Cost and Efficiency of Milk Hauling

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(Received December 5, 1971)

In Japan, the number of cows per dairy farm is still so small that milk has to be collected at collecting stations first, and shipped to a factory. In the case of a large milk shed in Fukuoka Prefecture, the hauling and shipping cost was calculated through investigation. It was considerably high. By an econometric method, it was made clear how the cost could be minimized by decreasing the number of and enlarging the scale of collecting stations under the can- and the bulk-hauling systems.

I. INTRODUCTION

In Japan, the can-hauling is still common for transporting milk from farmers to processing plants. However, for the process between collecting stations and processing plants, the bulk-hauling has been gaining importance. Bulk-tanks have been installed at collecting stations, and tank-trucks replacing can-trucks in the hauling process. In Kyushu where milk handling needs special care because of the high temperature and humidity, 17.4 per cent of collecting stations were equipped with bulk-tanks in 1966, while the percentage was only 3.5 for the whole country at the same date as shown in Table 1.

Farmers bring their own milk each to their neighboring collecting stations. For that, they use their own traditional *l-to*** milk-cans and various kinds of vehicles. The milk is cooled there and waits for the further transportation. Two alternative methods are used for cooling and transportation. Under the "can-hauling system", farmers' milk is poured into co-ops' *2-to* milk-cans at the stations, as farmers' cans are too small. These cans are dipped into water cooled by the refrigerator and handed over to the pick-up truck. Under the "bulk-hauling system", farmers' milk is dumped into the bulk tank at the station, and cooled there. Then the milk is pumped up by the tank truck and hauled to the processing plant.

In a specified milkshed, there is a close relation among the number of collecting stations, their size, the distance from farms to collecting stations and the length of pick-up truck routes. If the whole amount of milk shipped remains constant, the greater the number of collecting stations, the smaller the

Table 1.   Collecting stations classified in types (Precentage, 1966).

Agricultural district	No apparatus except weighing machine	Water tank for cooling cans	Water tank for cooling cans with refrigerater	Surface cooler, and milk tank for storage	Bulk cooler	Total
Hokkaido	33.3	59.7	0	7.0	0	100
Tohoku	15.8	79.0	2.6	0.9	1.7	100
Kanto	49.0	35.4	14:o	0.7	0.9	100
Hokuriku	15.6	63.1	18.3	2.7	3.3	100
Tozan	49.0	35.4	14.0	0.7	0.9	100
Tokai	25.3	34.5	34.3	2.4	3.5	100
Kinki	35.1	17.7	43.3	2.0	1.9	100
Chugoku, Shikoku	59.4	21.8	15.5	2.0	1.3	100
Kyushu	19.1	5.0	58.5	5.5	11.9	100
Whole country	42.6	34.0	19.9	1.5	2.0	100

Source: Present Situations of Milk Hauling and Dairy Industry (Shūnyū to Nyūgyō no Genjō), Ministry of Agriculture and Forestry, mimeographed, 1967.

size of a station, and the shorter the distance from farms to collecting stations, but the longer the pick-up truck routes. If the whole amount of milk shipped changes, the cost at each stage will be changed. Accordingly, the total cost of hauling composed of three parts, i. e., (a) the shipping cost from farms to collecting stations, (b) the handling cost at the stations, and (c) the hauling cost from the stations to a processing plant, will be affected mainly by the number of collecting stations and the amount of milk shipped.

II. PURPOSE OF STUDY

This is a case study of a milkshed located in northern Kyushu for the purposes of (1) to estimate the hauling cost at the three different stages of hauling as stated above, (2) to estimate two kinds of optimums, i. e., (i) the optimum number and size of collecting stations under the can and the bulk hauling systems respectively to minimize the average hauling cost, assuming the whole amount of milk shipped being unchanged, and (ii) the optimum number and size of collecting stations, and the optimum amount of milk shipped, assuming that the latter can be changed, to minimize the average hauling cost.

III. INVESTIGATION

The milksheds investigated are located in Fukuoka Prefecture and cover the north-western and southern parts of this prefecture. The north-western area is centralized by Fukuoka, and the southern area by Kurume. Fukuoka is commercial city, and had a population of 749,808 in 1964.   Kurume is an industrial city where rubber and many related factories are located.   It had a population of 158,974 in 1964. We may call these two areas Fukuoka and Kurume milksheds.

Necessary data were obtained through interviews and records for the 12 month period from September, 1964 to August, 1965. In this milkshed, there were 885 dairy farms, 127 collecting stations and 25 pick-up routes. Out of these, 281 dairy farms, 67 collecting statitos and 15 pick-up truck routes were selected for investigation as follows.   Only all pick-up routes managed by a co-op were

investigated. The number of the routes was 15. Along the each route, collecting stations were selected alternately. Farmers investigated were selected at random among each group of farmers shipping their milk to each collecting station in proprotion to the number of farmers of the group, taking the total number of farmers sampled as 270 to 290 which might be enough for analyzing the results of the investigation for our study from the statistical point of view. A large co-op, Fukuoka Federation of Dairy Co-operatives (FFDC), covers the entire area. The milk is collected daily and shipped to a processing plant of Yukijirushi (Snow Brand) Milk Co. Ltd. which is one of the three largest milk companies in Japan.

To get data necessary to infer the effect of introducing the bulk hauling system into this area, a milkshed in Kumamoto Prefecture was investigated where the bulk hauling system was already adopted. In Kumamoto Prefecture, there were 18 large collecting stations with bulk tanks, which were located in the major dairy regions, and 18 associated pick-up routes. Out of them, 14 stations and 18 associated pick-up routes were sampled and investigated.

IV. RESULTS OF INVESTIGATION

Before analyzing the data we got, some general situation of the dairy investigated is stated here.

1. Dairy Farms

All farmers investigated are shown in Table 2. They are classified into two categories, the amount of milk shipped per farm per year and the distance from

Table 2. Number of investigated farms and their cows classified.

Amount of milk shipped (ton)	Distance from farm to collecting stations (kilometer)	Number of investigated farms	Number of cows and heifers per farm		
			Cows	Heifers	Total
S (less than 10)	A (less than 1)	36	2.7	0.6	3.3
	B (1 — 2)	21	2.6	0 . 9	3.5
	C (2 — 3)	12	2.8	0.8	3.6
	D (over 3)	4	3.6	0.8	4.4
M (10 — 20)	A (less than 1)	77	4.7	1.2	5.9
	B (1 — 2)	36	5.5	0.9	
	C (2 — 3)	6	4.3	0:s	6.4 5.1
	D (over 3)		4.5	0.5	5.0
L (20 — 30)	A (less than 1)	36	6.0		7.0
	B (1 — 2)	16	5.9	1.0	7.6
	C (2 — 3)	11		1.3	7.4
	D (over 3)	2	7.5	0.5	8.0
E L (over 30)	A (less than 1)			1.2	11.3
	B (1 — 2)	14	10.1	3.3	
	C (2 — 3)	2	10.1 13.0	4:o	13.4 17.0
	D (over 3)	1	16.0	—	16.0
Total		281	1.407	299	1.706
Average per farm			5.0	1.1	6.1

the farm to the collecting station, since those two factors are most closely related to every aspect of dairy farms, particularly to the hauling cost. The number of cows and heifers per farm are also shown in categories. On the average, a farm kept 5.0 milk cows and 1.1 heifers. The number of cows per farm does not change consistently with the distance from the collecting station. According to the statistics of Fukuoka Prefectural Government, the number of milk cows per dairy farm was 3.3 on the average of the whole prefecture in the same period.

Dairy farms are not so specialized in Japan as in most western countries. So is the case with this district. As for the farms investigated, on the average, about two thirds of farm land was arable, and about three fourths of the arable land was paddy used for rice culture. The acreage of farm land per farm was 2.23 hectares. Meadow or pasture was very scarce there being only about 0.24 hectares per farm. The acreage of arable land per farm did not vary consistently with the number of cows kept on the farm, but the acreage of pasture increased almost proportionately to the number of cows.

The number of workers per farm was 3.4 on the average, though not converted into man-equivalent. Out of them, 2.6 workers were the full-time, and 0.8 the part-time. There were no workers hired permanently here, while some workers were hired temporarily mostly for rice culture on about one fourth of the farms.

As for machinery, the so-called motorization was fairly advanced in this district. On most farms investigated, motor-tillers, motor-threshers, and motor-choppers were used, and on a little more than half of them, motor-sprayers and milkers were used. However, no farms had the "pipe-line milking system (parlor system)". They shipped their milk in cans by small-trucks, light-vans, motor-bicycles, bicycles, motor-tillers, or hand-carts. Cans of two different sizes were used. They were l-to and 5–*sho* cans. On the average, each farm had 2.43 cans of *l-to* and 2 cans of 5–*sho*.

2. Milking and Cooling

Milking was done twice or thrice a day. On most farms, milking was done between 5 : 30 and 7 : 30 in the morning, and between 6 *: 00* and 8 *: 00* or between 9 *: 00* and 10 : 30 in the evening. On about two thirds of the farms, they milked in the afternoon, too. These milking times were decided according to: (1) other works of their farms, particularly, the busy time of rice culture in season, (2) for several months milking cows thrice a day after calving, and (3) the time schedule of the truck coming around to the collecting stations in the morning. Most of the farmers shipped their milk in the morning before the trucks came. In summer here, it is very hot and humid. Therefore, the shorter the time between milking and shipping, the better the quality of milk, because milk was not cooled at farm, even at collecting stations very well. Thus, some farmers want to milk late at night.

36.0 per cent of farms did not use milkers. They milked by hand. Most of them were small farms. They use buckets for milking, and poured it into cans. They cooled cans in various ways before shipping. There were 7 farms

having refrigerators for tanks at their farms. About one third of the rest placed the cans in small water tanks with no cooling machines. The rest of two thirds brought their milk to collecting stations for cooling which was milked in the evening too, and they dipped their milk cans into the water cooled by the refrigerator by the next morning. Especially, in rainy and summer seasons, the cooling is big problems for farmers.

In these seasons, out of all investigated farmers, more than 86 per cent of farmers brought their milk again in the evening or in the night to coollecting station, 1.8 per cent of them cooled their milk can by hanging in the deep well, and 1.4 per cent of them use their home-refrigerator, for cooling, as shown in Table 3.

Table 3. Cooling on farm.

(Percentage)

		Streams or ponds	Hanging in well	Refrigerator*	Water tank	Cooling machine	Shipping soon to collecting station without cooling	Total
S	B	..0	0	2.8	2.8	0	91.7	100
	C	16.7 9.5	14.3	9.5	9.5	0	57.1	100
			0	0	25.0	0	58.3	100
	D	25.0	0	0	25.0	0	50.0	100
M	B	0.6	0	0	*0*	3.0	*97.4*	100
	C	16 7	0	0	*6.1*	0	90.9	100
			0	0	16.7	0	66.7	100
	D	33:3	33.3	0	0		33.3	100
L	B	0	0	0	0	0	100.0	100
	C	0	0	0		0	93.7	100
		0	0	9.1	6.3		63.6	100
	D	0	0	0	0'9.1	18.2 0	100.0	100
	A			0	0	10.3	85.7	100
E	B	0	0	0	25.0	0	75.0	100
	C	0	0	0	0		100.0	100
	D	0	0	0	0	100.0	0	100
Total		3.6	1.8	1.4	4.6	2.5	86.1	100

* The same kind as used for food. Only used in summer.

The more the amount of milk shipped, and the longer the distance from the farms to the collecting stations, the more the farmers brought their milk to the collecting stations for cooling.

3. **Transporting Facilities**

All farmers investigated shipped their milk to the collecting stations themselves by their own several kinds of vehicles. The number of farmers classified according to the kind of vehicles for shipping is shown in percentage in Table 4. Taking all farms investigated as 100, **32.7** per cent of them shipped their milk by motorbicycles, 19.6 per cent by bicycles, 16.0 per cent by light-vans, *12.5* per cent by hand-carts, 4.6 per cent by small-trucks, 2.0 per cent by motor-tillers, and 12.6 per cent by no vehicles at all, because they were located very

Table 4. Kinds of vehicles used by farmers for shipping milk.

(Percentage in number of farms)

		Small-truck	Light-van	Motor-bicycle	Bicycle	Motor-tiller	Hand-cart	No vehicle	Total
Distance :	A	2.7	7.3	19.4	14.7 25 6.9	1.3 2.4	21.8	21.2 13	100 100 100
	B	6.7	29.3	46.7					
	C	13.8	24.1	55.2					
	D	—	35.7	64.3	—	—	—	—	100
Load Size:	S	1.4	2.7	44.6	31.1	—	6.8	12.2	100
	M	2.5	13.1	37.7	23.0	—	13.9	10.7	100
	L	9.2	32.3	20.0	4.6	4.6	15.4	12.3	100
	E L	14.3	33.3	—	4.8	9.5	19.0	28.6	100
Total		4.6	15.9	32.7	19.6	2.0	12.5	12.7	100

near the collecting stations. The kind of vehicle varies according to the dis tance and the load-size as in Table 4.

In Table 4, bicycles are used for a short distance and a small load, rear-car? for a short distance, and a larger load. Motorbicycles are used for a longer distance, but a small load, and light-vans for a longer distance and a larger load. Small-trucks are the largest vehicles, but not always used by the farmers belonging to the class of the largest load size and the longest distance. Because, the farmers purchased the vehicle to use mainly for the other purposes, i. e., transportations of feeds, manures and others. Some farmers told us that small-trucks were too big for their load size, and the transportation cost was high for shipping milk.

The average and the range of load size and distance of each class are shown in Table 5. The average load size was 18.131 tons per year, and the average hauling distance 0.977 km.

Table 5. Distances and load sizes.

(Average for a farm)

		Small-truck	Light-van	Motor-bicycle	Bicycle	Motor-tiller	Hand-cart	No vehicle	Average
Distance :		km	km	km	km	km	km	km	km
	A	0.600	0.292	0.498	0.419	0.480	0.178	0.067	0.315
	B	1.525	1.164	1.325	1.155	1.800	—	1.000	1.259
	C	2.275	2.143	2.081	2.000	2.000	—	—	2.113
	D	—	5.125	4.233	—	—	—	—	4.508
Average		1.580	1.606	1.429	0.576	0.671	0.195	0.096	0.977
Range		0.8-2.5	1.0-6.5	0.2-6.0	0.15~1.5	0.3~0.8	0.02-0.4	0.0-0.2	—
Load Size :		ton	ton	ton	ton	ton	ton	ton	ton
	S	5.223	6.871	7.062	6.676	—	6.107	5.720	6.738
	M	12.561	18.036	14.708	13.789	—	15.741	14.362	14.808
	L	24.592	25.496	23.639	22.258	26.544	25.064	23.596	24.515
	E L	50.290	45.730	71.026	32.654	44.018	48.584	30.676	45.845
Average		24.253	26.110	*14.227*	12.515	31.537	23.985	17.508	18.131
Range		6-49	5-41	*4-26*	3-21	14~29	8~42	5~35	—

4. Handling at Collecting Stations

Cooling machine was installed in all collecting stations under FFDC. The cooling machine can keep the temperature of water in the tank at 10℃ while it works. All of them usually worked from March to December. The water tank had a capacity of 3.9-*koku* on the average. But the actual level was 1.83–*koku* per day. Such under-utilization suggests inefficiency in the operation of collecting stations.

Farmers ship their milk usually in the morning before the co-op truck comes. The "manager" at the collecting station checks the quantity of each farmer's milk, and tests it with alcohol. If the milk passes the test, it is poured into larger, 2–*to* cans of the co-op, and loaded on the truck when it comes. The farmers wash their cans and come home. The "manager" was hired as a part-time worker by the co-op. The milk shipped in the afternoon has to be kept cool in the water until the next morning.

In Kumamoto, all collecting stations investigated had bulk tanks. These tanks can store milk cooling. Under this system, milk is cooled at about 1°C or any desired level, and pumped up into a pick-up truck. The capacity of tank on the average for collecting stations investigated was 31. 7–*koku*, and all tanks were used at almost full capacity.

5. Hauling from Collecting Stations to Plant

The pick-up trucks of FFDC came around to all collecting stations, and collected the 2–*to* cans, and brought them to the plant, once a day. The pick-up route was 47.28 kilometers long, and included 4.2 collecting stations, and by which 2.006 tons of milk was hauled per day on the average. The loading and unloading of these cans were done by hand. The handling of the shipped milk at the plant was composed of the quality alcohol-inspection, dumping, weighing, can washing, and reloading of empty cans on the truck.

In Kumamoto, a tank truck ran 79.8 kilometers, and hauled 4.085 tons of milk per day on the average. Under the bulk hauling system, the operations performed at collecting stations by the driver of the truck are very simple. He only connects the pick-up tank to the storage tank with a hose. The milk was pumped up by a motor automatically.

6. Hauling Cost

The hauling cost per 1 kilogram of milk was 6.23 yen on the average for the entire hauling process. The price of milk purchased at the plant was determined every month. The price was 36.49 yen per 1 kilogram on the year average. Therefore, the hauling cost stands at 16.79 per cent of the price. Of course, the hauling cost is not only composed of money expenses. It includes the labor cost paid by farmer's own labor. Such labor cost was 2.26 yen out of 6.23 yen per 1 kilogram of milk. It was estimated with the wage rate of temporary hired workers in this district. The hauling cost at each stage is as follws:

Stage I: from farms to collecting stations.	3.31 yen per kg	53.2 %
Stage II: at collecting stations.	1.09 〃	17. 5 〃
Stage III: from collecting stations to plant.	1.83 〃	29.3 〃
Total	6.23 〃	100.0 〃

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Under the bulk hauling system in Kumamoto, the hauling cost was 0.78 yen per kilogram at stage II, and 1.03 yen per kilogram at stage III, respectively. Both were much smaller than their counterparts in Fukuoka. The detail of the hauling cost for each stage was shown in Tables 6, 7, and 8.

Table 6. Hauling cost on first stage (yen per 1,000 kg of milk).

Kind of Vehicle	Small truck	Light-van	Motor-cycle	Bicycle	Hand-tractor	Hand-cart	No vehicle	Total
Number of Farms	13	45	92	55	5	35	36	281
Fixed Costs :								
Vehicles'	669.4	1,142.0	787.0	205.3	336.5	18.1	——	——
Tax and insurance for vehicle[2]	238.8	100.3	39. a	——	11.4	——	——	——
Cans[3]	309.7	38.3	47.9	59.4	23.5	35.0	23.1	
Sub-total	1,217.9	1,280.6	874.7	264.7	371.4	53.1	23.1	615.8
Variable Costs :								
Gas and oil	1,112.0	435.7	402.7	——	178.4	——	——	——
Repair	363.8	57.0	100.0	113.1	28. a	29.0	——	——
Wages[4]	2,903.8	1,907.1	1,407.8	3,929.0	1,448.0	1,968.8	2,521.8	——
Miscellaneous	194.0	176.4	158.6	27.0	45.3	5.1		——
Sub-total	4,573.6	2,576.2	2,069.1	4,069.1	1,700.5	2,002.9	2,521.8	2,700.8
Total	5,791.5	3,856.8	2,943.8	4,333.8	2,071.9	2,056.0	2,544.9	3,316.6

1, 3. Depreciation and interest (0.06). For the vehicles' depreciation, wheels, bodies, front tires and rear ones were estimated separately.

1, 2, 3. Hauling share was estimated through interviews.

4. Operator and his family's labor only. Estimated with the wage rate and labor hours of a temporary worker in every month. Labor hours included the time spent at the receiving station for handling, checking, and test.

Table 7. Hauling cost on second stage (yen per 1,000 kg of milk).

	Can Hauling System	Bulk Hauling System
Fixed Costs :		
Building and equipment'	202.6	156.4
Land rent and taxes	33. a	5.6
Machinery[2]	391.7	*
Sub-total	628.1	162.0
Variable Costs :		
Repairs	27.3	44.8
Electricity	384.5	200.0
Co-op's branch expenses[3]	33.0	
Miscellaneous	19.7	63.8
Wages	—	310.6
Sub-total	464.5	619.2
Total	1,092.6	781.2

1, 2. Depreciation and interest (0.06).

3. Receiving stations are managed by the co-op's branches. Co-op's branches ran other businesses than hauling milk. Here, hauling share was estimated.

* This cost is included in the item of building and equipment.

Table 8. Hauling cost on third stage (yen per 1,000 kg of milk).

	Can Hauling System	Bulk Hauling System
Fixed Costs :		
Vehicles[1]	201.0	323.5
Land rent and equipment2	2x. 4	*
Insurance for labors[3]	157.0	**
Tax and insurance4	50.8	44 9
Sub-total	437.2	368: 4
Variable Costs :		
Gas and oil	78.2	190.5
Repair	78.8	111.3
Wages[5]	442.0	246.8
Co-op's expenses[6]	104.2	98.8
Miscellaneous	32.2	13.6
Sub-total	735.4	*611.0*
Total	1,172.6	1,029.4

1, 2. Depreciation and interest (0.06).
3, 4, 5, 6. Hauling share estimated.
 * This cost is included in the item of vehicle.
** This cost is included in the item of wages.

V. ANALYSIS

1. Model of Average Cost Function

The hauling cost at each stage depends on several factors, i. e., the kind of vehicle, the load size, the hauling distance, the size of collecting station and the volume of milk handled. The relationship between the hauling cost and these factors can be expressed in terms of the following average cost functions.

Stage I. For farms using vehicle $i(=$small-truck, light-van, motorbicycle)

$$C_{Ii} = a_i + b_{1i}x_{1i} + b_{2i}x_{1i}^2 + c_{1i}x_{2i} + c_{2i}x_{2i}^2 + u_i \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(1)$$

where, C_{Ii}: hauling cost at Stage I from farm to collecting station per ton of milk per year (1,000 yen),

x_{1i}: volume of milk shipped from farm to collecting station per year (ton),

x_{2i}: distance from farm to collecting station (km),

$a_i, b_{1i}, b_{2i}, c_{1i}, c_{2i}$: parameters to be estimated,

u_i: error term.

Stage II. Under the hauling system $j(=$can hauling system, bulk hauling system)

$$C_{IIj} = k_j + m_{1j}\bar{x}_{1j} + u_j \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (2)$$

where, C_{IIj}: cost of handling at collecting station per ton of milk per year (1,000 yen),

$\bar{x}_{1j}$: volume of milk handled at collecting station per year (ton),

k_j, m_{1j}: parameters to be estimated,

u_j: error term.

Stage III. Under the hauling system $j(=$can hauling system, bulk hauling system)

$$C_{\text{III}j}=\alpha_j+\beta_{1j}X_{1j}+\beta_{2j}X_1^2+\gamma_{1j}X_{2j}+\delta_j\frac{X_{3j}}{R_j}+\nu_j \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (3)$$

where, $C_{\text{III}j}$: hauling cost from collecting stations to processing plant per ton of
        milk per year (1,000 yen),
   X_{1j}: volume of milk hauled per route (ton),
   X_{2j}: distance traveled per truck (1,000 km),
   X_{3j}: number of collecting stations per route,
   R_j: number of routes, given (=25),
   $\alpha_j, \beta_{1j}, \beta_{2j}, \gamma_{1j}, \delta_j$: parameters to be estimated,
   ν_j: error term.

By summing up the above equations, we may derive an aggregate hauling cost function covering the whole process of hauling as follows:

$$C_T=C_{1j}+C_{\text{II}j}+C_{\text{III}j} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (4)$$

where, C_T denotes the aggregate average hauling cost, C_{1j} the cost function on Stage I, $C_{\text{II}j}$ the cost function on Stage II and $C_{\text{III}j}$ the cost function on Stage III.

In the equation (4), some variables are related with each other by their definitions as follows:

$$\bar{x}_1=\frac{nx_1}{X_3},$$

$$X_1=\frac{nx_1}{R_j}.$$

where, n is the total number of dairy farms, given (=885). x_2, X_2, and X_3 are closely related with each other. From the investigated data, we derived the following equations.

    $x_2 = 6.5124\ -0.02887\ X_3$ $R^2=\textbf{\textit{0.7408}}$
            (0.01207)
    $X_1=48.6572-8.72774\ X_3$ $R^2=0.\textbf{\textit{9945}}$
          (0.67675)

Using these relations, several variables in equation (4) can be eliminated. Thus, we will obtain C_T as a function of two variables, x_1 and X_3 for farms using vehicle *i,* and for hauling system j.

$$C_{Tij}=kij+pijx_1+qijx_1^2+rijX_3+sijX_3^2+tij\left(\frac{x_1}{X_3}\right) \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots (5)$$

2. Estimation of Parameters

Stage I.

   Light-van; $C_I=3.56820-0.15201x_1+0.00172\ x_1^2-0.01514x_1+0.00052\ x_2^2\cdots\cdots (6)$
               (0.05863) (0.00070) (0.01001) (0.00032)
                                     $R^2=0.\textbf{\textit{9556}}$

   Motorbicycle ; $C_I = 4.44930-0.38994\ x_1+0.00784\ x_1^2+2.90170\ \dot{x}_2-0.31773\ x_2^2$
               (0.18670) (0.00744) (0.89543) (0.11738)
         $\cdots\cdots\cdots\cdots\cdots\cdots\cdots$ (7) $R^2=0.\textbf{\textit{9390}}$

Small-truck; $C_1 = 4.16500 - 0.33374\ x_1 + 0.00398\ x_1^2 + 0.62126\ x_2^2$ ················(8)
            (0.21125) (0.00363) (0.23233)

Stage II. $R^2 = 0.9366$

Can hauling system: $C_{11} = 3.20870 - 0.02692\ \bar{x}_1 \cdots \cdots *\cdots\cdots *\cdots *\cdots\cdots$ (9)
            (0.00725)

                    $R^2 = 0.6324$

Bulk hauling system; $C_{11} = 2.31900 - 0.00087\ \bar{x}_1 \cdots \cdots *\cdots\cdots$ (10)
            (0.00026)

                    $R^2 = 0.7343$

Stage III.

Can hauling system; $C_{III} = 1.48870 - 0.00150\ X_1 + 0.000000415\ X_1^2 + 0.16264\ X_2$
            (0.00053) (0.000000213) (0.10052)

$$+0.00334\left(\frac{X_3}{R}\right) \cdots\cdots\cdots\cdots\cdots\cdots *\cdots (11)$$
(0.00167)
                    $R^2 = 0.6956$

Bulk hauling system; $C_{III} = 0.57332 - 0.00049\ X_1 + 0.000000177\ X_1^2 + 0.02868\ X_2$
            (0.00059) (0.000000149) (0.00942)
··········· (12) $R^2 = 0.6956$

From these equations, the following aggregate hauling cost functions are derived.
Can hauling system:

Light-van; $C_T = 16.05841 - 0.20512\ x_1 + 0.00224\ x_1^2 + 1.41948\ X_3 - 23.82420\dfrac{x_1}{{}_{.3}V}$

··(13)

Small-truck; $C_T = 43.12439 - 0.38685\ x_1 + 0.00450\ x_2 + 1.30270\ X_3 - 23.82420\dfrac{x_1}{{}_{.3}V_3}$

··(14)

Motorbicycle; $C_T = 35.95730 - 0.44305 x_1 + 0.00836\ x_1^2 + 1.39545\ X_3 - 23.82420\dfrac{x_1}{X_3}$

····························*·····(15)

Bulk hauling system :

Light-van; $C_T = 7.77963 - 0.16936 x_1 + 0.00194 x_1^2 + 0.23393 X_3 - 0.76553\dfrac{x_1}{X_3}$ ··(16)

Small-truck; $C_T = 34.80117 - 0.35109\ x_1 + 0.00420\ x_2 + 0.11764\ X_3 - 0.76553\dfrac{x_1}{X_3}$

··(17)

Motorbicycle; $C_T = 14.15876 - 0.40729\ x_1 + 0.00806\ x_1^2 + 0.21040\ X_3 - 0.76553\dfrac{x_1}{X_3}$

··(18)

3. **Estimation of Optimums**

The estimation to get two kinds of optimums stated in II, the purpose of the study, were done of the three groups of farmers which use light-van, small-truck and motorbicycle. Using the average cost functions on three stages, we obtained the aggregate average cost function of whole processes for both haul-

ing systems of the can and the bulk as follows.

Using the aggregate cost functions, we can estimate the two optimums (i) and (ii) as stated above.

(i) Let x_1 take the magnitude of the current amount of milk shipped from a farm on the average, and differentiate the functions with respect to X,. Let the derivatives be equal to zero, examining the second order derivatives, and we can get the optimmum X_3 to minimize C_T under the current x_1.

(ii) Differentiate the functions with respect to x_1 and X_3, and let the derivatives be equal to zero respectively, examining the second order derivatives. Thus, we can get the optimums of x_1 and X_3 to minimize C,,

The results are as follows (Tables 9, 10) :

Table 9.   Optimum number and size of collecting stations to minimize hauling cost under current amount of milk shipped.

Hauling system	Kind of vehicle used at Stage I	Optimum number of collecting stations" X_3	Size of collecting stations under X_3** x_2	Hauling cost C_T
Can-hauling	Light-van	17	2.586 ton	685.5 yen/ton
	Small-truck	18	2.442	2,043.0
	Motorbicycle	18	2.442	1,753.5
Bulk-hauling	Light-van	8	5 . 4 9 5	313.4
	Small-truck	11	3.997	1,646.3
	Motorbicycle	8	5.495	3 7 8 . 8

* Current number of hauling stations is 127.

** $\bar{x}_2$: Current amount of milk shipped$\div X_3 \div 365$.

The current size of a collecting station was 0.7336 tons on the average, and the current amount of milk shipped per day per station was 0.3433 tons on the average.

Table 10.   Optimum number and size of collecting stations, and optimum amount of milk shipped to minimize hauling cost.

Hauling system	Kind of vehicle used at Stage I	Optimum number of collecting stations X_3	Size of collecting stations under X_3 and x_1 $\bar{x}_2$	Optimum amount of milk shipped per farm per year x_1	Hauling cost C_T
Can-hauling	Light-van	39	ton	ton	yen/ton
	Small-truck	45	1.127	107.30	107.1
	Motorbicycle	34	0.977	126.33	458.8
			1.293	62.43	550.7
Bulk-hauling	Light-van	18	3.140	91.67	74.4
	Small-truck	10	2.442	89.55	40.2
	Motorbicycle		3.848	48.07	241.9

* Current amount of milk shipped per farm on the average was 18.131 tons per year.

Using the results shown in Table 9, we caculated the optimum number and size of collecting stations to minimize the hauling cost under various amount of milk shipped for the practical purpose. The results are shown in Table 11.

Table 11. Optimum number and size of collecting stations to minimize hauling cost under possible various amount of milk shipped.

Hauling system	Kind of vehicle used at Stage I		2 times the current amount	3 times the current amount	4 times the current amount
Can-hauling	Light-van	X_3 $\bar{x}_2$ (ton) C_T(yen/ton)	25 3.517 344.6	30 4.396 200.7	35 5.024 183.3
	Small-truck	X_3 $\bar{x}_2$ (ton) C_T(yen/ton)	26 3.382 983.3	32 4.121 672.6	36 4.885 519.0
	Motorbicycle	X_3 $\bar{x}_2$ (ton) C_T(yen/ton)	25 3.517 860.8	31 4.254 699:5	35 5.024 *651.8*
Bulk-hauling	Light-van	X_3 $\bar{x}_2$ (ton) C_T(yen/ton)	11 7.993 3.16.9	13 30.345 76.2	**15** 11.723 76.0
	Small-truck	X_3 $\bar{x}_2$ (ton) C_T(yen/ton)	15 5.862 758.6	19 6.941 518.0	22 7.993 434.::
	Motorbicycle	X_3 $\bar{x}_2$ (ton) C_T(yen/ton)	31 7.993 269.7	14 9.420 290.9	16 10.990 371.1

VI. CONCLUSION

In this study, 281 dairy farms, 67 collecting stations and 15 pick-up routes of a milkshed under Fukuoka Federation of Dairy Co-operatives which was shipping milk to Yukijirushi (Snow Brand) Milk Company Ltd. were investigated to analyze the hauling cost. In this milkshed, there were 885 dairy farms, 127 collecting stations and 25 pick-up routes. This milkshed was under the can-hauling system. In order to infer the effect of introducing the bulk-hauling system into this milkshed, a milkshed in Kumamoto Prefecture was investigated, where the bulk-hauling system was adopted. The main results of the study were as follows:

(1) The hauling cost of milk from farms to the processing plant under the can-hauling system was 6,230 yen per ton, or 16.2 per cent of the f. o. b. milk price at the plant. (In the United States, the percentage was 5.0 under the can-hauling system in 1957. Sidney Ishee and W. L. Barr: "Effects of Bulk Milk Assembly on Hauling Cost." The Pennsylvania State University, College of Agriculture and Experiment Stations, Bulletin No. 641, 1958.) Under the bulk-hauling system, the hauling cost was estimated as 5,118 yen per ton, or 13.3 per cent of the f. o. b. milk price at the plant. If the amout of milk shipped increases, the hauling cost can be cut down much by substituting the bulk-hauling system for the can-hauling system.

(2) Under the current amount of milk shipped, the collecting stations will have to be reduced from the current number 127 to 17~18 under the can-hauling system, and 8~11 under the bulk-hauling system, to minimize the hauling cost. The hauling cost minimized will be about 1,494 yen per ton under the can-haul-

ing system, and about 446 yen per ton under the bulk-hauling system.

(3) Assuming that both the number of collecting stations and the amount of milk shipped can be changed, the former will have to be reduced to 34-45 under the can-hauling system, and 10∼14 under the bulk-hauling system, and the latter will have to be increased to 62.43-107.30 tons per farm per year under the can-hauling system, and 48.07-91.67 tons per farm per year under the bulk-hauling system, to minimize the hauling cost, while the current amount of milk shipped was 18.13 tons per farm per year.

(4) Even though the amount of milk shipped increases considerably, the current number of collecting stations will be too large. For instance, the amount of milk shipped increases to 2-4 times the current amount, the current number of collecting stations will have to be reduced to 25-36 under the can-hauling system, and 11-22 under the bulk-hauling system to minimize the hauling cost.