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Cost-Minimizing Transportation Model for Eggs in Japan

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This research aims at developing a cost-minimizing allocation of eggs from surplus areas to deficit areas in Japan using the linear programming. Based on 1987 data and simplified transportation routes throughout the country, important results were obtained. The Japanese largest egg market, Tokyo, should collect from not only nearby suppliers but also from remote supplier such as Miyazaki. Osaka, the second largest egg market, should be supplied mainly by Kagoshima, Kagawa, and Ehime. In fact, entire surpluses in Miyazaki and Kagoshima were estimated to be shipped to Tokyo and Osaka, respectively. This indicates that nationally most efficient supply allocation may not be to seek nearby markets at individual basis.

Introduction

Japan has maintained high rate of self-sufficiency in eggs at about 98 % since the 1950's. The egg industry in Japan achieved rapid growth in production in the past. During the 1980's, egg production was further boosted taking advantage of appreciation of yen, which greatly reduced costs of imported feedstuffs. Accordingly, the rate of self-sufficiency in eggs was further increased to 99.8 % in 1987.[4] Production of eggs in 1987 reached 2.3 million tons (t) (Table 1). The number of surplus prefectures was 29 for total surplus volume of 631,000t in the same year. The major surplus prefectures and their volumes were Kagoshima, Okayama, Ibaragi, and Miyazaki with 82,000t, 49,000t, 46,000t, and 44,000t, respectively (Table 2). On the other hand, the number of deficit prefectures was 17 prefectures, and the major ones were Tokyo, Osaka, and Kanagawa, which are all heavily populated (Table 3).

As egg producing areas are specialized with large volumes of surpluses, it is important to seek an efficient system of supply allocation. The main objective of this study is to determine the optimum distributing and marketing routes for eggs throughout the country such that total transportation costs are minimized. A linear-country egg transportation model is first formulated, and linear programming is used to determine the minimum total costs of transportation. This type of studies were previously done by Franzmann & Judge (1957)[1], Stemberger (1959)[3], and Heady & Candler (1963)[2].

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Table 1 Egg supply and demand in each prefecture in Japan, 1987.

Prefecture	Supply Volume[1] (tons)	Population[2] (100)	Population (%)	Estimated Consumption Volume (tons)
Hokkaido	100,910	5,671	4.638	105,478
Aomori	67,141	1,516	1.240	28,200
Iwate	55,019	1,426	1.166	26,517
Miyagi	80,541	2,206	1.804	41,027
Akita	27,972	1,245	1.018	23,152
Yamagata	11,400	1,262	1.032	23,470
Fukushima	46,499	2,091	1.710	38,889
Ibaragi	97,247	2,769	2.265	51,511
Tochigi	50,951	1,892	1.547	35,182
Gumma	64,651	1,939	1.586	36,069
Saitama	76,426	6,063	4.959	112,779
Chiba	93,739	5,299	4.334	98,565
Tokyo	5,240	11,989	9.731	221,304
Kanagawa	38,278	7,661	6.266	142,503
Nigata	55,000	2,479	2.028	46,121
Toyama	30,562	1,121	0.917	20,855
Ishikawa	39,193	1,157	0.946	21,514
Fukui	12,755	822	0.672	15,283
Yamanashi	8,163	842	0.689	15,669
Nagano	19,196	2,149	1.758	39,981
Gifu	70,700	2,045	1.673	38,048
Shizuoka	42,599	3,617	2.958	67,271
Aichi	143,191	6,555	5.361	121,921
Mie	71,192	1,766	1.444	32,840
Shiga	12,330	1,179	0.964	21,923
Kyoto	16,026	2,602	2.128	48,395
Osaka	12,961	8,739	7.148	162,561
Hyogo	84,908	5,323	4.354	99,019
Nara	18,498	1,336	1.093	24,857
Wakayama	18,241	1,082	0.885	20,127
Tottori	15,802	617	0.505	11,485
Shimane	12,996	793	0.649	14,760
Okayama	84,576	1,927	1.576	35,842
Hiroshima	79,923	2,839	2.322	52,807
Yamaguchi	36,077	1,596	1.305	29,679
Tokushima	15,997	836	0.684	15,556
Kagawa	54,423	1,026	0.839	19,081
Ehime	50,931	1,528	1.250	28,428
Kochi	9,269	837	0.685	15,578
Fukuoka	90,328	4,755	3.889	88,444
Saga	17,114	881	0.721	16,397
Nagasaki	36,606	1,587	1.298	29,519
Kumamoto	34,587	1,846	1.510	34,341
Oita	29,906	1,248	1.021	23,220
Miyazaki	65,964	1,176	0.962	21,878
Kagoshima	117,490	1,818	1.487	23,818
Okinawa	20,702	1,202	0.983	22,356
Total	2,274,220	122,264		

Sources: (1) *Annual Statistics on the Distribution and Marketing of Eggs and Broilers*, MAFF.
(2) *Census Report*, Statistics Bureau, Management and Coordination Agency, Japan.

Table 2 Egg surplus areas and volumes.

Prefecture	Surplus (tons)
Aomori	38,941
Iwate	28,502
Miyagi	39,514
Akita	4,820
Fukushima	7,610
Ibaragi	45,736
Tochigi	15,769
Gumma	28,582
Nigata	8,879
Toyama	9,707
Ishikawa	17,679
Gifu	32,652
Shizuoka	5,328
Aichi	21,270
Mie	38,352
Tottori	4,317
Okayama	48,734
Hiroshima	27,116
Yamaguchi	6,398
Tokushima	441
Kagawa	35,342
Ehime	22,503
Fukuoka	1,884
Saga	717
Nagasaki	7,087
Kumamoto	246
Oita	6,686
Miyazaki	44,086
Kagoshima/Okinawa	82,018
Total	630,916

Source: Calculated from figures in Table 1.

Table 3 Egg deficit areas and volumes.

Prefecture	Deficit (tons)
Hokkaido	4,568
Yamagata	12,070
Saitama	36,353
Chiba	4,826
Tokyo	216,064
Kanagawa	104,225
Fukui	2,528
Yamanashi	7,506
Nagano	20,785
Shiga	9,593
Kyoto	32,369
Osaka	149,600
Hyogo	14,111
Nara	6,359
Wakayama	1,886
Shimane	1,764
Kochi	6,309
Total	630,916

Source: Calculated from figures in Table 1.

Method

The approaching method used in this study was developed based on Heady & Candler. To describe their procedure in a simplistic manner, first, assume that there are only 2 supply areas, 1 and 2, for a farm product and also only 2 demand areas, 1 and 2 (Table 4). The transportation costs of distributing the product from supply area 1 to demand areas 1 and 2 are \$14 and \$89, respectively. And the costs from supply area 2 to demand areas 1 and 2 are \$15 and \$79, respectively. Further, assume that the total supply volume of the product from supply areas 1 and 2 are 638 and 446 units, respectively. Total demand in demand areas 1 and 2 are assumed to be 521 and 563 units, respectively. Based on this information of prices, 4 inequalities can be obtained:

$X_{11}+X_{12}<\text{or}=638$----Supply constraint in supply area 1

$X_{21}+X_{22}<\text{or}=446$----Supply constraint in supply area 2

$X_{11}+X_{21}>\text{or}=521$----Demand constraint in demand area 1

$X_{12}+X_{22}>\text{or}=563$----Demand constraint in demand area 2

Table 4 Transportation costs from supply areas 1 and 2 to demand areas 1 and 2.

	Demand area 1	Demand area 2
Supply area 1	\$ 14	\$ 89
Supply area 2	\$ 15	\$ 79

Supply of supply area 1=638
Supply of supply area 2=446
Demand of demand area 1=521
Demand of demand area 2=563

where,

X_{11} is volume of supply from supply area 1 to demand area 1
X_{12} is volume of supply from supply area 1 to demand area 2
X_{21} is volume of supply from supply area 2 to demand area 1
X_{22} is volume of supply from supply area 2 to demand area 2

To solve this problem with simplex method, both disposal activities and artificial activities are introduced into the inequalities:

$$1X_{11}+1X_{12}+0X_{21}+0X_{22}+1X_3+0X_4+0X_5+0X_6+0Q_1+0Q_2=638$$
$$0X_{11}+0X_{12}+1X_{21}+1X_{22}+0X_3+1X_4+0X_5+0X_6+0Q_1+0Q_2=446$$
$$1X_{11}+0X_{12}+1X_{21}+0X_{22}+0X_3+0X_4-1X_5+0X_6+1Q_1+0Q_2=521$$
$$0X_{11}+1X_{12}+0X_{21}+1X_{22}+0X_3+0X_4+0X_5-1X_6+0Q_1+1Q_2=563$$

where,

X_{11}, X_{12}, X_{21}, and X_{22} are real activities, X_3, X_4, X_5, and X_6 are disposal activities, and Q_1 and Q_2 are artificial activities.

Equation for minimum costs, C, is:

$$C=14X_{11}+89X_{12}+15X_{21}+79X_{22}+0X_3+0X_4+0X_5+0X_6-mQ_1-mQ_2.$$

The artificial activities are used when the inequalities have greater-than signs (>). The purpose of using artificial activities is to enable a diagonal set of 1's to be obtained so that an initial feasible plan can be found. Further, an unusual large value for cost, m, is attached to each artificial activity to ensure that it does not come into the final plan.

Based on the final option plan, allocation is calculated to be 521, 117, 0, and 446 for X_{11}, X_{12}, X_{21}, and X_{22}, respectively, with the minimum total costs to be \$52, 941. Namely, 521 units of the product should be distributed from supply area 1 to demand area 1, 117 units from supply area 1 to demand area 2, 0 units from supply area 2 to demand area 1, and 446 units from supply area 2 to demand area 2.

This approach is applied in this research for cost minimizing transportation of eggs from 29 surplus areas to 17 deficit areas in Japan. To do this, it was necessary to set up some assumptions. The first assumption made is that eggs are transported from the surplus prefectures to the deficit prefectures by means of a straight line cutting across the country as shown in Fig. 1. This may not be realistic but it is practical for this analysis. Without this type of assumption made, the analysis would be extremely hard due to the fact that there are a great number of highways all over the country.

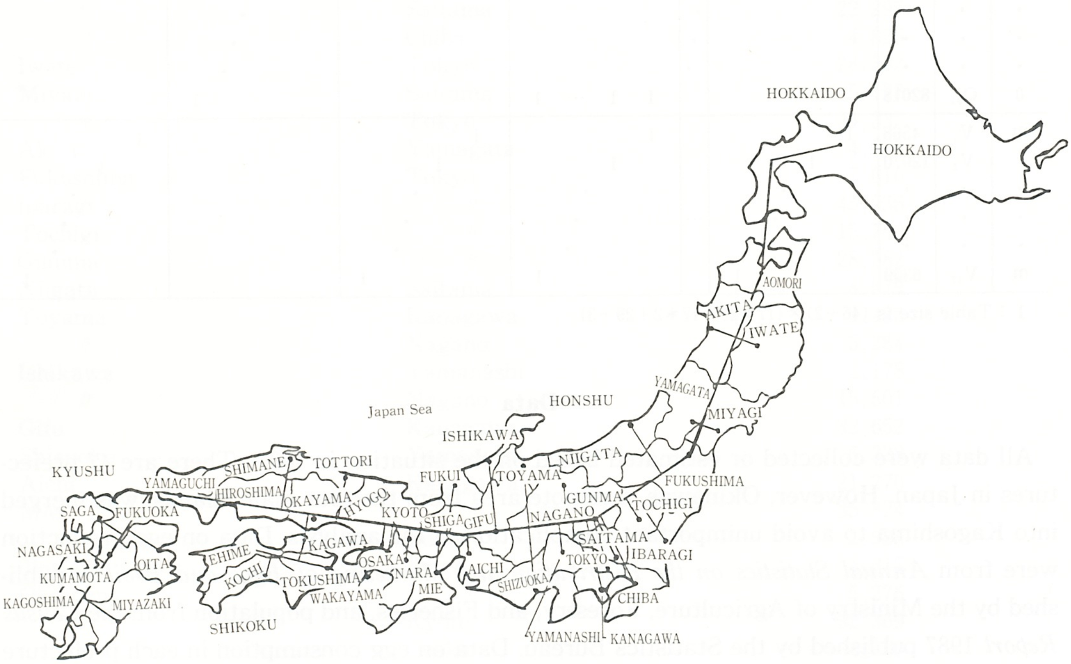

Fig. 1 Simplified national crossing transportation line from Hokkaido to Kyushu.

The second assumption is that egg prices are the same for all wholesale markets. This is based on the fact that wholesale prices of eggs did not differ much in different places over the last 15 years[4]. Wholesale prices, in particular, in the four major cities, Sapporo, Tokyo, Osaka, and Fukuoka from 1970 through 1987 have been very closely associated. Finally, level of egg consumption in each prefecture is assumed to be proportional to its population.

Table 5 shows the first step of the linear programming, in which surplus/deficit volumes of individual prefectures and distances from each surplus area to all deficit areas are used. Computer calculation takes several steps starting from this first step before reaching the final results. Q_1 through Q_{29} and their corresponding numbers at the next right column are volumes of surplus from individual surplus prefectures, and V_1 through V_{17} volumes of deficit prefectures. The size of the whole table matrix is $(46+2) \times (17*29+17*2+29+3)$, namely, 48×559.

Table 5 The 1st step simplex table used in solving linear-country egg transportation model[1].

C →			62 59 ··· 241	···	374 259 ··· 147	0 0 ··· 0	0 0 ··· 0	m m ··· m
↓			$x_{1,1}$ $x_{1,2}$ ··· $x_{1,17}$	···	$x_{29,1}$ $x_{29,2}$ ··· $x_{29,17}$	P_1 P_2 ··· P_{17}	Q_1 Q_2 ··· Q_{29}	V_1 V_2 ··· V_{19}
0	Q_1	38941	1 1 ··· 1				1	
	Q_2	28502					1	
·	·	·		·			·	
·	·	·		·			·	
·	·	·		·			·	
0	Q_{29}	82018			1 1 ··· 1		1	
m	V_1	4568	1		1	-1		1
	V_2	12070	1		1	-1		1
·	·	·	·		·	·		·
·	·	·	·	···	·	·		·
·	·	·	·		·	·		·
m	V_{17}	6309	1		1	-1		1

1 : Table size is (46+2) × (17∗29+17∗2+29+3).

Data

All data were collected or estimated based on the situation in 1987. There are 47 prefectures in Japan. However, Okinawas, a remote area from the four main islands, was merged into Kagoshima to avoid unimportant complication in the analysis. Data on egg production were from *Annual Statistics on the Distribution and Marketing of Eggs and Broilers* published by the Ministry of Agriculture, Forestry, and Fisheries, and population from the *Census Report* 1987 published by the Statistics Bureau. Data on egg consumption in each prefecture in 1987 were estimated based on population proportion. Egg surplus or deficit in each prefecture was calculated subtracting consumption from production. There were 29 surplus prefectures and 17 deficit prefectures, and their volume of total egg transactions was 630, 916t. Transportation costs of eggs were estimated based on a straight line cutting across the country from Sapporo in Hokkaido to Kagoshima in southern Kyushu (Fig. 1). Namely, egg transportation cost between a surplus area and a deficit area was estimated based on the distance between the two areas through the line. The very distance is regarded as costs of transportation between the two areas in this research. The shortest perpendicular length was used to measure a distance between a area and the national crossing line.

Results

Results of the linear-country model show quite interesting distribution of eggs from surplus areas to deficit areas with the most efficient way of allocation nationwide. Results in this research suggest that remote surplus areas such as Kagoshima, Miyazaki, and Aomori need to transport their eggs as far as Tokyo or Osaka due to their large volumes of surpluses (Table 6).

Table 6 Results of linear-country egg transportation model of Japan, 1987.

Egg Surplus Prefecture (From)	Egg Deficit Prefecture (To)	Transaction Volume (tons)
Aomori	Hokkaido	4,568
〃	Yamagata	7,250
〃	Saitama	22,297
〃	Chiba	4,826
Iwate	Tokyo	28,502
Miyagi	Saitama	5,177
〃	Tokyo	34,337
Akita	Yamagata	4,820
Fukushima	Tokyo	7,610
Ibaragi	〃	45,736
Tochigi	〃	15,769
Gumma	〃	28,582
Niigata	Saitama	8,879
Toyama	Kanagawa	4,423
〃	Nagano	5,284
Ishikawa	Yamanashi	2,178
〃	Nagano	15,501
Gifu	Kanagawa	32,652
Shizuoka	Yamanashi	5,328
Aichi	Kanagawa	21,270
Mie	〃	35,824
〃	Fukui	2,528
Tottori	Shiga	4,317
Okayama	〃	5,276
〃	Kyoto	32,369
〃	Osaka	4,730
〃	Nara	6,359
Hiroshima	Kanagawa	9,355
〃	Hyogo	14,111
〃	Wakayama	1,886
〃	Shimane	1,764
Yamaguchi	Tokyo	5,697
〃	Kanagawa	701
Tokushima	Osaka	441
Kagawa	〃	35,342
Ehime	〃	16,194
〃	Kochi	6,309
Fukuoka	Tokyo	1,884
Saga	〃	717
Miyazaki	〃	3,144
〃	Osaka	3,943
Kumamoto	〃	246
Oita	〃	6,686
Miyazaki	Tokyo	44,086
Kagoshima	Osaka	82,018

Total Transportation Cost=2,873,950,700 ton-kilometers.

A 〃 indicates being the same as one mentioned above.

Interestingly, 82,000t of total surplus in Kagoshima and 44,000t in Miyazaki were estimated to be entirely shipped to Osaka and Tokyo, respectively. This indicates that if all producers in the nation were to cooperate with one another aiming to achieve the most efficient transportation system, a big surplus prefecture may end up shipping its entire surplus to only one market. The total transportation cost in the nation was estimated to be 2,874 million ton kilometers, which means a ton of eggs was moved as far as 2,874 kilometers in total.

Individually, the largest deficit volume of 216,000t in Tokyo was collected from Ibaragi (46,000t), Miyazaki (44,000t), Miyagi (34,000t), Iwate (29,000t), and Gumma (29,000). For the second largest deficit prefecture, Osaka, with 150,000t, major suppliers are Kagoshima, Kagawa, and Ehime shipping 82,000t, 35,000t, and 16,000t, respectively. The third largest deficit volume of 104,000t in Kanagawa was collected from Gifu, Hiroshima, and Toyama with 33,000t, 9,000t, and 4,000t, respectively.

Limitations of the Research

Although various interpretations may be drawn from this research, the linear-country transportation model for eggs in Japan has some limitations. First, the national crossing line drawn to represent the main route for egg transportation has oversimplified the actual situation. Eggs are actually transported through various highways all over the country and the means of vessels. Although it is impossible to measure every single route in the whole nation, it is better to develop a more realistic procedure for a further research. Another limitation of the model is that egg price was considered to be the same in all wholesale and retail outlets. Actually, egg prices vary according to location and type of retail shops. Egg prices also vary depending upon grades, in which eggs of low grades normally receive low prices and are used for industrial purposes like producing mayonnaise, ice creams, and cakes.

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