Time-Motion Analysis of Feedlot Manure Collection Systems

John M. Sweeten, Donald L. Reddell
MEMBER ASAE MEMBER ASAE

ABSTRACT

MACHINE productivity, energy consumption and cost of feedlot manure collection were determined by time-motion analysis at four Texas cattle feedlots. Truck loading, hauling, and spreading time requirements were also determined, as was the performance of wheel loader operators. The wheel loader/chisel plow combination produced the highest manure collection rate of 160 t (metric tons)/h (at 100 percent operating efficiency), followed in order by the elevating scraper, wheel loader, and wheel loader/rototiller. The most energy efficient collection system was the elevating scraper (0.88 kWh/t). Plowing of the manure pack before the wheel loader collection reduced overall energy consumption by 30 percent and increased the collection rate by 46 percent. The average rate of manure loading into spreader trucks was 186 t/h or 3.0 min per truck. Performance of wheel loader operators varied by 85 percent. A prediction equation for spreader truck turn-around time versus haul distance was developed.

INTRODUCTION

Efficient collection of feedlot manure can mean savings for cattle feedlot operators and profit for manure contractors who sell manure for fertilizer. Other successful uses of manure—production of methane, synthesis gas, or animal feedstuffs—depend in part on having a low-cost manure supply available. Thus, for manure handling to be profitable, time, energy, and equipment costs must be controlled.

Butchbaker et al. (1971) reported that solid manure handling costs for a 20,000 head Southwestern feedlot were approximately 12 percent of the total feedlot operating expense. Similarly, Park (1972) found that manure collection and hauling costs accounted for 11.7 percent of the total operating expense of a 22,000 head feedlot in Oklahoma.

Approximately 1.8 t of manure per head of cattle must be "harvested" annually from open cattle feedlots. Management of solid manure involves three functions: collection, loading, and spreading. An intermediate step—composting and/or stockpiling—is employed in some feedyards. Machines are used to rip, lift, haul, and dump compacted manure. The most commonly used machines are the wheel loader, with or without chisel plow or rototiller, and the elevating scraper. Spreader trucks are used for hauling and distributing the manure to land.

Butchbaker et al. (1971) found that investment and operating costs of solid manure handling systems varied with feedlot size, manure hauling distance, and equipment usage. Equipment size requirements and costs decreased drastically as equipment usage increased from 25 to 100 days per yr. Equipment use rates above 100 days per yr did not appreciably decrease investment and operating costs. Operating costs per animal day decreased with increasing feedlot size, and increased with increasing haul distance.

Sweeten et al. (1974) determined that energy consumption for feedlot manure transportation and spreading varied with the distance traveled and the size of spreader truck. Using a 9-t spreader truck (single axle), energy requirements for manure transportation and spreading were 49 and 180 MJ/t of manure for 8.0 and 32.0 km (one way) haul distances, respectively. A tandem-axle (13 t) truck used 33 percent less energy and provided a 30 percent lower cost than the 9-t truck for 8.0 to 32.0 km haul distances. Use of 35 t semi-trailer trucks to haul farther than 8.0 km more than offset the added energy requirements for on-farm reloading into sreader trucks.

Hansen et al. (1976) determined the effects of climatic conditions and management practices on feedlot manure quality with regard to use as a fertilizer, fuel, or feed. Fiber and ash content increased and nitrogen loss occurred as a function of decomposition time. They concluded that the value of feedlot manure for feed and fertilizer was improved by frequent collection. Viscosity changes indicated that collection of "dry" manure (30 percent moisture) at frequent intervals required less energy than infrequent collection of "wet" manure (50 to 70 percent moisture).

Safley et al. (1976) used network analysis to determine costs for dairy manure handling systems. Network analysis can be used to select systems best suited to the needs of specific livestock operations. Operational advantages and limitations of alternate machinery for feedlot manure collection were previously described by Sweeten et al. (1976) and Sweeten and Reddell (1976). Feedlot manure collection machinery included wheel loaders, elevating scrapers, and motor graders.

The purpose of this study was to determine machine efficiency, energy requirements, and costs for alternate feedlot manure collection and hauling systems using time-motion analysis. Specific objectives were:

1 Compare alternate manure collection systems on the basis of machine productivity, energy consumption, and cost, and

2 Evaluate the productivity, cost, and operator performance for loading manure trucks and determine the time required to haul and spread manure.

Article has been reviewed and approved for publication by the Structures and Environment Division of ASAE.

The authors are: JOHN M. SWEETEN, Agricultural Engineer, Animal Waste Management, Texas Agricultural Extension Service; and DONALD L. REDDELL, Professor, Agricultural Engineering Dept., Texas A&M University, College Station.

This article is reprinted from the TRANSACTIONS of the ASAE (Vol. 22, No. 1, pp. 138, 139, 140, 141, 142, 143, 1979)
Published by the American Society of Agricultural Engineers, St. Joseph, Michigan

TABLE 1. TYPES OF FEEDLOT MANURE COLLECTION SYSTEMS OBSERVED IN THE TIME-MOTION STUDY AND A COMPARISON OF THEIR PRODUCTIVITY, ENERGY REQUIREMENTS, AND COSTS

Feedlots	Primary collection machine	Feedlot surface preparation	Finishing steps required	No. pens studied	Manure collection rate at 100 percent efficiency, t/h	Energy requirements at 100 percent efficiency, kWh/t	Collection cost, $/t
A	Elevating scraper	None	Wheel loader to clean pen corners	4	114	0.88	0.21
B	Wheel loader	Rototilled	None	1	106	0.99	0.19
C	Wheel loader	None	None	1	107	1.28	0.23
C & D	Wheel loader	Chisel-plowed 3 times	None	4	160	0.96	0.20

EQUIPMENT AND PROCEDURES

Time-motion analysis was used to analyze alternate methods of feedlot manure collection at four Texas feedlots that ranged in capacity from a low of 28,000 to a maximum of 100,000 head. The basic collection systems studied were: (a) elevating scraper, (b) wheel loader, and (c) wheel loader plus plowing or rototilling (Table 1). Manure loading and hauling operations were also examined. At each feedlot, different makes and sizes of wheel loaders were used to load manure trucks.

Time-motion data were collected from all four feedlots in August 1975. Additional data were obtained from Feedlot C in January 1976 and from Feedlot A in May 1976.

To facilitate time-motion measurements of machine operation in each feedpen, collection cycles for loader and scraper were broken into four steps or time elements—load, haul, dump, and return—as depicted in Figs. 1 and 2. Wheel loader collection sometimes involved only three steps which was achieved by pushing (dozing) manure directly into stacks in a manner which combined the "load" and "haul" elements. Loading manure trucks with a wheel loader involved a four step cycle as shown in Fig. 3.

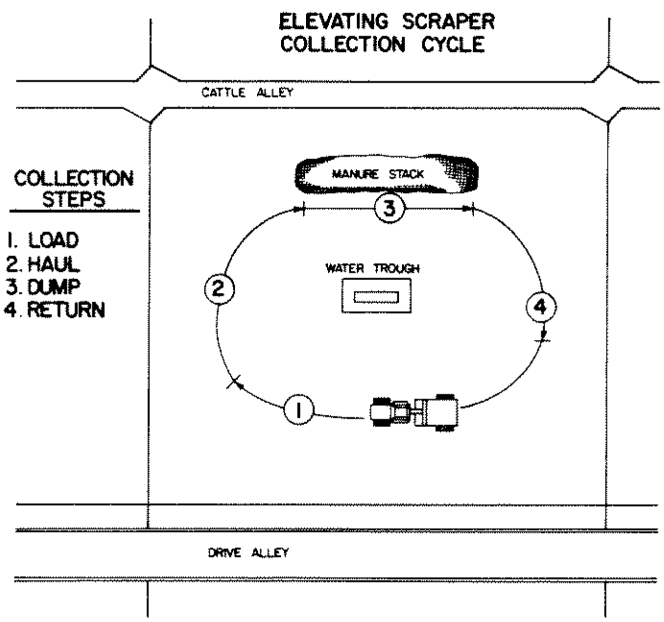

FIG. 1 Elevating scrapers collect feedlot manure in a continuous forward motion that required 2.0 min [average] to complete the 4-step cycle.

Time requirements for each element of the collection and loading cycles were manually measured and recorded to the nearest 0.01 min using a decimal minute stopwatch mounted to a clipboard. The continuous method of recording elemental time, all time delays, and nonproductive time was used to avoid a sizeable cumulative error which occurs when the "snap-back method" is used for short time elements such as those observed in this study (Niebel, 1972). The watch was read at the beginning of each element, using data forms suggested by Niebel (1972). Successive subtraction of consecutive readings determined elapsed elemental times.

The number of time observations per element in the collection and loading cycles equaled or exceeded accepted standards given by Niebel (1972) which called for a minimum of 20 and 50 repetitive measurements respectively for cycle times of 2.0 min (elevating scraper cycle) and 0.6 min (wheel loader cycle). No attempt was made to evaluate or adjust for individual operator performance by means of subjective performance ratings or fatigue factors (Niebel 1972). This refinement was not included because two different observers were used in the study and because reference values were not available for manure collection work.

From the time-motion measurements, the total elapsed time was divided into productive time (actual collection or loading time) versus nonproductive time. Nonproductive time was subcategorized as follows:

1 Waiting time (interferences and interactions with other machines or cattle),

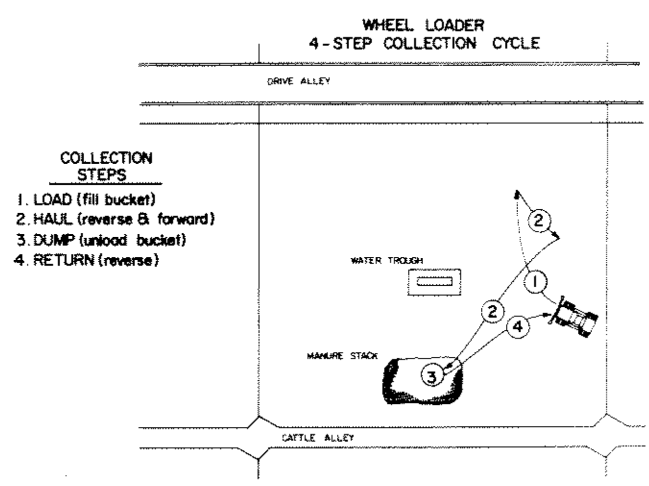

FIG. 2 The 4-step collection cycle of wheel loaders required 0.4 to 0.8 min to complete and required 300 to 500 gear shifts per hour.

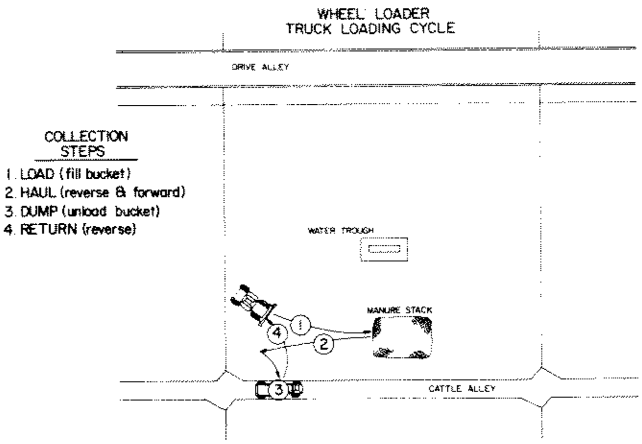

FIG. 3 Loading manure spreader trucks with a wheel loader entailed a 4-element cycle that took 0.6 min [average].

2 Personal delay time (breaks, conversations, etc.) and

3 Machine delay or travel time (refueling, travel to and between pens, breakdowns, etc.).

These nonproductive times were noted on the data sheet. Missed time increments which occurred when an observer failed to read the stopwatch at the beginning of the increment were omitted from the data analysis.

Time-motion measurements for the truck loading operation involved eight different operators and five different wheel loader models. Time-motion data on manure collection (i.e. stacking in the pens) were obtained on four pens and one operator at Feedlot A (elevating scraper); one pen, one loader and one operator at Feedlot B; two pens, two operators and three loaders at Feedlot C; and four pens, three operators and two loaders at Feedlot D. For Feedlots C and D, some switching of operators and machines took place between study dates.

To compute machine productivity, cost, and energy consumption on a per tonne basis, the quantity of manure collected and hauled was determined. Collection time measurements were only made when the complete collection process could be observed, i.e. from the time machines entered the pen until they left with all manure stacked. The quantity of manure hauled from the observed pens was calculated by weighing the empty and loaded manure trucks on the feedlot scales. Manure generally was not loaded, hauled, and weighed the same day it was stacked, and in one instance (Feedlot D) this led to failure to obtain manure tonnage for one of the observed pens.

Only the total elapsed time, productive time, and non-productive time were measured during one pen cleaning operation at Feedlot C. This technique was employed with an unskilled observer using a wristwatch. The observer was instructed to simply list each identifiable event (e.g. "start collecting", "stop to talk", "load truck", "resume collection", etc.) and the time that it occurred to the nearest 5 s. These data were useful in identifying, but not interpreting, differences in productivity, cost, and energy requirements.

At Feedlots B and D, the manure pack was scarified prior to collection by rototilling and chisel plowing, respectively. Total elapsed, productive, and nonproductive times for surface preparation were determined from event time recording rather than time-motion analysis.

Truck cycle times for hauling were recorded by an observer positioned near the wheel loader. Wait, load, and elapsed times were measured by wristwatch and recorded to the nearest 5 s. Truck odometer readings were obtained from drivers during each truck loading event. Most of the truck cycle times were obtained at Feedlot C on January 20, 1976.

Machinery costs for manure collection and loading were calculated using manufacturers' data (Caterpillar 1976) with appropriate assumptions for annual machine usage. Hourly fixed and operating costs were found to average 0.035, 0.029, and 0.053 percent of the purchase price for four elevating scrapers (800 h/yr), seven wheel loaders (1300 h/yr), and two farm tractors (500 h/yr), respectively. These factors were applied to purchase price quotations from distributors in the Amarillo-Lubbock, TX area to obtain hourly machine costs, which were then used in the data analysis. Truck operating costs were calculated from machinery management data provided by the American Society of Agricultural Engineers (Hahn, 1976). Labor costs were figured at $4/h for scraper and loader operators and $3/h for farm tractor operators. Energy consumption was computed using the machine flywheel kilowatts and the actual hours of machine operation during collection or loading.

RESULTS OF MANURE COLLECTION STUDY

Machine Productivity Comparison

Manure collection rates determined in this study are reported in Table 1 along with average energy consumption and costs. The collection rates reported in Table 1 represent the ratio of the tonnes of collected manure to the total productive time for each machine. To provide a basis for comparison, the collection rates were adjusted to 100 percent operating efficiency by subtracting delay and waiting times.

Elevating Scraper

The 101 kW elevating scraper used at Feedlot A (57,000 head capacity) gave an average collection rate of 114 t/h. The range for four pens was 82 to 152 t/h. The amount of collectable manure on the feedlot surface was only 39 to 59 kg/m^2, the thinnest manure pack of all the feedlots studied.

Machine time required to clean the pen corners with a wheel loader varied from 5 to 12.5 min per pen, accounting for 13 percent of the total productive time. This time was not considered in previous reports concerning this study (Sweeten et al., 1976).

A large difference in productivity of the elevating scraper was observed between the two observation dates (Table 2). The two pens cleaned in August, 1975 contained more manure (134 and 143 t) and yielded higher collection rates (123 to 152 t/h) than the two pens cleaned in May, 1976, wherein only 82 and 102 t/h was achieved.

The manure collected in May, 1976 appeared drier and less dense. Using 7.3 m^3 as the volume of the elevating scraper, the quantity of manure collected was only 3.4 t per cycle in May, 1976, compared to 4.4 and 5.5 t per cycle the previous August. Also, 4 1/2 months elapsed between collection in May, 1976 and loading/weighing/spreading in October, 1976, and decomposition in the manure stacks could have caused a substantial weight reduction. In all of the other pens

TABLE 2. RANGE OF PRODUCTION PERFORMANCE FOR ELEVATING SCRAPER

		Productive time, min				
Date	Pen no.	Scraper	Wheel loader to clean corners	Total	Amount collected, t	Collection rate, t/h
8/5/75	185	53.34	12.49	65.83	134	123
8/5/75	186	51.92	4.91	56.83	143	152
5/28/76	294	64.32	8.70*	73.02	82	82
5/28/76	295	72.50	8.70*	81.20	102	102

*Time for cleaning corners with wheel loader estimated at 8.70 min, the average for pens 185 and 186.

observed, loading and weighing occurred within 5 days of collection.

The productive time for collection with the elevating scraper appeared to be more closely related to the pen surface area than to the quantity collected. An average of 60.5 min was required to clean the pens with an elevating scraper, an average of 40 m^2/min.

Wheel Loader

The wheel loader/chisel plow combination produced an average collection rate of 160 t/h, with a wide variation existing among the four pens studied (one at Feedlot C and three at Feedlot D). Collection rates ranged from 83 to 277 t/h. More observations are probably needed to establish a meaningful average. Wheel loader sizes were similar at all pens, ranging from 97 to 108 kW. Operator skill was believed to be a major factor causing the wide variation in production rates. Pen size may also have had an effect, since the same (skilled) operator attained a collection rate of 277 t/h in a 1300 m^2 pen compared to only 103 t/h in a 743 m^2 pen. After the manure pack had been rototilled at Feedlot B, an average operator with a "small" (75 kW) loader could collect only 106 t/h. With no surface preparation, a large wheel loader (138 kW) with an above-average operator could achieve a collection rate of only 107 t/h at Feedlot C.

Comparison of Energy Consumption

Energy consumption for manure collection was estimated from the measured productive collection time for each machine and the machine flywheel power rating (kW). Where two or more machines were used to clean a feedpen, the energy consumption (kWh) of all units was considered.

The energy requirement for wheel loader collection with no surface preparation was 1.28 kWh/t (Table 1). Use of a chisel plow to break up the manure pack reduced energy consumption to an average of 0.96 kWh/t with a range of 0.65 to 1.59 kWh/t. Manure collection using the elevating scraper required only 0.67 to 1.22 kWh/t (0.88 kWh/t average). Hence, systems involving wheel loaders as the collection unit required an average of 9 to 46 percent more energy than the elevating scraper system.

Cost of Collection

Hourly costs of labor and machinery used in the analysis were \$23.32 for the elevating scraper, \$15.58 to \$25.09 for wheel loaders, and \$11.56 to \$14.68 for tractor-drawn scarifiers and rototillers. These figures were derived using a previously discussed procedure.

The total machine and labor cost of manure collection for each of the 11 observed feedpens ranged from \$22 to \$91, depending upon the type of collection system and the manure quantity (99 to 572 t). On a per-tonne basis, average collection costs ranged from 19 cents/t for the wheel loader/rototiller to 23 cents/t for the wheel loader with no surface preparation (Table 1). It would not appear justifiable to change collection systems solely on the basis of these small cost differences. Investment and hourly operating costs for the elevating scraper are similar to comparable-sized wheel loaders. Also, the requirement of a skilled operator is much less for the elevating scraper as compared to the wheel loader. The elevating scraper also leaves the feedlot surface in a much smoother condition than the wheel loader, which has a tendency to leave depressions in the feedlot surface. The smoother surface left by the elevating scraper provides better drainage and reduces odors. The minimum pen size requirement for efficient scraper operation is believed to be 1900 m^2 with alley widths of 3.7 m. Offset gates allow easier entry of machinery into the feedpens, and are desirable.

Productive Capacity of Tractor-Drawn Scarifiers

The time required for scarifying the manure pack using a rototiller (Feedlot B) or chisel plow (Feedlots C and D) ranged from 43 to 76 min for pens with 1300 to 2090 m^2 of surface area. Collectable manure on the feedlot surface ranged from 132 to 273 kg/m^2.

Despite these differences, manure handling capabilities of tractor-drawn plows and rototillers proved very consistent, with less than 10 percent variation among five feedpens at three feedlots. Tractor-drawn cultivator/tillers performed the "breakout" operation at an average rate of 28 m^2/min (range of 26 to 30 m^2/min). The energy requirement for the rototiller and chisel plow was 0.28 kWh/t of manure behind both 82 and 119 kW tractors.

Operating Efficiency for Collection Machinery

The values for machine productivity, energy efficiency, and cost in Table 1 are based on the assumption of 100 percent operational efficiency, or 60 min of productive work per hour. However, nonproductive time is necessarily spent in travel to the job site, machine and personal delays, waiting for other feedlot machinery or cattle to move through areas, and similar events. A "rule of thumb" estimate of operating efficiency for wheel loaders is 75 percent, or 45 min/h (Caterpillar, 1975). In this study, wheel loaders collected manure for more than 1 h in six of the pens at three feedlots. The operating efficiency for these cases ranged from 70 to 87 percent, and averaged 79 percent.

The operating efficiency for the elevating scraper, operating in four feedpens at Feedlot A, ranged from 78 to 98 percent and averaged 90 percent. Refueling and travel to the job site were the primary sources of nonproductive time incurred with the elevating scraper.

The operating efficiency of tractor-drawn scarifiers (chisel plows and rototillers) ranged from 56 to 93 percent over elapsed times of 0.78 to 2.25 h. The average for five pens at three feedlots was 84 percent. Operator inexperience and conversational delays were responsible for the low (56 percent) efficiency at one feedpen. If this value were excluded, the mean operating efficiency for tractor-drawn scarifiers would have been 90 percent, which is probably more representative of actual operations.

TABLE 3. TIMES REQUIRED FOR WHEEL LOADER COLLECTION STEPS AND CYCLES

Feedlot	Collection step time, min				Total cycle time, min†
	Collect†	Haul†	Dump	Return*	
B	0.32	0.24	0.05	0.17	0.78
C	0.17	0.24	0.04	0.13	0.59
D	0.19	0.17	0.05	0.13	0.55
Average	0.23	0.22	0.05	0.14	0.64

* Differences among means were significant (α = 0.05).
†Differences among means were highly significant (α = 0.01).

Predicting Manure Collection Rates

Manure collection rates with a wheel loader were closely related to the amount of manure collected per cycle, or per bucketful. A regression equation to express this relationship was developed:

$$CR = 120\ MC - 25.5, \qquad [1]$$

where

CR = collection rate (t/h) and

MC = manure collected per cycle, i.e. per bucketful (t)

The correlation coefficient for this linear relationship was r = 0.97. Thus, conditions and techniques that enable the operator to obtain a "full bucket" each collection cycle will result in high productivity. This explains why plowing or rototilling the manure pack increased productivity. Preparation steps that enhance collection efficiency may also tend to improve manure spreading uniformity and, hence, farmer/customer satisfaction.

Cycle Times for Manure Collection

Time-motion analysis allowed computation of mean cycle times for the four-step manure collection process at Feedlots B, C, and D. Wheel loader operations required an average of 0.64 min to complete each collection cycle. At 100 percent operating efficiency, wheel loaders could average 94 collection cycles per hour with 376 gear shifts.

Statistical analysis revealed highly significant differences among the mean collection cycle times at the three feedlots using the wheel loader (Table 3). This was largely attributable to significant differences between the "collect", "haul", and "return" elements of the cycle.

Cycle times for the three-step manure collection process averaged 0.57 min. Individual element times were as follows: Collect—0.24 min; dump—0.12 min; and return—0.20 min. This shorter cycle time, plus the fact that the loader blade can move more manure by dozing than by lifting and hauling, undoubtedly accounted for the fact that loader operators who frequently used the three-step collection cycle achieved a higher collection rate than operators who used only the four-step collection cycle. Presence of cattle in some pens at Feedlot D had no discernable effect on either cycle times or collection rate for the wheel loader.

Collection of manure from large feedpens (2,420 m^2) using the elevating scraper required from 26 to 40 cycles. With essentially no gear-shifts to perform, the operator could pay greater attention to depth control of the scraper blade, leaving a smoother surface. Average cycle time for the elevating scraper was 2.01 min. Average times for individual elements and 95 percent confidence intervals around these means are given in Table 4. Those cycles just before finishing a pen take longer (up to 4.3 min) because the scraper must travel farther to fill the bowl.

TABLE 4. CYCLE AND ELEMENT TIMES FOR MANURE COLLECTION WITH ELEVATING SCRAPER

Collection step or element	Number observations	Mean time, min	Confidence interval 95 percent	
			Lower limit, min	Upper limit, min
1. Collect	111	1.33	1.22	1.45
2. Haul	111	0.26	0.23	0.27
3. Dump	109	0.19	0.18	0.19
4. Return	109	0.22	0.21	0.24
Total	109	2.01	1.89	2.13

TRUCK LOADING RESULTS

Loading Efficiencies and Costs

In each of the four study feedlots, stacked manure was loaded into spreader trucks with wheel loaders. Truck loading rates were calculated for individual feedpens as the ratio of net truck loaded weight (payload) to the average truck loading time in hours. The truck loading cost ($/t) was computed as the ratio of the hourly fixed and variable cost for loader operation ($/h) to the loading rate (t/h).

Measured rates of manure loading ranged from 145 to 254 t/h, adjusted to 100 percent time efficiency. The average loading rate was 186 t/h. It took from 2.3 to 3.7 min to load single- and dual-axle spreader trucks averaging 9.3 t/load. The mean loading time was 3.0 min.

The main factor governing loading efficiency appeared to be the cycle time achieved by the loader operator, which varied from 0.45 to 0.77 min/cycle. The average for eight feedpens involving various operator-machine combinations was 0.60 min/cycle, or 100 loading cycles/h. This data includes cycle times from one feedpen at a fifth feedlot.

The cost of loading feedlot manure with wheel loaders (75 to 108 flywheel kW) was calculated for nine of the feedpens as the ratio of unit hourly costs (machine and labor) to loading rate. Loading cost varied from $0.09 to $0.15/t of manure loaded, and averaged $0.13/t. The highest and lowest unit loading costs were garnered at the same feedyard using the same loader, but with two operators of widely different abilities.

Cycle Times for Truck Loading

There was a highly significant difference among loading cycle times for the five feedlots. The mean for 278 observations was 0.61 min/cycle, ranging from a high of 0.78 min/cycle at Feedlot A to 0.50 min/cycle at Feedlot B. Overall mean times for the load, haul, dump, and return elements for truck loading were 0.12, 0.23, 0.10, and 0.16 min, respectively.

The operator at Feedlot A was out of practice and slower than the average on all four steps. The fastest operator for loading (Feedlot B) produced the slowest cycle times during collection. This suggests that loader operators in a large feedlot could be specialized to achieve maximum productivity.

Spreader Truck Turnaround Time

A round trip haul-cycle curve (Fig. 4) for spreader trucks was obtained from elapsed time and truck odometer readings after each trip to the fields. Most of the data were obtained at Feedlot C. Fig. 4 shows that it takes about 48 min to complete a 16 km one-way haul.

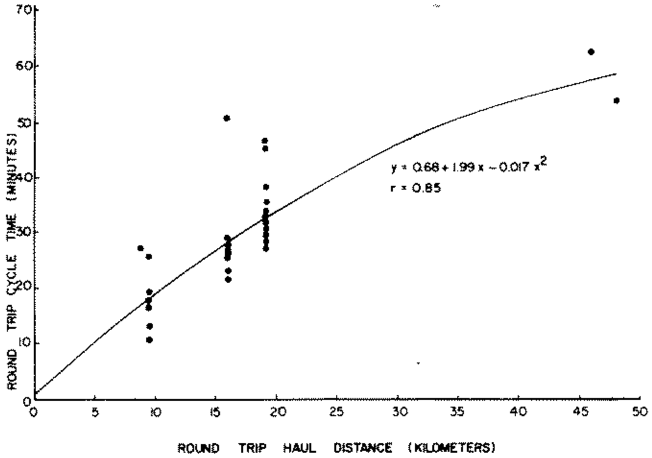

FIG. 4 Round trip cycle time for manure spreader trucks as a function of distance. Variation was caused by waiting time and delay factors.

Delays such as refueling, coffee breaks, lunch, and waiting time accounted for much of the wide variation among the data points for similar haul distances. These values represent a limited set of conditions. Contractors and feedlot supervisors can easily develop similar control charts to serve as management tools for their own conditions.

SUMMARY AND CONCLUSIONS

Time-motion analysis was used to compare alternate methods of feedlot manure collection at four Texas feedlots (28,000 to 100,000 head capacities) on the basis of machine productivity, energy consumption, and cost. Collection systems studied were elevating scraper, wheel loader, and wheel loader plus plowing or rototilling. Other objectives were to compare wheel loader operator performance for efficient feedlot manure loading and to determine time requirements for hauling and spreading.

From the time-motion analysis, the following conclusions were drawn:

1 The maximum manure collection rate of 160 t/h was obtained with the wheel loader/chisel plow combination. This was followed in order by the elevating scraper (114 t/h), wheel loader (107 t/h), and wheel loader/rototiller (106 t/h). These values are based on 100 percent operating efficiency (i.e. 60 min operation/h).

2 Assuming 100 percent operating efficiency, the most energy efficient system for manure collection was the elevating scraper (0.88 kWh/t). Plowing or rototilling the manure pack prior to wheel loader collection reduced energy consumption by 30 percent (0.96 and 0.99 kWh/t) as compared to collection with only the wheel loader (1.28 kWh/t).

3 Manure collection costs were similar for the four systems studied, averaging $0.21/t (at 100 percent operating efficiency).

4 Operating efficiencies for the elevating scraper, wheel loaders and tractor-drawn scarifiers engaged in manure collection averaged 90, 79, and 84 percent, respectively.

5 The average rate of manure loading into spreader trucks by wheel loaders was 186 t/h. Time required to load spreader trucks (9.3 t/truckload) averaged 3.0 min (2.3 to 3.7 min range). Loading rates were governed mainly by the cycle time achieved by the loader operator.

6 Cost of loading feedlot manure ranged from $0.09 to $0.15/t and averaged $0.12/t.

7 The spreader truck haul distance versus cycle time curve developed from the time-motion study can be a useful tool in controlling operator performance.

References

1 Butchbaker, A. F., J. E. Garton, G. W. A. Mahoney, and M. D. Paine. 1971. Evaluation of beef cattle feedlot waste management alternatives. Report No. 13040 FXG, Office of Research and Monitoring, U.S. Environmental Protection Agency, Washington, DC. 322 p.

2 Caterpillar. 1976. Caterpillar performance handbook. 6th ed., Caterpillar Tractor Company, Peoria, IL.

3 Hahn, R. H., Jr. (ed.). 1976. AGRICULTURAL ENGINEERS YEARBOOK. American Society of Agricultural Engineers, St. Joseph, MI. 675 p.

4 Hansen, R. W., J. M. Harper, M. L. Stone, G. M. Ward, and R. A. Kidd. 1976. Manure harvesting practices: Effects on waste characteristics and runoff. EPA-600/2-76-292, U.S. Environmental Protection Agency, Ada, OK. 112 p.

5 Niebel, B. W. 1972. Motion and time study. 5th ed., Homewood, IL; Richard D. Irwin, Inc. 709 p.

6 Park, W. G., Jr. 1972. A cost-center analysis for a commercial feedyard. Unpublished report, Master of Agriculture/Feedlot Management Program, Animal Science Department, Texas A&M University, College Station. 40 p.

7 Safely, L. M., Jr., D. R. Price, and D. C. Ludington. 1976. Network analysis for dairy waste management. TRANSACTIONS of the ASAE 19(5):920-924.

8 Shaffer, L. R. and A. C. Brooks. 1971. Queueing models for production forecasts of construction operations. Construction Research Series No. 16, College of Engineering, University of Illinois, Urbana-Champaign.

9 Sweeten, J. M., G. S. Nelson, D. L. Reddell and J. S. Cochran. 1976. Comparison of feedlot manure collection systems. Paper presented at the ASAE Southwest Section Meeting, Little Rock, AR.

10 Sweeten, J. M. and D. L. Reddell. 1976. Managing feedlots for odor control. ASAE Paper No. 76-4016, ASAE, St. Joseph, MI 49085.

11 Sweeten, J. M., D. L. Reddell, and B. R. Stewart. 1974. Feedlot manure as an energy source. Paper presented at the 1974 Texas Section Meeting, American Society of Agricultural Engineers, Abilene, TX.