techniques help to overcome the problems that arise from differences between harvesting seasons and consuming seasons. Moreover, increasing income urges people to buy specific products: fruit, specialty, etc. However, most of agricultural products are supplied from distributed fields to production sales, so difference in price at different regions are inevitable.

Node and arc data table consist of monthly shipping quantity, regional population, daily consumption per one person, monthly demand index, limit speed of roads, distance between origins and destinations. Consumption, production, and logistics quantities are calculated through composed functions.

Arcs indicate all the routes for movement and nodes express all the regions for production and consumption. Node data have index, destination, shipping quantity and transaction quantity. Arc data have index, origin, destination, distance and speed limit.

Consumption is calculated based on regional population, consumption per 1 person, monthly demand index, and days per 1 month.

Especially cities having cold storage warehouses are regarded as nodes. When storage occurs, a node is regarded as a consumption node. When shipping occurs, a node is considered as a production node. Arcs have the distance between nodes, and the speed limit of the road. Unit transportation cost, unloading cost should be considered. The fitness of transportation routes is estimated, and the optimal route for each node is selected.

Ⅳ. Application

In this study, the selected product is garlic. Nodes are composed of big wholesale market-places and main production regions in South Korea. Arcs consist of road among regions.

1. Selection of an Applied Product

We chose the garlic for the model application because garlic has different seasonal production and consumption according to species and contributed to export and import. Moreover, most of data for garlic are provided by MAF (Ministry of Agriculture and Forestry), AFMC (Agricultural and Fishery Marketing Corporation), and Nonghyeoup (Agricultural Cooperative Congre-gations), so recent situation of logistics and database of the garlic can be easily understood and constructed.

2. Data Analysis

Used data are shipping amount of main production regions, transaction amount presumed by population and daily consumption per 1 person of consuming regions which have wholesale market, The remaining amount will be stored in cold storage warehouse. The price of each wholesale markets is forecasted by the price-fluctuation curve of each market.

Transportation cost is calculated through the shipping amount of each market times transportation cost per kilometer divided by transport unit factor. Total sales is the shipping amount of each market times forecasting price of each market. Fig. 1 is the monthly demand index. Fig. 2 is the price-fluctuation of garlic in Seoul Garak wholesale market.

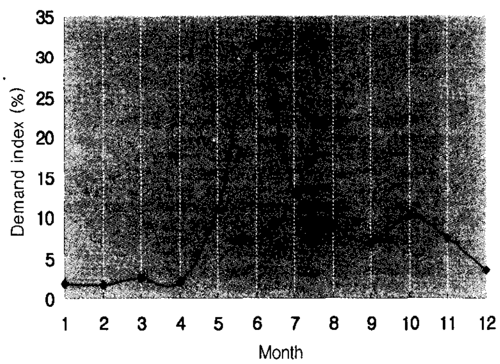

Fig. 1 Monthly demand index

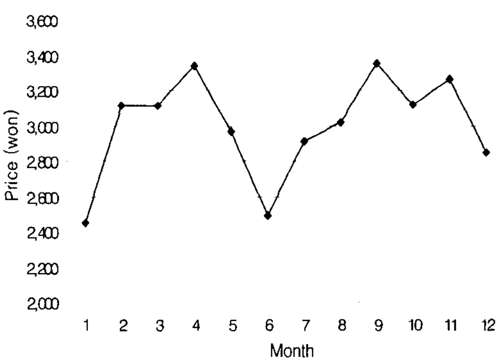

Fig. 2 The price-fluctuation curve (Seoul)

3. Result and Discussion

In case of general business logistics model, the total gross earnings excluding transportation cost was 798,621,362 won. In case of an optimal routes selection model, the total gross earnings excluding transportation cost was 883,676,713 won. The increment of the total gross earnings excluding transportation cost was 85,055,351 won. Consequently the increase rate of the gross earnings excluding transportation cost was 10.65%.

However, the cost of general business logistics model is smaller than that of an optimal routes selection model in terms of the total cost of transportation. In case of general business logistics model, the total cost of transportation was 57,290,837 won. In case of an optimal routes selection model, that of transportation was 57,852,482 won. The general business logistics model could save 561,645 won.

Each model was applied to other case, too. In these cases, the price differences are very small as in the cases of general goods. Therefore, the increment of the profit is too small.

According to all the results, general logistics model can't be used in the logistics of agricultural products and the logistics model of agricultural products should reflect the different price of each market. The effect of this consideration is very important of increasing the gross earnings excluding transportation cost. The more different price at each market is, the bigger the difference of the the gross earnings excluding transportation cost is. Table 1 and Table 2 show the results of applications. Table 1 shows that general business logistics model is applied by the process

Table 1 Result in case of the general business logistics model

(Unit : won)

Wholesale market	Distribution (kg)	Distance (km)	Transport cost	Market price	Total sales	Gross earnigs
Namhae						
Seoul Garak	0	350	0	2,702	0	0
Gwangju	24,686	125	1,542,875	1,435	35,424,410	33,881,535
Guri	0	361	0	2,456	0	0
Busan	65,889	150	4,941,675	1,150	75,772,350	70,830,675
Daejean	0	216	0	2,456	0	0
Ulsan	0	195	0	800	0	0
Jeonju	0	151	0	1,604	0	0
Incheon	0	362	0	1,300	0	0
Chungju	0	254	0	1,966	0	0
Iksan	0	176	0	1,275	0	0
Goheung						
Seoul Garak	10,667	358	1,909,393	2,702	28,822,234	26,912,841
Gwangju	0	99	0	1,435	0	0
Guri	0	374	0	2,456	0	0
Busan	8,771	228	999,894	1,150	10,086,650	9,086,756
Daejean	24,326	234	2,846,142	2,456	59,744,656	56,898,514
Ulsan	18,621	273	2,541,767	800	14,896,800	12,355,034
Jeonju	10,957	165	903,953	1,604	17,575,028	16,671,076
Incheon	0	374	0	1,300	0	0
Chungju	9,973	273	1,361,315	1,966	19,606,918	18,245,604
Iksan	6,329	187	591,762	1,275	8,069,475	7,477,714
Sinan						
Seoul Garak	96,479	341	16,449,670	2,702	260,686,258	244,236,589
Gwangju	0	72	0	1,435	0	0
Guri	0	355	0	2,456	0	0
Busan	0	297	0	1,150	0	0
Daejean	0	218	0	2,456	0	0
Ulsan	0	343	0	800	0	0
Jeonju	0	156	0	1,604	0	0
Incheon	0	356	0	1,300	0	0
Chungju	0	254	0	1,966	0	0
Iksan	0	155	0	1,275	0	0
Muan						
Seoul Garak	96,064	317	15,226,144	2,702	259,564,928	244,338,784
Gwangju	0	50	0	1,435	0	0
Guri	2,757	331	456,284	2,456	6,771,192	6,314,909
Busan	0	275	0	1,150	0	0
Daejean	0	194	0	2,456	0	0
Ulsan	0	321	0	800	0	0
Jeonju	0	131	0	1,604	0	0
Incheon	45,301	332	7,519,966	1,300	58,891,300	51,371,334
Chungju	0	230	0	1,966	0	0
Iksan	0	130	0	1,275	0	0
Total			57,290,837		855,912,199	798,621,362

Table 2 Result in case of an optimal routes selection model

(Unit : won)

Wholesale market	Distribution (kg)	Distance (km)	Coefficient	Transport cost	Market price	Total sales	Gross earnigs
Muan							
Seoul Garak	167,537	317	159	26,554,615	2,702	452,684,974	426,130,360
Gwangju	0	50	25	0	1,435	0	0
Guri	0	331	166	0	2,456	0	0
Busan	0	275	138	0	2,150	0	0
Daejean	0	194	97	0	2,456	0	0
Ulsan	0	321	161	0	800	0	0
Jeonju	0	131	66	0	2,604	0	0
Incheon	0	332	166	0	1,300	0	0
Chungju	0	230	115	0	1,966	0	0
Iksan	0	130	65	0	1,275	0	0
Shn-an							
Seoul Garak	35,673	341	171	6,082,247	2,702	96,388,446	90,306,200
Gwangju	12,973	72	36	467,028	1,435	18,616,255	18,149,227
Guri	2,757	355	178	489,368	2,456	6,771,192	6,281,825
Busan	0	297	149	0	2,150	0	0
Daejean	24,326	218	109	2,651,534	2,456	59,744,656	57,093,122
Ulsan	0	343	172	0	800	0	0
Jeonju	10,957	156	78	854,646	2,604	28,532,028	27,677,382
Incheon	0	356	178	0	1,300	0	0
Chungju	9,793	254	127	1,243,711	1,966	19,253,038	18,009,327
Iksan	0	155	78	0	1,275	0	0
Namhae							
Seoul Garak	0	350	175	0	2,702	0	0
Gwangju	11,713	125	63	732,063	1,435	16,808,155	16,076,093
Guri	0	361	181	0	2,456	0	0
Busan	27,052	150	75	2,028,900	2,150	58,161,800	56,132,900
Daejean	0	216	108	0	2,456	0	0
Ulsan	0	195	98	0	800	0	0
Jeonju	0	151	76	0	2,604	0	0
Incheon	45,301	362	181	8,199,481	1,300	58,891,300	50,691,819
Chungju	180	254	127	22,860	1,966	353,880	331,020
Iksan	6,329	176	88	556,952	1,275	8,069,475	7,512,523
Goheung							
Seoul Garak	0	358	179	0	2,702	0	0
Gwangju	0	99	50	0	1,435	0	0
Guri	0	374	187	0	2,456	0	0
Busan	47,608	228	114	5,427,312	2,150	102,357,200	96,929,888
Daejean	0	234	117	0	2,456	0	0
Ulsan	18,621	273	137	2,541,767	800	14,896,800	12,355,034
Jeonju	0	165	83	0	2,604	0	0
Incheon	0	374	187	0	1,300	0	0
Chungju	0	273	137	0	1,966	0	0
Iksan	0	187	94	0	1,275	0	0
Total				57,852,482		941,529,199	883,676,718

sequence of Muan, Sinan, Namhae and Goheung. Table 2 shows that an optimal routes selection model is applied by the process sequence of Muan, Sinan, Namhae and Goheung.

An optimal routes selection model could get the maximum gross earnings excluding transportation cost when the process sequence is Muan, Sinan, Namhae and Goheung. On the other hand, the general business logistics model could get the minimum cost of transportation when the process sequence is Namhae, Goheung, Sinan and Muan.

10 key producing districts and 10 main wholesale markets were selected for applications of two models. Whole processes are sequentially repeated until finding the minimum value for general business logistics model and the maximum value for an optimal routes selection model.

The unit transport is a 1t (1,000 kg) truck. Transportation cost is 500 won/km. It is assumed that unloading cost is the same in all the markets, transaction amount is consumption, and average production is average shipping amount. 10 key producing districts and 10 main wholesale markets were selected for applications of two models.

Ⅴ. Conclusion

We have studied how an optimal routes selection model can be used to select optimal routes for maximizing the gross earnings excluding transportation cost of logistics.

1. The functions for production and consumption were composed, and then calculated.

2. The objective function was made for maximizing the gross earnings excluding transportation cost.

3. An optimal routes selection model was applied to the logistics of garlic. Real-time data collecting system was constructed based on web technology.

4. An optimal routes selection model used network simplex method and successive linear programming for optimization.

Logistics model for agricultural products should be different from general logistics model because of reflection of different market prices. Applications to garlic show the difference of the gross earnings excluding transportation cost (10.65% increase) comparing an optimal routes selection model with a general logistics model in spite of expensive cost in transportation. Results of each model explain how the degree of price fluctuation in the market affects the gross earnings excluding transportation cost.

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