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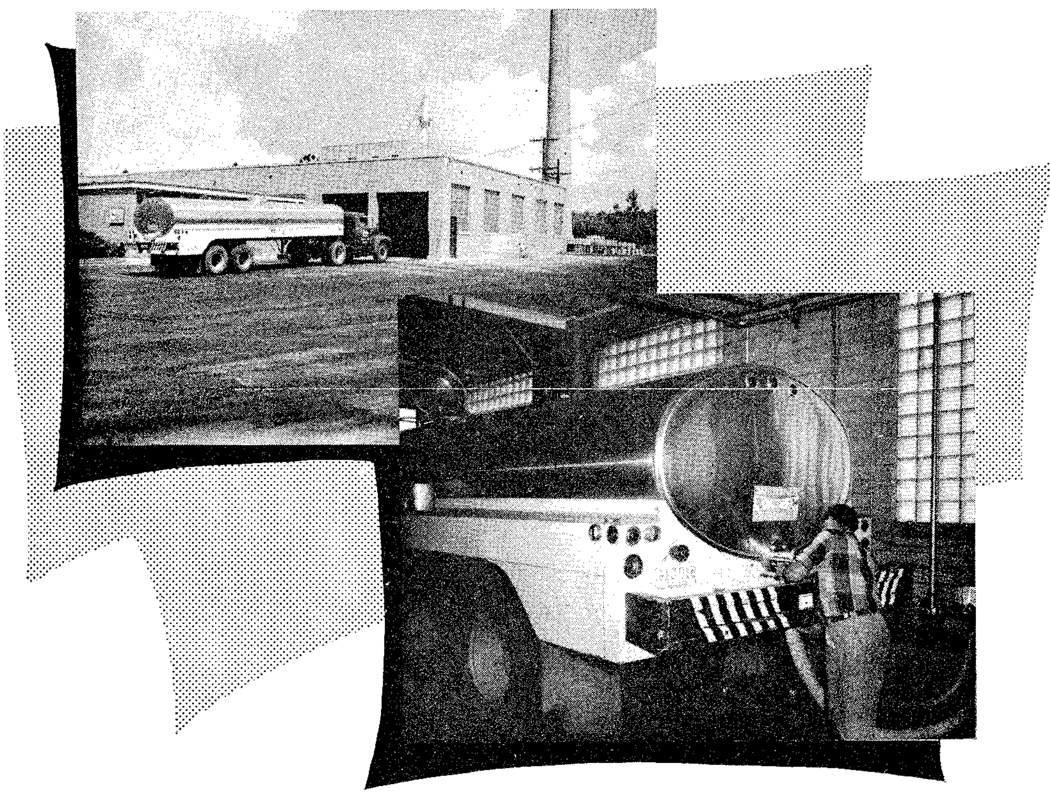
INTERPLANT MILK TRANSPORTATION Costs

Russell G. Thompson — E. Fred Koller



AGRICULTURAL EXPERIMENT STATION
UNIVERSITY OF MINNESOTA

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ON THE COVER: Top—A large interplant tank truck arriving at the central processing plant with its load of milk. **Bottom**—Driver making pipeline connections to unload a truckload of milk at the central plant.

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Russell G. Thompson and E. Fred Koller

DURING THE LAST 20 YEARS numerous technological changes and government farm programs resulted in major changes in Minnesota's dairy industry. New types of equipment and improved techniques significantly affected the costs of producing, transporting, and processing milk. Relatively stable and favorable prices for nonfat dry milk stimulated farm sales of whole milk and the development of a dry milk industry.

In this period both size and volume of output of Minnesota's dairy manufacturing plants grew steadily. In 1940 butter plants in the state had an average annual output of about 315,000 pounds of butter. By 1961 butter output per plant increased to 860,000 pounds. In 1942 only six milk-drying plants produced over 5 million pounds of powder a year. By 1960, 43 plants were producing over 5 million pounds. Twelve of these produced over 10 million pounds annually.

A large volume of output is necessary to justify investment in new and larger equipment and plant facilities. Significant economies of size and lower per unit costs can be obtained as the output of dairy manufacturing plants is expanded.[1]

As milk-processing plants become bigger, they generally must obtain milk from larger supply areas. Milk assembly costs relative to processing costs become a more important consideration. Some of the milk needed is assembled on direct pickup routes from producers in the immediate plant supply area, but the amount received is generally limited. Most of the milk needed by bigger plants is assembled through a satellite group of supplying creameries and milk-receiving stations located at widely varying distances.

Some supplying creameries receive whole milk, separate it, process the cream into butter, and send the skim milk by tank truck to the central processing (milk-drying) plant. Some local creameries and receiving stations receive whole milk from their producers, weigh it, merely cool it, and then reload it on tank trucks for shipment to the larger processing plants. A central processing plant may receive skim milk and whole milk from as many as 30 local feeder plants.

In Minnesota the volume of milk involved in interplant milk transfers of this type is great. A 1961 survey by the Department of Agricultural Economics, University of Minnesota, of all Minnesota milk-drying plants found that 66 out of a total of 76 plants received substantial quantities of milk from local creameries and receiving stations. In 1960 about 4.5 billion pounds of milk

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[1] Arvid C. Knudtson and E. Fred Koller. *Manufacturing Costs in Minnesota Creameries.* Minn. Agr. Expt. Sta. Bull. 442, June 1957, pp. 19-24.

were transported by tank trucks from these local feeder plants to central processing plants. This milk constituted 65 percent of the total receipts of the central plants.

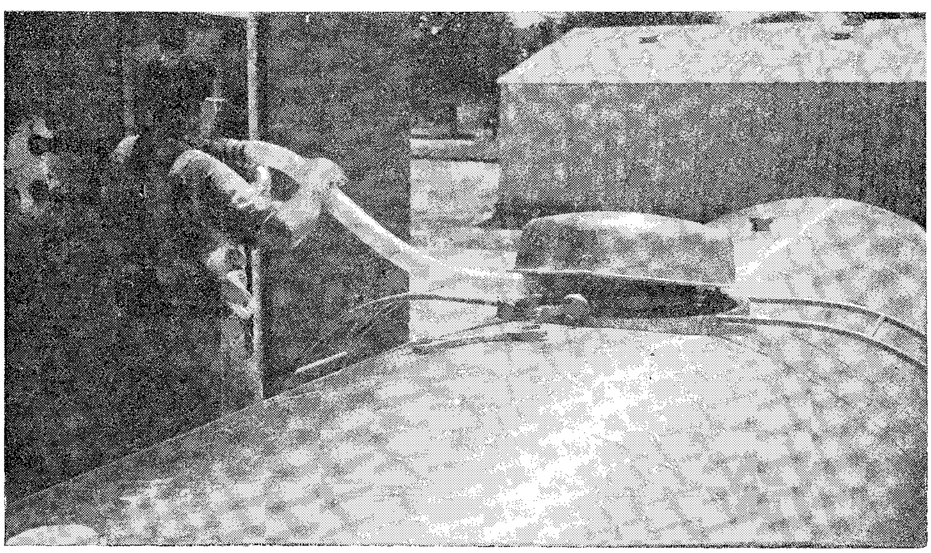
Many dairy plants, particularly drying plants, have a big investment in interplant milk-hauling units. One large plant had a peak daily volume of 1.5 million pounds of milk, which it procured from 30 receiving stations and local creameries. It operated a fleet of 16 tank trucks over a supply area with a radius of about 60 miles. In the peak period of production trucks were operated about 18 hours a day. The original cost of interplant tank truck units ranged from about $10,000 to $30,000 each.

The total cost of transporting milk from local receiving points to central processing plants in Minnesota is great. Assuming that the cost of interplant transportation of milk averages about 10 cents per hundredweight (cwt.), the total outlay for this purpose is about 4.5 million dollars annually.

Efficient low cost interplant transportation of milk is of great importance to Minnesota's dairy industry. With adoption of more efficient practices and modern techniques and equipment, these costs may be reduced from present levels in most cases. This can result in worthwhile savings to dairy plants and, in turn, to their member producers.

The primary objective of this study was to estimate the relationships between interplant milk transportation costs and factors influencing these costs. This involved a study of the relationships between: (1) interplant hauling costs and truck capacities, (2) interplant hauling costs and miles driven, (3) truck costs and utilization of hauling capacity, (4) truck costs and miles driven, (5) truck costs and weight efficiency, (6) labor costs and miles driven, (7) labor costs and sizes of loading equipment, and (8) labor costs and sizes of unloading equipment.

Another objective was to develop accurate estimates of interplant milk transportation costs. Dairy plant managers constantly strive to improve their decision making. But to do this well they need accurate cost estimates. Then they can evaluate the efficiency of their operations; and, in the case of hauling, they have a basis for judging the efficiency of their trucks and drivers.



Driver making pipeline connections to load a tank truck at a local creamery.

Research Procedure

The logical framework formulated to explain interplant transportation costs consisted of a truck cost relationship and a labor cost relationship. Truck costs were considered as related to miles driven, hauling capacity, weight efficiency (tare weight divided by loaded gross weight), and fuel type. Labor costs were considered as related to miles driven, volume hauled, number of loading stops, loading equipment, and unloading equipment.

The labor relationship, in turn, was broken into independent variable and fixed components. Variable components were driving time, loading time, and unloading time. Relationships were formulated for each of them. Driving time was considered as related to miles driven. Loading time was considered as related to volume loaded and loading equipment. Unloading time was considered as related to volume unloaded and unloading equipment utilized.

The fixed components of time were route preparation, local plant hookup, local plant unhook, local plant waiting, central plant hookup, central plant unhook, central plant waiting, personal, cleaning, and miscellaneous.

Source and Characteristics of Data

The data used for estimating interplant milk-hauling costs were obtained from 10 relatively large milk-drying and butter-powder plants. These plants were located throughout Minnesota's principal

Classification of Interplant Hauling Costs

Truck Costs		Labor Costs	
Variable	Fixed	Variable	Fixed
Fuel	Depreciation	Driving	Route preparation
Oil	Insurance	Loading	Local plant: Hookup* Unhook† Waiting
Repair labor	Interest (opportunity costs)		
		Unloading	Central plant: Hookup‡ Unhook§ Waiting
Repair expenses for parts	License		
Tires	Miscellaneous		Personal
			Cleaning
			Miscellaneous

* Local plant hookup: time used to prepare the truck unit for loading.

† Local plant unhook: time used to prepare the truck unit for departure from the loading stop after it was loaded.

‡ Central plant hookup: time spent preparing the truck unit for unloading.

§ Central plant unhook: time spent getting the truck unit ready for the next load after it was unloaded.

dairy producing area. At the time of this study, each plant had a maximum daily processing capacity of more than 300,000 pounds of milk. Also, each plant operated more than five interplant (bulk tank) milk-hauling units.

The processing plants used straight trucks and tractor-trailer combinations (semi-trucks) for interplant milk hauling. Straight trucks had a capacity of between 13,000 and 25,000 pounds and semiunits between 28,000 and 43,000 pounds.

Some plants operated transports that used fuels other than gasoline, especially tractors with tandem-driving axles. All of these used either liquefied petroleum or diesel oil.

Excellent truck records were kept by five of the plants studied. Each manager had recorded on a monthly basis the physical amounts of fuel, oil, and repair labor as well as the costs of all factors. So it was possible to remove the effect of price changes for these variable costs. This was especially important for fuel costs—the largest variable cost component.

The situation differed in the case of labor costs. No manager kept labor records for their individual routes. As a result, individual hauling tasks were not estimable from the accounting records. To overcome this lack of data a time-and-motion study was made. Seventy-six drivers were selected at random and timed over their interplant routes. With these data, estimates were made of the time needed for each interplant hauling task.

Organization of Truck and Labor Data

All data used to estimate interplant milk-hauling costs were organized in terms of: (1) truck costs, and (2) labor costs. Both sets of costs were separated further into their respective variable and fixed cost components. The following classification of interplant hauling costs was used.

Estimation Procedures

Truck Costs—In this study total truck costs represent the sum of variable and fixed costs for each truck unit. Variable truck costs vary with the number of miles driven and the amount of milk transported. Fixed truck costs have to be met whether the truck units are used or not.

Variable truck costs were estimated mainly from physical data. Fuel, oil, and repair costs were computed with one set of prices: gasoline, 24 cents per gallon; diesel oil, 20 cents per gallon; liquefied petroleum, 17 cents per gallon; oil, 20 cents per quart; and repair labor, $3 per hour.

Tire costs were estimated by replacing each truck's tires at fleet prices. It was assumed that each set of original tires would run an average distance of 60,000 miles, would be retreaded twice, and give an additional 80,000 miles of service. Retread prices were also calculated at fleet prices. Original tire costs as well as retread costs were then allocated on a per mile basis.

Fixed truck cost components were estimated in two different ways. Relatively minor components of fixed costs—insurance, license, and miscellaneous—were estimated from truck records. But more accuracy was desired for depreciation and opportunity costs which are influenced considerably by price changes. To overcome this influence each truck unit was valued at 1958 fleet prices. Then depreciation and opportunity costs were estimated from these adjusted values.

Depreciation costs for trucks, tractors, and trailers were calculated with the straight line method. A 5-year depreciation period was used for trucks and tractors and a 10-year period for bulk-milk tanks. Allowances for salvage values also were made for trucks and tractors; these were based upon trading experience in the Twin City area. Allowances for gasoline and liquefied petroleum trucks were 20 percent of their initial costs; allowances for diesel units were 40 percent of their initial costs. Diesel units have been worth relatively more after 5 years of use than either gasoline or liquefied petroleum trucks.

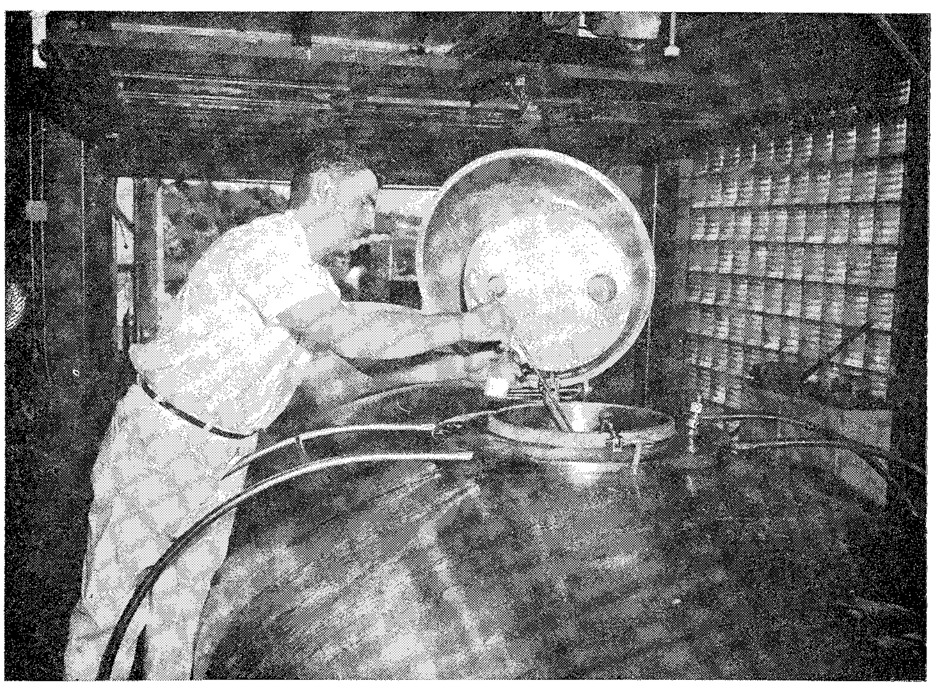
Opportunity costs represent an earnings allowance that managers could have received from alternative investments. On an annual basis they represented 5 percent of the average investment in each truck unit.

All these components of variable and fixed costs were summed to obtain total variable costs and total fixed costs. In turn, total variable costs and total fixed costs were summed to obtain total truck costs. Each summation was made for each truck unit on a monthly basis. A statistical analysis was then made of the relationship between total truck costs and miles driven, hauling capacity, weight efficiency, and fuel type. This statistical estimate was used to predict total truck costs for various levels of mileage utilization and hauling capacity.

Labor Costs—Labor costs were estimated initially on a load basis. Estimates were made of the labor needed for typical sets of route conditions: (1) route lengths—25, 50, 75, and 100 miles; (2) one, two, and three loading stops; (3) 2-inch loading lines; (4) 3-inch unloading lines; and (5) a 90-percent level of capacity utilization.

To convert these labor estimates into costs, a wage rate of $1.80 per hour was used. This $1.80 per hour wage rate was the typical rate of remuneration at the study time.

Labor costs per month were calculated from these load estimates. First, the number of loads that an individual truck could haul was calculated. It represents the quotient of the specified number of miles per month for each truck unit and the specified length of route for a load of milk. Labor costs per month represent the product of labor costs per load and the number of loads each truck could haul.



Milk samples are taken from each truckload for the purpose of making various tests.

Estimates Of Truck Costs

Total Truck Costs

Estimates of truck costs for four sets of capacities and four levels of mileage utilization are presented in table 1. They are broken down into fixed, variable, and total costs so that you may see the relative importance of each type of cost under different conditions.

By studying the estimates for total truck costs, significant economies of size may be seen—especially for the 5,000- and 7,000-mile categories. For truck units driven 5,000 miles per month, total truck costs were $442 and $979 for the smallest and largest units, respectively. This comparison highlights the fact that the largest size category—41,300 to 43,000 pounds—which was more than three times larger than the smallest one—13,000 to 13,500 pounds—had total truck costs per month that were considerably less than three times as large.

Fixed Truck Costs—Fixed truck costs per month were about 1 cent per pound of capacity (figure 1). This relationship may be important to managers considering replacements for their interplant truck fleets.

Variable Truck Costs—Variable truck costs were determined mainly by the capacity of each truck unit and the number of miles that it was driven (see Appendix figures A, B, C, and D). Other less significant factors were fuel types and weight efficiency.[2]

The use of fuels other than gasoline, such as propane and diesel oil, resulted in lower variable truck costs. Propane

Table 1. Variable, fixed, and total truck costs per month for selected capacities and miles driven per month (truck and tank costs only)

Pounds of capacity	Total fixed costs per month	Total variable costs — Miles driven per month 3,000	5,000	7,000	Total truck costs — Miles driven per month 3,000	5,000	7,000
				dollars			
13,000 to 13,500	137	124	305	487	261	442	624
18,800 to 21,000	215	169	351	532	384	566	747
35,400 to 38,700	380	323	504	686	703	884	1,066
41,300 to 43,000*	441	356	538	720	797	979	1,161

* Trucks in this size category used only propane and diesel fuels.

[2] The effects of these less significant variables were held constant at their average values in computing estimates of truck costs presented in table 1.

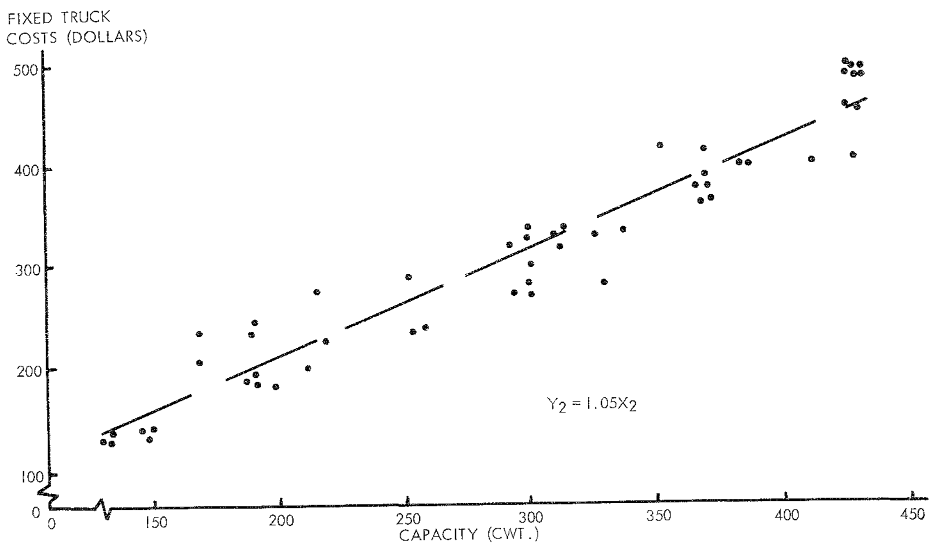


Fig. 1. Fixed truck costs per month in relation to capacity of each truck unit.

trucks operated cheaper than gasoline trucks and diesel trucks cheaper than propane trucks. With 4,300 miles driven per month the 18,800-to 21,000-pound propane units had costs $32 less than comparable gasoline models. But on the basis of 7,600 miles driven per month, the 41,300- to 43,000-pound diesel trucks had costs that were at least $80 less than comparable propane units.

Table 2. Total truck costs per mile for selected capacities and miles driven per month (truck and tank costs only)*

Pounds of capacity	Miles driven per month		
	3,000	5,000	7,000
		cents	
13,000 to 13,500	8.7	8.8	8.9
18,800 to 21,000	12.8	11.3	10.7
35,400 to 38,700	23.4	17.7	15.2
41,300 to 43,000	26.6	19.6	16.6

* These costs were derived from table 1.

Trucks and tanks become more efficient almost every passing year. The ratio of tare weight to loaded gross weight (weight index) has decreased over time. It varied from a high of 0.519 for some relatively old trucks to a low of 0.346 for some new ones. Truck costs were influenced significantly by the size of this weight index. For each 1 percent that this index deviated from its average of 41.6 percent, truck costs changed by $13 per month. Trucks with a weight index of 42.6 percent had costs $13 greater than those with an index of 41.6. The opposite cost relationship existed for truck units with an index of 1 percent below this average.

Truck Costs Per Mile, Per Cwt., and Per Cwt.-Mile

Estimates of truck costs per mile, per cwt., and per cwt.-mile were derived from estimates of total truck costs per month. The per mile estimates are presented in table 2; the per cwt. and per cwt.-mile estimates are in table 3.

Many managers stated their truck costs on a per mile basis. This represented a good measure of truck costs if payload differences were taken into account. For instance, on the basis of the costs in table 2, truck units with capacities between 13,000 and 13,500 pounds cost 8.8 cents per mile while truck units with capacities between 41,300 and 43,000 pounds cost 19.6 cents. The largest units cost 2.2 times more than the smallest ones on a per mile basis. But they were the cheapest in terms of capacity—they could haul over three times as much.

The same economies of size relationship may be seen from the estimate of truck costs per cwt. and per cwt.-mile. For a given level of mileage utilization, both types of costs decreased for larger truck units. Also, truck costs per cwt. and per cwt.-mile decreased with miles driven for all categories of truck sizes except the smallest one. For relatively small truck units, variable truck costs per cwt. increased faster with miles driven than fixed costs decreased.

Table 3. Truck costs per cwt. and per cwt.-mile when only 90 percent of each truck's capacity is utilized (truck and tank costs only)*

Pounds of capacity	Truck costs per cwt.						Truck costs per cwt.-mile		
	50-mile route			100-mile route					
	Miles driven per month			Miles driven per month			Miles driven per month		
	3,000	5,000	7,000	3,000	5,000	7,000	3,000	5,000	7,000
					cents				
13,000 to 13,500	3.7	3.7	3.8	7.2	7.4	7.4	0.146	0.148	0.148
18,800 to 21,000	3.6	3.1	3.0	7.1	6.3	6.0	0.142	0.126	0.120
35,400 to 38,700	3.6	2.7	2.3	7.0	5.3	4.6	0.140	0.106	0.092
41,300 to 43,000	3.6	2.6	2.2	7.0	5.1	4.3	0.140	0.102	0.086

* These costs were derived from table 1 for a 90-percent level of capacity utilization. (Each truck unit is loaded to 90 percent of its capacity over one-half of the miles it is driven.) A study of eight plants for a 3-month summer period and one plant for a 12-month period showed this to be the typical level of capacity utilization.

Estimates Of Labor Relationships

Variable Labor Per Load

Driving Time—The amount of driving time needed for an interplant route was closely related to the route length. By studying figure 2, you can see that a straight line represents a good estimate of the average relationship between driving time and miles driven.[3] The number of miles driven was the only important variable influencing driving time. Other factors such as drivers, roads, and truck units were relatively insignificant. The drivers averaged close to 42 miles per hour regardless of the size truck driven or the road traveled.

Loading Time—Loading time varied with the amount of milk loaded and sizes of loading equipment utilized (figure 3). In this study the diameter of each loading line was found to be a good index of loading capacity. For 1.50, 1.75, and 2.00-inch loading lines, milk was loaded at the maximum rates of 0.18, 0.12 and 0.09 minutes per cwt., respectively. Thus, it took 18 minutes to load 100 cwt. of milk (10,000 pounds) when a 1.50-inch loading line was used (figure 3).

Unloading Time—Unloading time was closely related to the amount of milk unloaded and equipment utilized. The diameters of drain lines were also used as indices of unloading capacity. For 2.00, 2.50, 2.75, and 3.00-inch drain lines, milk was unloaded at the maximum rates of 0.092, 0.068, 0.054, and 0.042 minutes per cwt., respectively. Thus, it took 9.2 minutes to load 100 cwt. (10,000 pounds) of milk when a 2.00-inch unloading line was used (see figure 4). Milk was unloaded twice as fast with the 3.00-inch drain lines as with the 2.00-inch lines. These differences were largely associated with differences between cross-sectional areas of the 2.00- and 3.00-inch lines. The cross-sectional area of a 3.00-inch line is over twice as large as that of a 2.00-inch line.

Fixed Labor Per Load

Fixed labor tasks were defined as tasks for which the time was about the same for each route. Fixed tasks included route preparation, local hookup and unhook time, central test time, central hookup and unhook time, central rinse, waiting time, and personal and miscellaneous time.

Route Preparation—Every morning each driver received a route assignment and prepared his milk sample box. Some plants also required their drivers to inspect and service their truck units. Since no uniformity existed between plants for this classification of time, all time used for truck servicing was included in miscellaneous truck costs. Using this method a minimum of 5 minutes was found necessary for route preparation.

Local Hookup and Unhook Time—Various tasks had to be performed at each local plant before and after the truck was loaded. This time was classified as local hookup and unhook time. Hookup time started when the truck unit was parked and continued until it was ready for loading. Unhook time started when the truck unit was loaded and ended when the driver departed from the loading stop. Both categories varied with the number of tank compartments in the truck units (table 4). The two tasks averaged 6.5 minutes for single compartment tanks, 9.0 minutes for two compartment tanks, and 10.2 minutes for three compartment tanks.

[3] This straight line was fitted statistically using least squares.

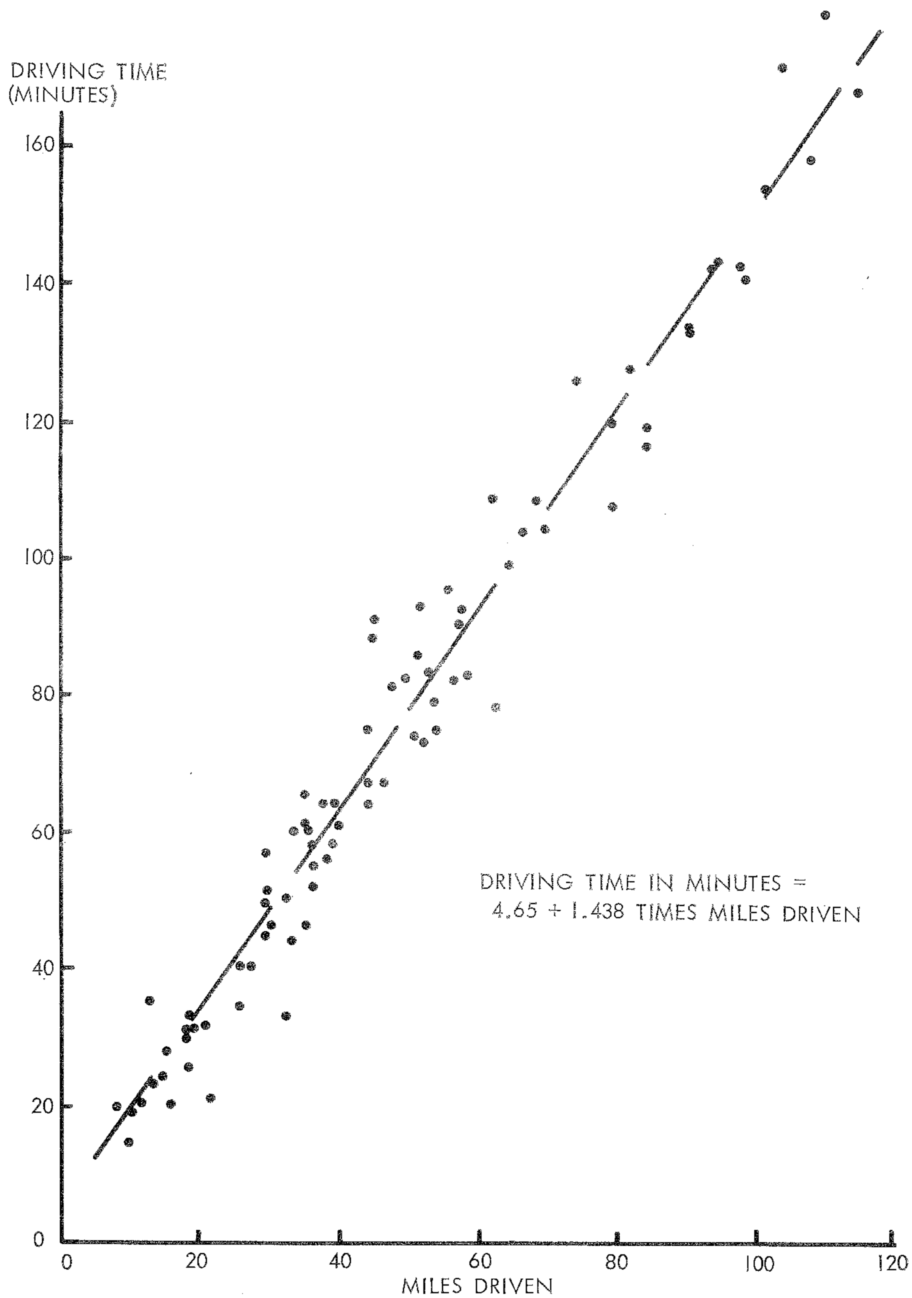


Fig. 2. Driving time in relation to miles driven between local creameries and central processing plants.

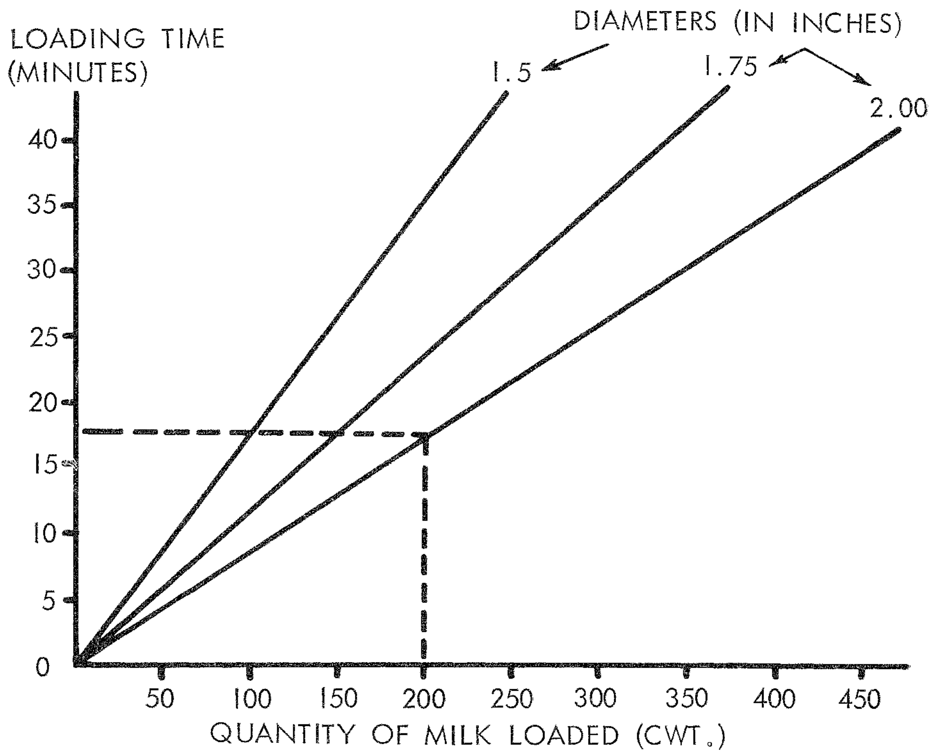


Fig. 3. Loading time by diameter of loading lines and quantity of milk loaded.

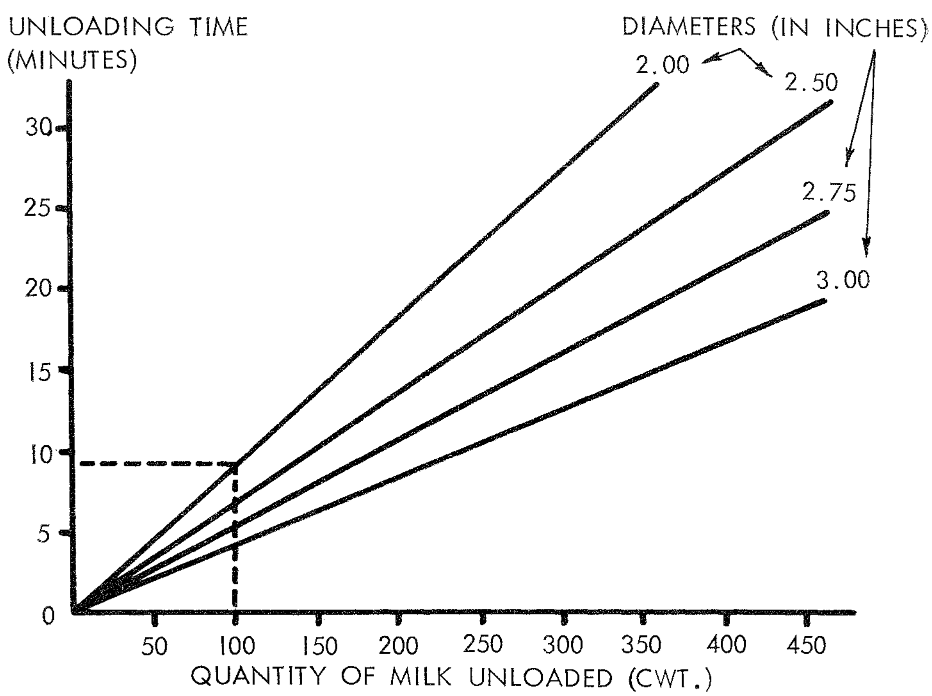


Fig. 4. Unloading time by diameter of unloading lines and quantity of milk unloaded.

Table 4. Labor time required for local hookup and unhook tasks for all local plants

Number of tank compartments	Local hookup time	Local unhook time	Local hookup plus unhook time
	minutes		
1	2.9	3.6	6.5
2	4.7	4.3	9.0
3	6.2	4.0	10.2
Weighted average for all plants	3.3	3.9	7.2

Central Test Time—At four of the seven plants studied, a butterfat test was made prior to unloading each load of skim milk. This was done to insure that the dry nonfat milk solids would meet Commodity Credit Corporation purchase requirements. The amount of time needed for this test depended mainly upon whether a "Setascope" light or a centrifuge was used (table 5). The "Setascope" light required only 3.0 minutes while the centrifuge required an average of 14.2 minutes. The centrifuge method used 4.7 times more time than the "Setascope" light.

Table 5. Labor time required per load for milk testing by type of testing equipment

Central processing plant	Test equipment	Testing time per load
plant number		minutes
1	Setascope light	3.0
2	Centrifuge	11.9
4	Centrifuge	19.6
7	Centrifuge	11.2

Central Hookup and Unhook Time—Various tasks other than testing, waiting, and unloading also were performed at the central plant. They were classified as central hookup and unhook time. Central hookup was the time used to prepare the truck unit for unloading. Central unhook was the time used to disconnect the unloading lines and prepare the truck for the next load. These classifications are summarized in table 6. For all plants central hookup averaged 3.4 minutes and central unhook 2.0 minutes.

Central Rinse—Rinsing time partly depended upon the type of milk transported. But rinsing policies of each central plant were by far the most influential factors (table 7). Rinsing time varied from none to 3.2 minutes per load. For all plants it averaged 1.9 minutes per load.

Table 6. Labor time required for central plant hookup and unhook tasks

Central processing plant	Central hookup time	Central unhook time	Central hookup and unhook time
plant number		minutes	
1	4.1	2.5	6.6
2	3.5	1.7	5.2
3	1.6	1.6	3.2
4	5.4	2.3	7.7
5	1.8	1.9	3.7
6	5.5	0.8	6.3
7	2.2	3.0	5.2
Weighted average for all plants	3.4	2.0	5.4

Waiting Time—Waiting time is that time when the driver could not perform some productive milk-hauling task. This time was classified into time spent waiting to load and unload. Each classification was influenced by different factors.

Table 7. Rinsing time per load for truck tanks

Central processing plant	Rinsing time
plant number	minutes
1	2.0
2	0.8
3	......
4	2.3
5	1.9
6	3.2
7	0.9
Weighted average for all plants	1.9

Time spent waiting to load generally varied with the coordination a central plant worked out with its feeder plants. Time spent waiting to unload was influenced by scheduling policies and storage capacities at central processing plants.

All waiting time is summarized in table 8. This information brings out some management differences among plants. Plant 6 lost 31.1 minutes per load while Plant 5 lost only 3.0 minutes. For illustration purposes, let us assume that each plant had five trucks assembling three loads each day. Each day Plant 6 would lose about 8 hours of labor while Plant 5 would lose only 45 minutes. With a wage rate of $1.80 per hour, the labor costs of Plant 5 would be about $13 per day less that those of Plant 6.

Table 8. Labor time spent waiting to load and unload each milk load

Central processing plant	Waiting to load	Waiting to unload	Total waiting per load
plant number		minutes	
1	0.4	2.9	3.3
2	1.5	5.8	7.3
3	9.3	9.2	18.5
4	6.0	7.6	13.6
5	0.7	2.3	3.0
6	16.5	14.6	31.1
7	5.1	4.4	9.5
Weighted average for all plants	4.7	6.3	11.0

Large amounts of waiting time were generally associated with poor scheduling. Plants 3, 4, and 6 usually scheduled their truck units to depart simultaneously and too early each morning. Their drivers had to wait at their local plants because the milk was not available. And they had to wait at the processing plants because their trucks tended to return at the same time. This resulted in congestion and additional waiting time at the central plant.

Table 9. Personal and miscellaneous time required per load*

Central processing plant	Personal time per load	Miscellaneous time per load
plant number	minutes	
1	4.0	1.6
2	1.9	4.0
3	3.6	2.2
4	2.8	8.7
5	......	1.9
6	4.0	4.8
7	......	......
Weighted average for all plants	2.9	3.1

* No personal time was observed for Plants 5 and 7; no miscellaneous time was observed for Plant 7.

Personal and Miscellaneous Time—Personal time represents the time spent for coffee breaks, lunch, and other personal needs. Drivers used an average of 2.9 minutes per load for personal time (table 9).

Miscellaneous time represents all time spent doing tasks unrelated to milk assembly. Most of these tasks were sporadic and nonrepetitive. They took an average of 3.1 minutes per load.

Table 10. Average labor time required per load for various fixed interplant milk hauling tasks

Milk hauling tasks	Average time per load
	minutes
Route preparation	5.0
Local hookup	3.3
Local unhook	3.9
Milk testing	3.0
Central hookup	3.4
Central unhook	2.0
Central rinse	1.9
Waiting	11.0
Personal	2.9
Miscellaneous	3.1
Total per load	39.5

Summary of Fixed Labor Components—All fixed components of labor, except testing time, were averaged for all plants. It seemed unreasonable to average the time required for the two different methods of testing. Thus, testing time represents the amount of time used by the "Setascope" light method. This set of summaries for fixed labor components is presented in table 10; these tasks required a total of 39.5 minutes per load where one loading stop was made.

Total Labor Per Load

Labor requirements per load were related to route length, amount of milk hauled, number of loading stops, loading equipment, and unloading equipment. Estimates of this relationship were made from estimates of its underlying variable and fixed components (table 11). These estimates showed that drivers of trucks with 13,000 to 13,500 pounds of capacity used 133 minutes to drive a 50-mile route and make one loading stop. Drivers of truck units with 41,300 to 43,000 pounds of capacity used 171 minutes for the same trip; they used an additional 38 minutes to load and unload an extra 30,000 pounds.

On a cwt. basis, 59 percent less labor was used by the largest truck units than by the smallest ones. Similar comparisons were made in terms of different route lengths, number of loading stops,

Table 11. Estimated labor time required per load by size of truck, number of loading stops, and length of interplant routes*

Pounds of capacity	Loading stops per load	Length of routes—miles 25	50	75	100
		minutes			
13,000	1	97	133	169	205
to	2	104	140	176	212
13,500	3	112	148	184	220
18,000	1	106	142	178	214
to	2	113	149	185	221
21,000	3	120	156	192	228
35,400	1	128	164	200	236
to	2	135	171	207	243
38,700	3	143	179	214	250
41,300	1	135	171	207	243
to	2	142	180	214	250
43,000	3	149	185	221	257

* Loading time is 0.0873 minutes per cwt. Unloading time is 0.0424 minutes per cwt. Driving time in minutes is 4.65 + 1.438 times miles driven. Fixed time per load is based on table 10.

and hauling capacities. They all demonstrated the same conclusion for a given set of route conditions—less labor time was used per cwt. with large truck units than with small ones.

Cleaning Time Per Day

Each central plant cleaned its transport tanks once each day. Some plants performed this task by hand while others used mechanical-in-place cleaning. Both methods required about 20 minutes regardless of the size of the truck that was cleaned.

Managers using the mechanical methods justified them on the basis of quality; they claimed they got a better cleaning job.

Estimates Of Total Transportation Costs

Total Transportation Costs Per Month

Estimates of total transportation costs were developed for representative truck units on a monthly basis (table 12). They represent the sum of truck costs per month and labor costs per month. Truck costs were taken from table 1. Labor costs were calculated from table 11, and a wage rate of $1.80 per hour was used.

By studying table 12 for any one set of specifications—miles driven, route lengths, and number of loading stops—

Table 12. Total monthly transportation costs, when only 90 percent of the truck's capacity is utilized, by length of route, miles driven, pounds of capacity, and number of loading stops*

Pounds of capacity	Loading stops per load	Total transportation costs					
		50-mile route			100-mile route		
		Miles driven per month			Miles driven per month		
		3,000	5,000	7,000	3,000	5,000	7,000
		dollars					
13,000	1	515	855	1,194	462	765	1,069
to	2	528	876	1,225	468	776	1,084
13,500	3	541	898	1,255	475	787	1,099
18,800	1	653	1,002	1,350	592	901	1,209
to	2	666	1,023	1,381	599	911	1,224
24,000	3	679	1,045	1,411	605	922	1,239
35,400	1	1,007	1,380	1,753	929	1,249	1,569
to	2	1,020	1,402	1,783	935	1,260	1,584
38,700	3	1,033	1,423	1,813	942	1,271	1,600
41,300	1	1,113	1,493	1,873	1,029	1,353	1,677
to	2	1,126	1,514	1,903	1,035	1,363	1,692
43,000	3	1,139	1,536	1,933	1,042	1,374	1,707

* Truck costs were taken from table 1; labor costs were taken from table 11. A wage rate of $1.80 per hour was used for drivers.

you can observe that size economies were greater for total transportation costs than they were for truck costs. This may be illustrated for the case where trucks were driven 5,000 miles per month, routes were 50 miles long, and only one loading stop was necessary per load. Transportation costs per month were $855 for trucks with 13,000 to 13,500 pounds of capacity and $1,493 for units with 41,300 to 43,000 pounds of capacity. The largest trucks had costs which were 1.75 times greater than those of the smallest ones. For truck costs alone the largest trucks had costs which were 2.2 times greater than those of the smallest units

Savings in labor costs increased the transportation economies associated with truck size. For comparable routes, driving and fixed labor required about the same amount of time for small trucks as for large ones. Thus, greater size economies were associated with total transportation costs than with truck costs.

Total Transportation Costs Per Mile, Per Cwt., and Per Cwt.-Mile

From estimates of transportation costs per month, transportation costs per mile, per cwt., and per cwt.-mile were derived (tables 13 and 14).

Analysis of table 13 shows the same results discussed above. This is distinctly evident when you use the same specifications for comparison purposes: 5,000 miles per month, 50-mile routes, one loading stop, and a 90-percent level of capacity utilization. For this case, transportation costs per mile were 17.2 and 30.2 cents for the smallest and largest truck capacities, respectively; 30.2 ÷ 17.2 = 1.75. The largest trucks—41,300 to 43,000 pounds of capacity—cost 1.75 times more per mile than the smallest ones—13,000 to 13,500 pounds of capacity—but they hauled over three times as much milk.

The information in table 14 again brings out clearly the economies of size relationship. And it also shows the econo-

Table 13. Total transportation costs per mile for selected length of routes, miles driven per month, capacities of truck units, and number of loading stops per load*

Pounds of capacity	Loading stops per load	50-mile route: Miles driven per month 3,000	5,000	7,000	100-mile route: Miles driven per month 3,000	5,000	7,000
				cents			
13,000	1	17.3	17.2	17.2	15.4	15.4	15.3
to	2	17.7	17.6	17.6	15.7	15.6	15.5
13,500	3	18.1	18.1	18.0	15.9	15.8	15.8
18,800	1	21.9	20.2	19.4	19.8	18.1	17.3
to	2	22.3	20.6	19.9	20.0	18.3	17.6
21,000	3	22.8	21.0	20.3	20.2	18.5	17.8
35,400	1	33.9	27.9	25.3	31.1	25.1	22.6
to	2	34.3	28.3	25.8	31.3	25.3	22.8
38,700	3	34.7	28.8	26.2	31.5	25.6	23.0
41,300	1	37.4	30.2	27.1	34.5	27.2	24.1
to	2	37.8	30.6	27.5	34.7	27.4	24.3
43,000	3	38.3	31.0	27.9	34.9	27.6	24.5

* These costs were derived from table 12. Only 90 percent of each truck unit's capacity was used.

Table 14. Transportation costs per cwt. when only 90 percent of the truck's capacity was utilized by length of route, miles driven per month, capacity of the truck units, and number of loading stops*

Pounds of capacity	Loading stops per load	Costs per cwt.						Costs per cwt.-mile					
		50-mile route			100-mile route			50-mile route			100-mile route		
		Miles driven per month			Miles driven per month			Miles driven per month			Miles driven per month		
		3,000	5,000	7,000	3,000	5,000	7,000	3,000	5,000	7,000	3,000	5,000	7,000
		cents											
13,000	1	7.2	7.1	7.1	12.9	12.8	12.8	0.29	0.28	0.28	0.25	0.25	0.25
to	2	7.3	7.3	7.3	13.0	13.0	12.9	0.29	0.29	0.29	0.26	0.26	0.26
13,500	3	7.5	7.5	7.5	13.2	13.2	13.1	0.30	0.30	0.30	0.26	0.26	0.26
18,800	1	6.0	5.5	5.3	11.0	10.0	9.6	0.24	0.22	0.21	0.22	0.20	0.19
to	2	6.2	5.7	5.5	11.1	10.1	9.7	0.24	0.23	0.22	0.22	0.20	0.19
21,000	3	6.3	5.8	5.6	11.2	10.3	9.8	0.25	0.23	0.22	0.22	0.20	0.19
35,400	1	5.0	4.1	3.7	9.2	7.4	6.7	0.20	0.16	0.15	0.18	0.15	0.13
to	2	5.1	4.2	3.8	9.3	7.5	6.7	0.20	0.17	0.15	0.18	0.15	0.13
38,700	3	5.1	4.2	3.8	9.4	7.6	6.8	0.20	0.17	0.15	0.18	0.15	0.13
41,300	1	4.8	3.9	3.5	9.0	7.1	6.3	0.19	0.15	0.14	0.18	0.14	0.12
to	2	4.9	3.9	3.5	9.0	7.1	6.3	0.19	0.16	0.14	0.18	0.14	0.12
43,000	3	5.0	4.0	3.6	9.1	7.2	6.4	0.20	0.16	0.14	0.18	0.14	0.12

* These costs are derived from table 12.

Table 15. Total transportation costs per cwt. with a maximum of 8,000 pounds per axle for selected lengths of routes, miles driven per month, numbers of loading stops, and pounds of capacity

Pounds of capacity	Loading stops per load	Number of axles: Truck or tractor	Number of axles: Trailer	Average load under restrictions	50-mile route: Miles driven per month 3,000	50-mile route: 5,000	50-mile route: 7,000	100-mile route: miles driven per month 3,000	100-mile route: 5,000	100-mile route: 7,000
					cents per cwt.					
13,000	1	2	......	4,400	18.8	18.7	18.7	34.3	34.1	34.0
to	2				19.3	19.2	19.2	34.7	34.6	34.5
13,500	3				19.8	19.7	19.7	35.3	35.0	35.0
18,800	1				16.0	14.7	14.1	29.6	27.0	25.8
to	2	3	......	6,500	16.3	15.0	14.4	30.0	27.3	26.2
21,000	3				16.7	15.3	14.8	30.3	27.6	26.5
41,300	1				12.4	9.9	8.8	23.6	18.5	16.3
to	2	3	2	14,100	12.6	10.0	8.9	23.8	18.6	16.4
43,000	3				12.8	10.2	9.1	23.9	18.8	16.6

mies associated with mileage utilization. To illustrate this, let us compare transportation costs per cwt. for the following specifications: (1) 3,000 miles per month, 50-mile routes, one loading stop, and a 90-percent level of capacity utilization; (2) 7,000 miles per month, 50-mile routes, one loading stop, and a 90-percent level of capacity utilization. In the first case, transportation costs per cwt. were 7.2 cents for the smallest trucks and 4.8 cents for the larger ones. Economies of size are evident even for truck units driven only 3,000 miles per month. In the second case, transportation costs per cwt. were 7.1 and 3.5 cents for the same truck sizes.

This comparison brings out that:

- The largest trucks hauled milk for 33 percent less in the first case and for 51 percent less in the second case than the smallest ones.

- Significant economies were only associated with additional mileage utilization of the large trucks. For the relatively small trucks, transportation costs per cwt. were about the same for 3,000, 5,000, or 7,000 miles per month.

Transportation Costs Per Cwt. Under Road Restrictions

Seasonal road restrictions throughout Minnesota affect utilization of transport capacity from March 20 to May 15 each year. The maximum that may be transported over roads surfaced with materials other than concrete is 8,000 pounds per axle. For the four size categories used in this report, these road restrictions limited the maximum load that can be hauled on most secondary roads. The maximum load sizes were as follows:

Truck capacity in pounds:			
13,000 to 13,500	18,800 to 21,000	35,400 to 38,700	41,300 to 43,000
Maximum load sizes in pounds under road restrictions of 8,000 pounds per axle for each of the above capacities:			
4,400	6,500	....	14,100

Road restrictions generally preclude the operation of truck units with 35,400 to 38,700 pounds capacity. They have only three axles under the transport tank while the 41,300 to 43,000 pound units have four.

Transportation costs during these road restriction periods were much greater than they were normally. This is brought out by the cost estimates in table 15. Transportation costs per cwt. for the 13,000 to 13,500 pound trucks were 18.7 cents and for the 41,300 to 43,000 pound units, 9.9 cents. This assumes that the truck units were driven 5,000 miles per month, route lengths were 50 miles, and one loading stop was made. If you compare these estimates with those in table 14, you may observe that transportation costs under road restrictions were about 2.6 times greater than they were otherwise.

Summary And Conclusions

The objectives of this study centered around estimating the costs of hauling milk between receiving stations or local creameries and central processing plants. To accomplish these objectives, interplant transportation costs were broken into truck costs and labor costs. Truck costs were considered as related to miles driven, hauling capacity, weight efficiency, and fuel type. Labor costs were considered as related to miles driven, volume of milk hauled, number of loading stops, and types of loading and unloading equipment.

Statistical analyses were then made of truck records of 10 large dairy plants and a time-and-motion study of 76 truck drivers. Estimates were then made of truck costs and labor costs. These, in turn, were summed to obtain estimates of total interplant transportation costs.

Truck costs were estimated for three levels of mileage utilization—3,000, 5,-000, and 7,000 miles per month—and trucks capable of hauling loads of four different sizes—13,000 to 13,500, 18,000 to 21,000, 35,400 to 38,700, and 41,300 to 43,000 pounds. These estimates were expressed as total truck costs per month, per mile, per cwt. and per cwt-mile. From these different expressions of truck costs, especially those for 5,000 and 7,-000 miles per month, one economic relationship was evident. *Relatively large truck units cost much less to operate on a capacity basis for a given level of mileage utilization than small ones.*

These economies can be illustrated for different sizes of truck units driven 5,000 miles per month over a 50-mile route. Under these conditions the smallest truck units, 13,000 to 13,500 pounds capacity, had truck costs of 3.7 cents per cwt. and the largest ones, 41,300 to 43,000 pounds, costs of 2.6 cents where 90-percent capacity was utilized.

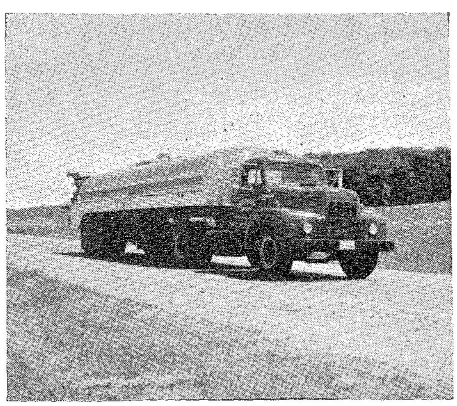
Labor costs were estimated on a load basis from estimates of the time required for each variable and fixed hauling task using a wage rate of $1.80 per hour. Again, significant economies were associated with hauling capacity for each set of hauling conditions analyzed: (1) route lengths of 25, 50, 75, and 100 miles, (2) one, two, and three loading stops, (3) 2-inch loading lines, (4) 3-inch unloading lines, and (5) a 90-percent level of capacity utilization. *Labor costs per cwt. were considerably less for relatively large trucks than small ones.*

The significance of this relationship is seen immediately when studying the amount of time used on a 50-mile route where one loading stop was made. Under these conditions, drivers operating the smallest trucks used 133 minutes per load of milk while drivers operating the largest units used 171 minutes. Pumping time really accounted for the 38 minute difference. It took the same time to drive the small trucks between stops as the large ones and to perform all tasks associated with getting the truck units ready for loading and unloading.

When labor and truck costs were summed to obtain total interplant transportation costs, the labor relationship magnified the economies associated with truck size. Again, these economies can be illustrated for the same set of hauling conditions used for truck and labor costs. Total transportation costs per cwt. in this case were 7.1 cents for truck units hauling between 13,000 and 13,500 pounds and 3.9 cents for units hauling between 41,300 and 43,000 pounds. Greater size economies were associated with total transportation costs than with truck costs.

An analysis of transportation costs was also made for a period of spring road restrictions when trucks are limited to 8,000 pounds per axle. This analysis showed that planning of the truck fleet was especially important where many local plants were located on posted roads. Minnesota road restrictions generally preclude the use of semi-trucks with just one driving axle. Estimates of transportation cost per cwt. were much higher also for various types of route conditions in this period. Costs of trucks operating on restricted roads averaged 2.6 times more than normal.

Results of this study show that relatively large truck units can haul milk between receiving stations or local creameries and central processing plants for significantly less than small ones.



Interplant milk trucks are a familiar scene on Minnesota's highways.

Appendix

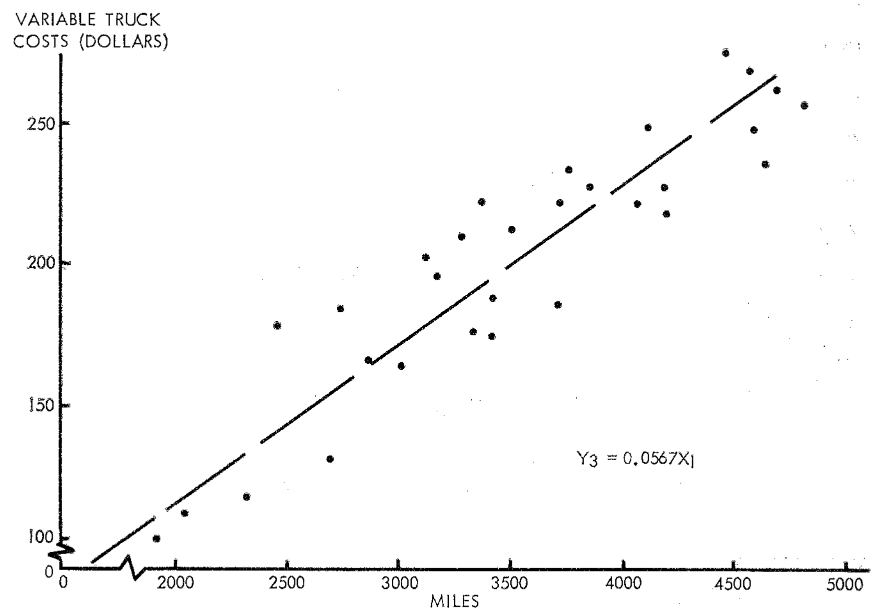


Fig. A. Variable truck costs for trucks with capacities between 13,000 and 13,500 pounds in relation to miles driven per month.

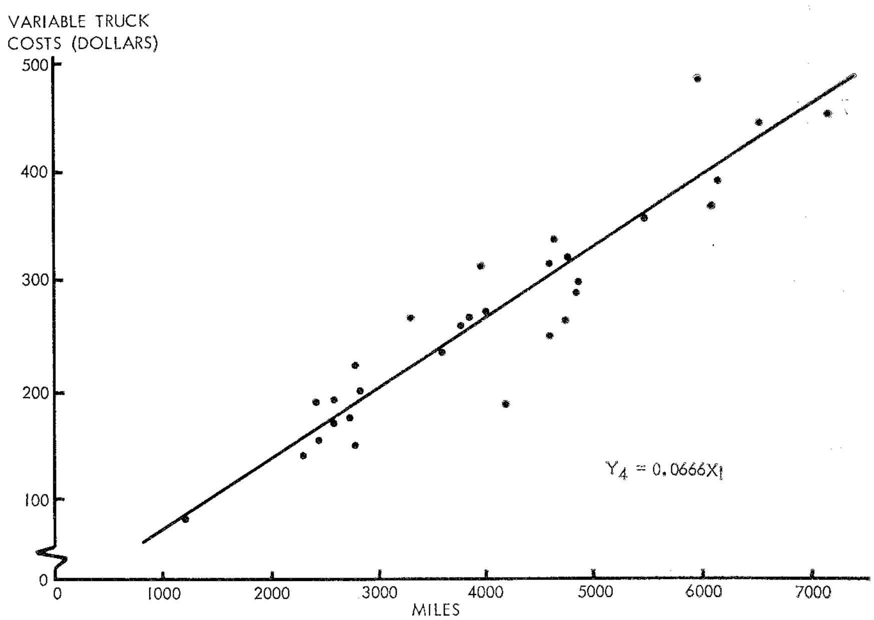


Fig. B. Variable truck costs for trucks with capacities between 18,800 and 22,000 pounds in relation to miles driven per month.

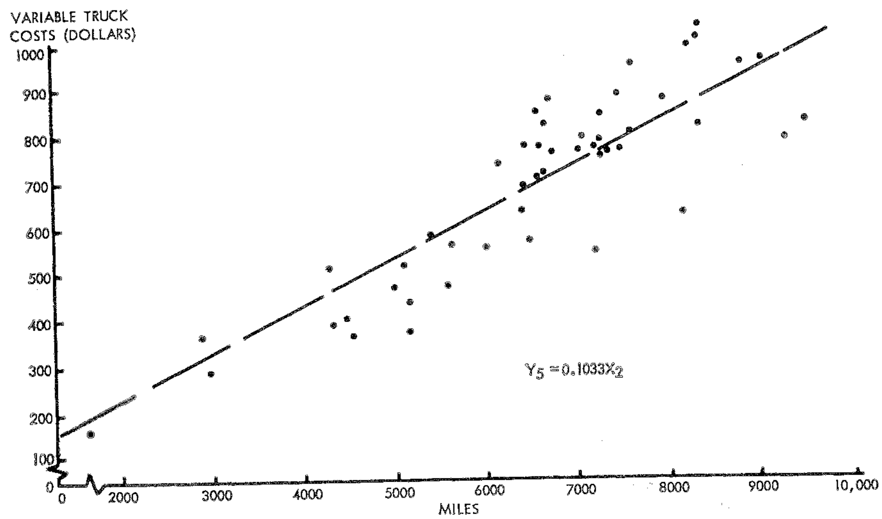


Fig. C. Variable truck costs for trucks with capacities between 35,400 and 38,700 pounds in relation to miles driven per month.

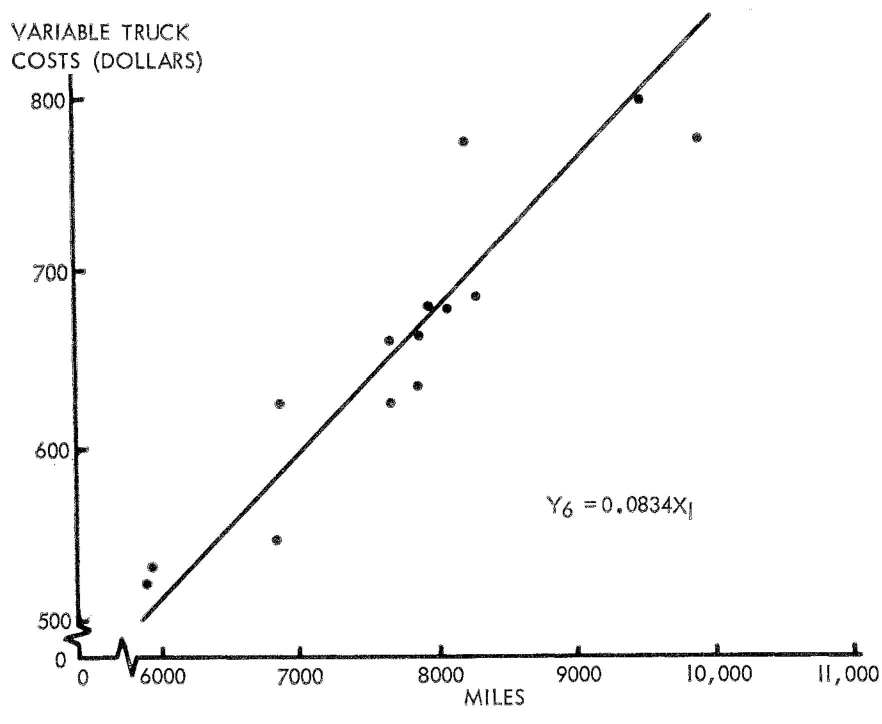


Fig. D. Variable truck costs for trucks with capacities of 41,300 to 43,000 pounds in relation to miles driven per month. (Variable costs for these trucks increase at a lesser rate than for the 35,400-to 38,700-pound units. The 41,000 to 43,000 pound trucks all used liquified petroleum and diesel oil while the 35,400 to 38,700 pound trucks used mainly gasoline.)