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Evaluation of a contract breeding management program in selected Ohio dairy herds with event-time analysis I. Cox proportional hazards models

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Abstract

An observational study was conducted in order to assess the impact of a contract breeding program on the reproductive performance in a selected group of Ohio dairies using event-time analysis. The contract breeding program was offered by a breeding co-operative and featured tail chalking and daily evaluation of cows for insemination by co-operative technicians. Dairy employees no longer handled estrus detection activities. Between early 2002 and mid-2004, test-day records related to production and reproduction were obtained for 16,453 lactations representing 11,398 cows in a non-random sample of 31 dairies identified as well-managed client herds of the breeding co-operative. Of the 31 herds, 15 were using the contract breeding at the start of the data acquisition period, having started in the previous 2 years. The remaining 16 herds managed their own breeding program and used the co-operative for semen purchase.

Cox proportional hazards modeling techniques were used to estimate the association of the contract breeding, as well as the effect of other significant predictors, with the hazard of pregnancy. Two separate Cox models were developed and compared: one that only considered fixed covariates and a second that included both fixed and time-varying covariates. Estimates of effects were expressed as the hazard ratio (HR) for pregnancy.

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Results of the fixed covariates model indicated that, controlling for breed, herd size, use of ovulation synchronization protocols in the herd, whether somatic cell score exceeded 4.5 prior to pregnancy or censoring, parity, calving season, and maximum test-day milk prior to pregnancy or censoring, the contract breeding program was associated with an increased hazard of pregnancy (HR = 1.315; 95% CI 1.261–1.371). The results of the time-varying covariates model, which controlled for breed, herd size, use of ovulation synchronization protocols, somatic cell score above 4.5, parity, calving season, and testing season also found that the program was associated with an increased hazard of pregnancy (HR = 1.387; 95% CI 1.327–1.451).

The fixed and time-varying covariates models both found similar sets of predictors when analyzing the association of the contract breeding program with hazard of pregnancy. Both models identified a 30% or greater increase in hazard of pregnancy associated with use of the contract breeding program, suggesting that herds subscribing to the program achieved pregnancies in a more timely fashion.

Keywords: Dairy; Cattle; Reproductive management; Cox proportional hazards models

1. Introduction

Reproductive inefficiency is a major factor limiting the success of modern dairy herds (Lucy, 2001). As pregnancy rate declines, calving interval increases, which in turn lead to lower herd milk production (Louca and Legates, 1968), increased overall culling (Bascom and Young, 1998; Grohn and Rajala-Schultz, 2000; Rajala-Schultz and Grohn, 1999), limitations in strategic culling opportunities and potential reliance on purchased replacements, and increased veterinary costs.

A major reason for reproductive failure in dairy herds is the inefficient detection of estrus (Heuwieser et al., 1997; Rocha et al., 2001). In the United States, it is estimated that estrus detection rate (EDR) is below 50% and that failure to detect estrus costs the dairy industry more than $300 million per year (Senger, 1994). It has been suggested that estrus detection is so poor in dairy herds that managers should consider increasing EDR even at the risk of reduced pregnancy rate in order to improve pregnancy rates and reduce calving intervals (Stevenson et al., 1983).

Over time, a number of aids have been developed to assist dairy producers in identifying cows for insemination, including pressure-sensitive heat mount detectors (Gwazdauskas et al., 1990; Williamson, 1975), tail paint and chalk marking (Kerr and McCaughey, 1984; Williamson, 1980), teaser animals with marking devices (Stevenson and Britt, 1977), pedometers (Kiddy, 1977; Peter and Bosu, 1986), radiotelemetric pressure sensing devices (At-Taras and Spahr, 2001; Dransfield et al., 1998), and hormonal synchronization of ovulation (OvSynch) with administration of prostaglandin and gonadotropin releasing hormone (Pursley et al., 1997). The use of multiple estrus detection aids improves EDR, and has been found to be an economically favorable strategy compared to single methods of estrus detection (Holmann et al., 1987; Williams et al., 1981). Many of these estrus detection aids require daily attention to interpret information and make insemination decisions, but time constraints may preclude proper management of these aids. Some, such as radiotelemetry and pedometers, can automatically record and signal estrus behavior (At-Taras and Spahr, 2001).

However, these require significant capital investment (devices, signal detectors, computer software) that may limit their adoption.

Recently, in Ohio, at least one dairy breeding co-operative has begun offering a new contract breeding management program to its customers. This program is referred to as a full service technician program (FSTP), and uses tailhead chalk or paint as an estrus detection aid. More importantly, on a daily basis, an artificial insemination (AI) technician visits the farm and assesses chalk/paint marks. Based on the mark's status and other signs such as vulvar edema, presence of clear mucus discharge, and feel of the reproductive tract, the cow is inseminated. Alternatively, the mark is touched up with new chalk or paint and the cow remains in the breeding pool. The FSTP effectively liberates the producer from management of estrus detection and insemination.

Under the FSTP, it is expected that number of cows submitted for insemination will increase and producers will be able to devote more time and effort to other aspects of dairy herd management, such as nutrition, cow comfort, udder health, and heifer rearing. A potential drawback of the FSTP is that there is increased reliance on secondary signs of estrus for submitting cows for insemination, which can result in reduced conception efficiency (Reimers et al., 1985). However, FSTP is introduced as an intervention to increase pregnancy rate by increasing the number of cows inseminated and reduce the calving to conception interval.

Event-time analysis, or survival analysis, has been previously used for the evaluation of calving-to-conception interval in dairy herds. In most instances the Cox proportional hazards model has been used (Eicker et al., 1996; Harman et al., 1996a,b,c; Lee et al., 1989; Suriyasathaporn et al., 1998). With respect to the calving-to-conception interval, the time component is days in milk, and the outcome or event of interest is pregnancy. A desirable feature of event-time analysis is that it is able to utilize information for censored subjects, namely cows that fail to conceive while under observation (Harman et al., 1996a; Lee et al., 1989).

Many event-time analyses of the calving-to-conception interval have exclusively used fixed covariates (FC), which are explanatory variables that do not change in value during the time the subjects are under observation (Eicker et al., 1996; Harman et al., 1996a,b,c; Lee et al., 1989). This approach is somewhat unnatural in that some covariates, such as season, milk yield, somatic cell count (SCC) and its logarithmic transformation somatic cell score (SCS) can change during lactation. At least two studies have used time-varying covariates (TVC) while modeling the effect of disease occurrence (Maizon et al., 2004) and body condition score (Suriyasathaporn et al., 1998) as they change throughout lactation on the hazard of pregnancy.

The main objective of this study was to evaluate the effect of the FSTP on hazard of pregnancy and to identify and control for other significant predictors using the Cox proportional hazards model. A second objective was to compare results from two separate Cox proportional hazards models—one that exclusively used FC and a second that considered TVC for milk yield, season, and SCS.

2. Materials and methods

Data in this study came from dairies that were clients of the breeding co-operative, which sells products and services to approximately 1700 herds in Ohio, approximately 90

of which were using the FSTP. Herds that were targeted for inclusion and approached by investigators were 42 ‘‘well-managed’’ herds, as judged by the breeding co-operative, and included 21 herds that managed their own estrus detection as well as 21 herds that participated in FSTP.

2.1. Herd interviews

Individual herds identified by the breeding co-operative were contacted and asked about their willingness to participate in an evaluation of the FSTP. As an incentive measure, herds were offered a $300 certificate upon study completion redeemable for products and services from the breeding co-operative if they opted to participate.

Between March 2001 and April 2002, 38 herds agreed to participate and were visited for an approximately 90-min pre-study interview to collect information concerning herd characteristics, housing, nutrition, and management. A standard form was used to collect information by three different interviewers, and a minimum of two of the interviewers traveled to all herds for interviews. The use of a standard form and at least two interviewers was expected to maintain consistency of questioning and recording of information. During the interview, permission to electronically access dairy herd improvement association (DHIA) test-day information through contact with dairy record processing centers (DRPC) was requested. Herds that did not process DHIA data at a DRPC were not included in the study because of insufficient data access. Herd-level information and characteristics were entered into a database using Microsoft Access 2002 (Microsoft Corporation, Redmond, WA).

2.2. Test-day data

There were 32 herds that agreed to participate in the study and also used DRPCs to process test-day data. Test-day data were accessed using specialized software applications (DHI-Plus for Consultants, DHI-Provo, Provo, UT; PCDART for Consultants, Dairy Records Management Systems, Raleigh, NC). Between February 2002 and August 2004, test-day updates were received via e-mail or by initiated data download sessions through Internet access at regular intervals (between 4 and 6 weeks).

With each test-day update, data including cow identification, parity, calving date, test date, days in milk on test day, test-day milk, fat, and protein yield, test-day somatic cell count and somatic cell score, date of any recent inseminations, and date and result of any veterinary pregnancy check were archived by generating reports in the DRPC-specific software. These test-day reports were exported to Microsoft Excel 2002 (Microsoft Corporation, Redmond, WA) and saved for merging with other test days from other herds. As herds were followed for at least 18 months, it was possible to obtain test-day information on a cow from more than one lactation.

Individual test-day reports from all study herds were combined together into a single file and exported to Stata 7.0 (Stata Corporation, College Station, TX) for review of data quality and analysis. This database had 170,080 test-day records at the level of the lactation, representing 27,756 lactations in 15,729 cows.

2.3. Review of data quality

Extensive checks of the data were performed in order to ensure integrity of the data. Cow identifications were checked to make sure that records with different birthdates, parities, and calving dates did not share the same identification. Records with missing cow identification were located and birthdates, calving dates, and lactation numbers used to identify sets of observations that belonged to a single lactation. Records with missing or non-sensical calving dates (for example in the year 1900) were removed. Records identified as replicates based on cow identification, lactation, calving date, test day, and test-day data were removed. For cows that calved more than once during the study, order of parity was checked to make sure that parity increased in the records when the cow recalved. The cleaning process removed 4406 records. With data integrity verified, the test-day data were merged with the herd-level management data obtained through the herd visit and interview.

An important consideration when performing survival analyses is that only records for subjects at risk of experiencing of the event should be considered. In practical terms, this suggests that lactations in which the cow was never inseminated should not be considered at risk, and within lactations, the at risk period should be limited to the period only up to the latest insemination (Harman et al., 1996b). Therefore, records were removed for entire lactations in which no inseminations were ever attempted and test-day records were removed if they occurred after the date of the latest insemination. There were 8231 records from 3736 lactations in 3736 cows in which no insemination occurred, and an additional 94,782 records that occurred after censoring or pregnancy.

2.4. Determination of pregnancy or censoring

In this data set, the unit of observation was a cow's lactation. In order to perform the event-time analysis, the pregnancy status of all at risk records in the data needed to be determined. This was accomplished with the following guidelines. Any cow having a lactation that was followed by calving and a new lactation was considered to have become pregnant, and the date of conception was determined based on the latest recorded breeding date. Logic checks were made to ensure that the date of conception occurred approximately 280 days, the average length of bovine gestation (Meyer et al., 2001), prior to calving.

For lactations that were not followed by calving, the veterinary check result with the latest date was used—cows that had a veterinary check code of pregnant were considered to have become pregnant on the latest of the recorded breeding dates. Other cows were considered to be censored as of their latest breeding date. Beyond this date they were not considered to be at risk for conception. At this point, additional database refining was performed—cows that were judged pregnant by the above criteria but which did not have a breeding date were removed.

2.5. Additional data preparation

Data for breed was available from the DRPCs as a herd description of ''Holstein'', ''Jersey'', or ''Mixed'' (Jersey and Holstein in the same herd). In this context, use of

"Mixed" as a breed descriptor for the individual cows did not make analytical sense—the cows were either "Jersey" or "Holstein". The "Mixed" breed indicator represented a single herd with 1595 records representing 385 lactations in 321 cows. Because this was a small fraction of the overall data, the information for this herd was not used in the analysis.

Additionally, for each record, the season of calving and season of testing were defined as: winter, December 21 through March 20; spring, March 21 through June 20; summer, June 21 through September 20; autumn, September 21 through December 20. Parity was recoded into one of five levels: first parity (L1), second parity (L2), third parity (L3), fourth parity (L4), and fifth or higher parity (L5+). Additionally, SCS was dichotomously coded depending on whether it was above or below 4.5. The SCS of 4.5 was chosen as a cut-off value because it has been suggested as a threshold for increased risk of embryonic loss (Moore et al., 2005). Finally, herd size was classified into three categories: small, less than 150 milking cows; medium, 150–249 milking cows; large, 250 or more milking cows. These size divisions were based on categorizing herds into three categories of roughly equal size.

Some herds did change status with respect to FSTP enrollment during the data acquisition period. The FSTP status of lactations in these herds was fixed as the status of the herd on the calving date.

The data were prepared for the TVC model first. For each lactation, there was a sequence of test-day measurements and the final test-day measurement represented the latest test day prior to the final insemination. Because test-day data were collected at intervals, it was likely that inseminations occurred between test days. Therefore, a modification was made to the date of the final test day to coincide with the actual date of the final insemination. This date change meant that a lag was introduced between the actual test-day date and the date assumed in the analysis. The greatest interval between successive test days was 70 days. However, if cows missed a test day (perhaps due to illness or because data was not properly recorded), then the lag between the assumed and actual test date could exceed 70 days. There were 452 records in which the lag exceeded 70 days, and these were removed prior to analysis.

Once the TVC dataset was prepared, the FC dataset was prepared by collapsing the TVC dataset so that each lactation was represented by a single record. During this collapse, maximum values for milk yield and SCS were recorded as well as whether or not any test-day SCS was above 4.5 prior to pregnancy or censoring.

2.6. Kaplan–Meier survival estimates

One convenient method to summarize time-to-event data is with the Kaplan–Meier estimate of the survival function (Dohoo et al., 2003). Graphs of survival estimates for FSTP and non-FSTP herds were constructed. A log-rank test was performed to compare overall survival of the two groups of cows (Dohoo et al., 2003).

2.7. Cox proportional hazards models

The FC model was developed first. Univariable Cox proportional hazards models were evaluated with FSTP status, breed, herd size classification, use of OvSynch protocol in

herd, whether SCS ever exceeded 4.5, parity, calving season, and maximum test-day milk yield prior to pregnancy or censoring as predictors. Significance testing of these predictors was performed by using the Wald χ^2-test for covariates with 1 degree of freedom and likelihood ratio (LR) test for covariates with multiple degrees of freedom. All predictors with P-value <0.20 were placed into a multivariable Cox proportional hazards model and covariates were removed in a backwards elimination process using P-value >0.05 as reason for removal. One exception was that FSTP status was included in all multivariable models, because the intent was to determine the relationship between FSTP status and hazard of pregnancy while controlling for other important factors.

The TVC model was developed in much the same way as the FC model. First, univariable Cox proportional hazards models were evaluated with FSTP status, calving season, parity, use of OvSynch protocols at the herd level, and breed as FC predictors. Season of test, test-day milk yield, and whether or not test-day SCS exceeded 4.5 were tested as TVC. The same guidelines as for the FC model were used with respect to significance testing and final model selection.

2.8. Testing assumptions of Cox proportional hazards model

Once final multivariable FC and TVC models were developed, validity of assumptions for Cox proportional hazards models were tested. As the name implies, the Cox proportional hazards model assumes that hazards are proportional over time. For categorical covariates, this assumption was tested by examining plots of the natural logarithm of cumulative hazard versus time, with the expectation that the plots would be parallel. For continuous covariates, a plot of scaled Schoenfeld residuals was plotted against natural logarithm of time, with the expectation that there would be no association between the residuals and analysis time (Dohoo et al., 2003).

Another assumption central to Cox models is that of non-informative censoring. This was performed by re-creating the final models under two new assumptions: positive correlation and negative correlation. For positive correlation, the data were changed so that all lactations ended in pregnancy. For negative correlation, the data were changed so that all censored observations were censored at the maximum of all censoring times. The final models were run for the positive and negative correlation data sets and compared to the original final model to assess for extreme changes in inferences (Dohoo et al., 2003).

Model fit was assessed by use of Cox–Snell residuals from the final models. Final Cox models were re-fit using the Cox–Snell residual as the time variable. The cumulative hazards of the new models were plotted against the Cox–Snell residuals with the expectation of a zero intercept and unit slope (Dohoo et al., 2003).

3. Results

3.1. Characteristics of study herds and cows

In the state of Ohio, the breeding co-operative was providing services to over 1700 herds, with approximately 90 clients using the FSTP. There were 31 herds used in this

analysis. Fifteen herds subscribed to the FSTP—26 herds were Holstein herds (13 FSTP herds) and 5 were Jersey herds (2 FSTP herds). Four herds did change program status during the course of data collection. Two program herds became non-program herds, while two non-program herds became program herds.

The final dataset for analysis with TVC had 58,948 records for 16,453 lactations in 11,398 cows. The collapsed dataset for FC modeling had 16,453 records representing 11,398 cows. There were 9978 lactations managed under FSTP, and Table 1 shows a breakdown of characteristics of lactations managed under FSTP and non-FSTP.

3.2. Kaplan–Meier survival curves

Fig. 1 shows Kaplan–Meier survival curves for cows that were managed under FSTP and non-FSTP status. A log-rank test of the equality of the survivor functions for FSTP and non-FSTP indicated that there was a difference between groups ($P < 0.001$). Further comparison of the FSTP and non-FSTP program was warranted.

Table 1
Characteristics of the data from 31 Ohio dairy herds enrolled in the study with respect to full service technician program (FSTP) status

Characteristic	FSTP	Non-FSTP	Total
Herds	15	16	31
Use of ovulation synchronization protocol in herd			
Yes	9	8	17
No	6	8	14
Herd size classification			
Small (<150 lactating cows)	4	7	11
Medium (150–249 lactating cows)	5	5	10
Large (250 or more lactating cows)	6	4	10
Lactations	9978	6475	16453
Breed			
Holstein	8247	5751	13998
Jersey	1731	724	2455
Parity			
First lactation	3592	2524	6116
Second lactation	2681	1818	4499
Third lactation	1847	1076	2923
Fourth lactation	991	581	1572
Fifth lactation or higher	867	476	1343
Calving season			
Winter (December 21–March 20)	2557	1876	4433
Spring (March 21–June 20)	2051	1191	3241
Summer (June 21–September 20)	2565	1305	3871
Autumn (September 21–December 20)	2805	2103	4908
Somatic cell score ever exceeded 4.5			
No	6273	4083	10356
Yes	3033	2007	5040

Note: Some data missing for some lactations.

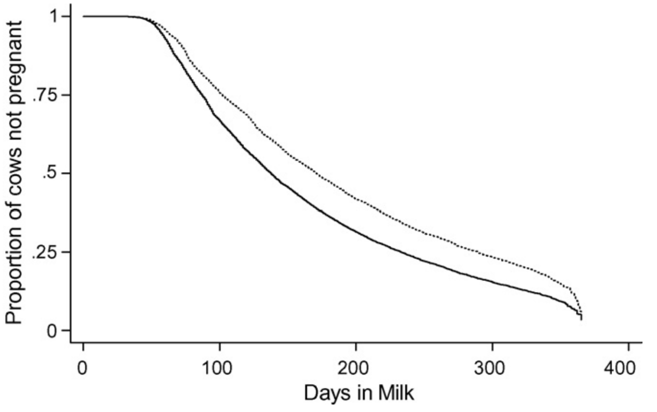

Fig. 1. Kaplan–Meier survival curves by full service technician program (FSTP) status: upper curve (· · ·) non-FSTP herds; lower curve (—) FSTP herds.

3.3. Results of analysis using fixed covariates

All predictors that were tested were highly significant in the univariable regression models. Therefore, all covariates were used as the first step in the backwards elimination phase of model building. Table 2 shows the results for the final multivariable model. All variables tested in the multivariable model were significant, and no covariates were removed. Because the objective of this model was to estimate the effect of FSTP on hazard of pregnancy while controlling for other covariates, only main effects were

Table 2
Final multivariable Cox proportional hazards regression model for pregnancy using fixed covariates

Predictor	Hazard ratio	*P*-value	95% CI
Full service technician program	1.315	<0.001	1.261–1.371
Breed (Jersey relative to Holstein)	1.182	<0.001	1.112–1.257
Herd size (relative to small herds)*			
Medium (150–249 lactating cows)	1.175	<0.001	1.100–1.254
Large (250 or more lactating cows)	1.265	<0.001	1.188–1.347
Use of OvSynch in the herd	1.199	<0.001	1.151–1.250
Somatic cell score ever exceeded 4.5	0.670	<0.001	0.642–0.699
Parity (relative to first lactation)*			
Second lactation	1.084	0.002	1.030–1.141
Third lactation	1.158	<0.001	1.090–1.229
Fourth lactation	1.142	<0.001	1.060–1.230
Fifth lactation or higher	0.991	0.818	0.914–1.074
Calving season (relative to winter)*			
Spring (March 21–June 20)	0.844	<0.001	0.796–0.896
Summer (June 21–September 20)	0.891	<0.001	0.844–0.941
Autumn (September 21–December 20)	1.002	0.944	0.952–1.055
Maximum milk, per 10 kg	0.830	<0.001	0.810–0.851

* *P*-value <0.001 by likelihood ratio test.

examined—interactions were not considered. While controlling for other covariates, an increased hazard of pregnancy was noted for cows managed in FSTP herds compared to non-FSTP herds (HR = 1.315; 95% CI 1.261–1.371).

Visual inspection of natural logarithm of cumulative hazard versus time for categorical covariates suggested that proportional hazards assumptions were satisfied. For maximum milk yield, a plot of scaled Schoenfeld residuals against natural logarithm of time indicated that proportional hazards assumption was satisfied. Positive and negative correlation models differed from the final model, as expected, but indicated that the censoring was indeed non-informative. Use of Cox–Snell residuals from the final model suggested that model fit was good.

3.4. Results of analysis using time-varying covariates

Except for test-day milk yield (a TVC), all covariates tested in the univariable regressions were significant and entered into the initial multivariable model. All covariates tested in the initial multivariable model were significant. Table 3 shows the results for the final multivariable model. While controlling for other covariates, an increased hazard of pregnancy was noted for cows managed in FSTP herds compared to non-FSTP herds (HR = 1.387; 95% CI = 1.327–1.451).

Visual inspection of natural logarithm of cumulative hazard versus time for categorical covariates suggested that assumptions about proportional hazards were satisfied.

Table 3
Final multivariable Cox proportional hazards regression model for pregnancy using time-varying covariates

Predictor	Hazard ratio	*P*-value	95% CI
Full service technician program	1.387	<0.001	1.327–1.451
Breed (Jersey relative to Holstein)	1.495	<0.001	1.407–1.589
Herd size (relative to small herds)*			
Medium (150–249 lactating cows)	1.153	<0.001	1.076–1.235
Large (250 or more lactating cows)	1.121	<0.001	1.052–1.196
Use of OvSynch in the herd	1.228	<0.001	1.174–1.285
Somatic cell score above 4.5	0.896	<0.001	0.849–0.946
Parity (relative to first lactation)*			
Second lactation	0.950	0.051	0.902–1.000
Third lactation	0.943	0.056	0.888–1.002
Fourth lactation	0.899	0.006	0.833–0.970
Fifth lactation or higher	0.819	<0.001	0.754–0.891
Calving season (relative to winter)*			
Spring (March 21–June 20)	0.811	<0.001	0.759–0.867
Summer (June 21–September 20)	0.887	<0.001	0.834–0.943
Autumn (September 21–December 20)	1.047	0.120	0.988–1.109
Testing season (relative to winter)*			
Spring (March 21–June 20)	0.936	0.022	0.884–0.990
Summer (June 21–September 20)	1.056	0.105	0.989–1.127
Autumn (September 21–December 20)	1.244	<0.001	1.174–1.318

* *P*-value <0.001 by likelihood ratio test.

Positive and negative correlation models differed from the final model, as expected, but indicated that non-informative censoring was satisfied. Use of Cox–Snell residuals from the final model again suggested that model fit was good.

4. Discussion

This was an observational study, and the 31 herds studied here were not randomized to FSTP enrollment. As a result, the population studied here is unique, a purposefully selected subset of client herds of a single breeding co-operative. The purposeful selection of these herds and the possibility that that FSTP herds differ from non-FSTP herds, and that breeding co-operative clients differ from other Ohio herds, may introduce bias. However, it was expected that the selection biases would favor inclusion of ‘‘well-managed’’ (albeit a somewhat subjective term) herds with reasonable baseline reproductive performance. Use of herds with better baseline performance would make it more challenging to improve reproductive performance with FSTP, because marginal improvements in reproductive performance are more difficult to achieve and identify in herds with better baseline performance (de Vries and Conlin, 2003; Pecsok et al., 1994; Plaizier et al., 1997).

Additionally, attempts were made to control for potential systematic differences of herds in this study by including herd characteristics such as use of OvSynch protocols and herd size indicator variables in the models. Also, cow-level covariates such as breed, parity, calving season, testing season, milk yield, and somatic cell score were adjusted for in the Cox proportional hazards models when indicated.

The primary objective of this study was to evaluate the association between the FSTP and the hazard of pregnancy, while identifying and controlling for potential confounders and other important predictors. Only main effects were considered in this model, a decision based on limiting the complexity and facilitating the interpretation of the model. While additional predictors identified in the final models were statistically significant, inferences about these additional covariates should be considered with respect to how they were measured and coded in this study.

Another important consideration when making inferences is the outcome (pregnancy) itself. Pregnancy diagnosis was based on either a cow recalving or on a veterinary diagnosis recorded in the records. In order to be considered pregnant in this study, a cow had to have been inseminated, successful fertilization was necessary, and pregnancy had to be maintained at least to diagnosis and in some cases to calving. Thus, any inferences need to consider the effect of a covariate on management decisions whether to voluntarily delay insemination, as well as the effects on estrus expression, successful fertilization, and pregnancy maintenance to diagnosis.

In both the FC and TVC final models, breed was found to be significantly associated with hazard of pregnancy—Jerseys were found to have an elevated hazard of pregnancy relative to Holsteins. These findings are consistent with a recent examination of southeastern US dairy herds, which reported that Jerseys had significantly shorter calving-to-conception intervals than Holsteins (Washburn et al., 2002). It is possible that the Jersey cows in this study population were more fertile than Holsteins.

Alternatively, the finding of higher fertility may in Jerseys may be associated with the generally lower milk production found in Jerseys—some studies have identified associations between increased milk yield and decreased fertility. However, studies of associations between milk yield and fertility have yielded variable results. Increased milk yield has been associated with reduced hazard of pregnancy in at least one survival analysis study (Eicker et al., 1996), and other studies have found reduced odds of successful first AI service in cows with higher milk yields (Loeffler et al., 1999a,b). Another event-time analysis study found that high milk yield was associated with delayed time to pregnancy but only in cows that produced high-fat milk (Harman et al., 1996b). Furthermore, a simulation study has suggested that a bias introduced by retention of high producing low fertility cows could make milk yield appear to have a negative association with time to conception (Allore et al., 2001). Finally, some recent field studies have identified herd-level associations between milk yield and fertility, which may imply better overall management, and those results suggest that herds can have both good reproduction and good milk production (Kinsel and Etherington, 1998; Rajala-Schultz and Frazer, 2003). In the study reported here, the FC model did find a significant reduction in hazard of pregnancy as peak milk yield prior to pregnancy or censoring increased. However, there was no association between milk yield and hazard of pregnancy when milk yield was considered as a TVC. The finding of the association between increased peak milk and reduced hazard of pregnancy from the FC model may be a result of a management decision to delay breeding of high-yielding cows. The lack of significance in the TVC model may have arisen because there was little actual association between milk yield and fertility.

In both the FC and TVC models, cows in medium and larger sized herds were at increased hazard of pregnancy. This differs somewhat from another study that observed no significant differences in days open between large and small herds nationally (Oleggini et al., 2001). It was only in the southern US in which the largest herds (more than 450 cows) had fewer days open than smaller herds (100–149 cows) (Oleggini et al., 2001). A possible explanation for the findings in this study sample is that larger herds differed with respect to unmeasured parameters such as nutrition and overall cow health and comfort. However, herd visits indicated that herds were managed by similarly competent people. The finding of significance due to herd size indicated the need to control for it in the multivariable models.

In both models, cows in herds that used OvSynch protocols were at increased hazard of pregnancy. This is an expected finding, as OvSynch protocols have been developed to improve the reproductive efficiency of dairy herds. However inferences and effect estimates from this study are discouraged. The use of OvSynch protocols was coded at the herd level as either used or not used, and in this coding scheme, it was a significant predictor. However, there was no additional information available concerning specifically which cows were subjected to OvSynch protocols or even the intensity of use in the herd. Although application of synchronization protocols was not known at the cow level, it was important to have controlled for herd-level use in the final models. Other studies have found that OvSynch significantly reduces days to first service and days open (Pursley et al., 1997), as well as increases the proportion of eligible cows submitted for insemination and pregnancy rate (Britt and Gaska, 1998).

The FC model found a very strong association between udder health and hazard of pregnancy. Cows that had at least 1 test day with SCS greater than 4.5 had a 33% reduced hazard of pregnancy. This strong association may exist because herd managers and FSTP technicians in this study delayed insemination of cows with elevated SCS. In a study of Jersey cows, it was found that subclinical and clinical mastitis impaired reproductive performance compared to control cows (Schrick et al., 2001). In a survival analysis of Holstein cows, a 12% reduced hazard of pregnancy was identified in cows that experienced acute mastitis (Harman et al., 1996c). This estimate is consistent with the results of the TVC model, which identified a 10.4% reduced hazard of pregnancy when SCS exceeded 4.5 on test days over time.

In both models, parity was significantly associated with hazard of pregnancy. However, actual findings were not consistent between models. Other studies have found that cows of higher parity have reduced hazards of conception compared to lower parity (Eicker et al., 1996; Harman et al., 1996c), which is consistent with the findings of the TVC model. The FC model, however, indicated that higher parity was associated with greater hazard of pregnancy. The FC model included peak milk yield, which is associated with parity. It is possible that as cows aged in the herds in the current study, selection criteria included production and some fertility measures. If milk production was statistically controlled for, as in the FC model, then parity could appear to be associated with higher fertility cows. In the TVC model, milk yield did not enter the final model, and perhaps any negative associations between milk yield and reproductive efficiency were expressed entirely in the parity covariate. Although results were not shown, removing milk yield from the FC model showed that parity alone was associated with decreased fertility (HR < 1 for all parities relative to first parity). Thus, there was evidence that parity effects were confounded by peak milk yield in the FC model.

Season or climate has been shown to be associated with fertility in other studies of reproductive performance (Eicker et al., 1996; Harman et al., 1996a,c). In the FC and TVC models here, both spring and summer calvers had reduced fertility compared to winter calvers, perhaps because their breeding seasons commenced in warmer months with waning daylight. Shorter photoperiods have been suggested as a reason for reduced fertility in cows that calve in winter in northern latitudes (Harman et al., 1996c). However, photoperiod reduction during Ohio winters is not as drastic as in more northern regions.

It was anticipated that inclusion of testing season in the TVC model would reduce the importance of calving season in the final TVC model, or that the two would confound each other. However, there was little evidence of confounding, because HR point estimates for calving season changed little when testing season was added to the model. There was no significant difference between hazard of pregnancy for winter or summer test days. However, spring and autumn test days were associated with significantly higher hazards of conception. This could be related to more favorable ambient temperatures for breeding in the fall and spring, compared to temperature extremes (environmental stresses) that may occur in the summer and winter.

The final FC and TVC models were very similar in terms of identifying factors associated with hazard of pregnancy and both models arrived at similar conclusions with respect to the FSTP program. According to the FC model, cows managed under FSTP had a

31% increased hazard of pregnancy compared to non-FSTP cows. Likewise, the TVC model concluded that FSTP cows had a 39% increased hazard of pregnancy. This implies that the FSTP program, which tends to increase the proportion of cows submitted for insemination is associated with significantly higher pregnancy rates and shorter calving intervals. This is consistent with other findings in terms of the effect of increased insemination rates (de Vries and Conlin, 2003; Stevenson et al., 1983).

While this study made every effort to control for potential herd level influences, there were limitations in that the study data did not collect health event information. Health events, such as dystocia, milk fever, metritis, ketosis, displaced abomasum, and lameness have been found to be associated with reproductive performance in numerous studies (Eicker et al., 1996; Harman et al., 1996c; Lee et al., 1989; Maizon et al., 2004; Suriyasathaporn et al., 1998). The identification of well-managed herds was intended to help control for incidence of these events, at least at the herd level. However, the fact remains that these factors must be minimized in order to optimize dairy herd fertility.

Another factor that was not explored in the analyses described here was the non-independent nature of the observations—lactations are clustered within cow, which are in turn clustered within herds. Prior analysis of bovine reproductive performance have indicated that the majority of variation exists at the lactation level (Dohoo et al., 2001). This suggests that the inherent assumption of independence of lactations is acceptable. There are emerging techniques in event-time analysis, such as models with random frailty effects (Gutierrez, 2002) that may be able to account for the clustered nature of the data, however these were not explored in this study.

5. Conclusions

Most modern dairy herds are challenged with reproductive inefficiency, much of which is attributable to suboptimal detection of estrus. The study described here evaluated the effects of a breeding program in which reproductive management was contracted out to breeding co-operative technicians. Two separate event-time analyses, one using fixed covariates only and another that allowed for time-varying covariates, found similar sets of factors associated with reproductive efficiency, such as breed, size of herd, OvSynch usage, milk yield, udder health, calving season, and parity. While controlling for similar sets of predictors both models identified that the contract breeding program was associated with an increased hazard of pregnancy in the dairy cows studied here.

Notable differences between the two modeling approaches were that the association between udder health and hazard of pregnancy was greater in the fixed covariates model than in the time-varying covariates model and that there was no association noted between milk yield and reproductive efficiency in the time-varying covariates model. These differences may imply that associations between milk yield and udder health are driven as much by management perceptions as by actual biologic effects.

Still, in both modeling approaches, the full service technician program was found to increase the hazard of pregnancy by at least 30%, and the conclusion of this study is that increasing estrus detection is a suitable approach to improve pregnancy rates and shorten the time from calving to conception.

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