Distribution Fitting and Parameterization of Individual Operator Work Routine Times for Small Dairy Parlors

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ABSTRACT

A time and motion study was conducted at 13 small dairy farms with average herd sizes less than 100 cows. Parlors were configured with 3 to 6 stalls per side. A data acquisition methodology was developed using a video camera to gather work routine time data in the parlors. A computer-based data logger was used to extract individual event durations during video playback. Each parlor's video record was reviewed in the laboratory so that work routine times across all parlors and operators could be pooled to estimate typical operator performance. There were 34 operator work routine times associated with various procedures in milking parlors that were evaluated in this study. Individual times were compiled for each work routine and a data-fitting program called UNIFIT was used to fit the data to 1 of 4 data models: gamma, lognormal, Weibull, and Pearson #5. Each of 34 work routine variables was fitted, tested, and plotted to determine how well each of those models fit the actual data. Distributions for Pearson #5, lognormal, gamma, and Weibull models were best fitted to 12, 10, 8, and 4 work routine times, respectively. More common tasks such as attaching the milker, grabbing a towel, and drying the udder were more consistently executed and had smaller variances than routines in which the operator would leave the pit to go to the milk room or disassembled the milk collector after milking. One of the better fitting models was the lognormal distribution for the time to "attach milker," which had a low relative discrepancy to the P-P plot (model probability vs. data probability) of 0.019 and a moderate χ^2 test value of 0.358, thus demonstrating a good fit of the model to the data. Simulation tests were compared with observed data to validate models for work routine times and demonstrated that the models accurately predict parlor throughput in small- to medium-sized parlors.

Key words: dairy parlor, milk room, time and motion study, work routine time

INTRODUCTION

During the last 50 yr many dairy farmers have left the business and many remaining producers have increased herd sizes and production per cow as they try to improve production efficiency. New technology and equipment often gets adopted by growing farm businesses and there is concern about competitiveness of smaller, family-based dairy farms. National trends indicate that the number of dairy producers has declined significantly over the last half-century, due to several factors including shrinking farm labor availability and profitability, the dairy buyout program, and urban and environmental pressure. On a national level, the number of milk cow operations decreased by 41% between the 1993 and 2002 censuses (USDA-NASS, 2002). In Kentucky, the number of dairy producers dropped from 15,820 farms milking 325,000 cows (10 kg/cow per d) in 1972 to an approximate current level of 2,939 farms milking 121,000 cows (16 kg/cow per d; Turner et al., 1987; USDA-NASS, 2002).

To help small dairy producers make appropriate automation decisions, system analysis tools are needed to evaluate current facilities and production practices, and then provide a means for predicting potential performance improvements. Using simulation-modeling tools, producers can incrementally add automation and productivity tools that can improve labor efficiency and cow throughput. Numerous researchers have developed simulation models using various strategies. Thomas et al. (1994) reported the development of a network simulation model for large herringbone and parallel milking parlors. They developed a milking time prediction method, which can stochastically estimate individual cow milking time (Thomas et al., 1993). Chang et al. (1994) developed an object-oriented model for milking parlor operations. Thomas et al. (1996) reported a network simulation model for large double herringbone parlors (20 stalls per side) and double-parallel milking parlors with up to 40 stalls per side. They observed

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insignificant variation between simulated and observed mean throughput. Burks et al. (1998) developed a stochastic model for simulating cow throughput in small dairy parlors (4 to 12 stalls per side) using discrete modeling techniques. Hyde and Engel (2002) reported on a Monte Carlo simulation method for evaluating the breakeven economics of highly automated robotic milking systems.

Labor productivity models are highly dependent upon the work routine times (**WRT**) used to calibrate them. To assess the viability of a particular work routine, time and motion (**T&M**) studies are conducted. During the last 50 yr, a number of T&M studies have been completed by dairy researchers, each providing significant research findings in parlor operations. Research shows that WRT for different operators in herringbone parlors can vary dramatically (Armstrong, 1985). Armstrong categorized operators as either fast or slow with as much as a 10-fold increase for fast operators. He combined travel time with operator activity. Brown et al. (1959) conducted T&M studies on 42 parlors, consisting of herringbone, walk through, and side-opening configurations. They observed that operator walking distance was shown to be 5 to 15% greater in side-opening than in herringbone parlors. Armstrong and Seltz (1972) reported studies on 8 different double-8 herringbone parlors showing wide variation among parlors of similar configurations. Appleman and Micke (1973) conducted studies in side-opening and herringbone parlors on the effects of different work routines and mechanization levels. They found more apparent variation among the operator's WRT performance than between either parlor style or equipment. Armstrong and Quick (1986) compared the WRT of a double-16 herringbone to a 32-stall polygon; they found the greatest differences in cow entry, cow exit, and operator wait time.

Studies on T&M were conducted on several large parlors in Florida by Thomas et al. (1994). Video recording techniques similar to those of Burks (1989) were used to capture a permanent record of dairy parlor operations, followed by a laboratory extraction process to obtain individual WRT data. Thomas et al. (1994) then used probability distribution function analysis software to generate T&M models for the events used in a dairy parlor simulation model for large commercial facilities.

The major limitation of past T&M studies is the fact that different work routines are often grouped together. This creates significant limitations when applying simulation techniques to model the human operator's work routine. A new method of conducting dairy parlor time and motion studies is reported in this paper, which proposes that elemental operator work routines are common to all parlors, and that the major differences

are associated with the parlor layout, automation levels, operator efficiency, and unique production practices used by the dairy producer. Therefore, it should be possible to identify and parameterize distribution functions that can stochastically predict specific WRT for a dairy parlor simulation model, which includes estimation of operator travel times based on the parlor configuration, level of automation, operator efficiency, and production practices used.

Objectives

The objectives of this study were to 1) use dairy parlor work routine data in video format from typical small dairy farms; 2) develop a methodology for extracting individual WRT for the fundamental operator routines; 3) generate data models for each specific work routine that describe the time distribution and frequency of occurrence, so that those events can be incorporated into a dairy parlor performance simulation model; and 4) compare predicted parlor throughput from a stochastic simulation model, which used the WRT data models, with actual parlor performance to determine validity of data models.

MATERIALS AND METHODS

A T&M study was designed to isolate operator event durations from travel time. Major obstacles to data collection were the short time interval in which events occurred. A method of data recording was developed that was capable of meeting the goal of continuous event recording, by using video recording equipment, a multi-function timer, and data logger. Thirteen different parlors were filmed continuously (except to exchange a battery pack or video cassette) from the start to the finish of milking.

Apparatus Hardware and Software

The data acquisition equipment consisted of 5 components: 1) a videocassette recorder (**VCR**) with remote control, 2) a television monitor, 3) a Compaq portable computer, 4) a line printer, and 5) a timer function control panel. The VCR, television monitor, and line printer were all standard equipment, whereas the Compaq portable computer had a 24-bit parallel I/O port installed to allow interface with the custom-designed control panel.

The 24-bit parallel digital I/O interface was supplied by Keithley-Metrabyte (Cleveland, OH) and featured three 8-bit ports, 12- and 15-V power supply, digital common, and interrupt enable. The timer function control panel was specifically designed to afford the maxi-

Table 1. Characteristics of milking parlors evaluated during the time and motion study

Parlor ID	Breed	Herd size	Milk production ¹	Parlor type ²	Stalls/side
1	Holstein	42	23.5	D-Herr	5
2	Holstein	61	22.6	D-Herr	4
3	Holstein	55	24.9	D-Herr	4
4	Holstein	48	20.4	D-S.O.	3
5	Holstein	62	24.9	D-Herr	4
6	Holstein	47	20.8	D-Herr	3
7	Holstein	75	27.2	D-Herr	4
8	Holstein	66	26.2	D-Herr	4
9	Holstein	94	24.9	D-Herr	6
10	Holstein	55	20.4	D-Herr	4
11	Holstein	80	22.6	D-Herr	5
12	Holstein	76	18.1	D-Herr	4
13	Guernsey	52	18.1	D-Herr	4

¹The units for milk production were in kilograms per cow per day.

²D-Herr = Double herringbone parlor; D-S.O. = double side-opening parlor.

mum number of timer functions. It consists of 22 labeled time function switches and 2 isolated single switches in the upper left and right corners. Each timer function circuit includes a light emitting diode for "ON" function recognition. The 2 remaining port bits (C6 and C7) were used for last entry error action and stop program action.

Event recording was accomplished by providing the designated I/O port input bit with a high logic (2.0 to 5.0 V) for timer function "ON", and low logic (−0.5 to 0.8 V) for timer function "OFF". The software program to drive the timer function control panel was developed using the TURBO BASIC language (IBM Version, Microsoft, Redmond, WA). The software was designed so that each timer function had its own unique data file. Each of the three 8-bit ports was sampled at the rate of 18 Hz (18 cycles/s) for change in state. Once the change was detected and checked for stability, if the change was from low to high, the timer associated with the affected bit was activated. Otherwise, if the change was from high to low, the elapsed time was recorded and the event time was recorded in the appropriate data file.

Field Study Procedure

The field study was conducted at 13 parlors located randomly within a 200-km radius of Lexington, Kentucky. The owners were contacted several days in advance of the desired filming date, so that the parlor could be prescreened for desired features and operational techniques. The primary features sought were 1) parlors with 3 to 6 stalls per side, 2) single operator conducting milking, 3) varying degrees of automation (detachers, crowd gates, auto feed) with emphasis on manual operation, 4) various operational techniques,

and 5) herd sizes between 40 and 100 cows. The goal of the field study was not only to obtain film footage for T&M analysis, but also to establish typical operation techniques to be incorporated into a dairy parlor simulation model. Therefore, because the emphasis was on operator events, a representative study required investigation of parlors with varying degrees of automation and operation techniques. Table 1 presents a list of the 13 parlors and identifies the herd size, average yield, parlor type, and number of stalls. It should be noted that the purpose of this study was to isolate WRT events at the smallest possible level, so that simulation models could use the same distribution functions in various parlor configurations. Consequently, the WRT is independent of parlor type, and can thus be combined among parlor types, as long as the model adequately predicts parlor-dependent operations. This, in turn, requires a virtual model of the parlor layout, a technique for estimating operator and cow velocities, as well as random events.

Upon arrival at each parlor site, we accumulated preliminary data on the parlor and operation technique utilized. Photographs and parlor measurements were taken to provide a permanent record of the milking room layout. Filming began when the parlor entrance doors were opened for the first set of cows to enter the milking stalls. The equipment used during the field study included a VM-2000A Hitachi camcorder, a 35-mm camera, stopwatch, extra battery pack and videocassette, tape measure, and data sheet. Throughout the milking, which ranged from 1 h and 15 min to 2 h and 35 min, the VCR camera remained focused on the operator, except when the operator left the milking pit to go to the holding pen or milk room, or when the camera required a change of videocassette or battery. Operation filming continued until the last cow exited the parlor. At this time, overall milking time and final information from the operator were recorded.

Data Extraction Procedures

Time and motion studies were taken from each of the 13 dairy parlors filmed, utilizing a video review laboratory. The films were played individually from start to finish with all of the bit-assigned data being extracted in the primary review. After all of the tapes had been reviewed for primary data, each tape was reviewed again to selectively extract the remaining event durations. In most instances, the omission of an event was due to the restricted field of vision of the camcorder. The confined pit area and position of the cameraman resulted in a loss of some events that occurred at the end of the pit closest to the camera. Once the primary review was completed, all parlor data files

Table 2. Work routine event numbers, descriptions, observations, and start and stop definitions

Event	Description	No. of observations ¹	Start ²	Stop ³
1	Adjust milker	155	Arrives to adjust	Adjustment complete
2	Set up collector	16	Begins milk setup	Ready for attachment
3	Attach milker	761	Reaches for milker	Milker attached
4	Clean milker	168	Begin cleaning milker	Milker cleaned
5	Close gate	367	Begin closing gate	Gate closed
6	Dip cup	44	Begin dip cup filling	Completes dip cup filling
7	Disassemble collector	17	Begins disassembly	Ready for next milking
8	Dry udder	668	Towel in hand—starts to dry	Drying complete
9	Feed	181	Arrive at feed control	Begins to close doors
10	Grab dip cup	101	Arrive to grab dip cup	Dip cup in hand
11	Grab towel	91	Arrive to grab towel	Towel in hand
12	Milk room	23	Leaves pit to milk room	Returns to pit
13	Exit balk	18	Returns to assist exit	Resumes duty
14	Open door	69	Begins open entry door	Entry door open
15	Open gate	326	Begin opening gate	Gate open
16	Operator velocity	206	Departs stall station	Arrives at next stall
17	Predip teats	259	Begin predip	Predip complete
18	Prespray udder	380	Begin prespray	Prespray complete
19	Remove milker	326	Begin removal	Milker hung up
20	Strip-check	213	Begins hand strip	Hand strip complete
21	Postdip (cup)	622	Dip cup in hand—starts to dip	Dip cup placed down
22	Postdip (spray)	74	Sprayer in hand—starts to spray	Sprayer put down
23	Wash	499	Begin washing	Washing complete
24	Entry 1	36	Door open	First cow passes gate
25	Entry 2	36	First cow passes gate	Second cow passes gate
26	Entry 3	36	Second cow passes gate	Third cow passes gate
27	Entry 4	35	Third cow passes gate	Fourth cow passes gate
28	Exit 1	56	Exit gate open	First cow passes gate
29	Exit 2	53	First cow passes gate	Second cow passes gate
30	Exit 3	53	Second cow passes gate	Third cow passes gate
31	Exit 4	53	Third cow passes gate	Fourth cow passes gate
32	Side = opening entry	31	Door open	Cow passes gate
33	Side = opening exit	20	Exit gate open	Cow passes gate
34	Cow velocity	51		

¹Represents the number of times that work routine time data were collected for the listed event description.

²When the start event occurs, the elapsed time counter begins.

³When the stop event occurs, the elapsed time counter stops and the event time is recorded.

were backed up from the Compaq's hard disk to an individual floppy disk (1 floppy disk per parlor).

After completing the primary review of all parlors, a modified program was developed that assigned timer function control switches to the remaining events to be recorded. The videos for each parlor were reviewed again until the desired number of event occurrences were observed and recorded. Once all of the data had been extracted, a formatting and concatenating program was developed. This program formatted each data record with a parlor identification number. Then the data files for each event were concatenated to form a set of individual event data files that contained data from all 13 parlors. To predict the accuracy of the data extraction method, 2 additional tests were conducted. These tests showed that while observing an event with a distinct start and stop, the investigator was accurate to within approximately 0.25 s.

There were 34 specific routine events reported in this study. Table 2 provides a list of the events monitored,

the number of observations for each event, and a description of the start and stop event sequence. A complete description of the methodology used for the T&M study, data extraction, and analysis discussed in this manuscript is given in Burks (1989).

Distribution Fitting and Parameterization

To utilize the experimental T&M results in a simulation model, each of the 34 data sets was fitted to a standard distribution function recognized by SLAM II simulation language. Each operator event was assumed to be a continuous unbounded distribution with nonnegative values. Therefore, 4 general distribution functions were selected for testing analysis, each having 2 possible location parameters. The gamma, lognormal, Weibull, and Pearson #5 distributions were tested utilizing the distribution-fitting program UNIFIT. A complete discussion of the distribution functions and UNIFIT can be found in Law and Vincent (1983).

Each data set was fitted to 8 distributions: a) gamma, with default location parameter (0,0); b) gamma, all parameters estimated by method of maximum likelihood; c) lognormal, with default location parameter (0,0); d) lognormal, all parameters estimated by method of maximum likelihood; e) Weibull, with default location parameter (0,0); f) Weibull, all parameters estimated by method of maximum likelihood; g) Pearson #5, with default location parameter (0,0); and h) Pearson #5, all parameters estimated by method of maximum likelihood.

Once the distribution fitting was completed, each model was analyzed to determine which of the 8 models was the best representation of the data. The criteria for selecting the appropriate model were based upon 6 different comparisons.

The relative discrepancy between the model and the data for the probability-probability (**P-P**) plot and quantile-quantile (**Q-Q**) plot were analyzed. According to Law and Vincent (1983), the P-P plot is a graph of the model probability vs. the sample (data) probability, which amplifies the differences that exist in the middle portion of the sample distribution. The Q-Q plot is a graph of the model quantile vs. the sample (data) quantile and amplifies the differences that exist between the tails of the model distribution function and the sample distribution. The heaviest weight was given to the P-P plot comparison due to its representation of the probability of occurrence in the high frequency range. The models having the lowest relative discrepancy were flagged for further comparison. Next, the model moments were compared with the data moments. The respective means and variances were compared to prevent shifting of the distribution function away from the data mean. A frequency comparison was then conducted on the models that appeared to best represent the data. A frequency histogram was generated that compared the individual models to the data. The models having the best shape conformation to the data histogram were flagged for goodness-of-fit comparisons. The χ^2 goodness-of-fit test was conducted on the remaining models. The model having the lowest χ^2 statistic, which successfully exceeded the predetermined stated probability ($P \geq \alpha$, $\alpha = 0.05$), was selected as the best fitting distribution.

Once the model was selected, the parameter's 90% confidence interval was generated and the model was tested for the probability of generating an occurrence outside the range of the minimum and maximum value of the data. The test specifications were that at least 90% of the model's cumulative frequency must reside within the limits of the T&M data.

Model Validation

A stochastic simulation model termed PARSIM was developed by Burks et al. (1998) using the SLAM II modeling environment (Pritsker, 1984). The model used a discrete event modeling technique in which user-written subroutines defined the individual WRT events. Each WRT was written in FORTRAN 77, and included both randomly generated events based on the frequency of occurrence data, and logically sequenced WRT events based on the production practices selected. Appropriate distributions function were used for each WRT to estimate the random event duration based on the WRT data models generated through UNIFIT. One unique feature of PARSIM was that WRT events were separated from travel time, and could be scaled according to expected operator efficiency. Consequently, there would be no significant distinction between attaching a milker in a double herringbone parlor vs. attaching a milker in a double side-opening parlor because the WRT is the same.

The main difference between parlor types is the floor layout and thus elapsed time associated with operator and cow travel. Once the cow travels to its stall and the operator arrives at the stall, most WRT are similar, with the usual variation being due to operator efficiency. Options were built into PARSIM to accommodate various levels of automation, parlor size, and configurations. Typical parlor configurations are represented by theoretical operator work locations, operator and cow travel paths, and cow milking locations. In the virtual parlor model, the operator must travel to the appropriate stall location to execute all stochastic events associated with the cow located at that particular location. Meanwhile, the cow must travel to and from each theoretical stall location when entering and leaving the parlor. Traffic patterns are dependent on the parlor layout and the production practices identified during model option selection. The underlying assumption of this study is that once the WRT events are defined, the model can be extended beyond the parlor configurations used in the T&M study, because operator and cow travel is being simulated independently of the specific WRT events. Consequently, the simulation should demonstrate good results in predicting cow throughput in parlors different from those used in the T&M study.

Six typical parlor configurations were modeled using PARSIM to validate the WRT data models. The predicted cow throughput was compared with previous T&M study results to ensure validity. Each validation test consisted of 10 unique simulations using the same parlor configuration. A random number generator was used to assign unique event seed values for each simula-

Table 3. Data model specifications generated by UNIFIT probability distribution function analysis

Event ¹	Minimum ² (s)	Maximum ² (s)	Distribution ³	Location ⁴	Scale ⁴	Shape ⁴
1	2.0	31.9	Lognormal	0.00	1.86	0.61
2	5.8	26.6	Lognormal	0.00	2.57	0.43
3	5.1	36.4	Lognormal	0.00	2.47	0.29
4	1.3	37.6	Gamma	0.00	4.66	2.10
5	0.8	17.6	Pearson #5	0.00	15.72	5.96
6	2.5	22.4	Lognormal	0.00	1.91	0.50
7	8.7	82.1	Gamma	8.68	28.20	0.52
8	2.3	58.3	Lognormal	2.25	1.35	0.81
9	1.0	15.0	Pearson #5	0.00	14.24	7.07
10	0.7	2.1	Weibull	0.71	0.32	1.27
11	0.7	6.9	Gamma	0.68	1.06	1.12
12	7.5	136.3	Lognormal	0.00	3.26	0.72
13	7.1	31.3	Weibull	7.09	6.50	0.89
14	1.0	7.1	Lognormal	1.05	-0.57	1.03
15	0.9	16.6	Pearson #5	0.00	17.08	7.30
16	0.2	1.4	Pearson #5	0.00	8.84	15.47
17	1.9	12.2	Gamma	1.87	0.84	2.12
18	1.0	25.4	Gamma	0.00	1.99	2.43
19	1.7	22.2	Gamma	0.00	0.92	6.98
20	2.6	33.6	Pearson #5	0.00	35.73	5.05
21	1.2	13.4	Lognormal	0.00	1.29	0.32
22	1.2	3.5	Pearson #5	0.00	45.46	25.26
23	1.1	54.1	Gamma	1.12	5.70	1.79
24	3.5	25.5	Lognormal	0.00	2.04	0.50
25	2.4	6.9	Pearson #5	0.00	56.45	15.44
26	2.4	10.4	Pearson #5	0.00	52.98	13.50
27	2.5	19.7	Weibull	2.47	2.49	0.97
28	2.2	14.6	Pearson #5	0.00	36.75	7.80
29	1.9	15.4	Gamma	1.92	1.89	1.47
30	2.1	13.7	Pearson #5	0.00	30.95	8.06
31	2.3	13.5	Weibull	2.31	2.40	1.20
32	6.0	31.9	Pearson #5	0.00	71.72	6.53
33	4.8	18.8	Lognormal	3.10	1.57	0.52
34	0.6	2.5	Pearson #5	0.00	9.72	9.32

¹Refer to Table 2 for event descriptions.²The minimum and maximum duration of the population of event work routine time (WRT) recorded.³The best fitting frequency distribution for the WRT, selected by UNIFIT.⁴The frequency distribution location, scale, and shape parameters generated by UNIFIT.

tion run. This ensured that each of the 10 simulations could be considered an independent test of the model. The overall parlor throughput presented for each validation test was the mean of the 10 independent simulations.

RESULTS AND DISCUSSION

The results of the 34 distribution-fitting analyses are shown in Tables 3 and 4. Table 3 presents the data model specifications for each of the 34 data sets, minimum and maximum observations, best fitting distribution function, and the respective model parameters. Table 4 presents a comparison of the data vs. the model of each event. The data and model means and variances are given as well as the relative discrepancies from the P-P and Q-Q plots. In addition, the χ^2 goodness-of-fit test results are shown for each of the 34 data sets. There are several interesting results illustrated in Table 4. First, data means and variance generally matched very

well with the model means and variance; consequently, the goodness of fit of the data to the model distribution curves is the primary source of error between the two. This is evident from Figure 1, in which it can be seen that the model curve for event 3 (attach milker) does not perfectly fit the data needle lines, although the mean and variance shown in Table 4 are nearly identical. This is one of the better fitting data models, yet there will always be some variation between the actual data distribution and the generated data model. Another interesting aspect of this study is evident in Table 4, in which it can be seen that several events have extremely large variations. For instance, event 12 (go to milk room) has a mean duration of 33.9 s and a variation of 851.2 (standard deviation of 29.2 s). In this case, it is obvious that the time spent in the milk room is quite variable and any estimate will be highly variable. The same is true of other randomly occurring WRT events such as cleaning the milker, disassembling the collector, and so on. Meanwhile, the more common tasks

Table 4. Field data work routine times (WRT) vs. probability distribution function model work routine times comparisons

Event ¹	Field data WRT		Model WRT		Relative discrepancy		χ^2	
	Mean ²	Variance ²	Mean ²	Variance ²	P-P Plot ³	Q-Q Plot ⁴	DOF ⁵	$P > \alpha$ ⁶
1	7.9	33.1	7.8	27.7	0.07	0.17	5	0.381
2	14.2	36.3	14.3	42.5	0.05	0.12	6	0.996
3	12.3	14.0	12.3	13.7	0.019	0.16	6	0.358
4	9.8	44.5	9.8	45.6	0.082	0.05	7	0.010*
5	3.2	2.9	3.2	2.5	0.026	0.12	7	0.150
6	7.6	15.4	7.6	16.6	0.054	0.11	7	0.561
7	23.3	332.2	23.3	411.5	0.112	0.11	9	0.853
8	7.6	32.8	7.6	26.7	0.041	0.09	4	0.050
9	2.4	2.1	72.3	1.1	20.039	0.34	7	0.602
10	1.0	0.1	41.0	0.1	0.072	0.07	7	0.190
11	1.9	1.5	1.9	1.3	0.089	0.06	7	0.102
12	33.9	851.2	33.8	774.8	0.079	0.14	7	0.877
13	14.0	60.6	14.0	60.1	90.101	0.25	5	0.458
14	1.9	0.8	2.0	1.8	0.086	0.07	1	0.297
15	2.7	2.1	2.7	1.4	0.043	0.29	9	0.391
16	0.6	0.1	0.6	0.1	0.032	0.08	5	0.566
17	3.6	1.6	3.6	1.5	0.028	0.23	7	0.555
18	4.8	12.3	4.8	9.6	0.073	0.17	9	0.193
19	6.4	6.1	6.4	5.9	0.041	0.27	7	0.095
20	8.8	24.1	8.8	25.6	0.027	0.15	9	0.875
21	3.8	1.9	3.8	1.6	0.043	0.154	5	0.052
22	1.8	0.2	1.9	0.2	0.075	0.115	7	0.398
23	11.3	65.6	11.3	58.3	0.033	0.06	6	0.245
24	8.7	25.9	8.7	21.1	0.093	0.117	6	0.773
25	3.9	1.4	3.9	1.1	0.099	0.15	5	0.340
26	4.3	2.1	4.2	1.6	0.062	0.25	5	0.502
27	5.0	8.9	5.0	6.8	0.083	0.35	5	0.562
28	5.4	5.2	5.4	5.0	0.054	0.048	5	0.407
29	4.7	6.6	4.7	5.3	0.097	0.19	6	0.390
30	4.4	3.6	4.4	3.2	0.043	0.26	6	0.956
31	4.6	3.6	4.6	3.6	0.079	0.20	5	0.308
32	13.1	44.9	13.0	7.0	0.074	0.18	5	0.309
33	8.6	11.0	8.6	9.6	0.070	0.11	7	0.494
34	1.2	0.2	1.2	0.2	0.077	0.07	6	0.341

¹Refer to Table 2 for event descriptions.²All WRT are given in seconds.³P-P plot = model probability vs. data probability.⁴Q-Q plot = model quantile vs. the data quantile.⁵For the χ^2 goodness of fit test, $\alpha = 0.05$; if $P > \alpha$, the event's modeled probability distribution function passed the χ^2 test and was a good fit.⁶ $\alpha = 0.05$.* $P < 0.05$, failed the χ^2 test but was best-fitting distribution found, with mean and variance very similar to the field data, and thus was used in the simulation model.

such as attaching the milker, grabbing a towel, drying the udder, and so on are much more consistently executed, and thus, have smaller variance.

Each of the 34 models was compared with the data set utilizing a frequency vs. time duration plot. The plots were generated using frequency analysis results from UNIFIT for the data and the model. Then the frequency analysis results were transferred to SAS for plotting through GPLOT. An example plot for attaching the milker is given in Figure 1.

Special Operator Events

Special considerations were required for several of the T&M study data sets. The operator travel speed

was determined by normalizing the travel time for both the herringbone and side-opening parlors to units of velocity. This was accomplished by using the field measured distance between stall locations and dividing the respective herringbone and side-opening parlor travel distances by the travel time. Also, the data for postdipping of teats were divided into 2 categories: 1) postdip solution applied by dip cup, and 2) postdip solution applied by spray mechanism.

The cow entry and exit data for herringbone parlors were for parlors with feeding in stalls. Data were collected for parlors with 4 stalls. The data given in Tables 3 and 4 represent the time required for each successive cow to enter or exit the stall system. Side-opening par-

Figure 1. Probability distribution function for “attach milker” event: A lognormal distribution that plots event time duration vs. frequency of occurrence. Needle lines represent field data and the solid curve represents the probability distribution function model generated by UNIFIT.

lors include only single stall entry and exit, because each cow is individually handled.

There were 9 frequency-dependent data sets. Therefore, because their occurrence in the T&M study as well as in the simulation model is random, a frequency of occurrence determination was made. Table 5 presents each of the 9 frequency-dependent events, listing their description, number of observations, base for frequency determination, and the frequency of occurrence. As mentioned earlier, these randomly occurring events seemed to have a highly variable duration as evidenced in Table 4.

The WRT data models provided the basis for simulating cow throughput performance of various dairy parlor configurations (Burks et al., 1998). Parlors were configured in simulations to reproduce conditions observed

in previous T&M studies. Model validation results demonstrated good throughput prediction for small- to medium-sized parlors, thus adding validity to the accuracy of these WRT distributions. The results of these validation tests are presented in Table 6, where the parlor configuration parameters are listed. Results demonstrated the applicability of PARSIM across a broad range of parlor configurations including both side-opening and herringbone-style parlors. For example, simulation results predicted a throughput of 65 cows/h for a double-8 herringbone parlor configured with crowd gate, automatic feeding, detachers, power doors, and power gates. A comparable T&M study by Armstrong and Quick (1986) had observed 67 cows/h. Similarly, a simulation of a double-10 herringbone parlor predicted cow throughputs of 96 cow/h as compared with Arm-

Table 5. Special event frequency analysis data

Event ¹	Observations ¹	Base ²	Observations ²	Frequency ³
Fill dip cup	44	No. of cows teat dipped	761	0.0578
Adjust milker	155	No. of cows processed	813	0.1906
Set up milk collector	17	No. of cows processed	813	0.0209
Disassemble milk collector	17	No. of cows processed	813	0.0209
Cow balking during exit	18	No. of free exits	80	0.2250
Operator to milk room	23	No. of 10-min intervals observed	158	0.1455
Entry assist parlor feeding	22	No. of entries observed	58	0.3794
Entry assist no feeding	10	No. of entries observed	13	0.7962
Entry assist crowd gate	1	No. of entries observed	27	0.370

¹The number of times the special event occurred during the time and motion (T&M) study.

²The basis for the frequency analysis. For example, during the T&M study the operators filled the dip cup 44 times out of 761 times the dip cup was used to treat a cow.

³The frequency of occurrences of the special event.

Table 6. A comparison of simulated cow throughputs to observed throughputs

Parlor type	Simulation model		Observed		Difference, %
	Specifications ¹	Throughput, cows/h	Source ²	Throughput, cows/h	
Single-4 side-opening	Wash, dry, teat dip, feed, 22.6 kg/cow per d, 1 operator	24	Brown et al. (1959); time and motion study	20–35	
Double-2 side-opening	Wash, dry, teat dip, feed, 22.6 kg/cow per d, crowd gate, 1 operator	29	Appleman and Micke (1973); time and motion study	31	5.7% Low
Double-8 herringbone	Wash, teat spray, crowd gate, detachers, feed, power gate, 27.6 kg/cow per d, 1 operator	65	Armstrong and Quick (1986); time and motion study	67	3.4% Low
Double-10 herringbone	Wash, dry, teat spray, crowd gate, detachers, feed, power gate, 22.6 kg/cow per d, 2 operators	96	Armstrong and Quick (1986); time and motion study	94	2.4% High
Trigon 12	Wash, dry, teat spray, crowd gate, detachers, feed, power gate, 27.1 kg/cow per d, 1 operator	55	Bickert (1980); simulation	56	1.9% Low
Polygon 32	Wash, dry, teat spray, crowd gate, detachers, feed, power gate, 22.6 kg/cow per d, 2 operators	107	Armstrong and Quick (1986); time and motion study	133	19.2% Low

¹The specifications listed here are the unique management practices and parlor equipment features that were chosen for the simulation; they attempt to match the features documented in the source parlor time and motion studies listed.

²Sources of the data used for this comparison are listed. All source parlors and their results are from either previous time and motion studies, or simulations that have been conducted by others and published.

strong and Quick (1986), who observed 94 cows/h. A simulation of a double-2 side-opening parlor predicted 29 cows/h as compared with T&M studies by Appleman and Micke (1973), who observed 31 cows/h. In another example, PARSIM predicted 55 cows/h for an 18-stall trigon parlor, whereas Bickert (1980) predicted 56 cows/h. However, it appears that PARSIM does not adequately model the throughput of the 32-stall polygon, where it underpredicted the cow throughput by 19.2% (Table 6). It is believed that this may be due to inadequate modeling of the polygon flow patterns, or due to significant differences between operator performance in large, highly efficient parlors compared with that in small parlors. However, it is clear from the results of these validation tests that the data models developed from this T&M study accurately predict WRT events and can be effectively used in parlor simulation studies.

CONCLUSIONS

A time and motion study was conducted at 13 small dairy farms with average herd sizes of less than 100 cows. Parlor work routines were executed by personnel from the individual farm being studied. Parlors were configured as double herringbone with 3 to 6 stalls per side. One double-4 side-opening parlor was also studied.

A data acquisition methodology was developed using a video camera to gather WRT data in the parlors and a computer-based event duration data logger, which enabled individual event extraction and recording during video playback. Each parlor's video record was reviewed in the laboratory so that WRT across all parlors and operators could be pooled to estimate typical operator performance on all work routines. There were 34 operator work routines evaluated in this study. Once the individual WRT were compiled for each work routine, a data fitting program called UNIFIT was used to fit the data to 1 of 4 data models; gamma, lognormal, Weibull, and Pearson #5 models were selected for evaluation. Each WRT was fitted, tested, and plotted to confirm that the models were in fact good fits of the actual data. Of all models, the Pearson #5 distribution was fitted to the greatest number of WRT events, with the lognormal being the distribution used second most often. One of the better fitting models was event 3, attach milker, which had a low relative discrepancy to the P-P plot of 0.019 and a moderate χ^2 test value of 0.358, thus demonstrating a good fit of the model to the data. The differences between the actual data mean (12.32) and variance (14.03), and the model mean (12.32) and variance (13.69) were minimal.

These work routine data models provided the basis for further research that was conducted using computer simulation modeling techniques to evaluate the cow

throughput performance of various dairy parlor configurations when configured with certain labor-saving devices such as automatic detachers and power gates (Burks et al., 1998). Model validation results demonstrated good throughput prediction for small- to medium-sized parlors, thus adding validity to the accuracy of these WRT event times and distributions.

Future enhancements of the time and motion study and simulation model should focus on gaining a better understanding of the production practices in large-scale dairy operations. Poor simulation results for a 32-stall polygon parlor suggests that traffic patterns and operator difference in these larger parlors need further study. Additional research should also be conducted in cow entry times under various parlor conditions.

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