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**Epidemiological and economic study of repeat breeder cow
syndrome in Michigan dairy cattle**

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Michigan State University, 1989

**EPIDEMIOLOGICAL AND
ECONOMIC STUDY OF REPEAT BREEDER
COW SYNDROME IN MICHIGAN DAIRY CATTLE**

BY

Shawkat Qasim Lafi

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ABSTRACT

EPIDEMIOLOGICAL AND ECONOMIC STUDY OF REPEAT BREEDER COW SYNDROME IN MICHIGAN DAIRY CATTLE

BY

Shawkat Qasim Lafi

The objectives of this research study were to develop : (1) a quantitative epidemiological model that can be used for elucidating, ranking and assessing the direct and the indirect effects of hypothesized risk factors associated with the occurrence of Repeat Breeder Cow Syndrome (RBCS). (2) an economical model that can be used for evaluating the direct and indirect economic impact of related risk factors associated with RBCS. Methods and techniques used for detecting, quantifying and adjusting the regression coefficients for the effects of multicollinearity were reviewed. The ability of principal components analysis to detect and adjust the regression coefficients for its effects was evaluated using human and animal data sets. A two-year prospective study was conducted during two one-year phases to study the relationship between RBCS and managerial, environmental risk factors, nutrition during the dry period, milk production and other postpartum diseases in Michigan dairy cattle. A multistage sampling procedure was used to randomly select sixty herds in each phase. An epidemiological survey study was conducted at the beginning and at the end of each phase. Prospective data regarding management, environment, nutrition, veterinary services, diseases and milk production on each participating herd were collected on a monthly basis by veterinarians. Three epidemiological models (hierarchical regression, principal components and path model) of RBCS were developed. Herd characteristics and diseases which occurred within 72 hours of calving were significant determinants of RBCS. Milk

fever, dystocia and retained placenta occurred as a complex and contributed the most to the occurrence of RBCS. Dystocia and milk fever as individual risk factors were positively associated with RBCS. The average age of the herd was negatively associated with RBCS. The economic analyses (which utilizes the partial budgeting approach) were conducted based on a developed epidemiological model. The average cost per herd per year of milk fever, dystocia, and repeat breeder cow syndrome was \$ 226.86, \$ 494.93, and \$ 1043.74, respectively. Additionally, areas for further research were identified.

This work is wholeheartedly dedicated to my parents Qasim and Katebeh Hailat and to my brothers Bahjet, Mohamed, Moustafa, and Iman and to my sisters Ameneh, Houda, and Eman.

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CHAPTER I

INTRODUCTION

1.1 BACKGROUND

Epidemiology is a very old science, yet it was not fully utilized until the 1800s when the "germ theory" of disease causation was established. Since that time, and until the middle of the twentieth century, epidemiology has been considered as a very close ally with microbiology in the struggle against disease. After 1960, epidemiology has become a more independent discipline, because, in addition to the specific agent, many factors are evaluated to determine their role and contribution to the potential causes of disease (Schwabe, 1982).

Kaneene (1986) defined epidemiology as "the science of studying patterns of diseases in populations and the factors that determine such patterns and the utilization of such knowledge for diagnosis, prevention and control." A better and a more comprehensive understanding of epidemiology is achieved by elaborating this definition. First, it is noted that epidemiology is concerned about the patterns of diseases in terms of frequency and distribution and the determinant factors that contribute to the occurrence of disease in populations. In many instances, this information is the initial clue leading to the specific etiology of disease. Second, epidemiology is concerned about the implementation of programs for prevention and control of disease in populations. Such programs are not always economically beneficial in

veterinary medicine. Therefore, the recent concern for economic survival has led many farmers to change their objectives from obtaining maximum yields to achieving maximum efficiency in production. Indeed, veterinary epidemiology adapted this concept to be one of its ultimate goals regarding domestic animals.

As a response to the above concept, a herd health approach which was started around 1960, has been proposed and applied to the livestock farms. This approach applied the principles of epidemiology by placing emphasis on the herd as a whole, instead of individual animals. The primary goal of herd health programs is to improve the performance in livestock farms by providing farmers with a means to achieve better control and planning of animal health events (Blood et al., 1978). The rationale for this goal was that health problems affect profitability of the livestock industry through impairment of production efficiency. In fact, significant financial benefits have been reported for participants in herd health programs (Williamson, 1980; Dijkhuizen et al., 1984).

More recently, the animal diseases as well as their economic implications have been of great concern in different regions of the United States as they have been in other parts of the world. A cooperative states-federal-industry program known as the National Animal Health Monitoring System (NAHMS) was developed in 1981. The state of Michigan joined this program in the fall of 1986 and included only the dairy industry. The NAHMS program was facilitated, managed and coordinated by the Division of Epidemiology in the Department of Large Animal Clinical Sciences at Michigan State University.

The NAHMS program is a monitoring system, whose mission is to define the incidence, prevalence and the cost of the livestock and

poultry diseases on a state, regional and ultimately, on a national basis. This program became fully active in September of 1983, spearheaded by the Animal Plant Health Inspection Service (APHIS) in cooperation with other United State Department of Agriculture (USDA) agencies. It is supported by state departments of agriculture, diagnostic laboratories, practicing veterinarians, colleges of veterinary medicine and livestock owners and their associations.

The NAHMS objectives for the state of Michigan were to: 1) collect statistically valid data about animal health and production events in dairy cattle; and 2) produce statistically valid estimates of the incidence, prevalence, and cost of dairy cattle health and production-related events. Detailed information of the program implementation, design, personnel training, herd selection, and data gathering was described by Kaneene and Hurd (1989). A brief of summary information is presented in Chapter IV.

Results obtained from the initial epidemiological survey study that was conducted at the beginning of the first year, after the selected farmers agreed to participate in the NAHMS program, revealed that mastitis, metritis, and repeat breeder cow syndrome were the most frequent diseases in the state of Michigan, respectively. These foundations were validated by the results that were obtained from the prospective study at the end of the first year (Kaneene and Herd, 1989). Methods of herd selection, design, personnel training, and data gathering that were used in the first year study of the NAHMS program were also used in the second year study. The participant farms of the first year study were not included in the second year study. As it was expected, results obtained from the initial epidemiological survey and

the prospective study of the second year were also similar to the results of the first year. These results suggested further research needed to be conducted in the areas of mastitis and reproduction. In the instance of mastitis and metritis the specific agent of the disease cause could be easily determined and the mechanism of the disease is well understood. Thereafter, treatment and prevention programs can be implemented. While in the case of repeat breeder cow syndrome, no specific cause has been identified and the etiology is more complex.

Repeat Breeder Cow Syndrome (RBCS)

Repeat-breeding (conception failure) is one of the major forms of infertility of cattle. Its complex nature and the poor understanding of its etiology is responsible for the lack of rational therapy applicable to all cases of repeat-breeder cows. Repeat-breeding has been defined as failure to conceive from three or more regularly spaced services in the absence of detectable abnormalities (Zemjanis, 1980). This syndrome has long been a big problem for farmers and veterinarians all over the world. Previous studies attempted to evaluate the cause of this syndrome included different risk factors hypothesized to be associated with the occurrence of RBCS. In many instances these risk factors were studied and reported separately. The incidence rate of RBCS varies between herds and within herds from year to year. Hewett (1968) and Zemjanis (1963) reported that an increasing of the incidence rate of RBCS with increasing age, size of the herd and milk production. In general, etiologically, the cause of the RBCS is complex, although it is the cow that fails to conceive, in many instances the causative factors

of the conception failure may be found in the male or due to inadequate management.

Economically, RBCS is one of the most important reproductive problems. Every case is associated with an increase of the calving interval by three or more estrous cycles. The loss of reproductivity associated with RBCS leads to loss of production potential in terms of milk, calves and maintaining costs. Economic losses on U.S. farms due to this syndrome are estimated in millions of dollars, but there are no generally accepted methods of estimating these costs.

1.2 PROBLEM STATEMENT

Previous studies attempted to evaluate the association between different risk factors hypothesized to cause the occurrence of RBCS were not fully successful because these studies did not evaluate this syndrome as cow/bull/ environment/ management complex; and in most instances, a single risk factor was evaluated at a time. Furthermore, when several risk factors were included in the model the interrelation among the predictor risk factors (multicollinearity) was not evaluated.

Work related to the contribution of risk factors associated with RBCS used the individual cow as a unit of comparison and did not examine the direct and indirect effects of the risk factors contribution. Partial budgeting was used by Bartlett et al (1986a) to evaluate the economic impact of RBCS, while Dijkhuizen et al. (1985) and Jansen et al. (1987) used the same approach to address reproductive failure. These reports took a very good initiative to introduce economic concepts to animal health management. However, their approach did not include the epidemiological consideration of the direct and indirect individual

risk factors associated with the occurrence of RBCS. Therefore, the different approaches that evaluate the direct and indirect contribution of various risk factors and resulting economic consequences are needed.

1.3 OBJECTIVES OF THE STUDY:

Using the herd as a unit of comparison, the two primary objectives of the study were:

- A. To develop a quantitative model that utilizes multivariate analysis methods as an epidemiological tool for:
 - 1) Elucidating and ranking risk factors hypothesized to be associated with RBCS according to their relative contribution to the occurrence of RBCS in dairy herds.
 - 2) Assessing the direct and the indirect effects of various risk factors involved in the occurrence of RBCS.
- B. To develop an analytical model that can be used for :
 - 1) Evaluating the direct and indirect economic impact of RBCS and other related risk factors leading to the occurrence of RBCS.
 - 2) Estimating the cost effectiveness of changing selected risk factors associated with the occurrence of RBCS in dynamic populations.

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CHAPTER II

RISK FACTORS AND ASSOCIATED ECONOMIC EFFECTS OF REPEAT BREEDER COW SYNDROME IN DAIRY CATTLE

2.1 INTRODUCTION

A repeat breeder is defined as a condition in which cows or heifers which have regular estrous cycles and appear normal on superficial clinical examination have failed to become pregnant following three or more breedings (Francos, 1979; Zemjanis, 1980; Bartlett et al., 1986a).

The repeat breeder has long been a problem world wide to dairymen. With an overall incidence rate of 10 to 25 % (Hewett, 1968; Roussel et al., 1965; Bartlett et al., 1986a). Although the repeat breeding problem is usually a temporary one and most of the affected cows (60 percent) conceive normally by the fourth insemination (DeKruif, 1976; Bulman and Lamming, 1978), the principal losses are economic. Mackay (1981) estimated an \$800 million loss to the United States cattle industry due to reduced breeding efficiency. Of this amount 10% to 15% is due to repeat breeders.

Many risk factors have been reported as being associated with the occurrence of repeat breeder syndrome in dairy cattle. These factors, however, have been researched and reported separately. It is very difficult to assess their relative contribution to this problem. Furthermore, it is not possible to assess the economic importance of repeat breeder syndrome particularly in relation to alternative strategies for prevention and treatment.

The literature that specifically addresses the repeat breeder syndrome is limited; however, many investigators have done work in the area of reproduction using different terms, e.g. infertility, reproductive failure, conception rates, reproductive performance, and it is very difficult to assess the proportion of this work in regard to repeat breeder syndrome.

The objectives of this review, therefore, are to 1) assemble information regarding the various risk factors associated with the occurrence of repeat breeder syndrome, 2) review work related to the economic effects of the syndrome, 3) identify areas of further research in this complex syndrome. Nutrition, metabolic disease, hormonal disorder, infectious agents, abortion, early embryonic death, housing, heat detection efficiency, insemination procedure, and environmental risk factors are among the many factors that have been reported to be associated with repeat breeder syndrome.

In this review the repeat breeder cow syndrome is considered as a cow-bull-environment/management complex, and the economic effects of this syndrome will be presented. Also, areas of further research will be identified.

2.2 COW

There are many factors involving the cow which are associated with the repeat breeder syndrome in dairy cattle. Age, genetic anomalies of the reproductive tract, nutritional imbalances, abortions, infectious diseases, periparturient diseases, abnormal endocrine activities, abnormal embryonic development, and environmental factors are among the many factors that may be involved.

Age of the Cow

The age of the cow has a marked effect on the pregnancy rate and on reproduction in dairy cows. Hewett (1968) showed that the incidence rate of repeat breeders is associated with age. The incidence rate was lower in the younger age group when compared with the older age group. DeKruif (1978) observed a difference of 5% in the pregnancy rate between primiparous and secondiparous cows. In animals over 7 years of age, the pregnancy rate was also lower than it was in younger cows.

Erb et al. (1985) studied the direct and the indirect effects of age on postpartum disease and production performance. They reported that increasing age was associated directly with an increased risk of milk fever, and milk fever was associated with an increased risk of veterinary-assisted dystocia, retained placenta and metritis. Also, age was associated directly with an increased risk of total services per cow. More recently, Bartlett et al. (1986a) reported that cows older than 7 years of age had a higher incidence rate of repeat breeders (28.3%) compared with cows younger than 3 years of age (21.9%). It is concluded by nearly all investigators that primiparous cows were less likely to suffer diseases or breeding problems than multiparous cows. Most investigators attribute the reduction of fertility and the occurrence of repeat breeder syndrome among multiparous cows not to age per se but because of problems arising at the time parturition and during the puerperium.

This was verified by Morrison and Erb (1957) who reported that cows with normal parturitions required 2.0 services per conception and those with abnormal parturitions 2.8 services per conception. Also, Morrow (1971) reported that periparturient diseases increased the calving

interval by 17 days and the services per conception by 0.2.

DeKruif (1975) also compared primiparous cows that calved normally with a similar group of secondiparous, triparous and quadriparous cows and found no differences in regard to the total services received per cow. In another study, Bulman and Lamming (1978) reported that age distribution of the repeat-breeder cows was not significantly different from that of the population as a whole.

Genetic Factors

Genetic factors must be considered. The use of a bull that produces large calves increases the probability of causing dystocia and postpartum metritis which may cause the repeat breeder syndrome and infertility.

Linares (1981) compared the development of embryos from repeat breeder heifers with that of embryos from virgin heifers at seven days after standing heat. Two of the repeat breeder heifers were heterozygous for the 1/29 chromosome translocation, and one was an x-trisomy. In these heifers there was a tendency to a higher incidence of fertilization failure and morphologically deviating embryos than in normal heifers. Similar results were found by King and Linares (1983). It was suggested that the fertilization failure rather than embryonic death was an important factor of repeat breeders.

Anomalies of the Reproductive Tract

Woelffer (1969) stated that less than 10% of the cows which return to oestrus at regular intervals may be expected to have abnormalities of the reproductive tract. Roberts (1971) classified these anomalies into

two categories: 1) congenital anatomical defects, and 2) acquired anatomical defects. If oviduct obstruction is unilateral, a cow may conceive, especially if the semen is placed in the contralateral horn, but if both oviducts are completely obstructed to egg passage, the cow is classified as infertile (Woelffer 1969). In cases of abnormal endometrium, fertilized ova do not survive and form attachments, resulting in embryonic death. These defects are often difficult to diagnose clinically.

DeKruif (1976) surveyed cows up to the fourth insemination and 19% of 400 cows were classified as having anatomical defects. Of the 14 repeat-breeder cows, 10 were found, at slaughter, to have unilateral or bilateral defects of the oviducts.

Nutrition

The interrelationship between nutrition and reproduction in dairy cows is a topic of increasing importance and concern among veterinarians as well as among dairymen. Many veterinarians and nutritionists are directing their attention toward feeding programs as being a cause of some breeding problems (Gerloff and Morrow 1986).

Several authors have cited many studies showing a direct relationship between nutrients and the number of inseminations per conception (McDonald et al., 1961; Morrow, 1969). Curtis et al. (1985) have also shown direct, indirect, or a combination of direct and indirect evidence of nutrient involvement with postpartum diseases.

Carbohydrates

For maximum milk production, good health and efficient reproduction performance, cows must be neither fat nor thin at calving time. Adequate body reserves must be available for mobilization to sustain a high level of milk production especially during the early lactation period of negative energy balance when nutrient consumption cannot meet the demands of milk production (Thatcher, 1986). Fat cows have more calving difficulties and metabolic disorders, especially milk fever, ketosis, retained placenta and metritis, that secondarily increase the number of inseminations per conception (Morrow, 1975; Gerloff and Morrow, 1986; Thatcher, 1986).

Markusfeld (1985) studied the relationship between overfeeding before calving and metritis and ketosis in seven dairy herds in Israel. The overall rate of ketonuria in 695 adult cows tested routinely between 7 and 14 days postpartum was 18% but in those with post-parturient uterine diseases the rate was 56.5%. Eight percent of all cows with ketonuria concurrently suffered from post-parturient diseases.

Protein

Sonderegger and Schurch (1977), in an epidemiological field study, found that cows receiving excess protein required more services per conception and had a lengthened interval between parturition and first service. Jordan and Swanson (1979) reported that high-producing dairy cows fed a ration of 19.3% crude protein starting at 4 days postpartum and continuing for 91 days were observed in heat sooner but required more services per conception and had longer intervals to conception when compared with high-producing cows fed rations of 12.7% and 16.3% crude

protein, respectively. Davison et al. (1964) in their experiment showed that heifers fed daily 660 mg nitrate per kg of body weight beginning three oestrus cycles before breeding, required 2.6 services per conception versus 1.3 services per conception for the control group.

More recently, Maree (1986) reported that dairy cows fed high levels of concentrates had a higher incidence rate of dystocia and a longer duration of parturition than the control groups.

Phosphorus and Calcium

The effect of dietary phosphorus on conception has been of concern to many nutritionists, as well as to physiologists. Morrow (1969) reported a case study in which heifers fed a phosphorus deficient (0.12% phosphorus in dry matter) required 3.7 services per conception, compared to 1.3 services for heifers fed adequate phosphorus.

Carson et al. (1978) reported that dairy cattle with serum calcium and phosphorus levels of 8.98 mg % and 8.25 mg %, respectively, for a ration of 1.1:1 [normal serum calcium is 6 to 12 mg % and normal serum phosphorus is 3 to 6 mg % (Carnahan 1974)], had a higher incidence of dystocia, retained placenta, and postpartum metritis. Supplementing cows with steamed bone meal for three months increased the mean serum calcium to 10.26 mg % and reduced the mean serum phosphorus to 6.72 mg % (ration 1.51:1). As a result of this supplementation, dystocia was reduced from 75% to 10%, retained placenta from 35% to 8%, and postpartum metritis from 70% to 10%. According to Carnahan (1974) if normal reproductive efficiency is to be maintained, the ration of calcium to phosphorus should be between 1.5:1 to 2.5:1. Also, Kumar et al. (1986) reported that

serum concentrations of phosphorus and calcium were lower in repeat breeder cows than in normal cows.

Selenium

Selenium deficiency has been reported to increase the incidence of retained placenta in dairy cattle (Julien et al., 1976). Eger et al. (1985) showed that selenium alone was as effective as a combination of selenium and vitamin E in reducing the incidence of retained placenta. Hidiroglou et al. (1987) conducted an experimental trial to examine the effects of prepartum supplementation (21-10 days before parturition) of selenium and vitamin E on retained placenta in dairy cattle. From this study, it was concluded that retained placenta is not a selenium-responsive disorder in dairy cows.

Iodine

McDonald et al. (1961) reported that the rate of conception of repeat breeder cows was improved by administering in the feed 20 to 40 grains of ethylenediamine dihydriodide (organic iodine) for 8 to 12 days before the onset of oestrus. It was reported that the improved conception rate in these repeat breeder cows is due to increased uterine secretions and stimulation of gonadotrophic activity of the anterior pituitary through the thyroid gland.

Copper, Cobalt, Zinc, Manganese, and Magnesium

It has been reported that copper, cobalt and zinc are very important minerals for achieving a good pregnancy rate in dairy cattle (Alderman, 1963; Wilson, 1966; Hidiroglou, 1979; Annenokov, 1982;

Ingraham et al., 1987). Krupnik (1985) reported that using a magnesium supplement in the feed and using a fertilizer containing MgO and CaO on the grassland, reduced the frequency of retained placenta as well as puerperal endometritis. In the literature the direct association between these minerals and repeat breeder syndrome has not been reported.

Vitamin A and Beta Carotene

Vitamin A deficiency leads to infertility in female cattle. Depending on the degree of the deficiency and the time at which it occurs, the signs associated with the reproductive mechanisms included anestrus, repeat breeding, abortion, retained placenta, and metritis (King, 1971; Morrow, 1980; Gerloff and Morrow, 1986).

Lotthammer (1979) and Stolla et al. (1987) have reported that dairy cows and heifers consuming diets low in beta carotene had external symptoms of estrus which were less pronounced in comparison with the control group. In addition, the mean number of inseminations per pregnancy was lower in the treated group than in the control group.

A recent study by Wang et al. (1988) reported that reproductive performance in lactating Holstein cows was not improved by feeding supplemental beta carotene. A direct association between beta carotene and repeat breeder syndrome has not been reported.

Milk Fever

The occurrence of milk fever in cows is known to be associated with profound changes in mineral composition in their blood plasma. The most important change, which gives the clinical signs of the disease, is a rapid and large decrease in calcium concentration and concomitant

decrease in phosphorus. Curtis et al. (1983) reported that hypocalcemia is associated with dystocia, retained placenta, ketosis and mastitis. Erb et al. (1985) showed that cows with milk fever had 2 to 6 times more dystocia, retained placenta, and metritis than cows without milk fever. These results have led to an indirect association of milk fever with reduced breeding performance (more inseminations per cow) and an increased risk of being culled.

Dystocia

Thompson et al. (1983) reported that dystocia resulted in impaired reproductive performance, more days open, more services, more days to first breeding, and decreased 30-day milk production. In Sweden Bendixen et al. (1986) reported that a previous history of dystocia increased the risk of recurrence of dystocia in subsequent calvings and also increased the risk of being removed (culled) during the lactation. Erb et al. (1985) reported that cows with dystocia had 3.5 to 3.7 times more risk of metritis and culling than did cows without dystocia.

Retained Placenta

Retention of the fetal membranes is one of the major reproductive disorders that can occur in many of the domestic species. It is a serious problem causing great economic losses in dairy cattle (Muller and Owens, 1974; Carson et al., 1978; Shukla et al., 1983). Erb et al. (1981) reported that retained placenta caused an increase in the calving interval of 2.5 weeks. Martin et al. (1986) reported that retained placenta resulted in an increase of 4 days to first service, 19 days open, and 0.2 services per conception.

More recently, Erb et al. (1985) reported an indirect association between retained placenta and the total number of services per cow in first-calving heifers as well as in multiparous cows.

Metritis

Metritis is a common disease which has an adverse influence on the reproductive performance of dairy cattle (Sandals et al., 1979; Miller et al., 1980; Erb et al., 1981; Markusfeld 1982, 1984a, 1984b, 1987). Although a large amount of information related to retained placenta can be found in the literature, only a few articles deal with post-parturient metritis as a separate entity and both diseases are dealt with as a complex (Sandals et al., 1979; Erb et al., 1981, 1985).

Sandals et al. (1979) analyzed records of 293 dairy cows and 650 calvings to study the effect of retained placenta and metritis complex on reproductive performance. This study revealed that metritis complex, in the presence or absence of retained placenta, caused a significant increase in days open, services per conception, calving to first heat intervals and days from calving to first service.

Erb et al. (1985) found that cows with metritis had 4.35 days more to first service and about half as many conceptions at first service as cows without metritis. Additionally, metritis directly affected the total services per cow.

In contrast, Francos (1979) studied the relationship between the incidence of endometritis and repeat breeders in dairy herds. He reported 3.5% to 5.7% of the cows that suffered from metritis became repeat breeders. It was concluded that there is a trend toward an

inverse relationship between the incidence of endometritis and repeat breeders. Similar results were reported by Roini and Saloniemi (1971).

Ketosis

A common metabolic disorder in high producing dairy cows during early lactation is ketosis, which can occur in subclinical form as well as in clinical form. Dohoo and Martin (1984a) investigated the subclinical form of ketosis in 32 Holstein dairy cow herds in southern Ontario. The prevalence of ketosis was 12.1% in the first 65 days of lactation. In reviewing the literature, no significant correlation between milk acetone and repeat breeder syndrome was found on an individual basis.

Mastitis

Although numerous investigations have been conducted to assess the magnitude of mastitis (clinical and subclinical forms) problems, its effect on milk production and its economic cost (Meek et al., 1978; Salsberg et al., 1984; Fetrow and Anderson, 1987) only a limited number of studies have been done with the objective of determining the direct or indirect relationship between mastitis and other postpartum diseases.

Thompson (1984) studied the genetic interrelationship of parturition problems and production. He reported no association between mastitis and milk fever, nor between mastitis and dystocia, but a weak association with retained placenta was noticed. A recent work by Erb et al. (1985) reported that clinical mastitis was not associated with any other disorders or with repeat inseminations.

Kirk and Bartlett (1988) conducted an epidemiological study to

assess the economic impact of mastitis and its relationship to postpartum reproductivity. No significant difference was found between cows with clinical or nonclinical mastitis in respect to the numbers of services or inseminations received.

Cystic Follicles

Cows with cysts had 10 extra days to first service and one-third more total services than cows without cysts (Erb et al., 1985). This decrease of fertility in cystic cows was also found in several studies (Shanks et al., 1979; Erb et al., 1981; Markusfeld, 1984a).

Abortion

Although abortion can lead to retained placenta or metritis, neither the direct association between abortion and repeat breeder syndrome nor the indirect association through retained placenta, metritis or any other postpartum diseases has been reported in the literature.

Lameness

Although lameness in dairy cattle is a major problem, a review of the literature reveals that no work has been done to measure the direct or indirect association between repeat breeder syndrome and lameness. However, McDaniel et al. (1984) showed that cows with long hooves and shallow angles of the hooves had more days open. Obviously, this relationship is probably greater if cows are housed on concrete floors. Cows with sore feet that live in wet, slippery, concrete-floored stalls are more difficult to detect as being in heat.

Lucey et al. (1986) analyzed records of 1491 lactations in 770

Friesian Holstein and Ayrshire cross-bred cows to study the relationship between lameness and fertility. Lameness increased the interval between calving and first service by 17 days, the interval between calving and conception by 30 days, and increased the number of inseminations per lactation. Dohoo and Martin (1984b) reported a direct association between lameness or foot problems and abortion in dairy cattle.

Hormonal Factors

The hormonal state of the cow should be taken into consideration in regard to the repeat breeder. The possibility that progesterone therapy might improve fertility in cows which had not been settled after repeat breedings was explored by Herrick (1953), Dawson (1954) and Casida (1961). In the literature many investigators have noted that a progesterone administered 3 to 5 days after service and continued for a period of 2 to 3 weeks or longer improves the conception rate in repeat breeder cows over that for the controls (Herrick, 1953; Dawson, 1954; Remsen et al., 1982).

Hansel et al. (1960) conducted an experimental study of 114 repeat-breeder cows to investigate the effects of hormonal therapy, using progesterone or chorionic gonadotrophin, on the conception rate of repeat-breeder cows. It was noticed that the conception rate was the same in the control and progesterone-treated cows, but was lower in the chorionic gonadotrophin-treated cows.

Bulman and Lamming (1978) studied the relationship between milk progesterone levels and repeat breeder syndrome in dairy cows. Irregularity or a low progesterone profile was noted in only 23% of the repeat breeder cows. Zaayer and van der Horst (1986) administered 25 mg

of prostaglandin (PGF_{2a}) to 13 repeat breeder cows on that day of luteal phase when next to the corpus luteum no follicle was palpable. Ten of the 13 repeat breeder cows became pregnant.

More recently, research was conducted by Kimura et al. (1987) to clarify the incidence of luteal deficiency, in 21 repeat-breeder cows, as defined by milk progesterone profile. It was concluded that delayed formation of the corpus luteum, either combined or not combined with lowered secretion of progesterone during luteal phase, is one of the causes of repeat breeding in dairy cattle. Moreover, it was suggested that supplementation with progesterone, if indicated, should be started by the fourth or fifth day after insemination. Roberts (1986) suggested that more investigation should be done in regard to the progesterone level during and a few days after oestrus as a cause of repeat breeder syndrome in dairy cows.

Oestrogen concentrations have been a major concern in the field of endocrinology in regard to repeat-breeder cows. Randel et al. (1971) noted that repeat-breeder cows had either higher or lower urinary oestrogen levels during the first 9 days postinsemination compared to normal cows. In a later work, Erb et al. (1976) found no differences in urinary oestrogen, but plasma progesterone concentrations were higher in fertile cows from 12 hours before oestrus to eight days after oestrus.

Infectious Agents

DeKruif (1976) conducted a survey study of 400 repeat breeder cows. Only 4 of 25 endometrial biopsy specimens taken from cows with abnormal vaginal discharges were positive on bacteriological examination, yielding three pure cultures of Corynebacterium Pyogenes [Actinomyces Pyogenes]

and one mixed infection of Streptococcus and Staphylococcus sp. Also, Panangala et al. (1978) compared the microflora of the cervico-vaginal mucus of repeat breeder cows with normal cows. A chi-square test did not reveal any significant difference between them.

Ayalon (1978) reported that in cattle two microorganisms are generally considered to cause embryonic mortality, Trichomonas fetus [Tritrichomonas fetus] and Vibrio fetus [Campylobacter fetus], the effect of the latter having been demonstrated experimentally by Adler (1959). More recent research by Kaneene et al. (1986) indicated that Haemophilus somnus had an effect by increasing the early embryonic death rate in cows. Also, more degenerated embryos were recovered from H. somnus-infected heifers than from control heifers. Additionally, embryos from H. somnus-infected heifers survived in culture media for a significantly shorter time than embryos from control heifers.

Embryonic Development

Early embryonic death was reported by Roberts (1971) to be a major factor of repeat-breeder syndrome in dairy cows. Several studies including normal cows as well as repeat-breeder cows have been conducted to determine the fertilization rate, the incidence rate of early embryonic death, and the time of occurrence of the embryonic death (Graden et al., 1968; O'Farrell et al., 1983; Roche et al., 1985).

In repeat breeder cows the fertilization rate and embryo survival rate may be as low as 56% (Graden et al., 1968) and 21% (Tanabe and Casida 1949). Ayalon (1978) and Sreenan and Diskin (1986) reviewed the extent and timing of embryo mortality in heifers, normal cows, and repeat

breeder cows. They found that time of occurrence of embryo mortality in repeat breeder cows is inconsistent.

2.3 BULL

Foote (1986) reported that by 1982 two-thirds of the dairy cattle in the United States were inseminated artificially and in other countries, including Denmark, Japan and Israel, almost 100% of the dairy cattle are inseminated artificially. The important factors, therefore, are the quality of the semen used and the artificial insemination procedure.

Semen

The number of sperm used, sperm survival in the female tract, time and place of deposition of semen in the female tract, as well as other environmental and managemental factors, are among the many factors that may be involved in determining the success of insemination (Shannon 1978).

Sperm Numbers

Foote and Dunn (1962) indicated that 5 million motile sperm per ml of extender and per insemination was about the minimum insemination dose. The 60- to 90-day non-return rate was 75%. In New Zealand Macmillan et al. (1978) compared the fertility rate in cattle using deep-frozen and fresh-diluted semen. Deep-frozen semen used at a dosage of 25 million spermatozoa resulted in a similar fertility rate to semen diluted in caprogen and used at a dosage of 2.5 million spermatozoa. Reduction of

the dosage of deep-frozen semen to 12.5 million spermatozoa reduced the fertility rate by 6.5%.

Disposition of the Semen

Gwazdauskas et al. (1981, 1986) found that the best conception rate was obtained by placing the semen into the uterus (52.6%). There was a 22% reduction in conception rate if the inseminator could not penetrate through the cervical os and deposited the semen outside the cervix os. Additionally, much lower rates were observed if semen was placed in the vagina. Senger (1988) reported that "if conception rate has been 50 percent, [uterine] horn breeding will consistently increase it to 60 percent" in a well-managed herd.

Recently the importance of placement of the inseminating syringe in the uterus has been evaluated by radiography (Peters et al., 1984). There were great differences among inseminators in ability to position the syringe tip into the uterine body as 82% of inseminators were unable to place semen to the uterine body more than 60% of the time. Gwazdauskas et al. (1986) reported that 94.4% of inseminations were placed in the uterus, but according to Peters et al. (1984) only about 40% of inseminators actually had placed semen into the uterine body.

2.4 ENVIRONMENTAL AND MANAGERIAL FACTORS

The environmental factors which will be discussed in detail are season, size of the herd, and housing system. Managerial factors including hygiene at the time of calving, interval between parturition and the first insemination, heat detection, and time of insemination during estrus will also be examined.

Seasons

The efficiency of reproduction is not uniform throughout the year (DeKruif, 1978; Fulkerson and Dickens, 1985; Etherington et al., 1985). Hewett (1968) conducted an epidemiological survey which included more than 16,000 cows to study the incidence of repeat breeder syndrome with reference to herd size, season, age, and milk yield. The highest incidence of repeat breeder syndrome was observed in cows calving during the autumn and winter, and autumn calving cows had longer intervals between parturition and conception. In addition, cows inseminated in autumn and winter had much lower calving rates after first insemination. Fulkerson and Dickens (1985) compared the breeding performance of 2068 cows in 27 dairy herds, of which 15 herds calved in spring and 12 in autumn. The results clearly demonstrated significant seasonal differences in heat detection and conception between spring-calving cows and autumn-calving cows. These authors concluded that the difference in breeding performance associated with season of calving was not attributable to age, calving to mating interval, or on body condition of the cows.

In another study Coleman et al. (1985) reported higher incidence of infertility, longer days open period, and greater number of services required for cows that calved in spring compared with those calving in other seasons. Also, Etherington et al. (1985) reported that the incidence rate of dystocia in cows calving in the summer months was higher in comparison to cows calving in other seasons. Bartlett et al. (1986a) reported no association between the season of calving and the incidence of repeat breeder syndrome.

Size of the Herd

Several studies have been concerned with a possible effect of the size of the herd on reproductive efficiency (Zemjanis, 1980). Hewett (1968) showed that repeat breeders are more common in large herds than in small herds. In small herds 8.5% of the animals failed to become pregnant after four or more inseminations, whereas a 13.1% was reported in the larger herds. DeKruif (1975) concluded that the interval between parturition and conception was shorter as the size of the herd increased, but that the calving rate after the first insemination decreased as the size of the herd increased.

Housing System

There are conflicting reports about the effect of the housing system on reproductive performance. Willems (1971) found that the type of housing has an effect on the pregnancy rate after the first insemination. The rate was higher for cows kept in loose housing compared with those in tie stalls. The difference between the loose housing herds and conventional housing herds disappeared during grazing season. Kiddy (1977) and DeKruif (1977) concluded that the freedom of movement in free stalls increased the intensity of the signs of oestrus and stimulated the onset of the oestrus cycle after parturition by reactivating ovarian function. More recently, Gwazdauskas et al. (1983) compared the effect of the primary housing area on oestrus behavioral activity at the first observation of heat. Cows confined to the barn showed 3 mounts per hour more than those housed in dry lots or on pasture. Reimers et al. (1985) investigated the effects of the type of housing on error of oestrus detection and on conception rates, based on

milk progesterone measurements. The error rate of oestrus detection was significantly greater in free-stall housing than in conventional housing, but conception rates did not differ between housing types. Bendixen et al. (1987) reported that loose-housed cows had a lower incidence rate of retained placenta than tied zero-grazing cows.

Hygiene at the Time of Insemination and Calving

At the time of insemination, as well as at the time of calving, there are some important managerial factors that should be considered in order to achieve optimal reproductive efficiency (Foote, 1986). A comfortable, clean place to restrain the animal for insemination, an atmosphere of calmness, and the application of proper sanitary procedures are very important to protect the semen, the cow and the inseminator. Also, it has long been known that inadequate hygiene at the time of calving may result in causing endometritis and retained placenta. Such conditions will result in 5% to 10% lower pregnancy rates after the first insemination and a longer interval between parturition and conception (Morrow, 1969; Hartigan, 1980). In loose housing, hygiene is very important because cows come in closer contact with each other, resulting in a markedly increased risk of infection (DeKruif, 1975).

Interval between Parturition and the First Insemination

Boyd and Reed (1961), as well as DeKruif (1975), studied the interval between parturition and first insemination. Both studies agreed that increasing the interval between parturition and first insemination decreased the number of inseminations per conception. The highest pregnancy rate after the first insemination was achieved if the interval

between parturition and the first insemination was approximately 100 days. If this interval was shorter than 50 days, pregnancy rates markedly lower (DeKruif, 1978; Hillers et al. 1984).

Heat Detection

A poor or inadequate heat detection program is a very important factor that may contribute in increasing the incidence rate of repeat breeder syndrome. Williamson et al. (1972) reported that if heat detection was carried out by the milkers in addition to their other chores, up to 12% of the cows presented for insemination may not be in heat. This proportion increased to 36% when heat checks were made only at the time the cows were driven to and from the milking sheds. O'Farrell (1975) reported that in more than 25% of the cows their heat time lasted less than 6 hours, and 50% (of the 25%) these occur before 10 a.m. It was recommended that heat observation 5 times a day is adequate to capture more than 80% of the heats. Also, O'Farrell (1975) cited a study which reported about 3 percent of all pregnant cows showed standing heat. More recently, Rounsaville et al. (1979) and Bailie (1982) used computerized simulation models to assess the effect of heat detection rate on herd reproductive performance. They concluded that increasing the frequency of heat detection observations decreases the number of inseminations per conception and decreases the days open in dairy cattle.

Time of Insemination

With good detection of oestrus the optimal time to inseminate, according to Foote (1979), is found by following the so-called A.M., P.M. rule. Cows first seen in oestrus in the morning were best inseminated in

the afternoon of the same day. Cows first seen in oestrus in the evening should be inseminated the next morning. The conception rate was lower in cows first seen in oestrus in the evening but not inseminated until the next afternoon. In another study, Gwazdauskas et al. (1981) reported no difference in the rates of conception between early insemination (immediately after being first observed to be in oestrus) and 12 hours after they were first observed to be in oestrus. Similar results were reported by Gwazdauskas et al. (1986) in later work.

2.5 ECONOMIC EFFECTS

In the literature there are very few articles on attempts to specifically assess the economic effects of repeat breeder syndrome in dairy cows while excluding other reproductive disorders. The cost components arising from the repeat breeder syndrome, including number of days open, extra inseminations, extra veterinary treatments, and loss due to culling, have been manipulated and assessed by several investigators. Olds et al. (1979) estimated decreases of 4.5 kg and 8.6 kg in annual milk production for first-calf heifers and for cows in later lactation, respectively, for each day open between 40 and 140 days of lactation.

Also, James and Esslemont (1979) showed a reduction in annual milk production of up to 20.02 liters as a result of increasing the calving interval from 380 days to 381 days for first-calving heifers.

Oltenacu et al. (1980) reduced the number of days open from 123 to 119 and found an increase in net return of \$39 per cow per year, using average professional artificial inseminators obtaining a 50% conception rate. Holmann et al. (1984) reported a small gain in average income over feed cost \$0.21-\$0.41 per cow per day by increasing the calving interval

from 12 months to 13 months, but a reduction in average income if the calving interval increased from 13 months to 15 months.

In another study Congleton et al. (1984) reported an increase in average income of \$29.92 per cow per year by extending the average herd life from 2.8 to 3.3 lactations. These findings support the previous work of Renkema and Stelwagen (1979), Hill (1980), and Allaire (1981).

A survey of dairy producers, conducted by Steele et al. (1981) in the northeastern United States, revealed that 2.4% of culled cows were repeat breeders, but Bartlett et al. (1986a) reported that 23.9% of culled cows were repeat breeders. More recently, Marsh et al. (1987) compared four culling decision rules for reproductive failure in dairy herds. It was concluded that it is worthwhile continuing breeding cows with good milk production until 250 days after calving.

In a study of enhanced reproduction and its economic implication, Britt (1985) suggested that the economic profits will depend upon the improvement of day-to-day management in terms of heat detection, improvement of conception rate, biotechnical procedures, better methods of disease control, and rapidly changing populations. Bartlett et al. (1986a) estimated that the cost components resulting from repeat breeding included costs of days open, extra inseminations, extra veterinary services, and loss due to culling. Each lactation with repeat breeder syndrome was associated with a loss of income of approximately \$385.

2.6 SUMMARY OF RISK FACTORS

The following risk factors have been reported to have direct effects on repeat breeder syndrome: age, size of the herd, method of heat detection, inseminator expertise, time of insemination, quantity and

quality of semen, metritis, days to first service, and hormonal disorder. Similarly, the following risk factors have indirect effects on repeat breeder syndrome: age, days to first service, body condition of the cow during parturition, nutritional status of the cow after parturition (including inappropriate feeding of carbohydrates and protein or deficiencies in phosphorus, calcium, vitamins, and minerals), dystocia, retained placenta, metritis, and housing system. Many studies have been reported that increased incidence of repeat breeder cow syndrome reduced economic profitability.

2.7 AREAS FOR FURTHER RESEARCH

1) In the field of nutrition there are a great number of studies which have been done to investigate the effects of nutrition on various reproductive parameters. The direct effects of these nutrition components on repeat breeder syndrome need to be investigated.

2) In the field of epidemiology there are some conflicting reports about the association between various postpartum events and repeat breeder syndrome. Further investigation is needed to more fully understand these associations and any accompanying cause-effect relationships.

3) In the field of endocrinology there is a controversy about the role of progesterone in relation to repeat breeder syndrome. Therefore, more investigations need to be undertaken to evaluate this matter in dairy cows.

4) In the area of management, reports addressing the association between managerial and environmental factors and repeat breeder syndrome

have been inconsistent. Further investigation into this matter is recommended.

5) In the field of economics different approaches for assessing the economic effects of repeat breeder syndrome have been reported. Since these effects can vary widely, the need for developing a standardized methodology for analysis is essential.

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CHAPTER III

MULTICOLLINEARITY IN VETERINARY EPIDEMIOLOGICAL RESEARCH

3.1 ABSTRACT

This chapter was design to: (1) discuss symptoms and effects of multicollinearity in a data base; (2) evaluate the ability of Principal Components Analysis (PCA) to detect, identify and to quantify the interrelationships among the predictor variables; (3) evaluate methods used for reducing the effects of multicollinearity when its presence is deemed harmful. Four examples using different data sets were analyzed to evaluate the three above mentioned objectives. Example one used human data while the other three examples used data from a prospective animal health project. The PCA model was used as a method for addressing the problem of multicollinearity.

Results from the human and two of the animal data sets indicated that PCA is a useful technique for detecting whether there is a multicollinearity among the independent variables. Furthermore, this technique was effective in reducing multicollinearity among these variables. In the fourth example, however, the PCA method failed both in detecting and reducing multicollinearity among the independent variables. Possible explanations for this discrepancy and caution in using PCA are discussed. Combining sample and non-sample data seems to be an effective method for reducing the effects of multicollinearity when its presence in a data base is considered harmful.

3.2 INTRODUCTION

A number of epidemiological studies in the last ten years have focused on the elucidation of risk factors; development and application of multivariate analytical methods have steadily progressed. Multiple regression analysis, logistic regression and multivariate path analysis [see Pedhazur, 1982; Afifi and Clark, 1984; Dillon and Goldstein, 1984, for an introduction to the methods and Schervish, 1988, for a review of the literature] have become widely used as statistical methods because systematic interrelationships among diseases are considered.

Erb et al. (1981a) used multivariate path analysis to study the impact of retained placenta, metritis, cystic follicle, and luteal cyst on calving interval in dairy cattle. In a second study, Erb et al. (1985) used path analysis combined with logistic regression and showed that retained placenta had a significant, indirect association with the total number of services per cow in both heifers and multiparous cows. Etherington et al. (1985) used path analysis to describe the associations between postpartum events, hormonal therapy, reproductive abnormalities, and reproductive performance in dairy cattle. Salman et al. (1984) and Salman and Meyer (1987) described major risk factors associated with the prevalence of brucellosis antibodies in culled dairy cows, and Curtis et al. (1984, 1985) characterized the relationships between dry period nutrition and postpartum dairy cattle diseases.

Many of the epidemiological studies cited involved consideration of numerous risk factors where one or a combination of the step-wise regression procedures were used as an attempt to determine the relative importance of individual risk factors (Erb et al., 1981a, 1985; Dohoo et al., 1984b; Curtis et al., 1985, 1988). The step-wise regression

procedure was combined or followed by a multivariate path analysis model. The later model was employed because it has the ability to quantify both the direct and the indirect effects of the various risk factors involved. However, these studies and current work by the investigator suggest an important problem may remain: multicollinearity among risk factors.

3.3 OBJECTIVES

The objectives of this chapter were to: (1) discuss symptoms and effects of multicollinearity in a data base; (2) evaluate the ability of principal components analysis (PCA) to detect, identify and to quantify the interrelationships among the predictor risk factors; (3) evaluate methods used for reducing the effects of multicollinearity when its presence in the data base is deemed harmful.

3.4 MULTICOLLINEARITY

Multicollinearity refers to intercorrelation between risk factors and presents a problem because: (1) it is often difficult to detect and (2) when present, it may adversely affect the efficacy of statistical analysis, often precluding accurate assessment of the individual effects of correlated factors. If present, severe multicollinearity makes it difficult to accurately quantify (disentangle) and rank the contributions of individual factors deemed important.

Multicollinearity can be a serious statistical problem in non-experimental situations where the investigator observes a sample of the animal population that is managed in an economic manner by the producer. Thus, the investigator cannot always choose treatments to assure the orthogonality which is required of many experimental designs.

3.5 SYMPTOMS AND EFFECTS OF MULTICOLLINEARITY

Symptoms of multicollinearity include the following (Belsey et al., 1980; Dillon and Goldstein., 1984; Judge et al., 1985):

1. The standard errors of the coefficients are very large.
2. Certain coefficients have signs opposite those expected. Often, these explanatory variables are highly correlated with other explanatory variables which have the expected sign.
3. Several of the simple correlations between the predictor and the response measure are high, but the corresponding parameters are not statistically significant.
4. Some of the simple correlation coefficients among explanatory variables are large relative to the explanatory power of the overall equation.

None of these observations individually guarantee strong multicollinearity is present; they are merely symptoms that occur if strong multicollinearity is present. When any of the step-wise regression procedures is used and severe multicollinearity exists in the data base, two major problems arise (Mason and Gunst, 1975; Chatterjee, 1977). First, estimates of the regression coefficients are unstable because of the influence of the interdependency between the independent variables, and second, the standard errors of the regression coefficients are large causing the model to become extremely sensitive to the addition or deletion of independent variables (Scialfa and Games, 1987). Due to the aforementioned effects, decisions or inferences that are often based on the magnitude or on the tests of statistical significance for the individual coefficients can be misleading when strong multicollinearity is present in the data base. Thus, a prudent first step in the data

analysis is to run diagnostic tests to investigate whether the possibility of strong multicollinearity exist. If it does, corrective measures must be taken.

The economic statistics (econometrics) literature is extensive on techniques for detecting the presence of multicollinearity since much of the data used by economists is based upon field observation, as contrasted to designed experiments. Also, there is a large amount of statistics literature available that provides reviews and handbooks (Dillon and Goldstein, 1984; Judge et al., 1985).

3.6 DETECTING MULTICOLLINEARITY

A large number of proposals for detecting multicollinearity have been developed in the last 20 years; a significant number have been found to be defective as our understanding has improved. Schemes that examine the interdependence of the data by examining what would be called the design matrix in controlled experiments are becoming widely used. These include examination of the characteristic roots (eigenvalues), eigenvectors, and the Variance Inflation Factors (VIFs) and their reciprocal (tolerance) (Belsey et al., 1980; Gunst and Mason, 1980; Afifi and Clark, 1984; Neter et al., 1985). Dillon and Goldstein (1984) advocated a similar analysis called singular-value decomposition. It would appear, therefore, that PCA which utilizes the eigenvectors, eigenvalues, and the variance inflation factors is a useful method for detecting multicollinearity in a data set.

3.7 REDUCING THE EFFECTS OF MULTICOLLINEARITY

If strong multicollinearity is present and deemed harmful, two approaches are available to reduce the severity of the problem. First, statistical techniques result in biased estimators and second, combining sample and non-sample information.

Statistical Techniques

Statistical techniques can be used which results in biased estimators but for which the extent of the bias is deemed to be offset by the associated reduction in the variance of the estimator (Massy, 1965; Gunst and Mason, 1980; Judge and Brock, 1983). Among the many statistical procedures that were proposed to deal with this problem, principal components regression (PCR), ridge regression and latent root regression have received considerable attention in the literature of statistics, econometrics and chemical engineering (Mansfield et al., 1977; Fomby and Johnson, 1977; Fomby et al., 1984; Gunst and Mason, 1980; Judge et al., 1985; and Mason and Gunst, 1985).

Several authors have reviewed the relative merits of these biased estimators (Mayer and Willke, 1973; Hawkins, 1973; Gunst and Mason, 1977, 1980). The lack of distributional properties for the latent root method have harmed their acceptance. Ridge regression procedures have also been criticized on distributional grounds by several authors (Conniffe and Stone, 1973; Smith and Campbell, 1980) but it is generally accepted that ridge estimators are an improvement over the least square estimators when strong collinearity is present (Fomby and Johnson, 1977; Gunst and Mason 1980; Vinod and Ullah, 1981; Fomby et al., 1984; and Judge et al., 1985).

Advantages of PCR when compared with the other two procedures are that exact distribution theory is available for the estimates (Gunst and Mason, 1977) and PCA have been considered, particularly as an exploratory tool by several authors (Fomby et al., 1978; Fomby et al., 1984; Dillon and Goldstein, 1984; and Judge et al., 1985). Ginevan and Carnes (1981) and Carnes and Slade (1988) strongly recommended the use of PCA on any data set to identify the underlying dimensionality of the data structure and to quantify the interdependence that may exist among the independent variables. More recently, PCA have been recommended as a method for adjusting or overcoming the problem of multicollinearity in the observational studies (Scialfa and Games, 1987). Silvey (1969) and Carnes and Slade (1988) outlined the requirements for reducing the impact of multicollinearity. On the basis of above review a detailed discussion of PCA will be presented in a later section of this chapter.

Combining Sample and Non-Sample Data

The second approach is to combine sample and non-sample data, multicollinearity means that the sample data are sufficiently interrelated to preclude definitive disentangling of individual regression coefficients; thus, additional non-sample information is combined with sample information to obtain more precise estimates. This method is particularly relevant when the impacts of groups of factors can be well identified and when the contributions of individual components within the group cannot be separated. For example, Klein and Goldberger (1956) combined time-series data that were highly correlated with data obtained from cross sectional studies to reduce the effects of multicollinearity and to obtain more reliable regression coefficients.

These time-series data pertained to the relationship between total U.S. domestic consumption as a function of wage income, nonwage-nonfarm income, and farm income for the years 1928-1941, and 1945-1950. Specifically, the cross-sectional data were used to identify the relationship between the independent variables before the analysis and thereafter, a restriction concerning the relative size of the regression coefficients of the independent variables was specified base on the cross-sectional information. (for more information about the method see Klein and Goldberger 1956)

More recently, Fomby and Hill (1979) used the same method and data set of Klein and Goldberger (1956) and showed that utilizing the cross-sectional information lead to nearly the same variance reduction of the regression coefficients obtained from deleting components associated with small eiginvalues when applying PCR (see principal components regression). It was concluded that the use of external or non-sample information is necessary in order to obtain meaningful and reliable regression coefficients when multicollinearity is present in the data base.

In general, the problem of intercorrelations among risk factors has not been addressed properly in the animal health literature. Because, as discussed, the importance of individual risk factors cannot be reliably quantified and ranked in the presence of multicollinearity, subsequent prioritization of interventions is also debatable.

3.8 PRINCIPAL COMPONENTS ANALYSIS

The original application of PCA was in the field of education and psychology. This technique was developed by Hotelling (1933) to study the entry-examination tests, variable and quantitative ability. Over time, the PCA has been used more often and extensively in psychology for discovering some underlying structures than in other disciplines such as economics or biological sciences.

PCA is a method of transforming the original independent variables (risk factors) into new, uncorrelated variables. The new transformed variables are called principal components. Each principal component is a linear combination of all the original independent variables.

Among the many applications of the PCA is to reduce dimensionality, i.e., reduction in the number of variables without losing much of the information. Principal components obtained are arranged according to their variance; therefore, the first principal component explains the largest amount of variation among the variables and the last component explains the least. Since the first few principal components are the most informative, reduction of the dimensionality is usually achieved by choosing only the first few components to be used in the regression analysis.

This technique has been attractive to many investigators not only because of the variable reduction but also because the principal components obtained are orthogonal. Recently, in the field of veterinary epidemiology. Bigras-Poulin. (1985) used PCA to reduce the independent variables by constructing some general factors to study the farmers' attitudes and herd management of dairy herds in southern Ontario, Canada. In the last three decades several researchers have suggested and used

principal components tactics as a useful method for overcoming the problem of multicollinearity when it exists among the explanatory variables in a data base (Massy, 1965; Mason and Gunst, 1975; Chatterjee and Price, 1977; Gunst and Mason, 1980; Ginevan and Carnes, 1981; for more detailed information see Gunst and Mason, 1980; Afifi and Clark, 1984; Dillon and Goldstein, 1984; Fomby et al., 1984; and Judge et al., 1985).

The basic concept of PCA is to transform the original variables (risk factors) to new variables called components ($C_1, C_2, \dots, C_p$). The number of components is equal to the number of original variables. Each principal component is a linear combination of all independent variables involved. The coefficients of the components are chosen to satisfy the following requirements:

1. Variance of $C_1 \geq$ variance of $C_2 \geq$ variance of $C_3 \dots \geq$ variance C_p
2. All Principal components are orthogonal (uncorrelated)
3. For any principal component the sum of the squares of the coefficients is equal to one (Afifi and Clark, 1984).

To formulate the multiple regression model let Y' be a vector of response

$$Y' = (Y_1, Y_2, Y_3, \dots, Y_n)$$

on the dependent variable. Let X be an $(n \times k)$ matrix of predictor or independent variables (risk factors), where x_{ij} is the i th observation on the j th independent variables. X (variable) is standardized using the unit length standardization method so that each predictor variable has a mean equal to zero and $\sum X_{ij}^2 = 1$. (For more detail see examples at the end of the text).

The multiple regression model can be written as:

$$Y = B_0 I + XB + e \dots \dots \dots (3.1)$$

where:

I is a vector of ones $(n \times 1)$,

B_0 is unknown constant,

B is a $(k \times 1)$ vector of unknown constant (regression coefficients) and

e is an $(n \times 1)$ vector of uncorrelated errors with expectation mean equal to zero and common variance equal to σ^2 . Let V be a $(k \times k)$ matrix whose columns, V_j , are a unit length latent Vector of the simple correlation matrix $X'X$ of the independent variables. The principal components matrix of X is

$$Z = XV \quad \text{a matrix of } (n \times k) \dots \dots \dots (3.2)$$

The columns of Z are orthogonal with a variance equalling the corresponding eigenvalue (λ_k) . Some important properties of the latent vectors V and principal components Z are:

$$(X'X)^{-1} = \sum_{j=1}^k 1/\lambda_j V_j V_j'$$

where the diagonal elements of $(X'X)^{-1}$ are the values of Variance Inflation Factors (VIFs) of the independent variables (Gunst and Mason, 1980).

$$V'V = VV' = I \quad [\text{identity matrix of } (k \times k)] \text{ and}$$

$Z'Z = \Lambda$ is a diagonal matrix contains the eigenvalues of $(X'X)$. Order of the eigenvalues as $\lambda_1 \geq \lambda_2 \geq \lambda_3 \geq \dots \geq \lambda_k$ and the corresponding eigenvectors denoted by $V_1, V_2, \dots, V_k$.

The main objective of the analysis after obtaining the principal components is the application of the regression procedure using the principal component obtained as independent variables.

3.9 PRINCIPAL COMPONENTS REGRESSION

The principal components regression model can be written as:

$$Y = B_0 I + Za + e \quad \dots\dots\dots(3.3)$$

where:

a is a $(k \times 1)$ vector of unknown PCR coefficients

B_0 , e and Y as were defined previously in equation (3.1).

Z is a matrix of the principal components of $(n \times k)$.

When the matrix X is a full rank (has a unique inverse) the regular regression model conducted on the original data using equation (3.1) is equivalent with the regression model conducted on the components using equation (3.2):

Given that:

$$Z = XV$$

$$V'V = VV' = I$$

$$a = V'B$$

Substituting the appropriate values of Z and a in terms of X and B

$$Y = B I + Za + e$$

$$Y = B_0 I + X VV' B + e$$

$$Y = B_0 I + X I B + e$$

$$Y = B_0 I + X B + e$$

and

$$Z'Z = V'(X'X)V$$

$$Z'Z = \Lambda$$

where:

$$\Lambda = \text{diagonal matrix of } (\lambda_1, \lambda_2, \dots, \lambda_k)$$

Thus, The variance (Var) of a is:

$$\text{Var}(a) = (Z'Z)^{-1} \cdot \sigma^2$$

$$\text{Var}(a) = \Lambda^{-1} \cdot \sigma^2$$

$$\text{Var} (a_j) = \sigma^2 / \lambda_j$$

Showing that the two models are equivalent, the regression coefficients in terms of the original predictor variables then can be retrieved by the back transformation (reconstituted regression coefficients).

$$B = V a \dots\dots\dots(3.4)$$

This implies that the B's are a linear combination of the PCR coefficients such that

$$B_i = v_{i1} a_1 + v_{i2} a_2 + \dots + v_{ik} a_k \dots\dots\dots(3.5)$$

where:

v_{ij} is the element of an eigenvector in the i th row and j th column.

Therefore the variance of (B_i) is

$$\text{Var} (B_i) = v_{i1}^2 \cdot \text{var}(a_1) + \dots + v_{ik}^2 \cdot \text{var}(a_k)$$

$$\text{Var} (B_i) = v_{i1}^2 \cdot \sigma^2 / \lambda_1 + \dots + v_{ik}^2 \cdot \sigma^2 / \lambda_k$$

$$\text{Var} (B_i) = \left(\sum_{j=1}^k v_{ij}^2 / \lambda_j \right) \sigma^2 \dots\dots\dots(3.6)$$

This relationship clarifies that the variance of the regression coefficients is an inverse function of the eigenvalues. An eigenvalue close to zero, indicating collinearity (Silvey, 1969; Gunst and Mason, 1980; Dillon and Goldstein, 1984) and in the variance denominator inflates the variance of the regression coefficients. Therefore, a more precise estimation of the regression coefficients could be possible by using only components with large eigenvalues. As a result of this concept, the PCR has been suggested as a strategy for adjusting or overcoming the problem of multicollinearity in the data base (Massy, 1965; Chatterjee, 1977; Gunst and Mason, 1980; Mason and Gunst 1985; Scialfa and Games, 1987).

3.10 PRINCIPAL COMPONENTS ELIMINATION

Two methods were proposed by Massy (1965) for eliminating principal components to adjust the multicollinearity problem: (1) elimination of components associated with eigenvalues near zero and (2) elimination of components that have low correlation with the response variable. Mason and Gunst (1985) showed that using the first method guarantees variance reduction while using the second method does not, because low correlation between the component and the response variable does not necessarily indicate low eigenvalue and consequently, variance reduction.

3.11 EXAMPLES

The following examples will be used to evaluate the ability of PCA for: (1) detecting and quantifying the interrelationship among predictor risk factors when these risk factors are highly correlated; (2) reducing dimensionality of the independent variables without losing much of the predicted power of the model; (3) reducing the effects associated with the multicollinearity problem using PCR techniques.

Example 1

The data in data set of Table 3.1 were used to demonstrate this example. Table 3.2 presents the abbreviations and definitions of the dependent variable and the independent variables used in this example. The statistical analyses were performed using programs written in the programming language APL by a senior faculty in the Department of Statistics and Probability at Michigan State University.

Table 3.1. Body measurement for 33 black female police department applicants.

No.	HEIGHT	SITHT	UARM	FORE	HAND	ULEG	LLEG	FOOT	BRACH	TIBIO
1	165.8	88.7	31.8	28.1	18.7	40.3	38.9	6.7	88.36	96.53
2	169.8	90.0	32.4	29.1	18.3	43.3	42.7	6.4	89.81	98.61
3	170.7	87.7	33.6	29.5	20.7	43.7	41.1	7.2	87.80	94.05
4	170.9	87.1	31.0	28.2	18.6	43.7	40.6	6.7	90.97	92.91
5	157.5	81.3	32.1	27.3	17.5	38.1	39.6	6.6	85.05	103.94
6	165.9	88.2	31.8	29.0	18.6	42.0	40.6	6.5	91.19	96.67
7	158.7	86.1	30.6	27.8	18.4	40.0	37.0	5.9	90.85	92.50
8	166.0	88.7	30.2	26.9	17.5	41.6	39.0	5.9	89.07	93.75
9	158.7	83.7	31.1	27.1	18.3	38.9	37.5	6.1	87.14	96.40
10	161.5	81.2	32.3	27.8	19.1	42.8	40.1	6.2	86.07	93.69
11	167.3	88.6	34.8	27.3	18.3	43.1	41.8	7.3	78.45	96.98
12	167.4	83.2	34.3	30.1	19.2	43.4	42.2	6.8	87.76	97.24
13	159.2	81.5	31.0	27.3	17.5	39.8	39.6	4.9	88.06	99.50
14	170.0	87.9	34.2	30.9	19.4	43.1	43.7	6.3	90.35	101.39
15	166.3	88.3	30.6	28.8	18.3	41.8	41.0	5.9	94.12	98.09
16	169.0	85.6	32.6	28.8	19.1	42.7	42.0	6.0	88.34	98.36
17	156.2	81.6	31.0	25.6	17.0	44.2	39.0	5.1	82.58	88.24
18	159.6	86.6	32.7	25.4	17.7	42.0	37.5	5.0	77.68	89.29
19	155.0	82.0	30.3	26.6	17.3	37.9	36.1	5.2	87.79	95.25
20	161.1	84.1	29.5	26.6	17.8	38.6	38.2	5.9	90.17	98.96
21	170.3	88.1	34.0	29.3	18.2	43.2	41.4	5.9	86.18	95.83
22	167.8	83.9	32.5	28.6	20.2	43.3	42.9	7.2	88.00	99.08
23	163.1	88.1	31.7	26.9	18.1	40.1	39.0	5.9	84.86	97.26
24	165.8	87.0	33.2	26.3	19.5	43.2	40.7	5.9	79.22	94.21
25	175.4	89.6	35.2	30.1	19.1	45.1	44.5	6.3	85.51	98.67
26	159.8	85.6	31.5	27.1	19.2	42.3	39.0	5.7	86.03	93.20
27	166.0	84.9	30.5	28.1	17.8	41.2	43.0	6.1	92.13	104.37
28	161.2	84.1	32.8	29.2	18.4	42.6	41.1	5.9	89.02	96.48
29	160.4	84.3	30.5	27.8	16.8	41.0	39.8	6.0	91.15	97.07
30	164.3	85.0	35.0	27.8	19.0	47.2	42.4	5.0	79.43	89.83
31	165.5	82.6	36.2	28.6	20.2	45.0	42.3	5.6	79.01	94.00
32	167.2	85.0	33.6	27.1	19.8	46.0	41.6	5.6	80.65	90.43
33	167.2	83.4	33.5	29.7	19.4	45.2	44.0	5.2	88.66	97.35

Source: Dr. Ladislav P. Novak, Department of Anthropology, Southern Methodist University. Reprinted with permission.

Table 3.2. Abbreviations and definitions of the body measurements (33 police department applicants)

<u>Independent Variable</u>	
HEIGHT	Height in standing position measured in cm
<u>Dependent Variables</u>	
SITHT	Sitting height measured in cm
UARM	Upper arm length measured in cm
FORE	Forearm length measured in cm
HAND	Hand length measured in cm
ULEG	Upper leg length measured in cm
LLEG	Lower leg length measured in cm
FOOT	Foot length measured in inches
<u>INDICES</u>	
BRACH	= (FORE/UARM) x 100
TIBIO	= (LLEG/ULEG) x 100

Source: Novak, L.P., Department of Anthropology, Southern Methodist University. Reprinted with permission.

Standardization Techniques

The unit length standardizing method was used to standardize the independent variables

$$X_{ij} = (X_{ij} - \bar{X}_j) / d_j$$

Where:

$$d_j^2 = \sum (X_{ij} - \bar{X}_j)^2$$

X_{ij} = the i th observation on the j th independent variables

$\bar{X}_j$ = the mean of the j th independent variables

However, many epidemiologist are more familiar with the normal form standardization method

$$Z_{ij} = (X_{ij} - \bar{X}_j) / S_j$$

Where:

X_{ij} and X_j are the same as they were defined in the unit length scaling, and S_j is the standard deviation of the j th independent variables.

$$S^2 = \sum (X_{ij} - \bar{X}_j)^2 / (n-1)$$

n = Sample size

The two methods are related and results obtained from one method could be converted to the other method by using the following formula:

$$Z_{ij} = X_{ij} \times n^{0.5}$$

Multiple Regression Analysis

Equation (3.1) was applied using the data set in table 3.1. The least squares regression coefficients using the 9 independent variables in the model were calculated and are shown in Table 3.3, Column 1.

Unexpectedly, several of the regression coefficients were negative,

suggesting negative associations between those independent variables and the dependent variable, specifically, ULEG, FORE and TIBO. The interpretation of these coefficients could be difficult and not logical; for example, increases in the height are associated with decreases in the upper leg length and increases in lower leg length.

Table 3.3. Regression coefficients and principal components analysis results (33 police department applicants)

Variable	Regression	$\lambda_8=0.0009$	$\lambda_9=0.00005$		
name	coefficients ¹	V_8	V_9	VIF	R^2
Constant	164.563				
SITHT	11.899	-0.000	-0.010	1.524	0.345
UARM	4.752	0.586	0.135	433.127	0.998
FORE	-3.748	-0.522	-0.134	351.468	0.997
HAND	4.259	0.001	-0.004	2.425	0.588
ULEG	-10.008	0.142	-0.612	816.957	0.999
LLEG	25.804	-0.147	0.606	801.707	0.999
FOOT	3.371	0.000	0.002	1.775	0.437
BRACH	6.866	0.575	0.129	414.403	0.998
TIBIO	-9.792	0.104	-0.453	448.345	0.997
R^2	0.893				

¹ Standardized regression coefficients (using the unit length standardization method).

λ = eigenvalue number 8 and 9.

VIF_i $i = 1$ to 9 = Variance Inflation Factors.

Constant = mean of dependent variable (height).

$R^2 = (VIF_i - 1) / VIF_i$.

As previously mentioned, these negative associations may occur due to the existence of strong multicollinearity among the independent variables.

Principal Components Analysis

Detecting and Quantifying Multicollinearity

In order to obtain the uncorrelated principal components of the simple correlation matrix $(X'X)$, the analyses were conducted in three steps. First, the eigenvectors and the eigenvalues of the $(X'X)$ were calculated and the last two eigenvectors and eigenvalues are shown in Table 3.3. Second, the diagonal elements of the matrix $W = (X'X)^{-1}$ which are known as the Variance Inflation Factors (VIFs) were obtained and are also shown in Table 3.3. The individual R^2 were calculated and are also shown in Table 3.3 using the following formula:

$$R^2_j = (w_{ij} - 1) / w_{ij}$$

where:

w_{ij} = the j th diagonal elements of W matrix

Third, the uncorrelated principal components were obtained by utilizing equation (3.3).

Table 3.3 displays the last two eigenvectors and their corresponding eigenvalues. Small eigenvalues (close to zero) indicate that a strong multicollinearity exists among the predictor variables (Silvey, 1969; Dillon and Goldstein, 1984; Judge et al., 1985). V_9 (Table 3.3) indicates that large eigenvector values corresponded to ULEG, LLEG, and TIBIO, and V_8 indicates that the large values of the eigenvectors corresponded to the UARM, FORE, and BRACH. The individual values of the VIFs and individual R^2 corresponding to the six mentioned

variables are also very large. On the basis of VIFs and R^2 values, there are six multicollinear variables in the data base (Neter et al., 1985).

From the data, it was known that ULEG, LLEG, and TIBIO are collinear (they measure the same variability) to each other (group 1). The same could be said about the UARM, FORE, and BRACH (group 2). The data in Table 3.3 indicate that the large elements of V9 corresponded to the first collinear group of independent variables and the large elements of V8 corresponded to the second multicollinear group. Therefore, the individual VIFs values and R^2 could be used to identify and quantify (the larger the value, the more severe is the presence of multicollinearity in a data base) the multicollinear variables while the nature of the multicollinearity could be underlined by the small eigenvalues and their corresponding eigenvectors.

Reducing Dimensionality of the Independent Variables

The two principal components associated with eigenvalues near zero were deleted. Least squares regression coefficients (a 's) were calculated by regressing the height on the seven uncorrelated principal components using equation (3.3). The regression coefficients (a 's), their corresponding standard errors, t-statistic values and tolerance are shown in Table 3.4. The R^2 of the regression model using the seven principal components is very close to the R^2 obtained when all independent variables were used in the Ordinary Least Squares (OLS) multiple regression see Table 3.3. This indicates that elimination of the two principal components associated with the two smallest eigenvalues did not effect the prediction power of the model. Therefore, PCA reduces the number of the predictor variables (dimensionality) without losing

Table 3.4. Regression analysis results (a's) obtained from using the seven orthogonal principal components in the model (33 police department applicants)

Component number	Regression coefficients ¹	S.Error	t-Value	Tolerance
Constant	164.563			1.000
1	12.747	1.321	9.650	0.999
2	-5.167	1.595	-3.239	0.999
3	7.224	2.417	2.989	0.999
4	5.822	2.709	2.149	0.999
5	4.323	3.099	1.395	0.996
6	1.223	4.432	0.276	0.993
7	-6.455	5.045	-1.279	0.999
R ²	0.892			

¹ using the unit length standardization method.

much of the prediction power of the model.

Reducing the Problem of Multicollinearity

The interpretation of the regression coefficients obtained from applying equation (3.3) could be difficult because each principal component is a linear combination of all the variables. In order to gain more interpretability in terms of the original data, equation (3.4) was utilized. Regression coefficients (reconstituted regression coefficients), their corresponding standard errors and t-statistic values are shown in Table 3.5.

Table 3.5 also shows a comparison of regression coefficients obtained from the OLS and the reconstituted regression coefficients

Table 3.5. Comparison of regression coefficients and reconstituted regression coefficients after deleting principal components 8 and 9, and the VIFs (33 police department applicants)

Variable		<u>OLS</u>			<u>PCR</u>			<u>VIF</u> ²	
name	R.Coeff ¹	S.Error	t-Value	R.Coeff	S.Error	t-Value	M ₁	M ₂	
SITHT	11.898	2.333	5.099	12.194	2.147	5.677	1.524	1.293	
UARM	4.752	39.327	0.121	-0.479	2.141	-0.223	433.127	1.279	
FORE	-3.748	35.426	-0.105	1.298	2.395	0.542	351.468	1.607	
HAND	4.259	2.943	1.447	4.370	2.921	1.496	2.425	2.388	
ULEG	-10.008	54.011	-0.185	6.838	1.856	3.685	816.957	0.958	
LLEG	25.803	53.504	0.482	9.156	1.974	4.637	801.707	1.089	
FOOT	3.371	2.517	1.339	3.308	2.509	1.318	1.775	1.775	
BRACH	6.866	38.468	0.178	1.831	1.498	1.222	414.403	0.643	
TIBIO	-9.792	40.012	-0.245	2.686	2.052	1.309	448.345	1.178	
R ²		0.893			0.892				

¹ Using the unit length standardization method.

² M1= Variance Inflation Factors (VIFs) of predictor variables.(all independent variables are included).

² M2= Backtransformed Variance Inflation Factors (VIFs) of predictor variables after deleting components 8 and 9.

obtained from the PCR. It can be noted that regression coefficients of PCR are smaller than regression coefficients of the OLS (except for SITHT). Standard errors of the estimated regression coefficients obtained from PCR are much smaller than the standard errors obtained from the OLS, especially the ones that are corresponding to the collinear variables. Also, the negative associations between the independent variables and the dependent variable in the OLS model became positive in the PCR model. In general, the estimated regression coefficients of the PCR are more precise and might be more logical than the estimated regression coefficients of the OLS. Table 3.5 also displays a comparison of the VIFs using all independent variables and the backtransformed VIFs after the elimination of the two principal components associated with the two smallest eigenvalues. None of the backtransformed VIFs exceeded 2.388, suggesting no strong multicollinearity in the data base.

Analysis of Body Measurements Data After Eliminating the Last two Independent Variables

The data in Table 3.1 were reduced and analyzed without the last two independent variables (indices). Table 3.6 shows regression coefficients, their corresponding standard errors of the estimates, the t-statistic value, the VIFs and the eigenvalues of the correlation matrix ($X'X$). Comparing the data of Table 3.6 with the data of Table 3.5, it can be seen that the regression coefficients, the standard errors, the t-value of the estimates and the VIFs present in Table 3.6 are much closer to the regression coefficients, standard errors, t-values and the VIFs obtained from the PCR (Table 3.5). Therefore, when multicollinearity is present in a data base, the regression coefficients obtained from using OLS technique could be misleading. The PCR coefficients (reconstituted regression coefficients) are biased due to the elimination of the principal components associated with the smallest eigenvalues. However, these regression coefficients (reconstituted regression coefficients) are closer to the coefficients of OLS after removing the collinear variables from the data set.

Table 3.6. Regression coefficients and principal components results after deleting the last two independent variables (33 police department applicants)

Variable name	R. Coeff ¹	OLS S.Error	t-Value	VIF	Component Number	Eigenvalues (λ)
Constant	164.564					
SITHT	12.564	2.053	5.917	1.280	1	3.593
UARM	-2.311	2.919	-0.792	2.585	2	1.326
FORE	2.842	3.046	0.933	2.815	3	0.770
HAND	4.356	2.799	1.556	2.377	4	0.589
ULEG	3.156	3.636	0.868	4.010	5	0.113
LLEG	12.829	3.903	3.287	4.619	6	0.325
FOOT	3.306	2.408	1.373	1.759	7	0.284
R ²	0.893					

¹ Using the unit length standardization method.

Example 2

The data in Table 3.7 were used to demonstrate this example. Table 3.8 presents the abbreviations and definitions of the dependent variable and the independent variables used in this example. The procedures that were used to illustrate example 1 were also used to illustrate this example.

Equation (3.1) was applied using Data of Table 3.7. The least squares regression coefficients using the 6 independent variables in the model were calculated and are shown in Table 3.9, column 1. Table 3.9 also shows the regression coefficients using the six independent variables, the sixth eigenvalue and its corresponding eigenvector, VIFs, and the individual R².

Table 3.7. Diseases incidence rates and nutritional risk factors for 50 dairy herds of NAHMS in Michigan 1988-1989.

No.	RBCS	DYST	REPL	MILF	COSD	DHDC	HADC
1	25.530	0.000	12.500	0.000	0.000	0.000	80.000
2	0.000	0.000	19.050	9.520	0.000	0.000	100.000
3	4.969	2.500	17.500	5.000	34.455	0.000	39.730
4	0.000	2.500	0.000	2.500	32.272	9.037	58.691
5	0.000	5.560	0.000	5.560	30.011	8.403	54.576
6	0.000	2.440	12.200	4.880	31.623	8.855	57.508
7	2.444	0.000	0.000	2.080	30.011	8.403	54.576
8	0.000	2.560	0.000	2.560	30.435	0.000	69.565
9	0.000	14.630	2.440	0.000	16.279	0.000	83.721
10	0.000	6.980	11.630	11.630	46.281	53.719	0.000
11	5.581	21.050	2.630	5.260	100.000	0.000	0.000
12	3.187	2.860	17.140	0.000	24.911	46.263	28.826
13	0.000	2.040	2.040	2.040	35.479	0.000	64.521
14	14.670	0.850	0.850	0.850	0.000	86.795	0.000
15	2.196	0.000	6.980	5.430	0.000	75.414	0.000
16	0.000	3.850	3.850	7.690	35.714	41.454	11.480
17	8.054	0.000	1.890	5.660	14.170	13.158	54.656
18	5.980	10.090	1.820	7.270	28.146	16.553	38.600
19	4.335	7.690	7.690	8.970	0.000	11.797	88.203
20	4.475	4.400	3.300	6.590	46.154	14.286	39.560
21	0.000	1.190	2.380	1.190	100.000	0.000	0.000
22	3.997	12.200	4.880	12.200	23.974	16.268	51.336
23	3.109	0.000	0.000	2.600	0.000	0.000	100.000
24	9.215	3.030	3.790	3.030	0.000	48.987	30.146
25	4.700	8.000	4.000	6.000	17.073	12.683	70.244
26	3.364	34.620	1.920	0.000	36.842	0.000	63.158
27	6.926	1.000	13.000	1.000	28.112	0.000	36.145
28	3.877	0.000	13.400	2.060	0.000	0.000	89.217
29	0.000	10.670	5.330	25.330	14.653	0.000	80.380
30	0.000	0.000	0.000	10.000	28.000	0.000	72.000
31	5.786	0.000	10.310	1.030	0.000	0.000	100.000
32	0.000	1.790	7.140	7.140	39.414	0.000	40.541
33	3.617	16.670	18.520	12.960	37.634	13.978	48.387
34	5.822	8.890	5.560	4.440	42.787	0.000	57.213
35	8.043	1.820	0.000	0.000	77.765	0.000	0.000
36	30.064	14.290	4.080	3.060	26.179	17.764	56.057
37	0.935	2.110	0.000	0.000	0.000	5.865	87.710
38	2.604	0.400	0.800	1.190	4.636	0.000	95.364
39	0.000	2.780	0.000	1.390	0.000	39.634	60.366
40	9.531	1.490	0.500	0.500	16.279	0.000	83.721
41	14.926	1.490	0.000	1.490	0.000	0.000	100.000
42	3.262	5.110	9.360	2.980	0.000	0.000	66.914
43	16.399	2.680	3.570	1.790	53.069	46.931	0.000
44	3.733	1.740	2.610	4.350	49.296	0.000	50.704
45	7.289	1.490	1.490	8.960	12.422	0.000	63.886

Table 3.7. (cont'd.)

46	0.907	2.290	7.630	3.820	25.571	41.552	32.877
47	0.000	0.000	12.030	1.660	23.274	8.644	68.081
48	0.747	0.770	1.920	0.380	0.000	0.000	100.000
49	4.254	0.780	0.000	3.130	25.000	0.000	75.000
50	6.648	4.320	0.000	1.620	47.000	24.940	28.058

Small eigenvalue indicates that a strong multicollinearity exists among the predictor variables. V6 of the same Table indicates that large eigenvector value corresponded to DHDC. The individual values of the VIFs and individual R^2 corresponding to the DHDC is also very large. On the bases of VIFs and R^2 values, there is a multicollinear variable in the data base (Neter et al., 1985).

Reducing Dimensionality of the Independent Variables

Component 6 was deleted because it is associated with the small eigenvalue. The independent variable was regressed on the 5 uncorrelated principal components using equation (3.3).

Table 3.8. Abbreviations and definitions of the diseases incidence rates and nutritional variables (NAHMS data 1986-1989)

<u>Independent Variable</u>	
RBCS	Repeat Breeder Cow syndrome measured as an annual incidence density rate/100 cow years
<u>Dependent Variables</u>	
DYST	Dystocia measured as a cumulative incidence rate /100 calvings
REPL	Retained placenta measured as a cumulative incidence rate/100 calvings
MILF	Milk fever measured as a cumulative incidence rate /100 calvings
COSD	Amount of corn silage fed to dry cows measured as a percent of total dry matters
HADC	Amount of haylage fed to dry cows measured as a percent of total dry matters
DHDC	Amount of dry hay fed to dry cows measured as a percent of total dry matters

Table 3.9. Regression coefficients and principal components analysis results (50 dairy herds of NAHMS in Michigan, 1988-1989)

Variable name	OLS	$\lambda_6=0.04578$	VIF	R^2
	Regression coefficients ¹	V_6		
Constant	4.823			
DYST	7.884	-0.047	1.181	0.151
REPL	-0.658	0.044	1.096	0.088
MILF	-11.748	0.003	1.096	0.088
COSD	-23.503	0.538	6.904	0.855
HADC	-11.705	0.498	6.039	0.834
DHDC	-24.845	0.677	10.328	0.903
R^2	0.130			

¹ Standardized regression coefficient using the unit length standardization method.

λ = eigenvalue.

VIF_i $i = 1$ to 6 = Variance Inflation Factors.

Constant = mean of dependent variable (RBCS).

$R^2 = (VIF_i - 1) / VIF_i$.

Reducing the Problem of Multicollinearity

The interpretation of the regression coefficients obtained from applying equation (3.3) could be difficult because each principal component is a linear combination of all the independent variables. In order to gain more interpretability in terms of the original data, equation (3.4) was utilized. Regression coefficients (reconstituted regression coefficients), their corresponding standard errors and t-statistic values are shown in Table 3.10, column 4-6. Table 3.10 also shows a comparison of regression coefficients obtained from the OLS and the reconstituted regression coefficients obtained from the PCR.

Table 3.10. Comparison of regression results and reconstituted regression coefficients after deleting principal component 6 (50 dairy herds of NAHMS in Michigan 1988-1989)

Variable name	<u>OLS</u>			<u>PCR</u>		
	R.Coeff ¹	S.Error	t-Value	R.Coeff	S.Error	t-Value
DYST	7.885	6.753	1.167	6.194	6.611	0.936
REPL	-0.658	6.504	-0.101	0.909	6.377	0.142
MILF	-11.889	6.505	-1.827	-11.877	6.505	-1.826
COSD	-23.508	16.323	-1.439	-4.302	4.762	-0.903
HADC	-11.705	15.266	-1.245	6.067	4.919	1.233
DHDC	-24.845	19.963	-0.245	-0.663	3.450	-0.192
R ²	0.130			0.100		

¹ Using the unit length standardization method.

It can be noted that regression coefficients of PCR are smaller than regression coefficients of the OLS, standard errors of the estimated regression coefficients obtained from PCR are much smaller than the standard errors obtained from the OLS, especially the one that is corresponding to the collinear variable. Also, the negative associations between the HADC and the dependent variable (RBCS) in the OLS model became positive in the PCR model which would agree with non-sample information from clinical medical knowledge. Also the R² obtained in Table 3.11 without including DHDC (dropped because it was collinear with other variables) in the model is very close to the R² obtained from the PCR (Table 3.10).

Analysis of the diseases incidence rates and nutritional variables
after eliminating the last independent variable

The data set of Table 3.7 were reduced and analyzed without the last independent variable (DHDC). Table 3.11 shows regression coefficients, their corresponding standard errors of the estimates, the t-statistic values, VIFs, and the eigenvalues of the correlation matrix ($X'X$). Comparing the data of Table 3.11 with the data of Table 3.10, it can be seen that the regression coefficients, the standard errors, the t-value of the estimates in Table 3.10 are much closer to the regression coefficients, standard errors, t-values obtained from the PCR in Table 3.10.

Table 3.11. Regression coefficients and principal components analysis results after deleting the last independent variable (50 dairy herds of NAHMS in Michigan 1988-1989)

Variable name	<u>OLS</u>			Component Eigenvalues		
	R. Coeff ¹	S.Error	t-Value	VIF	Number	(λ)
Constant	4.823	0.884	5.457			
DYST	6.474	6.698	0.966	1.148	1	1.412
REPL	0.800	6.347	0.120	1.060	2	1.243
MILF	-11.881	6.546	-0.815	1.097	3	0.939
COSD	-4.903	6.604	-0.742	1.117	4	0.757
HADC	5.617	6.309	0.890	1.019	5	0.648
R ²	0.100					

¹ Using the unit length standardization method.

Example 3

The data set of Table 3.12 were used to demonstrate this example. Table 3.8 presents the abbreviations and definitions of the dependent variable and the independent variables used in this example. The procedures that were used to illustrate example 1 and 2 were also used to illustrate this example.

Equation (3.1) was applied using Data set in Table 3.12. The least squares regression coefficients using the 6 independent variables in the model were calculated and are shown in Table 3.13, column 1. Table 3.13 also shows the sixth eigenvalue and its corresponding eigenvector, VIFs, and the individual R^2 . Small eigenvalue indicates that a strong multicollinearity exists among the predictor variables. V6 of the same Table indicates that large eigenvector value corresponded to DHDC. The individual values of the VIFs and individual R^2 corresponding to the DHDC and HADC is also very large. On the basis of VIFs and R^2 values, there are two collinear variables in the data base (Neter et al., 1985).

Reducing Dimensionality of the Independent Variables

Components 5 and 6 were deleted because there are associated with the small eigenvalue. The independent variable was regressed on the 4 uncorrelated principal components using equation (3.3).

Table 3.12. Diseases incidence rates and nutrition variables for 46 dairy herds of NAHMS in Michigan 1986-1987.

No.	RBCS	DYST	REPL	MILF	CODS	DHDC	HADC
1	30.145	0.000	0.000	1.786	0.000	72.874	27.126
2	20.690	12.500	3.125	0.000	34.948	56.166	0.000
3	6.566	2.222	4.444	8.888	0.000	98.178	0.000
4	0.000	0.000	0.000	0.000	0.000	100.000	0.000
5	11.257	7.143	0.000	3.571	0.000	100.000	0.000
6	3.429	0.000	5.000	5.000	24.533	54.673	0.000
7	5.042	6.666	0.000	6.667	22.921	65.423	0.000
8	0.000	0.000	0.000	0.000	20.789	68.639	0.000
9	0.000	0.000	0.000	0.000	0.000	88.030	0.000
10	2.715	0.000	14.706	2.941	0.000	72.260	13.448
11	0.000	0.000	0.000	0.000	46.388	47.714	0.000
12	14.286	0.000	0.000	0.000	40.398	48.045	0.000
13	15.534	27.778	16.667	5.556	0.000	72.874	27.126
14	21.100	10.714	0.000	3.571	15.042	74.539	3.592
15	0.000	1.887	1.887	15.094	42.723	40.563	0.000
16	0.000	4.000	0.000	8.000	0.000	100.000	0.000
17	19.262	0.000	0.000	4.000	0.000	100.000	0.000
18	4.199	10.204	6.122	7.143	0.000	0.000	100.000
19	9.324	1.961	1.961	1.961	18.509	0.000	81.491
20	21.326	1.639	9.836	6.557	0.000	89.392	0.000
21	4.453	4.688	9.375	14.063	23.980	32.887	29.583
22	1.084	6.250	11.250	7.500	25.193	23.136	51.571
23	15.403	0.980	4.902	4.902	14.085	72.435	13.481
24	12.565	8.824	13.235	2.941	0.000	100.000	0.000
25	12.785	34.483	1.149	2.299	33.478	34.479	32.043
26	9.475	2.703	2.703	5.405	10.542	89.458	0.000
27	13.419	22.414	18.966	8.621	24.232	54.522	13.395
28	0.000	1.220	10.976	1.220	0.000	100.000	0.000
29	1.786	0.000	5.405	2.703	0.000	100.000	0.000
30	9.827	6.034	9.483	0.862	11.221	89.779	0.000
31	5.093	3.000	7.000	3.000	0.000	80.178	0.000
32	10.958	1.695	8.475	6.780	0.000	89.392	0.000
33	14.047	14.583	10.417	8.333	27.653	0.000	72.347
34	11.799	4.624	7.514	0.000	0.000	0.000	100.000
35	8.127	0.000	8.911	0.000	14.085	72.435	13.281
36	4.612	0.000	1.869	2.804	0.000	100.000	0.000
37	14.556	0.559	17.877	3.352	37.009	32.628	30.363
38	0.757	0.000	0.000	2.632	0.000	100.000	0.000
39	4.453	0.862	2.586	2.586	0.000	63.694	23.708
40	0.946	1.087	3.261	1.087	11.999	9.256	48.234
41	10.893	3.356	12.081	6.711	0.000	88.190	0.000
42	21.864	2.206	0.735	3.676	8.560	60.632	23.089
43	4.803	1.546	8.247	7.732	0.000	25.140	74.860
44	3.757	1.575	3.150	14.567	0.000	51.845	24.122
45	15.046	0.415	0.000	3.734	22.375	35.407	24.711
46	23.702	33.036	2.679	5.357	39.326	60.674	0.000

Table 3.13. Regression coefficients and principal components analysis results (46 dairy herds of NAHMS in Michigan 1986-1987)

Variable name	OLS	$\lambda_6=0.04578$		
	Regression coefficients ¹	V ₆	VIF	R ²
Constant	9.154			
DYST	18.189	0.064	1.325	0.245
REPL	-0.915	0.014	1.153	0.133
MILF	-5.484	-0.045	1.140	0.122
COSD	13.269	-0.371	6.294	0.841
HADC	25.355	-0.696	19.425	0.949
DHDC	20.734	-0.610	15.159	0.934
R ²	0.169			

¹ Standardized regression coefficient using the unit length standardization method.

λ = eigenvalue.

VIF_i i= 1 to 6 = Variance Inflation Factors.

Constant = mean of dependent variable (RBCS).

$R^2 = (VIF_i - 1) / VIF_i$.

Reducing the Problem of Multicollinearity

The interpretation of the regression coefficients obtained from applying equation (3.3) could be difficult because each principal component is a linear combination of all the independent variables. In order to gain more interpretability in terms of the original data, equation (3.4) was utilized. Regression coefficients (reconstituted regression coefficients), their corresponding standard errors and t-statistic values are shown in Table 3.14, column (4-6). Table 3.14 also shows a comparison of regression coefficients obtained from the OLS and the reconstituted regression coefficients obtained from the PCR. It can be noted that the standard errors of the estimated regression coefficients obtained from PCR are much smaller than the standard errors

obtained from the OLS, especially the ones that are corresponding to the collinear variables. Also, the negative associations between the COSD and the dependent variable (RBCS) in the OLS model became positive in the PCR model. REPL and DHDC were statistically significant at ($P \leq 0.10$) and ($P \leq 0.05$) respectively in the PCR, but they were not statistically significant in the OLS.

Analysis of the diseases incidence rates and nutrition after eliminating the last two independent variables.

The data set of Table 3.12 were reduced and analyzed without the last two independent variables (HADC and DHDC). Table 3.15 shows regression coefficients, their corresponding standard errors of the estimates, the t-statistic values, VIFs, and the eigenvalues of the correlation matrix ($X'X$). Comparing the data of Table 3.15 with the data of Table 3.14, it can be seen that the regression coefficients, the standard errors, the t-value of the estimates in Table 3.15 are much closer to the regression coefficients, standard errors, t-values obtained in the PCR in Table 3.14. Also the R^2 obtained from Table 3.15 is very close to the R^2 obtained from the PCR (Table 3.14).

Table 3.14. Comparison of regression coefficients and reconstituted regression coefficients after deleting principal component 6 (46 dairy herds of NAHMS in Michigan 1986-1987)

Variable		<u>OLS</u>		<u>PCR</u>		
name	R.Coeff ¹	S.Error	t-Value	R.Coeff	S.Error	t-Value
DYST	18.189	8.716	2.087	20.360	8.162	2.494
REPL	-0.914	8.130	-0.112	-0.450	8.103	-0.055
MILF	-5.483	8.086	-0.678	-7.017	7.793	-0.900
COSD	-13.268	18.997	0.698	0.740	7.045	0.104
HADC	25.355	33.374	0.760	1.829	4.105	0.446
DHDC	20.374	29.482	0.703	0.118	5.171	0.022
R ²	0.169			0.159		

¹ Using the unit length standardization method.

Table 3.15. Regression coefficients and principal components analysis results after deleting variable 6 (46 dairy herds of NAHMS in Michigan 1986-1987)

Variable		<u>OLS</u>		Component			Eigenvalues
name	R. Coeff ¹	S.Error	t-Value	VIF	Number		(λ)
Constant	9.154	1.097	8.344				
DYST	20.184	8.095	2.493	1.183	1		1.444
REPL	-0.603	7.869	-0.077	1.118	2		1.137
MILF	-7.178	7.644	-0.939	1.055	3		0.836
COSD	0.232	7.902	0.029	1.127	4		0.582
R ²	0.157						

¹ Using the unit length standardization method.

Example 4

Monte Carlo simulation was used to generate data sets with carefully defined characteristics for analysis. For simplicity, only three nutritional risk factors (independent variables) during the dry period were considered to evaluate the relative contribution of these risk factors on the occurrence of dystocia in dairy cattle. These risk factors were the amount of dry hay, corn silage, and grain fed to dry cows in pounds per cow per day on dry matter basis. The following assumptions were made in order to generate the data:

- 1) The body weight (C_1) of lactating cows is normally distributed with a mean equal to 1400 lb and a standard deviation equal to 75 lb. $C_1 = [N(1400, 75)]$.
- 2) The consumption of feed (C_2) by dry cows on dry matter basis is normally distributed with a mean equal to 1.9% of the cow's body weight and a standard deviation equal to 0.05%. $C_2 = [N(1.9\%, 0.05\%)]$.
- 3) The proportion of dry matter intake (C_3) derived from corn silage is normally distributed with a mean equal to 60% and a standard deviation equal to 20%. $C_3 = [N(0.60, 0.20)]$.
- 4) The proportion of the consumed feedstuffs derived from non-corn silage (C_4) coming from dry hay is normally distributed with a mean equal to 80% and a standard deviation equal to 10%. $C_4 = [N(0.80, 0.10)]$.

Using the above assumptions, Total Dry Matter (T.D.M.) intake is equal to:

$$T.D.M. = C_1 \times C_2.$$

The Corn Silage Intake (C.S.I.) is equal to:

$$C.S.I. = T.D.M. \times C_3.$$

The Dry Hay Intake (D.H.I) is equal to:

$$D.H.I. = [T.D.M. \times (1 - C_3) \times C_4].$$

The Grain Intake (G.I) is equal to:

$$G.I. = [T.D.M. \times (1 - C_3) \times (1 - C_4)]$$

Utilizing the coefficients that were reported by the (National Research Council, 1988) the Total Digestible Nutrients (TDN) using the three nutritional variables is equal to:

$$\text{TDN} = (\text{C.S.I} \times 0.7) + (\text{D.H.I.} \times 0.5) + (\text{G.I} \times 0.88)$$

For simplicity, it was assumed that dystocia is a linear function of TDN. The Cumulative Incidence (CI) rate of dystocia ranged between zero and 34.483% (NAHMS data 1986-1987). The dystocia variable was generated using equation 3.7.

Equation 3.7

$$\begin{aligned} \text{Dystocia} &= (\text{TDN} - 15) \times 6 \\ &= \{[(\text{C.S.I} \times 0.7) + (\text{D.H.I.} \times 0.5) + (\text{G.I} \times 0.88)] - 15\} \times 6 \\ &= -90 + 4.2(\text{C.S.I}) + 3.0(\text{D.H.I}) + 5.2(\text{G.I}) \end{aligned}$$

Where:

TDN as it was defined previously,

the 15 is an adjustment factor for the intercept in the regression model, and

the constant 6 was used to make the range of generated variable dystocia comparable with the range of dystocia obtained from the NAHMS data 1986-1987.

The data that were generated are in Table 3.16. The procedure that was used in the analyses of the previous 3 examples was also used in the analysis of this example.

Practically, the nutritional variables are highly correlated and the generated data were design based on the practical aspects of nutrition. The simple correlation coefficients of the generated data were: corn silage and dry hay ($r = -0.918$), corn silage and grain ($r = -0.551$) and dry hay grain ($r = 0.314$).

Equation (3.1) was applied using the data set of Table 3.16. The

least squares regression coefficients using the 3 independent variables in the model were calculated and are shown in Table 3.17, column 1. Table 3.17 also shows the third eigenvalue and its corresponding eigenvector, VIFs, and the individual R^2 . Small eigenvalue indicates that a strong multicollinearity exists among the predictor variables. V3 of the same Table indicates that large eigenvector value corresponded to corn silage and dry hay. The individual values of the VIFs and individual R^2 corresponding to the corn silage and dry hay are also very large. On the basis of VIFs and R^2 values, only two multicollinear variables are in the data base (Neter et al., 1985).

Column 4, of Table 3.17 are the regression coefficients obtained from the PCR. The coefficients obtained from OLS regression and the PCR are different from the coefficient the are shown in equation 3.7 indicating that both models did not perform well when estimating coefficients associated with highly correlated predictor variables.

Table 3.16. Monte Carlo simulation of the incidence rate of dystocia and nutritional risk factors during the dry period of 50 farms

No.	DYSTOCIA	CORNSILAG	DRYHAY	GRAIN
1	11.200	15.300	6.600	5.200
2	38.400	17.800	7.400	4.300
3	9.400	10.500	14.900	2.400
4	28.600	20.600	4.700	1.300
5	12.400	20.400	4.700	1.300
6	0.100	12.000	12.500	1.600
7	22.000	20.600	5.800	2.200
8	11.800	9.900	13.600	3.400
9	8.100	12.200	10.200	3.000
10	10.100	3.800	19.300	2.400
11	0.000	15.700	7.000	1.000
12	0.000	14.900	7.400	2.600
13	12.000	16.800	11.500	0.000
14	19.100	17.900	5.600	1.000
15	27.900	21.900	3.100	0.200
16	0.000	15.000	10.100	1.400
17	26.200	20.400	4.000	0.800
18	26.900	21.900	5.100	2.300
19	26.000	11.200	12.300	3.700
20	0.000	8.700	12.400	1.700
21	6.000	9.900	11.900	4.000
22	39.800	20.700	6.500	1.400
23	19.700	18.400	6.100	3.900
24	9.700	12.700	7.600	4.500
25	40.000	25.800	1.000	0.500
26	1.300	27.200	0.000	0.000
27	4.200	8.800	11.600	5.300
28	32.500	14.500	9.800	0.800
29	8.100	25.200	0.500	0.100
30	0.000	20.200	6.300	0.000
31	10.500	14.200	13.000	0.200
32	34.500	10.800	9.700	6.100
33	33.900	22.900	2.700	0.800
34	29.400	19.100	7.500	0.200
35	17.400	19.300	5.000	1.000
36	3.300	10.300	9.500	4.000
37	0.000	8.900	19.000	0.000
38	37.800	15.000	9.100	1.500
39	1.500	15.700	7.800	1.500
40	25.800	22.100	4.300	0.900
41	40.000	15.400	9.900	3.300
42	18.600	19.900	4.700	2.900
43	0.500	10.100	12.000	3.200
44	6.500	8.900	13.200	5.700

Table 3.16. (cont'd.)

45	17.300	13.100	10.400	2.200
46	0.400	9.700	14.000	2.900
47	12.500	11.600	14.500	3.200
48	6.900	11.400	12.000	3.900
49	16.400	14.900	6.800	4.800
50	16.900	12.500	10.000	3.800

Table 3.17. Comparison of regression and principal components results
(Data generated by using the Monte Carlo simulations).

Variable	<u>OLS</u>	<u>$\lambda_3=0.0446$</u>			<u>RCR</u>
name	R. Coeff ¹	V ₃	VIF	R ²	R. Coeff.
Constant	-62.172				
Corn silage	3.266	-0.739	12.454	0.919	0.494
Dry hay	2.065	-0.639	9.616	0.896	-0.832
Grain	3.581	-0.216	2.169	0.539	1.068
R ²	0.288				0.185

¹ Non-standardized regression coefficient using the normal standardization method.

λ = eigenvalue.

VIF_i = 1 to 3 = Variance Inflation Factors.

Constant = the mean of the dependent variable.

R² = (VIF_i-1)/VIF_i.

3.12 DISCUSSION

Principal Components Analysis

Detecting of Multicollinearity

The goal of using PCA is to obtain the orthogonal components. As it was shown through the algebraic demonstration of PCR, three intermediate steps took place before the orthogonal components are calculated, these steps are: (1) standardization of the predictor variables using the one unit length, advantages of this type of standardization is that the matrix $(X'X)$ is equal to the simple correlation matrix of the independent variables and also the diagonal elements of the matrix $W = (X'X)^{-1}$ are the VIF of the independent variables, (2) calculation the eigenvalues, (3) calculation the

eigenvectors.

Belsey et al.(1980), Gunts and Mason, (1980), Afifi and Clark, (1984), and Neter et al. (1985) suggested that when the regression model includes two independent variables, one simple way to check for multicollinearity is to examine the correlations among the independent variables. However, if the regression model includes more than two independent variables and the collinearity exist among more than two variables, the pair-wise correlation fails to show the real interrelationships among the predictor variables. These researchers proposed other methods which examine the eigenvalues, eigenvectors and the VIFs as an alternative procedure for detecting, identifying and quantifying the presence of multicollinearity in a data base. Therefore, PCA which calculate the VIFs, eigenvalues, and eigenvectors of the independent variables is a useful technique for detecting and quantifying the interrelationships among the predictor variables.

In example 1 PCA identified six multicollinear variables existed among the predictor variables. The last two predictor variables, BRACH and TIBIO, are actually function of the other multicollinear predictor variables. Specifically, $BRACH = FORE/UARM$ and $TIBIO = LLEG/ ULEG$. The measurements on the arms and legs for these female police department applicants are over such a narrow range that the nonlinear transformations given above are well approximated by linear ones. Therefore, that BRACH and TIBIO are redundant predictor variables.

In example 2 and example 3 the nutritional independent variables were measured as proportions on dry matter basis and the sum of these proportions is equal to 1 which produce a perfect multicollinearity if

all the nutritional parameters are included in the analysis. The proportion of dry matter come from grain fed to dry cows was not included in the analysis to make imperfect the collinearity among the remaining variables. Results of PCA indicate that the value of VIF associated with DHDC was large indicating that DHDC is a collinear variable. Also the value of the VIF of HADC and the COSD were moderate. In example 2 the value of VIF of HADC and DHDC were very large and the value of VIF of COSD was moderate indicating that collinearity exist among DHDC and HADC variables. These results are in agreement with the practical aspects of nutrition, farms who feed large amount of dry hay to dry cows tend to feed less haylage and less corn silage.

In example 4, the generated nutritional variables were perfectly collinear with a random error. Results of PCA indicated that the value of VIF was large only for corn silage, moderate for dry hay and small for grain indicating that corn silage alone is a strong collinear variable. Results of PCA obtained from example 4 disagree with pre-defined relationships among the three independent variables which indicate that both the pair-wise simple correlation and the PCA could not detect the collinearity among the independent predictors possibly because all the independent variables were collinear (100% collinearity) while in the first 3 examples only some of the variables were collinear and PCA were capable to identify the collinear variables. Further research is needed to answer the question; why PCA detected the multicollinear variables in the first 3 examples and failed in detecting the collinear variables in example 4.

Reducing Dimensionality of the Independent Variables

In example 1 analyzing the data after deleting principal components associated with small eigenvalues reduces the number of the principal component axes and did not alter much the predictor power of the model (R^2) indicating that the deleted principal components were not very important for explaining the variation in the dependent variable; the same can be said about example 3. In example 2 and example 4 the deleted components were correlated with the dependent variable and the R^2 obtained from PCR was smaller than the R^2 obtained from the OLS regression indicating that the deleted pieces of information are important in predicting the variation in the dependent variable. The R^2 obtained from PCR was very close to the R^2 obtained from the OLS regression after removing the collinear variables from the data set suggesting that the PCR adjusted the predictor power of the test for multicollinearity.

Reducing the Effects of Multicollinearity

In example 1, 2, and 3 the regression coefficients obtained from the OLS procedure were larger than the coefficients obtained from the PCR for the collinear variables. The same can be said about the standard errors and some coefficients that were negative in OLS became positive in PCR which would agree with non-sample information from clinical medical knowledge. In example 4 one coefficients PCR was negative and in general, the regression coefficients of PCR were smaller than the coefficients obtained from OLS. Regression coefficients of both models were not comparable with the coefficients of equation 3.7. These contrary results of PCR in example 4 require more research for

clarification, particularly since PCR worked very well in the first 3 examples.

Combining Sample and Non-Sample Information

From the literature, it appears that this method is more effective in reducing the effects of multicollinearity than the statistical methods which result in bias estimators. Especially, when the non-sample information is reliable. These findings are very relevant to the epidemiological research where prospective studies are conducted and field data are analyzed. The use of reliable results obtained from clinical trials, experimental, previous prospective or cross-sectional studies might be very useful in reducing the effect of multicollinearity when field data are analyzed.

3.13 CONCLUSIONS

1. Regression coefficients obtained from PCR analysis after deleting principal components associated with small eigenvalues were comparable with regression coefficient obtained from the OLS technique after the identified collinear variables based on the VIFs were removed from the data set.
2. PCA failed to detect the presence of multicollinearity (at least in example 4) when all the independent variables were highly correlated. Furthermore, the regression coefficients obtained from PCR analysis and OLS analysis, were not close to the regression coefficients that were defined in equation 3.7.
3. Further research is needed to clarify why PCA and PCR worked well

when some of the predictor variables were collinear, yet failed when all predictor variables were collinear (100% collinearity).

4. Combining sample and non-sample data could be one of the best alternatives for reducing the effects of multicollinearity in the data base.

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CHAPTER IV
INCIDENCE RATE OF REPEAT BREEDER COW SYNDROME
AND OTHER RELATED DISEASES

4.1 ABSTRACT

A two-year prospective study was conducted during two one-year phases to study the relationship between repeat breeder cow syndrome and managemental, environmental, nutritional risk factors during the dry period, milk production and other postpartum diseases in Michigan dairy cattle. A multistage sampling procedure was used to randomly select sixty herds for each phase. An epidemiological survey was conducted at the beginning and at the end of each phase, data were collected on a monthly basis by veterinarians. A total of ninety six herds had complete data and were used in the analyses of the study. Computation of the incidence rate of repeat breeder cow syndrome and other related diseases, coding and the descriptive epidemiology results are presented. The mean of the annual incidence rate of repeat breeder cow syndrome of phase one was significantly higher ($P \leq 0.05$) than the mean of repeat breeder cow syndrome in phase two of the study. The amount of corn silage (dry matter basis) fed to dry cows in phase two was significantly higher than the amount of corn silage fed to dry cows in phase one ($P \leq 0.01$). The amount of dry hay and haylage (dry matter basis) fed to dry cows in phase one was significantly higher than the amount of dry hay and haylage fed to dry cows in phase two ($P \leq 0.05$). The means and standard deviations of some of the risk factors involved were: age 2.720 ± 0.620 lactation,

annual incidence density (ID) rate of repeat breeder cow syndrome $6.887 \pm 7.271/100$ cow years, annual ID rate of mastitis $30.779 \pm 25.627/100$ cow years, annual ID rate of metritis $18.831 \pm 24.175/100$ cow years. The Cumulative Incidence (CI) rate of milk fever, retained placenta and dystocia were 4.400 ± 2.228 , 5.247 ± 5.499 and $4.94 \pm 7.484/100$ calvings, respectively. Mastitis, metritis and repeat breeder cow syndrome were the most frequent diseases in the State of Michigan.

4.2 Introduction

The Repeat Breeder Cow Syndrome (RBCS) in dairy cattle has been reviewed by several authors (Cacida, 1961; Zemjanis, 1980; Gunther, 1981; Lafi and Kaneene, 1988). Nutritional, hormonal disorder, health related events, management and environmental risk factors have been reported to be associated with the occurrence of this syndrome. These factors, however, have been researched and reported separately (McDonal, 1961; Morrow, 1969; Kimura et al., 1987). By researching the above risk factors separately, it is difficult to assess their relative contribution to the occurrence of RBCS; furthermore, it is not easy to assess the economic impact of this syndrome in dairy farms, especially on the herd level.

Although many investigators consider that RBCS is a temporary problem, it is believed that this syndrome is associated with a great deal of economic impacts (Bulman and Lamming, 1978; Dekruif, 1978; Bartlett et al., 1986a). It has been reported that more than 55.5% (581/1046) of the culled cows were culled because of failure to conceive (Young et al., 1983) of which 36% (209/581) had received three or more inseminations.

More recently, Bartlett et al. (1986a) reported that 54 % (103/190) of the repeat breeder cows were culled exclusively because of this syndrome, and a repeat breeder cow was associated with a loss of \$365 per lactation.

4.3 OBJECTIVES

The objectives of this Chapter were to: describe the study design and the data obtained, including the herd selection, data collection,

computation of the incidence rate of some health-related events, coding and the descriptive epidemiological results.

4.4 MATERIALS AND METHODS

Study Population

The data used for this study came from the National Animal Health Monitoring System (NAHMS) project in the state of Michigan. Detailed information of the program implementation, herd selection, and data gathering was discussed elsewhere (Kaneene and Hurd, 1989). Briefly, the state of Michigan joined NAHMS in the fall of 1986. The objective of NAHMS is to provide statistically valid data about animal and poultry health-related events. These data are used for estimating the incidence, prevalence and cost of these events. In Michigan, the program involved only the dairy cattle. This study was conducted in two twelve months phases. Phase one was during 1986-1987 and phase two was during 1988-1989. Since the procedures and methods that were used for the study design, herd selection, data collection, and calculation of the incidence rate of various diseases involved were the same in both phases, this chapter will discuss in detail the aforementioned procedures and methods of only phase one.

Study Design

The NAHMS project in Michigan was designed primarily as a cohort longitudinal (prospective) study. The cross-sectional study approach was used to gather information at the beginning and at the end of the study. For this study, a combination of a prospective and a cross-sectional study design was used.

Herd Selection

The state of Michigan is divided into six agricultural districts. Herds within each district were stratified into four strata according to their herd size. A random sample of sixty dairy herds was selected proportionately according to their size strata and district. The multistage sampling procedure methods were used for selection of the aforementioned herds. Stratum 1 included herds of 10-49 adult (milking and dry) cows; in this stratum sixteen herds were selected. Stratum 2 included herds of 50-99 adult cows; in this stratum twenty two herds were selected. Stratum 3 included herds of 100-199 adult cows; in this stratum sixteen herds were selected. Stratum 4 included herds of two hundred or more (200+) adult cows; in this stratum five herds were selected.

Data Collection

State, Federal and University Veterinary Medical Officers, following an initial basic training in interviewing skills, concepts of epidemiology and sampling, were assigned two to six herds from which to collect data. These data were collected on a monthly basis and continued for twelve months consecutively.

Special forms were designed to gather data in regard to management, environment, inventory, production and health-related events including prevention and treatment as well as their associated costs. Since some valuable information could not be gathered on a monthly basis or did not vary from month to month, two epidemiological surveys were designed to capture this information. The first survey was conducted at the beginning of the study after the selected farmers agreed to participate

in the NAHMS program. The second one was comprehensive and was designed to gather information that was not possible to be collected during the study and to validate the first survey. These surveys included questions about management structure, milking system procedure, preventive programs, utilization of veterinary services, reproductive management, nutrition and other farm-related information.

Determination of Repeat Breeder Cows

In regard to repeat breeder syndrome, 54.34% (25/46) of the participating herds that were included in the first year of the study used only artificial insemination. A bull was used exclusively for breeding in 7 herds (15.21%). A combination of a bull and artificial inseminations were used in 14 herds (30.43%).

In some herds, because of the unreported dates of breedings or inseminations and the use of both a bull and artificial insemination, the number of breedings or inseminations per cow was not possible to estimate. In such instances, when a cow was culled, the farmer was asked about the reason for culling. The cow was classified as a repeat breeder if the farmer indicated that the main reason for culling was failure to conceive after three or more services.

Incidence Rate and Population at Risk

Incidence rates measure the probability that healthy individuals will develop a disease during a specified period of time. It is the number of new cases of a disease occurring in a population at risk over a period of time. Thus, the incidence rate indicates the rate at which new cases of a disease occur in a defined, previously disease-free population

Schwabe, 1977; Schlesselman, 1982; Mausner and Bahn, 1985; Martin et al., 1987). The incidence rate can be calculated by dividing the total number of a new disease cases by the population at risk.

For this study, two methods were used to calculate the incidence rate of the diseases involved: the Cumulative Incidence (CI) rate and the Incidence Density (ID) rate.

Cumulative Incidence (CI) rate

The cumulative incidence rate is used as a measure of disease frequency and was calculated as the number of new cases occurring within a specified period of time, divided by the number of animals initially at risk (Kupper and Hogan, 1978). This rate can be interpreted as an estimate of the average risk of disease for individuals present in the group under study. In the literature many forms of disease incidence rate have been developed on the basis of the (CI) rate, e.g., lactation incidence rate that was introduced by Erb and Martin et al. (1980). For this study the incidence rate that was used by Bendixen et al. (1986) was also employed for calculating the incidence rate of dystocia, retained placenta and milk fever. This rate was expressed as a rate per 100 calvings (see equation 1).

Equation 1:

$$CI = \frac{\text{\# of cows developing the disease during the study period}}{\text{\# of calvings occurring during the same period of time}} \times 100$$

Incidence Density (ID) rate

This rate is also a measure of disease frequency, and it is defined as the number of new cases occurring in a specified period of time divided by the population-time over which they occur (Miettinen, 1976). In Michigan dairy farms, it is quite a frequent occurrence and natural for the farmers to sell and purchase some dairy cows for different purposes. Thus, the time of observation and the number of cows at risk was not uniform through the time period of this study. Furthermore, the exact date for the onset of diseases, entrance and removal of the animals was not reported. The month in which the events occurred, however, was known. The only date reported was the calving date. Keeping this in mind, it is not possible to estimate the exact time of observation for each cow at risk. Therefore, the approximation method of the ID rate that was discussed by Martin et al. (1987) was employed to estimate the total time of observation each month for each herd and to calculate the ID rate of abortion, cystic ovaries, ketosis, mastitis, metritis and repeat breeder cow syndrome. For calculating the monthly and the annual ID rate of the above diseases, equations 2 and 3 were used, respectively.

Equation 2:

$$ID = \frac{\text{\# of new cases occurring during the month}}{\frac{\left(\text{\# of cows at risk at the end of previous month} + \text{\# of cows at risk at the end of current month} \right)}{2}} \times 100$$

Equation 3:

$$ID = \frac{\text{\# of cases occurring during the study period (one year)}}{\text{Average number of cows in the herd for the 12 months}} \times 100$$

The monthly ID was expressed as a rate per 100-cow months and the annual ID was expressed as a rate per 100-cow years. For ketosis, mastitis and metritis, a minimum of one month had to elapse between two cases in order for them to be considered as separate episodes. This time period was chosen because the VMO visited the farm once a month and the date of the disease onset was not reported. Because it is critical to know what was considered as the population at risk for the diseases that were used as determinants of RBCS, a summary of calculating population at risk and incidence rate of the diseases involved will be presented.

Mastitis

Mastitis cases included all new clinical mastitis of specified and non-specified cause. The population at risk for computing the ID rate included all mastitis-free adult cows, milking and dry, that were present at the farm each month. Dry cows were included in the population at risk due to the fact that some cases of mastitis were reported during the dry period as well as during calving. Since there was a high rate of cow movement in and out of the herd during each month, the approximate ID rate method was employed for calculating the incidence rate of this disease (see equation 2). In this study, if a cow developed the disease during the month and did not recover by the end of the same month, she was excluded from being at risk for the following month. This condition was also valid for ketosis and metritis. Equations 2 and 3 were used for calculating the monthly and the annual ID rate of mastitis, respectively.

Ketosis

Ketosis cases included all new clinical primary and secondary ketosis. All non-diseased cows present at the farm were considered to be at risk each month of developing ketosis. The same procedure used in calculating the ID rate of mastitis was also employed to calculate the ID rate of ketosis.

Metritis

All the uterine inflammations were counted and reported as metritis. Since most cases of metritis are developed within the first three months postpartum or following an abortion see ID rate of abortion.

all the open non-diseased cows as well as the pregnant cows were considered to be at risk of developing metritis. The procedure that was used for calculating the ID of mastitis was also used for calculating the ID of this disease.

Abortion

Cases of abortion included those that were seen by the farmer. Since it is known that most early embryonic death occurs between 8 and 19 days after breeding (Roche, 1986), and cows that experienced abortions in the early stages of their pregnancy pass unnoticed, it was not possible to determine directly the number of cows at risk of developing abortion on a monthly basis. The records of Michigan Dairy Herd Improvement Association (DHIA) for 1987 indicated that the average days open in Michigan dairy herds was 113, and the average calving interval was 395 days. Utilizing these records, it was noticed that the days open were equal to $28.61\% [(113/395) \times 100 \ %]$ of the calving interval. Since the

time period of this study was one year, on the average 28.61% of the study time period [$365 \times 28.61\% = 104$ days] cows that were present at each farm could be considered to be open and not at risk of developing abortion. Basically, equation 3 was slightly modified in order to be used for calculating the annual incidence rate of abortion. Thus, the denominator was multiplied by 71.39% ($100\% - 28.61\%$) to obtain the total time of observation for cows at risk of developing abortion.

Cystic Ovaries

Cases of cystic ovaries included both the cystic follicle and the luteal cysts. It has been reported that 50% of cows developing cystic ovaries within 45 days postpartum recover spontaneously before 60 days postpartum (Morrow, 1966). Whitmore et al. (1974) reported that cows are at risk of developing cystic ovaries as long as they are open. In some herds, not all cows were checked for pregnancy at specified periods of time; therefore, it was not possible to estimate directly the number of cows at risk. The indirect method that was used to estimate the number of cows at risk of developing abortion was also used for estimating the number of cows at risk of developing cystic ovaries. Cows in each herd were considered to be at risk of developing cystic ovaries until they were pregnant. The constant 28.86% as a cut-off point was multiplied by the denominator of equation 3 to obtain the total time of observation for cows at risk of developing cystic ovaries.

Repeat Breeder Cow Syndrome

It was not possible to calculate the ID rate of this syndrome on a monthly basis. The annual ID rate was used (equation 3).

Dystocia, Milk Fever and Retained Placenta

Dystocia cases included dystocia assisted by the farmer and/ or by a veterinarian. Milk fever included cases that occurred any time before or after calving; retained placenta was reported as a case if the fetal membranes were expelled after 12 hours postpartum. The calculation of the incidence rate of these health-related events was accomplished by using equation 1.

Age

Ages of all adult cows (milking and dry) that were present at the farm were recorded at the initial visit for all but one selected herd. The ages were expressed in terms of number of lactations. It was decided to exclude the herd that had no reliable lactation numbers from the analyses of this study. Cows that calved during the period of the study were reported on a monthly basis, and their new lactation number was considered in calculating the herd age average for each month. First-calf heifers that joined the adult herd upon freshening were also reported on a monthly basis. These first caif heifers were counted as first lactation cows.

The herd age average at the beginning of the month was calculated by multiplying each cow by her number of lactations. The total number of lactations was then divided by the number of cows that were present in the herd. The same method was used to calculate the herd age average at the end of the month. The monthly herd age average was estimated as the mean of the herd age average at the beginning and at the end of the month. The annual herd age average was calculated as the sum of the twelve months' herd age, and then divided by twelve.

Herd Size

For calculation of the herd size, only adult cows were included. On a monthly basis, the herd size was calculated as the mean of the total number of cows at the beginning and at the end of the month. The annual herd size was calculated as the sum of the twelve monthly means and then divided by twelve.

Nutritional Risk Factors for the Dry Cows

To evaluate the nutritional risk factors during the dry period, all feedstuffs were converted to dry matter basis using the following steps:

- 1) The amount of each feed that was fed to dry cows in each herd was multiplied by its corresponding percent of dry matter using the values reported by the (National Research Council, 1978) the sum of which equals total dry matter.
- 2) The percent of the dry matter derived from each feedstuff was then determined.

Variable Definition and Data Coding

Abbreviations and definitions of the variables obtained from the prospective study and the epidemiological surveys are shown in Table 4.1. A summary of the responses to questions pertaining to herd reproductive management, housing, nutrition during the dry period, and environment in the epidemiological surveys that were conducted in phase one and phase two are shown in Table 4.2.

Table 4.1. Abbreviations and definitions of the risk factors used in the study (96 dairy herds of NAHMS in Michigan 1986-1989)

<u>Abbreviation Risk factor definition</u>	
	<u>Dependent Variable</u>
RBCS	Repeat breeder cow syndrome included cows that failed to become pregnant after 3 or more inseminations
	<u>Independent Risk Factors</u>
	<u>A. Risk factors obtained from the prospective study</u>
ABOR	Abortion seen by the farmer
AGE	Yearly herd age average in lactations
DYST	Dystocia included cases assisted by a veterinarian and/or by farmer
CYOV	Cystic ovaries included luteal cysts and follicle cysts
KETO	Ketosis included primary and secondary ketosis
MAST	Mastitis included clinical cases of specified and non-specified cause
METR	Metritis included all types of the uterine inflammation
MILF	Milk fever included cases that appeared before and after calving
REPL	Retained placenta included all cases of fetal membranes that were not expelled within 12 hours after calving
SIZE	Yearly herd size average
TMSO	Total milk sold to the milk processors in pounds
	<u>B. Risk factors obtained from the epidemiological surveys</u>
Bull	Bull was used exclusively for breeding at the farm
COSD	Amount of corn silage (D.M. basis) fed to dry cows lb/day
DHDC	Amount of dry hay (D.M. basis) fed to dry cows lb/day
HADC	Amount of haylage (D.M. basis) fed to dry cows lb/day
HOUS	Type of housing system of the farm
PERC	Percent of cows inseminated A.I.
TOBR	Time of insemination after cow seen in heat
YEAR	Phases of the study (1986-1987 or 1988-1989)

4.5 RESULTS

Phase One (1986-1987)

Forty-six of the 60 herds that were randomly selected to participate in the NAHMS project in Michigan 1986-1987 had sufficient data and were used in this study. Table 4.3 presents the number of the new disease cases that were reported in the 46 herds by their stratum during their participation in the study. Table 4.3 shows that cases of clinical mastitis, metritis and repeat breeder cow syndrome had the most frequent occurrence compared to the other diseases. The descriptive statistics of the diseases involved, age, and herd size of all participating herds by their size stratum and the nutritional risk factors during the dry period are in Table 4.4 and 4.5, respectively. For most diseases, the highest incidence rate was in stratum IV but the increase or the decrease in the incidence rate throughout the four size strata was not uniform. The overall incidence rate of various diseases, herd size, age, nutritional risk factors during the dry period and total milk sold are shown in Table 4.6. cystic ovaries and repeat breeder cow syndrome had the most frequent occurrence compared to the other diseases.

Phase Two (1988-1989)

Table 4.7 presents the number of new disease cases that were reported in the 50 herds by their stratum during their participation in this study. Table 4.7 shows that cases of clinical mastitis, metritis, cystic ovaries and repeat breeder cow syndrome had the most frequent occurrence compared to the other diseases.

Table 4.2. Summary of the responses to questions related to herd reproductive management and housing in the epidemiological surveys (96 dairy herds of NAHMS in Michigan 1986-1989)

Variable ¹ Abbreviation	Responses, coding and Frequency of responses ²	Mean	Median
<u>HOUSING SYSTEM</u>			
<u>Phase one (1986-1987)</u>			
HOUS: Free stall	Yes (1)= 27	0.587	1.00
Others	No (0)= 19		
<u>Phase two (1988-1989)</u>			
HOUS: Free stall	Yes (1)= 33		
Others	No (0)= 17		
<u>BREEDING AND INSEMINATION</u>			
<u>Phase one (1986-1987)</u>			
BULL	Yes (1)= 7	0.152	0.00
	No (0)= 39		
<u>Phase two (1988-1989)</u>			
BULL	Yes (1)= 12	0.240	0.00
	No (0)= 38		
<u>TIME OF INSEMINATION</u>			
<u>Phase one (1986-1987)</u>			
BULL	Yes (0)= 07		2.00
≤ 5 hours	Yes (0)= 05		
6-15 hours	Yes (1)= 34		
<u>Phase two (1988-1989)</u>			
BULL	Yes (0)= 12		2.00
≤ 5 hours	Yes (0)= 03		
6-15 hours	Yes (1)= 35		

Table 4.2. (cont'd)

PERCENTAGE OF COWS INSEMINATED A.I.Phase one (1986-1987)

PRAI

≤ than 25%	(1)= 9	4.00
25% to 50%	(2)= 2	
50% to 75%	(3)= 10	
75% to 100%	(4)= 25	

Phase two (1988-1989)

PRAI

≤ than 25	(1)= 14	4.00
25% to 50%	(2)= 03	
50% to 75%	(3)= 06	
75% to 100%	(4)= 27	

NUMBER OF HERDS IN EACH PHASE

Phases :

First phase	Yes (0)= 46
Second phase	Yes (1)= 50

- ¹ For risk factor abbreviation and definition see Table 4.1.
² Numbers in the parenthesis represent the variable coding.

Table 4.3. Reported disease problems obtained from the prospective study by stratum, phase one (46 dairy herds of NAHMS in Michigan 1986-1987)

STRATUM No.	<u>Diseases</u> ¹								
	KETO	MAST	CYOV	ABOR	METR	RBCS	DYST	MILF	REPL
STRATUM I (n = 17) ²	9	191	5	4	49	122	20	25	14
STRATUM II (n = 16)	30	395	26	10	164	103	80	60	104
STRATUM III (n = 9)	16	375	20	2	90	116	19	29	81
STRATUM IV (n = 4)	96	339	71	15	435	106	82	73	30
TOTAL	152	1300	122	31	738	447	201	187	229

¹ For disease definition and abbreviation see Table 4.1.

² n = number of herds in each stratum.

Table 4.4. Descriptive statistics of the risk factors involved by statum, phase one (46 dairy herds of NAHMS in Michigan 1986-1987)

Risk factor name ¹	<u>STRATUM I</u> (10 - 49) ² (n = 17)		<u>STRATUM II</u> (50 - 99) (n = 16)		<u>STRATUM III</u> (100 - 199) (n = 9)		<u>STRATUM IV</u> (200 +) (n = 4)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
<u>Dependent Variable</u>								
RBCS ³	8.825	9.646	8.203	4.563	6.093	6.010	3.519	3.444
<u>Independent Risk Factors</u>								
KETO ³	0.745	1.459	2.691	3.842	1.231	2.203	10.668	14.500
MAST ³	33.969	33.753	34.243	19.222	31.036	12.441	39.524	26.133
METR ³	9.350	11.841	15.628	22.153	7.162	8.540	49.951	44.275
ABOR ³	1.430	1.970	1.430	1.972	0.286	0.569	2.385	1.856
CYOV ³	4.265	8.955	8.025	12.900	5.110	8.574	27.355	33.361
DYST ⁴	4.288	7.288	7.542	9.315	1.410	1.652	9.143	15.938
MILF ⁴	3.827	4.148	5.265	3.495	2.539	2.075	7.848	4.771
REPL ⁴	2.696	5.175	8.203	4.563	6.093	6.007	3.519	3.444
SIZE	34.420	9.437	73.987	20.690	135.106	24.362	216.542	10.573
AGE ⁵	2.823	0.894	2.512	0.713	2.563	0.606	2.670	0.107

¹ For risk factor abbreviation and definition see Table 4.1.

² Herd size.

³ Expressed as annual ID rate /100 cow years.

⁴ Expressed as a rate rate /100 calvings.

⁵ Age measured in lactations.

Table 4.5. Descriptive statistics of nutritional risk factors during the dry period, phase one
(46 dairy herds of NAHMS in Michigan 1986-1987)

Risk factor name ¹	<u>STRATUM I</u> (10 - 49) ² (n = 17) ³		<u>STRATUM II</u> (50 - 99) (n = 16)		<u>STRATUM III</u> (100 -199) (n = 9)		<u>STRATUM IV</u> (200 +) (n = 4)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
COSD	14.573	4.206	11.806	3.492	7.961	3.510	15.425	4.371
DHDC	74.116	4.535	59.666	6.214	58.537	6.098	43.266	3.999
HADC	4.194	3.039	24.876	5.805	26.319	5.641	30.923	5.610
GFDC	7.117	2.611	3.652	2.518	6.959	3.213	10.385	3.505

¹ For risk factor definition and abbreviation see Table 4.1.

² Herd size.

³ n = number of herds in each stratum.

Table 4.6. Overall incidence rates of the diseases involved and a description of other risk factors involved, phase one (46 dairy herds of NAHMS in Michigan 1986-1987)

Risk factor name ¹	Mean	Maximum	Minimum	S.Deviation
<u>Dependent Variable</u>				
RBCS	9.154	30.145	0.000	7.734
<u>Independent Risk Factors</u>				
ABOR	1.189	6.530	0.000	1.918
DYST	5.279	34.483	0.000	8.470
CYOV	7.747	69.850	0.000	14.542
KETO	2.380	31.891	0.000	5.300
MAST	33.975	114.286	0.000	27.699
METR	14.701	105.655	0.000	22.103
MILF	4.426	15.094	0.000	3.823
REPL	5.348	18.966	0.000	5.444
AGE	2.652	4.985	1.154	0.729
SIZE	83.543	232.042	14.790	58.134
COSD	12.391	46.388	0.000	3.846
HADC	18.084	100.000	0.000	5.276
DHDC	63.359	100.000	0.000	5.623
GFDC	6.165	30.511	0.000	2.820
TMSO	1,187,210	4,310,224	85,172	950,537

¹ For risk factor abbreviation and definition see Table 4.1.

Table 4.7. Reported disease problems obtained from the prospective study by stratum, phase two (50 dairy herds of NAHMS in Michigan 1988-1989)

STRATUM No.	Diseases ¹								
	KETO	MAST	CYOV	ABOR	METR	RBCS	DYST	MILF	REPL
STRATUM I (n = 13) ²	15	159	10	8	61	10	24	18	31
STRATUM II (n = 23)	71	379	78	28	490	103	93	90	98
STRATUM III (n = 10)	17	519	159	17	393	79	33	38	44
STRATUM IV (n = 4)	10	173	1	8	156	25	12	16	34
TOTAL	113	1230	248	61	1100	217	162	162	207

¹ For disease definition and abbreviation see Table 4.1.

² n = number of herds in each stratum.

The descriptive statistics of the diseases involved, age, and herd size of the participating herds by their size stratum and the nutritional risk factors during the dry period are in Table 4.8 and 4.9, respectively. For most diseases the increase or the decrease in the incidence rate throughout the four size strata was not uniform. The overall incidence rate of various diseases, herd size, age, nutritional risk factors during the dry period and total milk sold are shown in Table 4.10. No statistically significant results were found when comparing the mean of overall incidence rate of each disease in phase one with the corresponding mean of each disease in phase two ($P \leq 0.05$, t-test) except for the ID rate of RBCS. COSD was fed more to dry cows during phase two, while HADC and DHDC were fed more to dry cows in phase one. These results were statistically significant at ($p \leq 0.05$) (t-test).

Pooling the Data of the Two Phases

Data of both phases were pooled together to be used in the analyses of the study. The overall incidence rates of various diseases involved, herd size, age, nutritional risk factors during the dry period, and the total milk sold of 96 herds are shown in Table 4.11.

4.6 DISCUSSION

The 60 herds were randomly selected in each phase of the study to obtain a representative sample of the dairy industry in the state of Michigan. Therefore, the generalization of the results to other dairy farms in the state might be valid. In phase one, seven (11.67%) of the

Table 4.8. Descriptive statistics of the risk factors involved obtained from the prospective study by stratum, phase two (50 dairy herds of NAHMS in Michigan 1988-1989)

Risk factor name ¹	<u>STRATUM I</u> (10 - 49) ² (n = 13) ³		<u>STRATUM II</u> (50 - 99) (n = 23)		<u>STRATUM III</u> (100 -199) (n = 10)		<u>STRATUM IV</u> (200 +) (n = 4)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	<u>Dependent Variable</u>							
RBCS	3.209	7.011	5.575	6.398	5.959	5.904	2.912	3.105
<u>Independent Risk Factors</u>								
KETO	3.374	5.886	4.285	4.285	0.938	1.895	1.056	1.547
MAST	32.371	30.049	22.932	17.461	37.663	26.441	16.231	17.231
METR	37.306	9.186	29.028	28.092	15.831	26.260	22.631	25.562
ABOR	2.642	4.098	2.228	2.439	1.575	2.012	1.084	1.304
CYOV	9.228	12.919	14.830	21.211	10.292	21.219	0.349	0.697
DYST	4.855	6.243	6.133	8.077	2.158	1.247	1.468	1.936
MILF	3.925	3.585	5.848	5.680	2.638	2.617	1.698	1.125
REPL	7.472	7.608	5.247	4.749	2.596	3.352	3.488	5.766
SIZE	37.660	10.297	69.605	19.742	139.204	39.224	233.510	27.689
AGE	2.849	0.398	2.789	0.498	2.709	0.696	2.706	0.352

¹ For risk factor abbreviation and definition see Table 4.1.

² Herd size.

³ n = number of herds in each stratum.

Table 4.9. Descriptive statistics of nutritional risk factors during the dry period, phase two (50 dairy herds of NAHMS in Michigan 1988-1989)

Risk Factor name ¹	<u>STRATUM I</u>		<u>STRATUM II</u>		<u>STRATUM III</u>		<u>STRATUM IV</u>	
	(10 - 49) ²		(50 - 99)		(100 - 199)		(200 +)	
	(n = 13) ³		(n = 23)		(n = 10)		(n = 4)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
COSD	31.751	4.950	25.939	5.064	16.127	4.515	23.819	4.382
DHDC	53.222	5.469	49.014	5.654	64.154	5.543	67.785	5.461
HADC	10.360	4.255	16.049	4.944	13.398	4.515	8.396	3.429
GFDC	4.667	2.882	8.997	3.255	6.320	3.465	6.616	3.171

¹ For risk factor definition and abbreviation see Table 4.1.

² Herd size.

³ n = number of herds in each stratum.

Table 4.10. Overall incidence rates of the diseases involved and a description of other risk factors involved, phase two (50 dairy herds of NAHMS in Michigan 1988-1989)

Risk Factor name ¹	Mean	Maximum	Minimum	ST.Deviation
<u>Dependent Variable</u>				
RBCS	4.824	30.064	0.000	6.239
<u>Independent Risk Factors</u>				
ABOR	2.114	11.319	0.000	2.803
DYST	4.632	34.632	0.000	6.518
CYOV	11.307	96.307	0.000	18.509
KETO	3.120	19.896	0.000	5.295
MAST	27.839	88.294	0.000	23.458
METR	22.631	93.506	0.000	25.562
MILF	4.376	25.330	0.000	4.608
REPL	5.155	19.050	0.000	5.603
AGE	2.782	4.125	1.230	0.500
SIZE	88.332	267.875	15.667	60.208
COSD	25.318	100.000	0.000	4.886
HADC	13.427	86.795	0.000	4.582
DHDC	54.638	100.000	0.000	5.557
GFDC	6.616	35.743	0.000	3.171
TMSO	1,313,943	3,946,230	176,434	905,079

¹ For risk factor abbreviation and definition see Table 4.1.

Table 4.11. Overall incidence rates of the diseases involved and a description of other risk factors after pooling the data of phase one and phase two (96 dairy herds of NAHMS in Michigan 1986-1989)

Risk Factor name ¹	Mean	Maximum	Minimum	ST.Deviation
<u>Dependent Variable</u>				
RBCS ²	6.877	30.145	0.000	7.271
<u>Independent Risk Factors</u>				
ABOR ²	1.671	11.319	0.000	2.451
DYST ³	4.942	34.620	0.000	7.484
CYOV ²	9.601	96.627	0.000	16.735
KETO ²	2.766	31.891	0.000	5.282
MAST ²	30.779	114.286	0.000	25.627
METR ²	18.831	105.655	0.000	24.175
MILF ³	4.400	25.330	0.000	2.228
REPL ²	5.247	19.050	0.000	5.499
AGE ⁴	2.720	4.985	1.154	0.620
SIZE	86.037	267.875	14.790	58.961
COSD	19.124	100.000	0.000	20.969
DHDC	58.817	100.000	0.000	31.375
HADC	15.659	100.000	0.000	24.496
GFDC	6.400	33.086	0.000	9.062
TMSO	1,253,217	4,310,224	85,172	924,420

¹ For risk factor abbreviation and definition see Table 4.1.

² Expressed as an annual incidence density (ID) rate/100 cow years.

³ Expressed as a cumulative incidence (CI) rate/100 calvings.

⁴ Measured in lactations.

elected herds refused to participate in the NAHMS project for various reasons. One herd failed to complete the period of study and dropped out after three months. One herd did not provide a complete monthly inventory report which made it impossible to estimate the total number of animals at risk. Another herd did not keep good records. Therefore, it was decided not to include these herds in the analyses of this study. Four herds agreed to participate in the program, but there was no VMO available to collect the data and to interview the farmer on a monthly basis. Thus, the total number of herds which completed the entire period of phase one was 46 herds. A total number of 50 herds was included in the analyses of the study came from phase two.

This study was primarily a prospective study with a two year duration. Farmers were paid \$300 a year for their participation in the NAHMS project. Confidentiality of the information about the farm and the farmer was maintained between the farmer and the VMO who was assigned to collect the data. In fact, nobody knew the farm or the farmer that participated in this study except the VMO who was assigned to collect the data from the farm. The task of the VMO was to collect the data and to visit with the farmer once a month. It was agreed that the VMO should not give any medical advice to the participating farmers during the period of the study.

Feedback on each herd's disease status was given to the farmer through his/ her VMO on a monthly basis to compare the monthly incidence rates of the diseases that occurred in his farm with the disease status of other farms in the same size stratum. A semi-annual and a final report, which included the statistics of the health status and disease expense status, were given to the participants at the end of six months

and again after one year of their participation.

The information gathered from the initial and the second epidemiological survey of each phase was very valuable in evaluating the farm performance; particularly regarding the maternity stalls, milking system procedure, general management procedure and reproductive management methods. In the case of nutrition, however, it was very common for some herds to change their feed according to the season of the year. Also, it was not surprising for some herds to change part of their feed, especially the minerals and the vitamins several times a year according to the market prices. Furthermore, in most herds the feed analysis was not done according to the frequency of the feed ration change.

Farmers that produced their own feed did not know the exact amount of feed that was used during their participation in the NAHMS program. Additionally, most of the farmers used a volume type of measurement and not the exact weight. Due to the aforementioned reasons, it was not possible to estimate the exact amount of intake feed ration per cow or on a herd level. The second epidemiological survey of each phase was useful in gathering data only on some nutritional parameters.

As in all observational epidemiological studies in veterinary medicine, the data validity and quality depend upon the level of cooperation of the farmers involved. Data about the disease occurrences were dependent on the farmers' and veterinarians' records and recall of some events that took place during each month of their participation.

The farmers' ability to keep records varied from farmer to farmer, and in a few cases it might have contributed to the difference in the disease incidence rates among farms. All herds that were included in

this study maintained individual identification for their cows, and the data were collected on a monthly basis by veterinarians. These approaches: confidentiality, feedback, the monthly visit by a veterinarian, the individual cow identification and the semi-annual report probably enhanced the type of data in terms of quality and precision.

The incidence rate approach is the most important and strongest foundation of epidemiology. In this study two methods were used for calculating the incidence rates: the CI rate and the ID rate. Among the many advantages that may result from using the annual incidence rate approach is creating a continuous variable which has many advantages when compared to a dichotomous variable in the statistical analyses.

In the literature, many investigators have used the individual cow as a unit of comparison in their analyses (Martin et al., 1982; Dohoo et al., 1983; Erb et al., 1981, 1984, 1985; Bartlett et al., 1986a and 1986b). In this study, it was decided to use the herd as a unit of comparison because cows at the farm may share the same environmental conditions, housing system, reproductive management as well as nutrition. Also, many management decisions are made based on the farm as a whole and not on an individual animal. This approach (using the herd as a unit of comparison) might reduce some of the confounding variations that may result in the data analyses. On the other hand, this approach causes reduction in the sample size and consequently, it might produce some difficulties in obtaining statistically significant results. For example, in order for the correlation coefficient to be statistically significant at ($p \leq 0.05$) with a sample size of 96 the absolute value of the correlation coefficient must be ≥ 0.20 .

Due to the unreported dates of the occurrence or the recurrence of any health-related events and the possibility for multiple occurrence of some diseases in dairy cattle in a short period of time, e.g., mastitis, it was not possible to determine or examine the time ordering of various health-related events within each month. For example, if a cow experienced metritis and mastitis during the time period between two consecutive visits of the VMO to the farm, it was not possible to determine which disease occurred first.

The results that are shown in Table 4.3 were obtained from the prospective study of phase one. These results clearly validated the results obtained from the first epidemiological survey that was conducted at the initial visit of the VMO to the farm. These results suggested further research to be conducted in the field of mastitis and reproduction. Similar results were also obtained from phase two.

When comparing disease incidence rates obtained from this study with other studies reported in the literature, many factors should be considered. Some of these factors are: the unit of comparison, methods of herd selection and data collection, disease definition, diagnosis criteria, methods used to determine the animal at risk for each specific disease problem and approaches of calculating the incidence rate. For example, the overall annual (ID) rate of mastitis ranged from 0 to 114.286 per 100 cow years with a mean of 30.779 per 100-cow year (Table 4.11). This rate is much higher than the rate reported previously by Bartlett et al. (1986b) in Michigan. This difference in the incidence rate was probably due to the method used for selecting the farms to serve in their data base, the time period of their study and the methods used for data collection. Nonprobability sampling (convenient sampling)

method was used in Bartlett et al (1986b). These researchers included herds that had good record keeping and relatively good management standards. Nonprobability sampling procedure, different diagnosis criteria and different methods of calculating the disease incidence rates were used in several veterinary epidemiological studies (Erb and Martin., 1980; Dohoo et al., 1983; Erb et al., 1984). Therefore, a comparison between the results obtained from those studies and this study could be difficult.

In defining the cows at risk of developing abortion, the 71.39% was multiplied by the denominator of equation 3 in order to obtain the time observation of cows at risk. This cut-off point is based on the DHIA records of Michigan for 1987, and it is known that the participating herds on the DHIA do not represent the Michigan dairy industry.

The overall annual ID rate of cystic ovaries in this study ranged between 0 to 96.627 per 100 cow years with a mean of 9.601 per 100 cow years. The 28.61% was also multiplied by the denominator of equation 3 in order to obtain the time observation of cows at risk of developing cystic ovaries. Cystic ovaries are mostly diagnosed by veterinarians and many herds included in this study did not utilize the veterinary services on a regular basis. Therefore, it is not surprising that some cases of cystic ovaries went unnoticed, and consequently, unreported.

The overall annual ID rate of repeat breeder cow syndrome ranged between 0 to 30.145% with a mean of 6.877 per 100 cow years. This rate is lower than the rates reported by Bartlett et al. (1986a). Since 15.21% of the participating herds exclusively used a bull for breeding cows and others used a combination of both a bull and artificial insemination, in those herds, it was difficult to estimate accurately the

number of breedings that the cow had received to achieve conception. The overall CI rate of dystocia, milk fever and retained placenta were in agreement with the rates reported in other studies (Bendixen et al., 1986; Bendixen et al., 1987) because diagnosis criteria used in those studies and this study were similar to each other and the rate was expressed per 100 calvings.

The annual ID rate of RBCS in phase one was significantly higher than the annual ID rate of RBCS in phase two. In phase two the diagnosis criteria were slightly modified to include the exact date of each insemination or breeding that the cow had. All cows that were considered repeat breeders had a reported exact date of each breeding. In farms that a bull or a combination of bull and artificial insemination was used, some difficulties occurred in reporting the date of each breeding. Consequently, many cases of RBCS went undetected.

The amount of COSD fed to dry cows was significantly higher in phase two than in phase one while the amount of dry hay and haylage fed to dry cows was significantly lower in phase two than in phase one. The rain fall in the summer of 1988 was very low and consequently, farmers had and fed more COSD to dry cows.

The herd age average was smaller than the herd age average reported by Erb and Martin (1980) and Dohoo et al. (1983) but this age average was in agreement with the cow age average reported by the DHIA in Michigan 1988.

The information about the milk sold was gathered based on the receipts of the milk processors. The amount of milk fed to the calves or consumed by the farmer was not reported.

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CHAPTER V

EPIDEMIOLOGICAL MODELING OF REPEAT BREEDER COW SYNDROME

5.1 ABSTRACT

Three epidemiological models of Repeat Breeder Cow Syndrome (RBCS) were developed using data obtained from both surveys and prospective studies of 96 dairy herds participating in the National Animal Health Monitoring System (NAHMS) in Michigan. These models were designed to study the relationship between RBCS and six common risk factors: (1) herd characteristics and environment, (2) nutrition during the dry period, (3) diseases which occurred within 72 hours of calving, (4) diseases which occurred after 72 hours after calving, (5) reproductive management, and (6) milk production. Principal components analysis was used to examine the interrelationships among the predictor risk factors. In Model 1 the variable synthesis approach was utilized to combine related risk factors into one common risk factor. Herd characteristics and diseases which occurred within 72 hours of calving were significant determinants of RBCS ($p \leq 0.01$). Milk fever, dystocia and retained placenta occurred as a complex and contributed the most to the incidence density (ID) rate of RBCS. In Model 2 the hierarchical regression technique was applied to measure the relative contribution of each individual risk factor involved in RBCS. Dystocia and milk fever as individual risk factors were positively associated with RBCS, while herd age average was negatively associated with RBCS. In Model 3 a path model was developed to display and to quantify the associations among the

significant risk factors that were obtained from Model 2. Dystocia was positively associated with the ID of RBCS. Milk fever was indirectly associated with RBCS through dystocia. Increasing the ratio of corn silage to alfalfa fed to dry cows was positively associated with the cumulative incidence (CI) rate of milk fever and was negatively associated with the CI rate of dystocia. Results of this study revealed that the ration of the dry cow should be balanced in order to prevent dystocia, milk fever and ultimately RBCS.

5.2 INTRODUCTION

A recent review of the literature by Lafi and Kaneene (1988) showed that many risk factors have been incriminated as influencing the occurrence of Repeat Breeder Cow Syndrome (RBCS). In general, many investigators agree that the cause of this complex syndrome appears to involve a combination of environmental, managerial, nutritional and diseases risk factors (Cacida 1961, Gunther 1981, Zemjanis, 1980). The major specific risk factors that were reported to be associated with the occurrence of this syndrome are age of the cow (Erb et al., 1985), anomalies of the reproductive tract (DeKruif, 1976), poor nutrition (Gerloff and Morrow, 1986; Curtis, et al., 1985; Thatcher, 1986), low levels of phosphorus and calcium (Kumar, 1986), dystocia (Thompson et al., 1983; Erb et al., 1985; Bendixen et al., 1986), retained placenta (Shukla et al., 1983; Martin et al., 1986), metritis (Francos, 1979), season (Hewett, 1968), herd size (large) (Zemjanis, 1980), and housing (Gwazdauskas et al., 1983).

From an intervention standpoint, studies reported about this syndrome have two weaknesses. First, the effects of the individual risk factors have largely been investigated and reported separately, thus making it difficult to rank them according to their relative contributions. Second, when studies simultaneously considered many risk factors, the multicollinearity problem was not examined.

5.3 OBJECTIVES

The objective of this chapter was to reexamine the relative contribution of various risk factors to the occurrence of RBCS after evaluating the multicollinearity problem among the predicted risk

factors. Specifically, the objectives were to: (1) quantify the relationship between RBCS and environmental, nutritional, disease, management, and production risk factors; (2) elucidate individual risk factors that significantly contribute to the occurrence of RBCS; and (3) predict the incidence rate of RBCS using significant risk factors obtained from objective 2.

5.4 MATERIALS AND METHODS

Study Population

The data used for the analyses of this study came from the National Animal Health Monitoring System (NAHMS) in Michigan. A detailed account of the herd selection, data collection tools and methods were presented by (Kaneene and Hurd, 1989). Complete definitions, codings, descriptive statistics of risk factors involved, computation of the incidence rates of various diseases involved and the study design were presented in Chapter 4.

Variables and Unit of Comparison Used in the Study

The dependent (response) variable was the RBCS which was measured as an annual incidence density (ID) rate expressed per 100 cow years. There were 18 independent risk factors. Related risk factors were grouped together into one category. Each category was considered as an independent unit and was named as a common risk factor (CRF). Six common risk factors (CRFs) were constructed and each individual risk factor of the 18 was determined to belong to only one of the 6 common risk factors. The 18 independent risk factors were chosen based on the literature, the

information obtained from the monthly interviews with the farmers, and on results of the epidemiological surveys of the 96 participating farms in the study. The herd was used as a unit of comparison.

The abbreviations, definitions, description statistics and codings of the risk factors involved are shown in Chapter IV (Tables 4.1 and 4.2). Common risk factor one (CRF 1) included risk factors related to the herd characteristics and environment of the farm. Common risk factor two (CRF 2) included risk factors related to nutrition during the dry period. Common risk factor three (CRF 3) included disease risk factors which occur within 72 hours after calving. Common risk factor four (CRF 4) included disease risk factors occurring after 72 hours after calving. Common risk factor five (CRF 5) included risk factors related to reproductive management. Common risk factor six (CRF 6) included the amount of total milk sold in pounds to the milk processors during the study period.

Analytical Methodology

Model 1

Model 1 was designed to achieve objective 1. The following statistical methods were used:

1. Principal Components Analysis

Principal components analysis (PCA) procedure was utilized as a diagnostic technique to identify the underlying dimensionality of the data structure and to quantify the interdependency that might exist among the hypothesized risk factors. Eighteen principal components were created using the 18 independent risk factors. Each principal component

is a linear combination of the 18 independent risk factors. These principal components are orthogonal and are arranged in order of decreasing variance. Thus, the most informative principal component is the first and the least informative is the last. For more information about the method and its algebraic demonstration, see Chapter III.

The interdependency among the 18 risk factors was quantitatively measured using PCA techniques. The eigenvalues and the percent of the total variance explained by each component are shown in Table 5.2. It was concluded that severe multicollinearity is present among the predictor risk factors because there was one eigenvalue close to zero. Due to the presence of severe multicollinearity within these risk factors, Principal Components Regression (PCR) technique was utilized, and the generated principal components were used as independent variables in the model. Principal components associated with the smallest eigenvalue were eliminated. Regression coefficients were calculated by regressing the dependent variable RBCS on the remaining orthogonal components. The reconstituted regression coefficients (see Chapter III) were obtained (Massy, 1965; Mansfield et al., 1977; Gunst and Mason, 1980; Mason and Gunst 1985).

Construction of the Synthetic Risk Factors

Regression coefficients obtained from PCR using the 18 independent risk factors were utilized to construct the synthesized common risk factors (SCRFs). Synthetic variables were suggested by Ginevan and Carnes (1981) and Deimling and Bass (1986) and were used to reduce dimensionality and to increase interpretability. Risk factors within each common risk factor were combined and weighted to construct the

synthesized common risk factors using equation 5.1.

$$\text{SCRf} = \sum_{i=m}^n B_i X_i \dots\dots\dots(5.1)$$

Where:

B is a matrix of the reconstituted regression coefficients and
 X_i are the original independent risk factors.

2. Multivariate Path Analysis

Synthetic common risk factors were then viewed from logical, temporal aspects to hypothesize a model of the sequence of events leading to the occurrence of RBCS. Figure 1 is the diagram of the hypothesized recursive (one direction) causal model 1 of RBCS in relationship to all risk factors involved. Multivariate path analysis was used to display and to quantify the relationships among the SCRf's and RBCS (Figure 2). Synthetic common risk factor one (SCRf 1) and synthetic common risk factor two (SCRf 2) were entered in the path model as exogenous variables while all the other SCRf's and RBCS were considered as endogenous variables. The direct and the indirect effects of each SCRf on RBCS were calculated using the Ordinary Least Squares (OLS) regression procedure. All SCRf's were ranked based on the total effects (Lewis-Beck, 1974) of their relative contribution to the (ID) rate of RBCS.

Model 2

Model 2 was designed to achieve objective 2. The following statistical method was used:

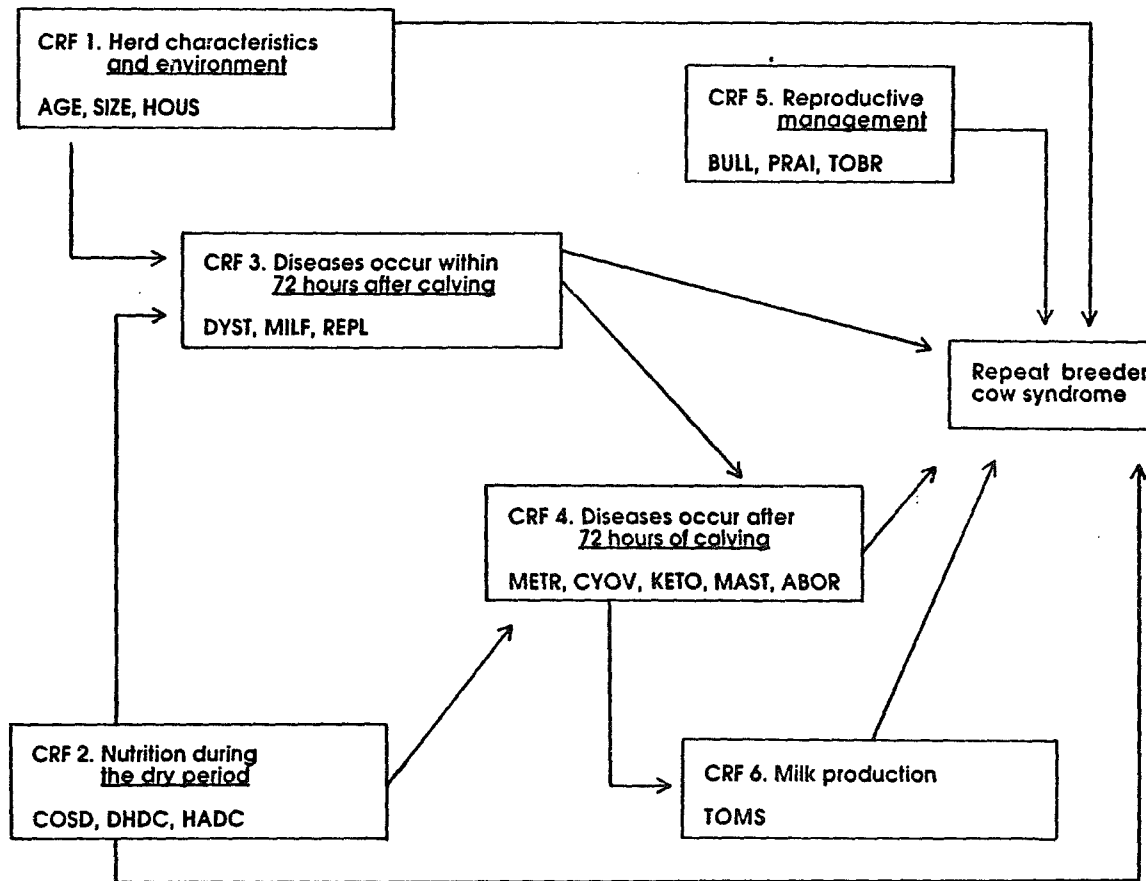


Figure 5.1 Hypothesized causal model of RBCS (96 dairy herds of NAHMS in Michigan 1986-1989)

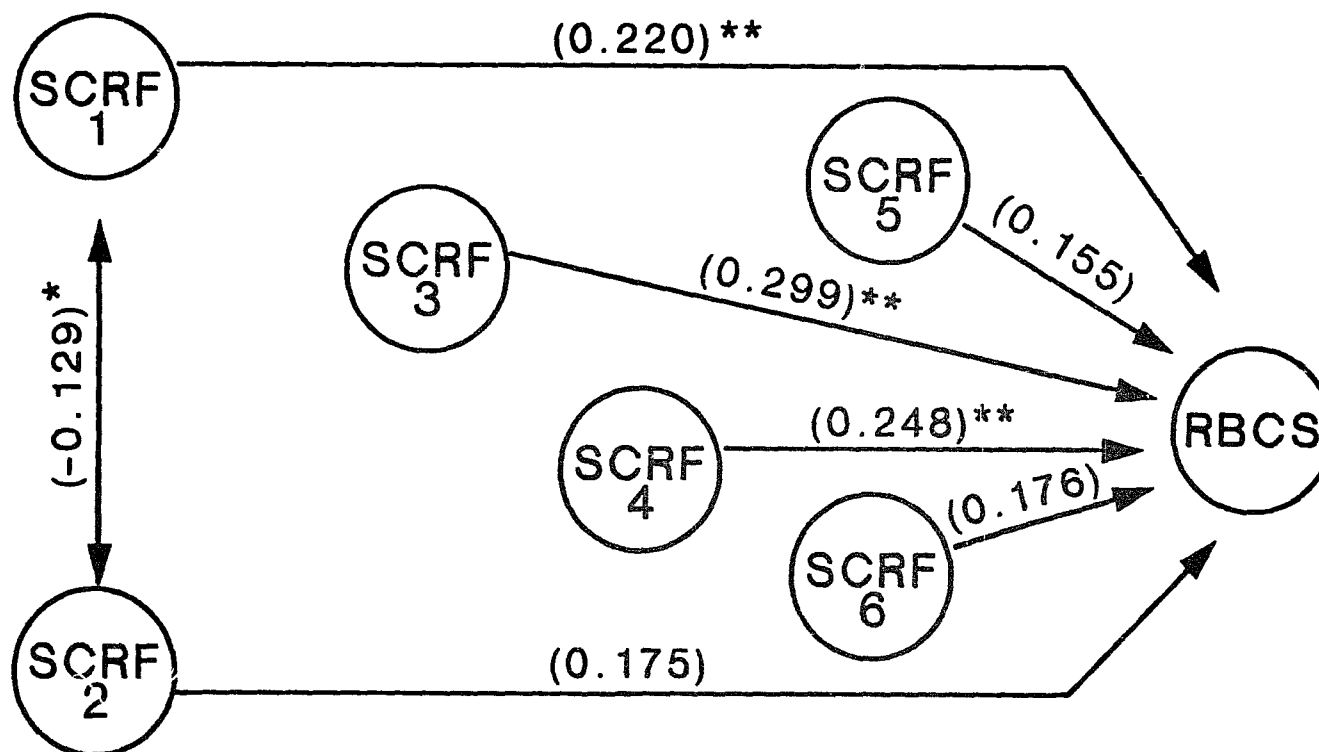


Figure 5.2 Final path model of the synthetic common risk factors
(96 dairy herds of NAHMS in Michigan 1986-1989)

* Significant at $P \leq 0.05$

** Significant at $P \leq 0.01$

Hierarchical Regression Procedure

In order to satisfy objective 2, the incidence density rate of RBCS was proposed as a linear function of the 6 CRFs. Figure 3 is the hypothesized heuristic of model 2. For evaluating the relative contribution of each individual risk factor on the (ID) rate of RBCS, the hierarchical regression analysis procedure was employed. The analyses were conducted by utilizing a series of regression models using OLS regression techniques. In each step of the regression series, principal components analysis approach was employed as a diagnostic method to identify and quantify the interdependency among the predictor variables before the application of the OLS procedure. When severe collinearity was present among the predictor variables, PCR procedure was also applied.

Regression coefficients obtained from PCR (when it was applied) in each step were compared with regression coefficients obtained from OLS. The first regression equation included only risk factors of herd characteristics and environment. Risk factors of nutrition during the dry period were added to the herd characteristics and environment in the next regression equation. This step-wise fashion of adding risk factors of only one common risk factor at a time was used and continued until all the common risk factors were added and included in the model.

Model 3

Model 3 was designed to achieve objective 3 and will be the foundation for the economic analysis to be conducted in the next chapter. The following statistical method was used:

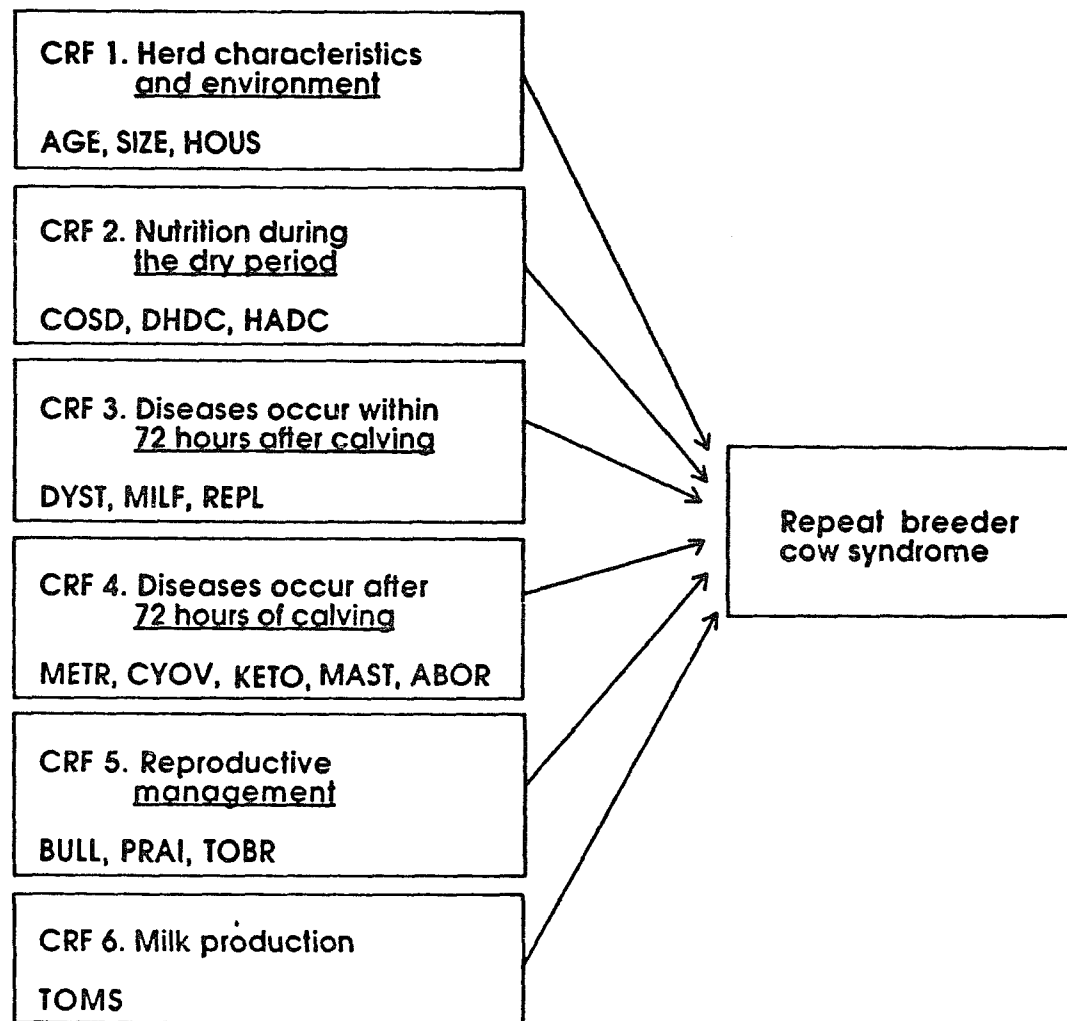


Figure 5.3 Hypothesized heuristic model of RBCS (96 dairy herds of NAHMS in Michigan 1986-1989)

Multivariate Path Analysis

Predictor risk factors that were statistically significant at $p \leq 0.10$ in PCR or OLS models in each step of the hierarchical regression procedure were isolated. These risk factors were arranged according to their time order of events in the reproduction cycle to construct a new multivariate path model. This new model was used to predict the ID rate of RBCS. The arrangement of these risk factors in the model and the time order of events was based on the literature and on clinical observation.

Figure 4 is the hypothesized path diagram of Model 3 using the statistically significant risk factors obtained from the hierarchical regression procedure. Since the nutritional risk factors during the dry period are highly collinear, DHDC and HADC were combined together to construct one common factor. This common risk factor was called full dry hay to dry cows (FDHC). A ratio $[(\text{FDHC}) : (\text{FDHC} + \text{COSD})]$ was obtained using equation 5.2. Since there is some evidence of a strong association between nutrition during the dry period and postpartum diseases, e.g., dystocia, this ratio was forced in Model 3 as an exogenous variable (Curtis et al., 1985; Georloff and Morrow, 1986; Thatcher, 1986).

Ratio of nutrition during the dry period:

$$(\text{RATIO}) = \frac{\text{FDHC}}{(\text{COSD} + \text{FDHC})} \times 100 \dots\dots\dots (5.2)$$

All statistical analyses used in this study were performed using the Systat Statistical package (Version 3.0, 1986) plus programs written in the programming language APL, by a senior faculty member in the Department of Statistics and Probability at Michigan State University.

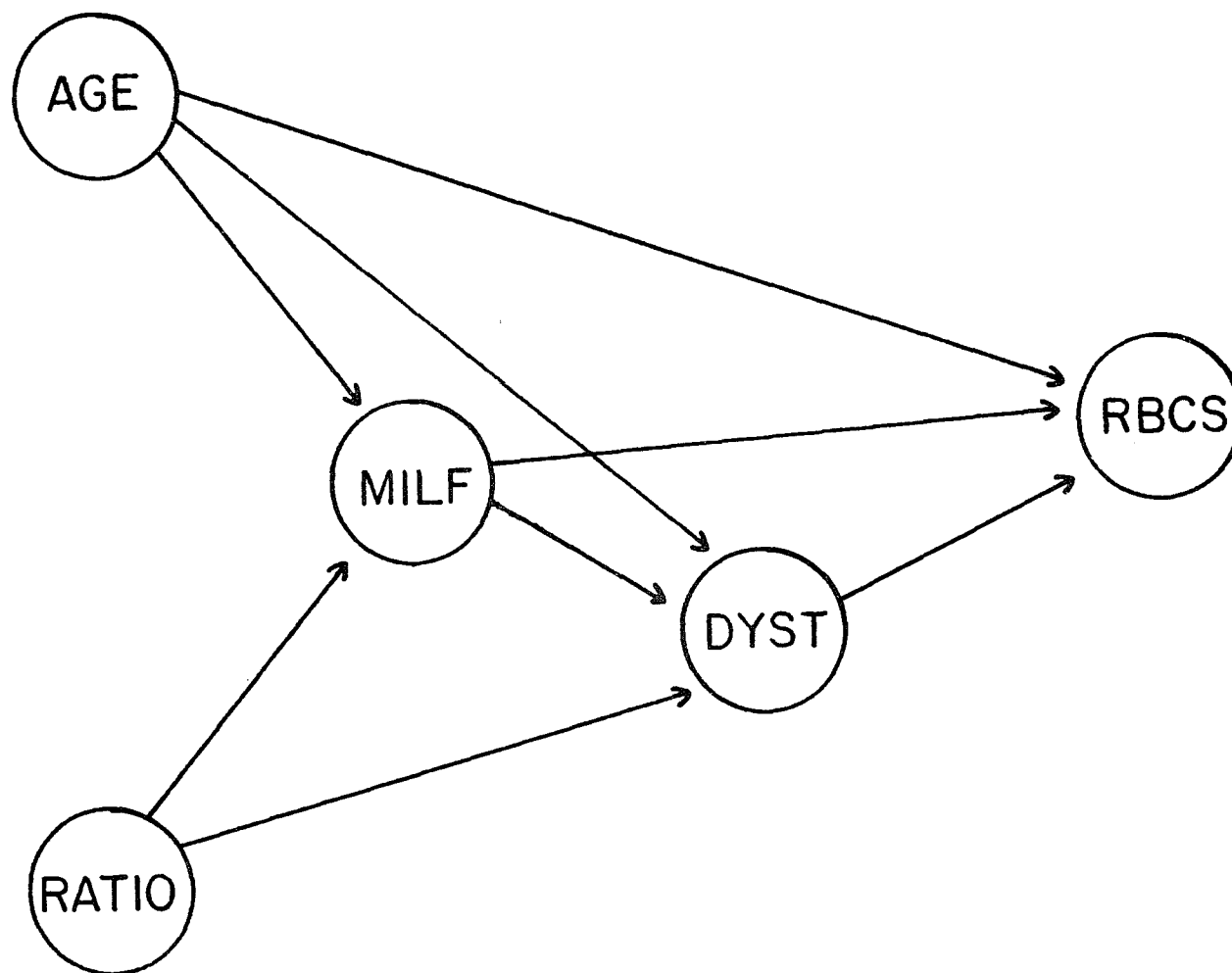


Figure 5.4 Hypothesized path model of RBCS (96 dairy herds of NAHMS in Michigan 1986-1989)

5.5 RESULTS

Model 1

Components, eigenvalues and the percent of total variance explained associated with each component of the correlation matrix using the 18 independent risk factor simultaneously were calculated and are shown in Table 5.1.

The eigenvector associated with the last component, Variation Inflation Factors (VIFs) of the 18 independent risk factors, and the individual R^2 were also estimated and are shown in Table 5.2.

A comparison between regression coefficients obtained from the OLS techniques using the 18 risk factors simultaneously and regression coefficients obtained from PCR analysis after deleting the principal component associated with the smallest eigenvalue is in Table 5.3. The R^2 in both models was identical. Regression coefficients obtained from PCR of the nutritional risk factors were smaller than the corresponding regression coefficients of the same risk factors obtained from OLS model.

Table 5.4 shows the simple correlation between the synthetic common risk factors. None of the correlation coefficients were statistically significant at $p \leq 0.05$. Table 5.5 shows the results of principal components analysis used to quantify and identify the interdependency among the SCRFs, none of the eigenvalues were close to zero. Also, Table 5.5 contains results of the regression analysis using the six synthetic common risk factors as independent risk factors in the model.

Figure 2 displays quantitatively the relationship among the SCRFs

Table 5.1. Eigenvalues and percent of total variance explained by each component (96 dairy herds of NAHMS in Michigan 1986-1989)

Component number	Eigenvalues (λ_i)	% of the total variance Explained by each component
1	2.727	15.149
2	2.469	13.716
3	1.975	10.973
4	1.689	9.381
5	1.331	7.395
6	1.259	6.993
7	0.993	5.514
8	0.905	5.027
9	0.820	4.556
10	0.743	4.129
11	0.680	3.777
12	0.571	3.172
13	0.481	2.673
14	0.436	2.422
15	0.344	1.193
16	0.325	1.804
17	0.222	1.233
18	0.030	0.168

Table 5.2. Principal components analysis results using all risk factors involved (96 dairy herds of NAHMS in Michigan 1986-1989).

Risk factor name	$\lambda_{18} = 0.03027^1$		
	V18	VIF ²	R ²
SIZE	-0.003	1.791	0.442
AGE	0.023	1.283	0.221
HOUS	0.034	1.275	0.216
COSD	-0.474	8.276	0.879
DHDC	-0.680	15.612	0.936
HADC	-0.544	10.477	0.905
MILF	-0.027	1.294	0.227
DYST	0.062	1.410	0.291
REPL	-0.004	1.247	0.198
ABOR	0.000	1.246	0.197
MAST	0.014	1.154	0.133
METR	0.004	1.479	0.324
KETO	-0.005	1.544	0.350
CYOV	-0.059	1.523	0.343
BULL	0.057	3.042	0.671
TOBR	0.005	2.412	0.585
PRAI	0.062	2.417	0.586
TMSO	-0.005	1.725	0.420

¹ λ - Eigenvalue associated with component no. 18.

² VIF = $1/(1-R^2)$, where R^2 is the squared multiple correlation between any dependent variable and the remaining independent variables.

Table 5.3. Comparison between ordinary least squares regression and principal components regression results, component no. 18 was deleted (96 dairy herds of NAHMS in Michigan 1986-1989)

Risk factor name	<u>OLS</u>			<u>PCR</u>		
	Coeff.	S.Error	Beta	Coeff.	S.Error	Beta
SIZE	-0.014	0.016	-0.118	-0.014	0.016	-0.117
AGE	-2.089	1.275	-0.179*	-2.052	1.267	-0.175
HOUS	-1.033	1.630	-0.069	-0.941	1.604	-0.062
COSD	-0.019	0.096	-0.055	-0.048	0.031	-0.139
DHDC	0.034	0.088	0.147	0.005	0.013	0.025
HADC	0.055	0.092	0.184	0.025	0.024	0.086
MILF	0.350	0.188	0.203*	0.358	0.186	0.208*
DYST	0.233	0.111	0.240 ¹	0.244	0.106	0.251 ¹
REPL	-0.019	0.142	-0.014	-0.020	0.142	-0.015
ABOR	0.005	0.318	0.002	0.005	0.318	0.001
MAST	0.029	0.029	0.101	0.029	0.029	0.104
METR	-0.023	0.035	-0.075	-0.022	0.035	-0.074
KETO	0.192	0.164	0.140	0.191	0.164	0.139
CYOV	0.068	0.051	0.156	0.063	0.049	0.145
BULL	-1.515	2.983	0.085	-1.330	2.929	-0.075
TOBR	2.170	2.399	0.135	2.184	2.399	0.136
PRAI	-0.475	0.867	-0.082	-0.410	0.843	-0.071
TMSO	0.000	0.000	0.177	0.000	6.999	0.176
R²		0.2901			0.2891	

Coeff. = non-standardized regression coefficient.

Beta = standardized regression coefficient.

¹ Significant at $p \leq 0.10$

* Significant at $p \leq 0.05$

Table 5.4. Simple correlation among the synthetic common risk factors
(96 dairy herds of NAHMS in Michigan 1986-1989)

	SCRF 1	SCRF 2	SCRF 3	SCRF 4	SCRF 5	SCRF 6
SCRF 1	1.000					
SCRF 2	-0.129	1.000				
SCRF 3	0.105	-0.161	1.000			
SCRF 4	0.014	0.0568	0.087	1.000		
SCRF 5	-0.033	-0.077	-0.100	-0.048	1.000	
SCRF 6	-0.139	0.141	0.0519	0.072	0.135	1.000

Table 5.5. Principal components and regression results obtained by regressing the dependent variable on the six synthetic common risk factors (96 dairy herds of NAHMS in Michigan 1986-1989)

Component number	(λ)	VIF	factor Number	Reg. Coeff.	BETA	S.Error
1	1.345	1.043	1	1.001	0.220**	0.415
2	1.151	1.079	2	0.999	0.175	0.529
3	1.093	1.067	3	0.999	0.299**	0.308
4	0.911	1.019	4	1.000	0.248**	0.364
5	0.840	1.048	5	1.001	0.155	0.589
6	0.660	1.075	6	0.999	0.176	0.526
			R ²	0.2891		

** Significant at $P \leq 0.01$

Reg. Coeff. = non-standardized regression coefficients

Beta = Standardized regression coefficients

and RBCS. Paths with path coefficients (Betas) that are not statistically significant at $p \leq 0.05$ were deleted from the model. Results in Table 5.6 and in Figure 2 reveal that SCRF 3, SCRF 4, and SCRF 1 are statistically significant at $P \leq 0.01$ and contribute the most to the occurrence of RBCS, respectively.

Model 2

In Table 5.6 and Table 5.7 are the OLS regression coefficients of the independent risk factors in each of their hierarchical regression steps of the hypothesized Model 2 (steps 1 through 6). Table 5.8 shows the regression coefficients obtained from PCR analysis (step 2 through step 5). The regression coefficients are comparable in both models for all the risk factors except for the collinear variables (DHDC and HADC) in all steps.

Model 3

Figure 5 displays quantitatively the relationship between the risk factors that were identified to be significant from the hierarchical regression analysis on the RBCS. Paths with path coefficients (Betas) that were not statistically significant at $p \leq 0.05$ were deleted from the model. The direct and the total effect of each risk factor involved in the new constructed model (Model 3) are shown Table 5.9.

Table 5.6. Hierarchical regression coefficients (OLS) of model 2 (96 dairy herds of NAHMS in Michigan 1986-1989)

Risk factor name	<u>Step 1</u>		<u>Step 2</u>		<u>Step 3</u>	
	Coef.	Beta	Coef.	Beta	Coef.	Beta
SIZE	0.004	0.036	0.004	0.029	0.003	0.027
AGE	-3.481	-0.297**	-3.468	-0.296**	-2.894	-0.247*
HOUS	-0.003	-0.000	-0.698	-0.046	-0.808	-0.054
COSD			0.020	0.057	-0.068	-0.196
DHDC			0.055	0.238	-0.009	-0.038
HADC			0.068	0.230	0.003	0.010
MILF					0.269	0.157
DYST					0.295	0.303*
REPL					0.016	0.012
R ²	0.092		0.107		0.194	

* Significant at $P \leq 0.05$ ** Significant at $P \leq 0.01$

Coef. = non-standardized regression coefficients

Beta = standardized regression coefficients

Table 5.7. Hierarchical regression coefficients (OLS) of model 2 (96 dairy herds of NAHMS in Michigan 1986-1989)

Risk factor name	<u>Step 4</u>		<u>Step 5</u>		<u>Step 6</u>	
	Coef.	Beta	Coef.	Beta	Coef.	Beta
SIZE	0.000	0.000	-0.003	-0.023	-0.014	-0.118
AGE	-2.636	-0.225*	-2.571	-0.219*	-2.098	-0.179 ¹
HOUS	-0.986	-0.066	-1.133	-0.075	-1.033	-0.069
COSD	-0.032	-0.092	-0.026	-0.076	-0.019	-0.055
DHDC	0.024	0.103	0.033	0.140	0.034	0.147
HADC	0.037	1.126	0.053	0.178	0.055	0.184
MILF	0.300	-0.174	0.331 ¹	0.193	0.350	0.203 ¹
DYST	0.240	0.247*	0.243	0.250*	0.233	0.240*
REPL	-0.037	-0.028	-0.037	-0.028	-0.019	-0.014
ABOR	0.011	0.004	-0.018	-0.006	0.005	0.002
MAST	0.030	0.106	0.025	0.089	0.029	0.101
METR	-0.012	-0.040	-0.020	-0.065	-0.023	-0.075
KETO	0.172	0.125	0.195	0.142	0.192	0.140
CYOV	0.063	0.146	0.071	0.163	0.068	0.156
BULL			-1.612	-0.091	-1.515	-0.085
TOBR			2.207	0.137	2.170	0.135
PRAI			-0.398	-0.069	-0.475	-0.082
TMSO					0.000	0.177
R ²	0.246		0.272		0.2901	

* Significant at $P \leq 0.05$ ¹ Significant at $P \leq 0.10$

Coef. = non-standardized regression coefficients

Beta = standardized regression coefficients

Table 5.8. Hierarchical principal components regression coefficients (PCR) of model 2 (96 dairy herds of NAHMS in Michigan 1986-1989)

Risk factor name	<u>Step 2</u>		<u>Step 3</u>		<u>Step 4</u>		<u>Step 5</u>	
	Coef.	Beta	Coef.	Beta	Coef.	Beta	Coef.	Beta
SIZE	0.003	0.026	0.003	0.029	0.000	0.000	-0.002	-0.023
AGE	-3.409	-0.291*	-2.932	-0.250*	-2.609	-0.223*	-2.527	-0.260*
HOUS	-0.471	-0.031	-0.883	-0.059	-0.935	-0.062	-0.050	-0.070
COSD	-0.032	-0.092	-0.047	-0.137	-0.047	-0.134	-0.053	-0.152
DHDC	0.003	0.014	0.011	0.048	0.010	0.041	0.000	0.031
HADC	0.014	0.047	0.025	0.079	0.023	0.077	0.027	0.090
MILF			0.263	0.153	0.303	0.176 ¹	0.339	0.197 ¹
DYST			0.288	0.296 ¹	0.246	0.253*	0.253	0.260*
REPL			-0.018	-0.014	-0.037	-0.028	-0.038	-0.029
ABOR					0.012	0.003	-0.017	-0.006
MAST					0.030	0.108	0.026	0.092
METR					-0.012	-0.040	-0.020	-0.065
KETO					0.171	0.125	0.194	0.141
CYOV					0.061	0.141	0.067	0.154
BULL						-1.445	-0.085	-0.081
TOBR						2.219	0.135	0.138
PRAI						-0.340	-0.082	-0.059
R ²	0.103		0.194		0.246		0.271	

* Significant at $P \leq 0.05$

¹ Significant at $P \leq 0.10$

Coef. = Reconstituted non-standardized regression coefficients.

Beta = Reconstituted standardized regression coefficients.

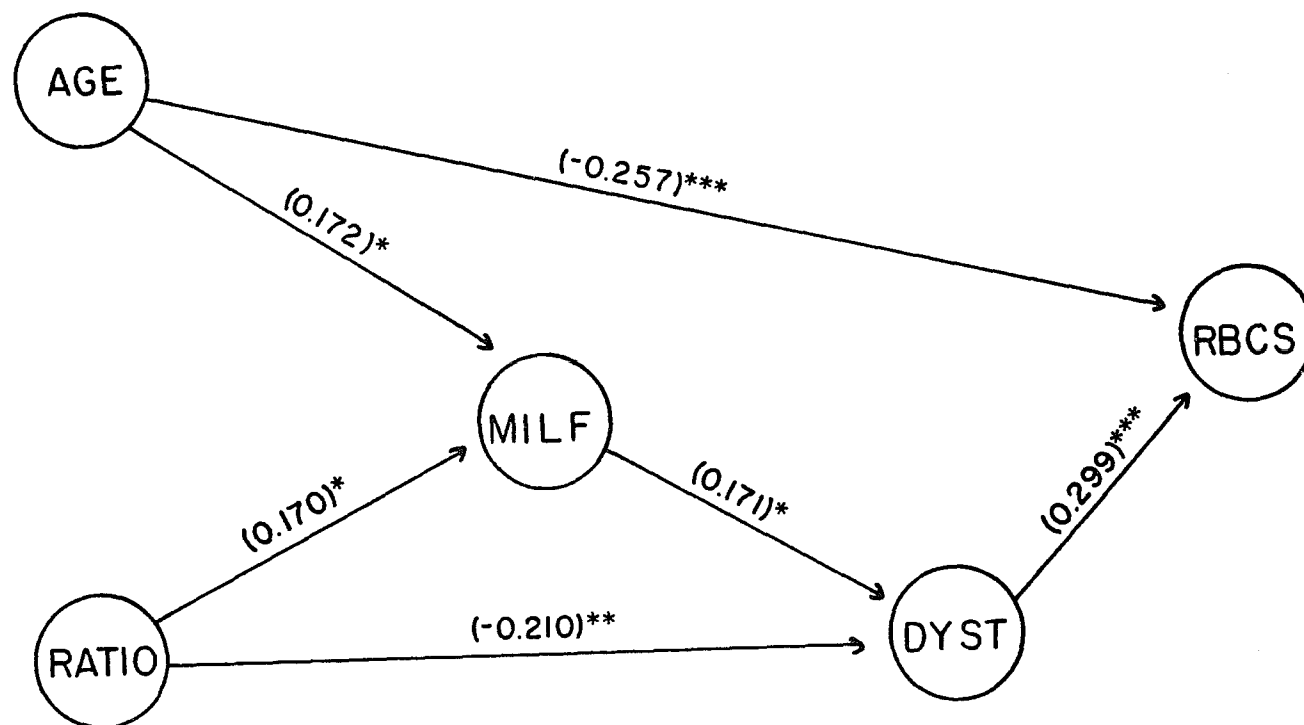


Figure 5.5 Final path diagram of RBCS (96 dairy herds of NAHMS in Michigan 1986-1989)

* Significant at $P \leq 0.05$
 ** Significant at $P \leq 0.01$
 *** Significant at $P \leq 0.001$

Table 5.9. Summary of path analysis results of (standardized regression coefficients) model 3 (96 dairy herds of NAHMS in Michigan 1986-1989)

Dependent Variables		<u>Independent Variables</u>			
		AGE	RATIO	MILF	DYST
MILF	Direct effect	0.172	0.170	-----	-----
	Indirect effect	0.172	0.170	-----	-----
DYST	Direct effect	0.000	-0.210	0.171	-----
	Indirect effect	0.029	0.029	0.000	-----
REBC	Direct effect	-0.257	0.000	0.000	0.299
	Indirect effect	0.009	-0.053	0.051	0.000

Total effect = [Direct effect + indirect effect]

5.6 DISCUSSION

Model 1

An eigenvalue near zero that was associated with principal component 18 indicates that severe multicollinearity exists among the independent variables (Silvey, 1969; Greenberg, 1975; Gunst and Mason, 1980; Dillon and Goldstein, 1984; Neter et al., 1985). Large values of the Variance Inflation Factors (VIFs) and high values of the individual R^2 combined identify the variables that are responsible for the multicollinearity problem that exists among the independent variables (Neter et al., 1985). Results of Table 5.2 indicate that the nutritional risk factors during the dry period are collinear with each other. Obviously, these risk factors are collinear because they were measured as the proportion of each feedstuff fed to dry cows on a dry matter basis. The amount of grain was not included in the analyses of this study because a small number of farmers reported that dry cows were fed grain. Additionally, including the proportion of grain's dry matters in the model will create a perfect multicollinearity and consequently, the OLS regression procedure cannot be performed.

The elimination of principal components associated with minor eigenvalues reduces the dimensionality of the analysis without serious loss of information. Component 18 explained $\approx 1.7\%$ of the total variation among the predictor risk factors as defined by the amount of variation in the data retained for the analysis. The data of Table 5.3 indicate that R^2 of the OLS model and R^2 of the PCR model were identical, indicating that the elimination of the principal component associated with the smallest eigenvalue did not reduce the prediction power of the model.

Table 5.4 and Table 5.5. show that severe multicollinearity did not exist among the SCRFs. This result indicates that collinearity exists within variables of the synthetic common risk factor and not among synthetic common risk factors. The R^2 obtained from regressing RBCS on the synthesized variables was equal to the R^2 obtained from PCR model after deleting the last principal component, suggesting that the method used for weighting the SRFs did not alter the predicting power of the model.

Model 1 counted for 28.91% ($R^2 = 0.2891$) of the variation in the RBCS. On the average, the synthetic variable of diseases which occurred within 72 hours of calving (SCRF 3) was statistically significant at $p \leq 0.01$ and contributed positively to the ID rate of RBCS. This result is in agreement with other results that were reported by Erb et al. (1981), Thompson et al. (1983), Mangurkar et al. (1984), and Erb and Grohn (1988), indicating that MILF, REPL and DYST usually occur as a complex. These diseases are intercorrelated and highly associated with the postpartum reproductive performance in dairy cattle. Synthetic common risk factors 1 and 3 were also statistically significant at $p \leq 0.01$ suggesting that herd characteristics and diseases which occurred within 72 hours after calving are important determinants of RBCS.

Model 2 and Model 3

Results in Tables 5.3, 5.7, and 5.8 indicate that age and DYST were the only statistically significant individual risk factors in the first 4 steps of the hierarchical regression analyses in the PCR and OLS procedures. Milk fever was statistically significant only in steps 4, 5 and step 6. The statistically significant risk factors in the

hierarchical regression procedure, then, were entered in the new path Model 3.

Herd Age Average

Herd age average was negatively associated with the ID rate of RBCS. This negative association runs contrary to the positive association found on an individual cow basis (Hewett, 1968; DeKruif, 1978; Erb et al., 1985; Bartlett et al., 1986a) suggesting an increase in the survivorship of good fertile cows in the herd when compared with low or non-fertile cows.

Milk Fever

Milk fever appeared to be a significant risk factor for RBCS in step 5 and step 6 in the hierarchical regression model but not in step 3 or step 4, suggesting that the effects of milk fever were confounded when other risk factors were entered in the model in step 5 and in step 6. This suggestion was clarified in Model 3 where no significant direct association was found between MILF and RBCS, but positive indirect effects mediated through dystocia clearly appeared in Model 3. Also, in Model 3 herd age average was positively associated with the CI rate of MILF. These results are consistent with previously reported results of other studies which were based on an individual cow (Block, 1984; Erb et al., 1985; Curtis et al., 1985). Model 3 shows that milk fever was also positively associated with DYST. This association suggests decreased muscular activity of the uterus due to hypocalcemia which can be found in many cases of dystocia. Thompson et al. (1983) found an increased incidence rate of milk fever among cows with dystocia. Erb et al.

(1985) reported cows with milk fever had 4.2 times more dystocia than cows with no milk fever.

Dystocia

Dystocia was the most significant risk factor and was directly associated with RBCS in both models. This result is in agreement with previous reports which found a positive association between dystocia and fertility problems on an individual cow basis (Thompson et al., 1983; Mangurkar et al., 1984). Several epidemiological studies that used the cow as a unit of comparison reported no direct association between dystocia and the number of inseminations per conception or between dystocia and the rate of conception (Shanks et al., 1979; Erb et al., 1981; Oltenacu et al., 1983; Dohoo and Martin, 1984; Erb et al., 1985). No direct association between herd age average and the ID rate of dystocia was found in this study which is consistent with previously reported studies that were conducted on an individual cow basis (Erb and Martin, 1980; Dohoo and Martin, 1984). Bendixen et al. (1986) and Erb and Martin (1980) reported that younger cows were at increased risk for dystocia than older cows.

Corn Silage

Most of the participating farmers in this study fed corn silage to dry cows, especially during the second year of the study. The feeding of a low calcium diet prepartum has been reported to be associated with a reduced risk of milk fever (Jonsson, 1978; Dohoo et al., 1984). In this study farms which fed corn silage [ratio = (FHDC / COSD + FHDC)] (a low calcium feed) to dry cows did have a reduced risk of MILF.

Curtis et al. (1985) reported a positive direct association between energy intake and veterinary assisted dystocia. Morrow (1976) reported that overconditioned, obese cows had more dystocia and metabolic disorders than non-obese cows. Corn silage is high energy feed and the total digested nutrient (%) of corn silage is also higher than the alfalfa. Farms which fed large quantities of corn silage to dry cows were at a higher risk of developing dystocia.

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CHAPTER VI

ECONOMIC ANALYSIS OF REPEAT BREEDER COW SYNDROME AND OTHER RELATED DISEASES

6.1 ABSTRACT

Prospective data from ninety-six dairy herds randomly selected in the state of Michigan were used to: (1) estimate the economic impact of repeat breeder cow syndrome (RBCS) as well as related risk factors leading to the occurrence of RBCS, and (2) evaluate the economic effects of changing the amount of some nutritional risk factors during the dry period on RBCS as well as diseases leading to RBCS. The economic analyses were based on an epidemiological model which considered both the direct and the indirect effects of the significant risk factors involved. The mean cost per herd per year of milk fever, dystocia, and repeat breeder cow syndrome was \$226.86, \$494.93, and \$1043.58 respectively. Farms that fed 100% dry hay or haylage to the dry cows had an increase in the cumulative incidence rate of milk fever and a reduction in the cumulative incidence (CI) rate of dystocia in comparison to cows that fed corn silage. Increasing the annual cumulative incidence (CI) rate of milk fever in a herd by 1% was associated with an increased cost per herd per year of \$128.39. Increasing the annual CI rate of dystocia in a herd by 1% was associated with an increased cost per herd per year of \$133.84. These results suggest that proper nutrition during the dry period to prevent milk fever and dystocia is essential for reducing the incidence and cost of repeat breeder cow syndrome.

6.2 INTRODUCTION

During the last decade, the assessment of economic impact of animal diseases has received increasing attention because of a growing concern among producers and veterinarians regarding reduction in productive efficiency caused by diseases. In the literature there are very few articles on attempts to specifically assess the economic effect of the Repeat Breeder Cow Syndrome (RBCS) in dairy cattle, while excluding other reproductive disorders. The cost components arising from the RBCS and other reproductive diseases, including number of days open, extra veterinary treatments, cost of labor, less number of calves born, and loss due to culling and replacement, have been manipulated and assessed by several investigators (Lineweaver, 1975; James and Esselmont, 1979; Olds et al., 1979; Britt, 1981; Steele et al., 1981, Oltenacu et al., 1980; Thompson et al., 1983; Holmann et al., 1984).

Several investigators attempted to assess the economic effects of reproductive diseases and culling in dairy cattle using the partial budgeting technique as an analytical approach for their analysis. Dijkhuizen et al. (1985) and Jansen et al. (1987) evaluated the economic impact associated with reproductive failure. Olds et al. (1979) and Holmann et al. (1984) assessed the economics associated with days open caused by reproductive diseases. Oltenacu et al. (1981) evaluated the economic impact of three heat detection and three breeding programs on production and profit in dairy herds. Bartlett (1986a) addressed the economic effects of repeated insemination in Michigan dairy cattle. All these studies cited have focused on the economic effects of one disease entity. However, they only considered the disease components that were thought to be associated directly with the occurrence of the disease.

Risk factors leading to the occurrence of each disease were not evaluated.

It is known that reproductive diseases are interrelated and do not occur as independent events. A number of epidemiological studies in the last ten years have focused on quantifying the direct and indirect relationships among reproductive diseases as well as between reproductive diseases and managemental, nutritional and environmental risk factors (Erb et al., 1981b; Erb et al., 1985; Etherington et al., 1985; Salman et al., 1984; Salman and Meyer, 1987; Curtis et al., 1983, 1985; Erb, 1987). Results obtained from these studies indicate that the indirect effects among reproductive diseases is important and in some instances exceeded the direct effects.

Two outcomes should be realized from these studies. First, the indirect effects among reproductive diseases and between reproductive diseases and managemental, nutritional and environmental risk factors are biologically important. Second, the previous attempts to assess the economic impact of the reproductive diseases considered the diseases as events occurring independently of each other and consequently, did not take into consideration these indirect effects in the economical analyses. Therefore, our hypothesis is that the interrelationships among reproductive diseases are significant economically, and an economic approach similar to the epidemiological approach, the latter of which considers both the direct and the indirect effects, should also be used when financial consequences of diseases are estimated.

6.3 OBJECTIVES

Using the epidemiological model that was developed in chapter V as the basis for these economic analyses, the objectives of this chapter were: (1) to estimate the economic impact of RBCS as well as related risk factors leading to the occurrence of RBCS, and (2) to evaluate the economic effects of changing some nutritional risk factors during the dry period on RBCS as well as diseases leading to RBCS.

6.4 MATERIALS AND METHODS

Study Population

Data for this study were obtained from the National Animal Health Monitoring System (NAHMS) in Michigan. The methods of data collection, herd selection, and study design have been described elsewhere (Kaneene and Hurd 1989).

Epidemiology and Economic Analysis

Descriptive epidemiology of the risk factors involved were presented in chapter IV. Figure 6.1 is the hypothesized path model of RBCS and other risk factors leading to the occurrence of RBCS. This model was considered as the basis for the economic analyses of this study. For practical purposes, the average age of the herd described in the epidemiological model was not considered in the economic analyses. Figure 6.1 shows that four risk factors were associated directly and/or indirectly with the ID rate of RBCS. In the parentheses are the direct effects which are expressed as path coefficients (standardized regression coefficients). The values which are not in the parentheses represent the non-standardized regression coefficients.

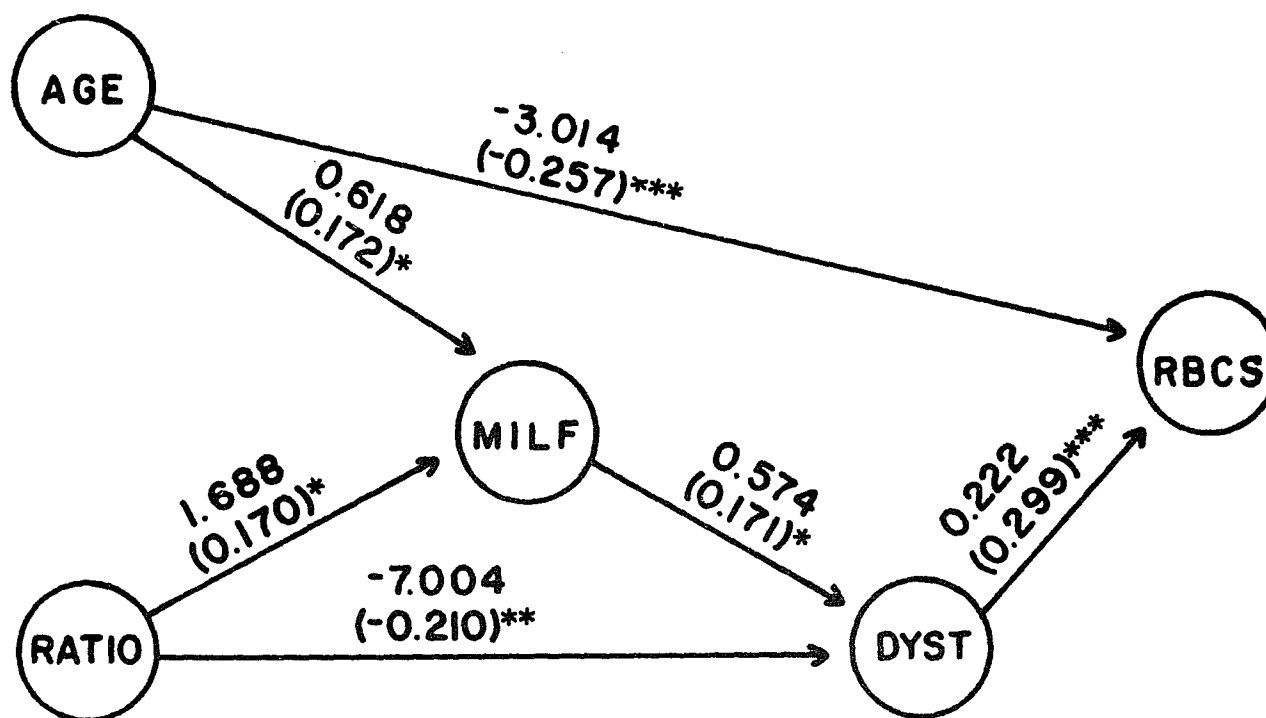


Figure 6.1 Path model of RBCS and other related diseases (96 dairy herds of NAHMS in Michigan 1986-1989)

* Significant at $P \leq 0.05$
 ** Significant at $P \leq 0.01$
 *** Significant at $P \leq 0.001$

Incidence Rate and Herd Size

The methods used for calculating the herd size and the incidence rates of RBCS, Milk fever (MILF), and Dystocia (DYST) were presented in chapter V. The annual average herd size was 86.04 ± 59 cows. The annual mean incidence density (ID) rate of RBCS was (Mean $\pm$ SD) 6.877 ± 7.271 . This ID rate of RBCS was expressed as a rate per 100 cow years. The annual mean cumulative incidence (CI) rates of MILF and DYST were 4.40 ± 2.228 and 4.942 ± 7.484 ., respectively. These CI rates of MILF and DYST were expressed as rates per 100 calvings.

Milk Production and Price of Milk

The data on milk production were collected on a monthly basis. Milk production included only the total milk sold to the milk processors. Prospective data on an individual animal regarding milk production were not available. The average milk production per cow per year was $14,400 \pm 3,377.41$ pounds, and the average milk price per pound was \$ 0.122. According to Nott et al (1988) the cost associated with milk hauling, freight, advertising and marketing for each pound of milk sold was equal to \$ 0.01. Therefore, the net price of milk was \$0.112 (\$0.122-0.01) per pound.

Cows Experiencing More than One of the Three Diseases

The data were searched to isolate cows that experienced more than one of the above three diseases. Seventeen cows from phase one and nine cows from phase two were diagnosed with MILF and DYST. Five cows from phase one and one cow from phase two were diagnosed with DYST and RBCS.

Four cows from phase two were diagnosed with MILF and RBCS, and none of the cows were diagnosed with all three of the diseases.

ANALYTICAL ECONOMIC MODEL

After the significant risk factors have been identified, and the diseases indirect effects desegregated and quantified, the next step is to attach monetary values to the quantified impacts. In order to satisfy objective 1, the partial budgeting procedure was used to estimate the economic effects of MILF, DYST, and RBCS.

Partial Budgeting

A partial budgeting is a description of the economic consequences of a specific change in farm procedure. In this context, the change may be for example, a diseases preventive program or a new milking system. A partial budgeting is typically made up of four sections: (1) additional revenue realized from the change; (2) reduced cost as a result of the change; (3) revenue foregone as a consequence of the change; and (4) extra cost incurred due to the implementation of the change (Harsh, et al., 1981). When the elements in each section are identified, then the decision rule is to adapt the change if the sum of (1) and (2) (revenues) is greater than that of (3) and (4) (expenses).

In our situation, the change is the disease occurrence, namely MILF, DYST, and RBCS. In this paper the expenses and income associated with the occurrence of each of the three diseases will be examined. The expenses and revenues of the dairy farm that were not affected by the disease occurrence will be ignored. Since some data that are very critical for calculating the expenses and the revenues associated with

the occurrence of each of the three diseases were not available in our data base, for example, the exact amount of feed intake, some assumptions were made. Before the calculation of the partial budgeting of each disease takes place, a brief discussion of these assumptions will be presented under system bounds.

System Bounds

1. Feed Cost

The nutritional aspects and the methods used for collecting information on feeds were discussed in chapter IV. Briefly, it was quite common for some participating farms to change their feed according to the season of the year, and many of the participating farms that produced their own feed did not know the exact amount of feed that was used during their participation in the study. In addition, many farms did not analyze their feed on a specified period of time or according to the frequency of the feed ration change. Consequently, it was not possible to estimate the exact amount of feed intake for cow maintenance and/or milk production using our data base. Because of the aforementioned reasons, the data collected on the nutritional aspect of the farms were not used in the analysis of this study. Thus, a hypothetical feed ration was formulated based on the Nutrient Requirements of Dairy Cattle (NRC) (1988). It was also assumed that all participating farms used this hypothetical feed ration for all lactating cows during their participation in the study. The hypothetical feed ration was consisted of corn, soybean meal, alfalfa hay and corn silage. Proportions, associated crude protein, Mcal/lb (NEm), and the price of each feed stuff used are shown in Table 6.1. Approximation cost of this ration was

calculated using the average feed prices that were reported in Michigan Agricultural Statistics of (1987 and 1988)¹.

Table 6.1. Hypothetical feed ration used in the analysis of this study

	Corn ¹	Soybean	Alfalfa	C.silage	Total
Proportion	0.375	0.050	0.287	0.287	1.000
NEm	0.890	0.870	0.610	0.770	0.728
Crude P.	0.100	0.490	0.180	0.080	0.166
Price ²	4.517	10.389	2.710	0.026	3.772

¹ Price of corn \$/bu = \$2.150 (Michigan Agricultural Statistics 1987 and 1988)

² Price (\$) per 100 pounds

¹ Michigan Agricultural Statistics 1987 and 1988, Michigan Department of Agriculture. Lansing Michigan.

2. Herd Size

In Michigan dairy farms as in other parts of the U.S.A., it is quite a frequent occurrence and natural for farmers to sell and purchase some dairy cows for different purposes. However, it was assumed that the number of milking cows in each herd was fixed during their participation in the study. This assumption does not agree with the real situation at the farm but will simplify and reduce the number of assumption needed for calculating the economic effects of the diseases involved. For example, based on this assumption some variable costs such as utilities, bedding, and fixed cost such as labor charge, interest, insurance on the cows and calves, equipment charge, building charge and management charge will be constant through out the period of the study.

3. Days Open

As it was mentioned previously, in phase 1 of the study the exact date of breeding or insemination was not reported. The time period of each phase of this study was 12 months, and none of the participating herds in the first phase were included in the second phase study. Therefore, following all cows that experienced MILF, DYST or RBCS until the end of their lactation was not possible. In order to obtain reasonable estimates for the economic effects associated with the disease occurrence, a calving interval of 365 days for a disease (RBCS, MILF or DYST) free herd was assumed (305 milking days and a 60 days dry period)

A repeat breeder cow was defined as a cow or a heifer that failed to become pregnant following three or more breedings or inseminations.

DeKruif (1976), Bulman and Lamming (1978) reported that 60 percent of the repeat breeder cows conceived normally by the fourth insemination and about 16 to 25 percent conceived by the fifth insemination. Considering these reports, it was decided to assume that each case of RBCS is associated with 60 extra days open and 2.5 extra inseminations.

In case of MILF, several studies that were conducted on an individual cow basis revealed that MILF did not increase the days open or the number of inseminations per conception. Furthermore, MILF was not directly or indirectly associated with the milk yield in the previous or in current lactation (Dohoo and Martin, 1984b; and Erb et al., 1985). Based on these reports, it was assumed that cases of MILF were not associated with extra days open.

In the literature, there are some conflicting reports about the effects of DYST on milk production, many investigators reported that DYST did not effect milk production (Philipson, 1976a, 1976b, 1976c; Erb and Martin, 1980; Erb et al., 1981b; Martin et al., 1982; Dohoo and Martin, 1984b; Erb et al., 1985), however, Schneider et al. (1981) found that cows unaffected by dystocia, retained placenta, or endometritis within one month postpartum had greater milk yields. Thompson et al. (1983) reported that difficult calving (DYST) was associated with a significant increase in the days open by 20.36 days and slightly decreased milk production immediately postcalving, but only a small negative effect of 165 Kg mature equivalent for cows averaging 8574 Kg of milk carried through the lactation. This difference in milk production was not statistically significant. On the basis of the results reported by Thompson et al. (1983), it was decided to consider that each case of DYST is associated with an extra 20 days open.

Since it was assumed that MILF does not effect the days open or the number of inseminations per conception, cows that had MILF and DYST, or MILF and RBCS were considered as two independent diseases and the cost components of each disease was estimated separately.

In cases where cows were diagnosed with DYST and RBCS, the two diseases were also considered as independent events, however, Since a small number of cows (only 6 cows) experienced the two diseases, an adjustment for the days open associated with their occurrence which should be considered, was ignored in the analysis of this study.

For estimating the net effect of each disease involved, two examples will be demonstrated. These examples will involve a comparison between two herds with different incidence rates. The two herds will have the same age average (2.72 lactations), herd size (86.04 cows, for the analysis of these examples, all the cows in the herd are considered at risk of developing the three specific diseases), and an average milk production of 14,400 pounds per cow per year. These data were obtained from the study and represent the statistics of an average herd in the state of Michigan (chapter IV).

Partial Budgeting of RBCS

A. REVENUES ASSOCIATED WITH RBCS

In general the revenues in a dairy farm come from milk production, calves sold and culling.

1. Milk Production

In order to evaluate the effects of RBCS on revenues generated from milk production, the assumptions that were discussed under system

bounds were utilized. Since prospective data on an individual cow regarding milk production were not available, a computer program was written based on Wood's model (1969) to project the average daily milk yield for each month within a lactation.

a. Herd with a 6.877 ID Rate per 100 Cow Years

In this herd, 5.92 cows ($86.04 \times 6.877\%$) experienced RBCS and 80.12 cows did not experience RBCS during the year. Thus, the 80.12 cows had 365 days calving interval and each of the 5.92 cows had a calving interval of 425 days ($365 + 60$). Because of the 5.92 repeat breeder cows, the calving interval of this herd is equal to 369.13 days $[(5.92/86.04) \times 425 + (80.12/86.04) \times 365]$. Using Wood's equation (1969) and Shultz's (1974) standardized values for the parameters involved in Wood's equation, the extra total amount of milk produced due to RBCS was 7,044.8 (1190×5.92) pounds. The herd average milk production per day is 3,375.56 $\{[(14,400 \times 86.04) + 7,044.8] / 369.13\}$. The annual revenue obtained from milk production equal to \$ 137,992.89 ($3,375.56 \times 365 \times 0.112$).

b. Herd with a Zero ID Rate of RBCS

Based on the assumptions that were previously made, the calving interval of this herd (86.04 milking cows) is 365 days (305 milking days and a 60 days dry period). Therefore, the average daily milk production of the herd is equal to 3,394.45 pounds $[(14,400 / 365) \times 86.04]$. Consequently, the annual revenue obtained from milk production equal to \$ 138,765.12 ($3,394.45 \times 365 \times 0.112$)

2. Calves Sold

a. Herd with a 6.877 ID Rate per 100 Cow Years

The annual mortality rate of calves obtained from this study was 13 per 100 calvings. This mortality rate included all stillborn and neonatal death due to various causes. Assuming that 50% of the born calves are males and all males calves were sold at birth for \$ 60 each and all females were kept for replacement, the annual total revenue obtained from sold calves in the 86.04 cows herd was \$2,220.50 $[(86.04/369.13) \times 365 \times (1-0.13/2) \times 60]$ (assuming none of the calves died because of RBCS).

b. Herd with a Zero ID Rate of RBCS

Using the same herd size, The annual total revenue obtained from sold calves is equal to 2,245.64 $[(86.04/365) \times 365 \times (1-0.13)/2 \times 60]$.

3. Culling

The overall death rate for cows obtained from this study was 3.6% (301/8256) and the culling rate due to RBCS was 60.8% (404/664). According to the annual summary of production records published by the Dairy Herd Improvement Association (DHIA) in Michigan for 1987 and 1988, the average culling rate in dairy farms was 33% of which 7.4% (2.44% of the herd) were culled for dairy purposes. Therefor, the total culling and death rate is equal to 36.6% (33% + 3.6%). The value of these rates will be maintained and used for estimating the cost associated with culling through out the analyses of RBCS, DYST and MILF.

a. Herd with a 6.877 ID Rate of RBCS

Using the herd size assumption and the DHIA culling and death rates, the total number of dead cows due to different causes in the herd was equal to 3.1 ($86.04 \times 3.6\%$). The number of culled cows because of different causes (including RBCS, DYST, MILF) was equal to 28.29 cows of which 2.1 cows were culled for dairy purposes and 26.29 cows were soled for beef. Based on results obtained from this study, the average cow price sold for dairy was \$1,100 and a cow soled for beef was worth \$350. The disposal cost of a dead cow was equal to \$22.

$$\begin{aligned} \text{the annual revenues (\$)} &= (2.1 \times 1100) + (26.29 \times 350) - 22 \times 3.1 \\ &= 11,443.30 \end{aligned}$$

b. Herd with a Zero ID Rate of RBCS

Using the same example, 3.598 cows ($60.8\% \times 5.92$) were culled due to RBCS. These cows were culled for beef and dairy. In order to keep the culling and the death rate fixed in the farm (with or without the presence of the disease), the 3.598 cows need to be proportionally allocated between cows culled for dairy and beef; the total number of cows sold for dairy is equal to 2.40 [$2.1 + (3.598 \times 2.1/24.792)$]. Similarly, the total number of cows sold for beef would be reduced by 0.30 cows ($26.29 - 0.30$).

$$\begin{aligned} \text{Annual revenue (\$)} &= (2.40 \times 1100) + (25.99 \times 350) + (- 3.10 \times 22) \\ &= (2640 + 9096.5) - 68.2 \\ &= 11,668.30 \end{aligned}$$

B. EXPENSES ASSOCIATED WITH RBCS

For estimating the yearly total cost of RBCS in the herd with a 6.788 ID rate of RBCS, the following equation was employed.

$$\text{Yearly total cost} = \text{VETC} + \text{DRUG} + \text{DSML} + \text{EXAI} + \text{FEED}$$

Where:

VETC = Veterinary services including veterinary treatments

Drug = Drug cost used by farmer

DSML = Discarded milk

EXAI = Cost of extra breedings or inseminations

FEED = Cost of feed (saving) associated with less milk production due to RBCS

The cost of veterinary services was based on the receipts received from the veterinarian. The cost of drugs was estimated by the farmer based on the amount and the price of the drug used. These costs were collected on a monthly basis by the Veterinary Medical Officers (VMO's). Because some assumption were made regarding discarded milk, cost of semen and cost of feed a brief summary of calculating the cost of these items will be presented.

Discarded Milk due to Treatment of RBCS

The amount of discarded milk due to treatment were estimated by the farmer and in a few instances included milk production lost due to an acute disease. In such cases the loss was estimated as the difference between what the cow was producing before and during the illness.

Results from this study indicated that some of the discarded milk due to treatment was fed to calves as milk replacers. Therefor, some

money was saved in buying milk replacers (approximately \$7.00 per cwt)². To correct for this discrepancy, the estimates were adjusted to account for the discarded milk fed to calves. Based on these results, 60% of the discarded milk was fed to calves as milk replacers. The amount of the discarded milk fed to calves was considered as a revenue while the truly discarded amount of milk was considered as expense.

Expenses of Extra Breeding or Insemination

There were 19 participating herds that used exclusively bulls for breeding, and a combination of bull and artificial insemination was used in 23 herds. Typically, when cows are rebred several times (RBCS), cheaper semen from lower caliber sires or a clean-up bull was used, thus offsprings with lower genetic potential were produced. In the analyses of this study, the cost associated with producing offsprings with lower production potentials was not considered. According to the Michigan Animal Breeder's Cooperative (MABC)³ the price of semen for 1987-1989 ranged between \$ 4 to \$ 90 with an average of \$10.70 per dose. Considering these reports, an estimate of \$ 7 for each extra breeding or insemination associated with RBCS was used for the analyses of this study. In the example used, each of the 5.92 cows received 2.5 extra inseminations.

Feed Cost

According to the NRC (1989) each pound of milk produced require

² Price of reconstituted milk replacer based on a sample (n=4) of Michigan feed suppliers, October 1987.

³ Michigan Animal Breeder's Cooperative., 1988. MABC- selected sires. 3655 Forest Road. East Lansing, Michigan 48823-9990.

0.32 NEm. In the example used, the amount of less milk produced due to RBCS per year was 6894.85 pounds. Each pound of the hypothetical feed ration is enough to produce 2.275 pounds of milk. Thus, a 3,030.70 pounds/year of feed were saved because of RBCS. The net cost of the saved feed is equal to \$114.32 $[(3.772 \times 3,030.70)/100]$

Partial Budgeting of DYST

A. REVENUES ASSOCIATED WITH DYST

1. Milk Production

In order to evaluate the effects of DYST on revenues obtained from milk production, the assumptions that were discussed under system bounds were utilized. The example and the method that was used to calculate the net revenue due to RBCS was also utilized for estimating the net effect of DYST on milk revenue.

a. Herd with a 4.942 per 100 Calvings CI Rate of DYST

In this herd 4.25 cows experienced DYST and 81.79 cows did not experience DYST during the 12 months period. Thus, the 81.79 cows had 365 days calving interval and each of the 4.25 cows had an increase in the calving interval by 20 days (365 + 20). Therefore the calving interval of this herd was equal to 366 days $[(4.25/86.04) \times 385 + (81.79/86.04) \times 365]$. Using Wood's equation (1969) and Shultz's (1974) standardized values for the parameters involved in Wood's equation, the extra total amount of milk produced due to the increased days open associated with DYST was 1,744.84 pounds (410.55×4.25) . The herd average daily milk production is equal to 3389.95 pounds $[(14,400 \times$

$86.04) + 1,744.84) / 366]$. The annual revenue from milk production was \$138,581.06 $[3389.95 \times 365 \times 0.112]$

b. Herd with a Zero CI Rate of DYST

Based on the assumptions that were previously made, the calving interval of this herd was 365 days, Thus, the average daily milk production and consequently the annual revenues are the same as it was previously estimated for milk production of the disease free herd (see Milk production of herd with a zero ID rate of RBCS).

2. Calves sold

a. Herd with a 4.942% CI Rate of DYST

The annual total revenue obtained from the sold calves was \$2,239.51 $[(86.04/366) \times 365 \times (1-0.13)/2 \times 60]$.

b. Herd with a Zero CI Rate of DYST

Results of this study revealed that 39% of the DYST cases ended with dead calves. Using the same example, a total of 1.66 calves $(86.04 \times 4.942\% \times 39\%)$ $[0.83 \text{ males and } 0.83 \text{ females}]$ died because of DYST. Assuming that the value of the dead calves (males and females) was \$60 each, The annual total revenue obtained from sold calves was equal to \$2,295.39 $[86.04/365 \times 365 \times 1 - (0.13 - (0.04942 \times 0.39)/2) \times 60]$.

3. Culling

The culling rate and the death rate for the cows due to DYST obtained from the study were 2.75% $(10/363)$ and 9.64% $(35/363)$, respectively.

a. Herd with a 4.942 per 100 Calvings CI Rate of DYST

The annual revenue is the same as in the herd with 6.877 ID rate of RBCS.

a. Herd with a Zero CI rate of DYST

$$\begin{aligned} \text{Number of cows died due to DYST} &= 4.25 \times 9.64\% \\ &= 0.41 \end{aligned}$$

$$\begin{aligned} \text{Number of cows died due to other causes} &= 3.1 - 0.41 \\ &= 2.69 \end{aligned}$$

Using the DHIA culling rate of 33%, the number of cows culled in the herd of size 86.04 cow is

$$= 28.39$$

$$\begin{aligned} \text{Number of cows culled due to DYST} &= 2.75 \times 4.25 \\ &= 0.117 \end{aligned}$$

In order to maintain the same total culling and death rate, the 0.41 cows need to be added to the culled cows, the total number of culled cows for dairy was equal to:

$$2.1 + (0.527 \times 2.1/28.273) = 2.14$$

$$\text{Number of cows culled for beef} = 26.66$$

$$\begin{aligned} \text{Total revenue (\$)} &= 2.14 \times 1,100 + 26.66 \times 350 - 2.69 \times 22 \\ &= 2,354 + 9331 - 59.18 \\ &= 11,625.82 \end{aligned}$$

B. EXPENSES ASSOCIATED WITH DYST

For estimating the yearly total cost of DYST in a herd, the following equation was employed.

$$\text{Yearly total cost} = \text{VETC} + \text{DRUG} + \text{FEED}$$

Where:

VETC = Veterinary services including veterinary treatments

Drug = Drug cost used by farmer

FEED = Feed cost (saving) associated with less milk
production due to DYST

The costs of VETC and DRUG were collected on a monthly basis by the VMO's. The procedure that was used to adjust for the discarded milk in estimating the partial budgeting of RBCS was also used in estimating the partial budgeting of this disease.

Expenses Associated with Feed

The method that was used to estimate the cost of feed associated with the less milk produced due to RBCS was also used to estimate the cost of feed associated with the less milk produced due to DYST. A 86.04 cows herd with 4.942 CI rate of DYST produced a 1,643.39 less pounds/year of milk. Therefore, the amount of saved feed is equal to 722.37 pounds (using the hypothetical feed ration). The net saving in feed is equal to \$27.25.

Partial Budgeting of MILF

A. REVENUES ASSOCIATED WITH MILF

Based on the previous assumptions that were made regarding MILF, the revenues associated with MILF come from culling and discarded milk.

1. Culling

The culling rate and the death rate for cows due to MILF obtained from the study were 2.29% (8/349) and 7.74% (27/349), respectively. The method that was used to estimate the total revenue associated with culling due to DYST was also used to estimate the revenue associated with culling of MILF.

a. Herd with a 4.400 per 100 Calvings CI Rate of MILF

The annual revenues was same as in the herd with 6.877 ID rate of RBCS.

b. herd with a Zero CI Rate of MILF

The number of cows that had MILF was equal to 3.79 ($86.04 \times 4.4\%$) cows. of the 3.79 cows, 0.29 ($3.79 \times 7.74\%$) cow died due to MILF, the total number of dead cows in the herd due to other causes was 2.81 cows ($3.1 - 0.29$). A 0.09 cow was culled due to MILF ($2.29\% \times 3.79$). On the basis of the culling rate of the DHIA (see RBCS), the total of culled cows for dairy was 2.128 [$2.1 + (0.38 \times 2.1 / 28.3)$] and the total number of cows culled for beef was equal to 26.55 [$(28.39 + 0.29) - 2.128$].

$$\begin{aligned} \text{Annual revenue}(\$) &= 2.129 \times 1,100 + 26.55 \times 350 - 2.81 \times 22 \\ &= 2,341.9 + 9,292.85 - 61.82 \\ &= 11,572.93 \end{aligned}$$

2. Discarded milk

The same method that was discussed in the early section regarding the adjustment for the discarded milk for RBCS was also used for this disease.

B. EXPENSES ASSOCIATED WITH MILF

For estimating the expenses associated with MILF in a herd, the following equation was employed.

$$\text{Total cost} = \text{VETC} + \text{DRUG}$$

Where:

$$\text{VETC} = \text{Veterinary services including veterinary treatments}$$

Drug = Drug cost used by farmer

The VETC and DRUG were collected on a monthly basis by the VMO's. The procedure that was used to adjust for the discarded milk in estimating the partial budgeting of RBCS was also in estimating the partial budgeting of this disease.

Sensitivity Analysis

In order to achieve objective 2, sensitivity analysis was conducted to show how changes in the ratio of feed ration would affect the cost of MILF, DYST and RBCS. The ratio [(hay and /or haylage dry matter (FHAY) / FHAY + corn silage dry matter (COSD)] ranged between 0.469 and 100 %. Three values of the ratio within this range were chosen to illustrate the sensitivity analysis. These values were 1, 0.565 and 0.469.

The ratio was equal to 1 when farmers fed 100% hay to dry cows. The ratio was equal to 0.469 when 0.531 of the dry matter ration came from COSD and 0.469 came from hay and/or haylage. The ratio was equal to 0.562 when the proportion of dry matters came from COSD was 0.281 and the proportion of dry matter ration from hay or haylage was 0.361.

Reading the Path Coefficients

The interpretation of path coefficients in the path model is similar to the interpretation of the regression coefficients. Notice in the path model some risk factors were also dependent variables (end product). For example, MILF, and RATIO were risk factors for DYST and at the same time DYST was a risk factor (independent variable) for RBCS. In the path model, it can be seen that some risk factors were directly

associated with each other and others were connected indirectly together through other risk factors. For example, DYST was connected directly with RBCS, and MILF was connected indirectly with RBCS through DYST.

The total effects of DYST on RBCS equal to the value (regression coefficient) attached to the arrow between them (0.222), and no indirect effect was involved. Therefore, the total effects of DYST on RBCS equal only to the direct effect. Both MILF and RATIO were indirectly associated with RBCS. Total effects of MILF or RATIO equal to their indirect effect, e.g., the indirect effect of RATIO on RBCS was equal to the sum of: (1) indirect effect through DYST (-7.004×0.222), (2) indirect effect through MILF and DYST ($1.688 \times 0.574 \times 0.222$). The same method was used to calculate the total effects of MILF on RBCS.

6.5 RESULTS

The partial budget analysis of RBCS, DYST and MILF is shown in Tables 6.2, 6.3, and 6.4, respectively. The cost associated with RBCS, DYST and MILF per case and per 1% incidence rate is in Table 6.5. The sensitivity analysis results are shown in Table 6.6.

Calculation Direct and Indirect Cost

Increasing the annual CI rate of MILF (independently from the ratio) from zero to 1%, had an associated cost of 51.56 more per year because of MILF, and a \$57.49 (100.15×0.574) cost per year due to DYST and indirectly would increase the cost of RBCS per year by \$ 19.34 [$(0.222 \times 0.574) \times 151.75$]. Therefore, increasing the annual CI rate of MILF by 1% in a herd would cost a total of \$128.39 ($51.56 + 57.49 + 19.34$) per year. Increasing the annual CI rate of DYST by 1% more in a

Table 6.2. Annual partial budget of repeat breeder cow syndrome in Michigan (96 dairy herds of NAHMS in Michigan 1986-1989)

Item	(\$)
A. Revenues:	
1. Milk production	- 772.23
2. $(2.5 \times 0.6 \times 0.112)$	
3. Calves sold	- 25.14
4. Culling	- 226.00
B. Expenses:	
1. Veterinary services	- 22.04
2. Drug used by the farmer	- 10.23
3. Semen	- 102.20
4. Discarded milk	- 0.17
5. Feed saved from less milk produced	+ 114.32
Total annual cost	- 1043.58

Table 6.3. Annual Partial budget of dystocia /herd in Michigan (96 dairy herds of NAHMS in Michigan 1986-1989)

Item	(\$)
A. Revenues:	
1. Milk production	- 184.06
2. (carded milk fed to calves (86.51 x 0.6 x 0.112)	+ 5.81
3. Calves sold	- 55.88
4. Culling	- 182.52
B. Expenses:	
1. Veterinary services	- 94.54
2. Drug used by the farmer	- 7.11
3. Discarded milk	- 3.88
4. Feed saved from less milk produced	+ 27.25
Total annual cost	- 494.93

Table 6.4. Annual Partial budget of MILF/ herd in Michigan (96 dairy herds of NAHMS in Michigan 1986-1989)

Item	(\\$)
A. Revenues:	
1. Discarded milk fed to calves (108 x 0.6 x 0.112)	+ 7.26
2. Culling	- 129.63
B. Expenses:	
1. Veterinary services	- 60.83
2. Drug used by the farmer	- 38.82
3. Discarded milk	- 4.84
Total annual cost	- 226.86

Table 6.5. Annual cost associated with RBCS, DYST and MILF per case and per 1% annual incidence rate (96 dairy herds of NAHMS in Michigan 1986-1989)

Disease name	Exp. number of cases ¹	Cost/case (\$)	Cost/1% Incidence Rate (\$)
RBCS	568	176.38	151.75
DYST	408	116.45	100.15
MILF	363	60.00	51.56

¹ Expected number of cases =
Herd size x Disease specific incidence rate x Total number of herds

Table 6.6. Sensitivity analysis on ratio with other variables held constant (96 dairy herds of NAHMS in michigan 1986-1989)

RATIO	<u>COST (\$)</u>		
	MILF	DYST	RBCS
1.000	87.03	-701.45	-204.12
0.562	48.91	-394.22	-114.27
0.469	40.82	-328.98	- 95.73

¹ For variable definition and abbreviation see text.

herd would cost \$100.15 per year due to DYST and would cost \$33.68 per year due to RBCS (total = \$133.84).

6.6 DISCUSSION

Milk Production

The average milk production per cow per year was 14,400 pounds. This average is very close to the average milk production per cow per year reported by the United State Department of Agriculture (USDA) for the year of 1986 and 1987. The USDA results were based on a sample of 10% of the total herds in the state of Michigan. Results of this study were base on a sample of 1% of the total herds population indicating that the sample used in this study represented the total herd population in Michigan.

Hewett (1968) and Bartlett et al. (1986a) reported that repeat breeder cows produced more milk (305 ME) than cows without RBCS. A possible explanation of this phenomenon is that cows with RBCS probably were better milk producer cows and not because they were repeat breeder. This study could not investigate this event, therefore, more research about the cause effect relationship between RBCS and milk production is in need.

Assumptions

Many assumptions were made in the analyses of this study to demonstrate the methodology used and not the specific results. For examples, the fixed number of cows in the herd, the hypothetical feed ration, culling rate of the DHIA. Some of these assumptions might

introduced biases in the calculation of the costs and the income associated with the diseases involved.

Repeat Breeder Cow Syndrome

About 74% of the cost components of RBCS were due to milk loss and about 22% were due to culling. The net cost of RBCS was \$ 176.38 per case. In this study, it was not possible to segregate the number of inseminations or breedings that the cow received until the conception was achieved. This was due to the fact that the exact date of breeding or insemination was not available for all the participating herds. This was the case in phase one and in herds that had a bull running with cows. Earlier studies in Michigan (Bartlett et al., 1986a) estimated a \$385 loss associated with repeat breeder cows that had 3 inseminations and a \$429, \$612 for cows that had four and five inseminations respectively. In their analysis most cost was due to days open, because they assumed that each day open cost \$2.5. In this analysis different methodology was used for calculating the costs and the revenues of RBCS, therefor, it is not surprising to have these cost differences.

Dystocia

The largest cost component associated with DYST was also due to reduced amount of milk (37%). About 11% of the total cost associated with DYST was due to reduction in number of calves sold, and about 37% of the cost was associated with reduced value of the culled cows. The total annual cost of increasing the annual CI rate of DYST by 1% was associated with a total loss of \$133.97 of which \$33.82 due cost associated with RBCS.

Milk Fever

On the average, 57% (129.63/226.86) of the cost associated with MILF was due to reduced values of culled cows. About seventeen percent of the annual total cost was due to drugs used by farmers. Treatment of acute hypocalcemia is highly successful in that the clinical condition of the cow usually improves dramatically. This may cause some kind of false security for farmers by making them believe that MILF can be prevented with no significant cost if they watch closely their cows around calving. Results of this model indicate that a total annual cost of \$128.46 is associated with each 1% increase of the CI rate of MILF suggesting more attention is required to prevent and reduce the incidence rate of this disease.

Prevention

Results of this study suggest that prevention of these diseases is essential for reducing cost and increasing dairy farm profitability. In order to the farmer to maintain some profit, the amount of money that can be spent to prevent the occurrence of each disease must be less than the cost associated with its occurrence. Practically, a zero incidence rate of these diseases in a given herd is not quit feasible. Therefor, more research is needed to identify the optimum incidence rate of these diseases associated with the minimum cost that farmers can allow to be in the farm.

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CHAPTER VII

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1 SUMMARY

The objective of this research study was to develop analytical epidemiologic methodologies to be used for studying the economics of animal diseases. The first objective of the study was to develop a quantitative model that utilizes the multivariate analysis methods as an epidemiological tool for: (1) elucidating and ranking hypothesized risk factors associated with RBCS according to their relative contribution to the occurrence of RBCS in dairy herds. (2) assessing the direct and the indirect effects of various risk factors involved in the occurrence of RBCS. The second objective of this study was to develop an economical model that can be used for: (1) evaluating the direct and indirect economic impact of RBCS and other related risk factors leading to the occurrence of RBCS. (2) estimating the cost effectiveness of changing selected risk factors associated with the occurrence of RBCS.

Methods and techniques used for detecting, quantifying and adjusting the regression coefficients for the effects of multicollinearity when its present deemed harmful in a data base were reviewed. The ability of principal component analysis techniques to detect and adjust the regression coefficients for the effects of multicollinearity was evaluated using human and animal data sets. Combining sample and non-sample (when it is available) information was

the ideal method for over coming the problem of multicollinearity in a data base.

A two-year prospective study was conducted during two one-year phases to study the relationship between Repeat Breeder Cow Syndrome (RBCS) and managemental, environmental, nutritional risk factors during the dry period, milk production and other postpartum diseases in Michigan dairy cattle. A multistage sampling procedure was used to randomly select sixty herds for each phase. An epidemiological survey was conducted at the beginning and at the end of each phase, data were collected on a monthly basis by veterinarians. A total of ninety six herds had complete data and were used in the analyses of the study. Three epidemiological models of RBCS were developed. Herd characteristics and diseases which occurred within 72 hours of calving were significant determinants of RBCS. Milk fever, dystocia and retained placenta occurred as a complex and contributed the most to the occurrence of RBCS. Dystocia and milk fever as individual risk factors were positively associated with RBCS, while the average age of the herd was negatively associated with RBCS.

The economic analyses were based on the developed epidemiological model which examined the direct and the indirect effects of the risk factors involved. The direct and the indirect economic effects of diseases lead to the occurrence of RBCS were evaluated.

7.2 CONCLUSIONS

In addition to meeting the objectives of the study, this research reveal that multicollinearity is a serious problem in veterinary epidemiology research where observational data are used in the analysis.

Principal components analysis which utilizes the eigenvectors and eigenvalues of the correlation matrix failed to detect its presence when all predictor variables were highly correlated. Combining sample and non-sample information such as results from clinical or experimental trials appear to be more effective than the statistical method approach which is usually used in adjusting the regression coefficients for its effect. Diseases occurring early in the lactation were directly associated with RBCS. Nutrition during the dry period was indirectly associated with RBCS through the diseases which occur early in the lactation. Adequate ration during the dry period is essential to prevent diseases occurring within 72 hours of calving and consequently RBCS. Economically, risk factors associated with RBCS were more costly than it might be especially, when the indirect economic effects were considered.

7.3 RECOMMENDATIONS

As a result of this research study, there is need for further research in:

- 1) The field of nutrition there are a great number of studies which have been done to investigate the effects of nutrition on various reproductive parameters. The direct effects of these nutrition components on repeat breeder syndrome need to be investigated.
- 2) The field of epidemiology there are some conflicting reports about the association between various postpartum events and repeat breeder syndrome. Further investigation is needed to more fully understand these associations and any accompanying cause-effect relationships.
- 3) The field of endocrinology there is a controversy about the role of

progesterone in relation to repeat breeder syndrome. Therefore, more investigations need to be undertaken to evaluate this matter in dairy cows.

- 4) The area of management, reports addressing the association between managerial and environmental factors and repeat breeder syndrome have been inconsistent. Further investigation into this matter is recommended.
- 5) Data collection. For example, information from the DHIA records was used in the economic analysis because the information needed were not available in the data base of this study. Mixing the two sources of information might introduced biases in the estimates obtained.
- 6) The field of economics, different approaches for assessing the economic effects of repeat breeder syndrome have been reported. Since these effects can vary widely, the need for developing a standardized methodology for analysis is essential.

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