The Development of a Computer Model for the Replacement of Dairy Cattle in Seasonally Calving Herds in New Zealand

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Abstract

A culling model for use in seasonally calving New Zealand dairy herds (CowCHOP) was developed. The model uses information retrieved from an on farm information system (DairyWIN) as well as farmer input to calculate an economic ranking of all animals within the dairy herd. This economic ranking is used to identify those animals that are most and least desirable for retention in the herd. Culling information was obtained from current DairyMAN user herds. This information was analysed using survival analysis to determine the current removal risks of cattle from DairyMAN herds for inclusion in the model. Additional economic information was obtained from the literature and incorporated into the CowCHOP model.

To understand removal risks and rates for culling, herd demographic data was analysed from a study on reproductive performance for the 1993/94 season. The study was limited to spring calving seasonal herds, typical of the New Zealand dairy industry. The New Zealand dairy industry is reliant on a largely pasture based production system which entails that herds calve annually during the spring months (July to September) with a condensed calving pattern to optimise pasture utilisation. Cows are dried off in the late autumn (April to June) for a dry period prior to the onset of calving the next season. This management system results in two periods of the season where cows are at greatest risk for removal, primarily early lactation and drying off.

Rates and risk factors for removal of dairy cattle internationally and nationally are introduced in Chapter 1. The study designs used to investigate the risks and rates of removal are fully summarised in a series of tables comparing the different methodologies and numbers of animals utilised in each of the studies presented. Economic factors associated with the replacement issue are discussed in detail and this is followed by a comprehensive review of the most important models built that investigate the economics of replacement in dairy cattle. Finally a comparison of the differences in removal rates and risk factors between seasonal and non-seasonally based calving systems in New Zealand and Australia are reviewed. The greatest limitation to the application of internationally developed replacement principles is the paucity of information and studies performed using seasonally calving pasture based farming systems for their development.

modelled the economics of replacement in dairy herds. This spreadsheet was modelled in four sections, the Input module, General calculations module, Individual calculations module and the Output module. A detailed description of each of these modules and the formulae used to perform the calculations is given.

Sensitivity analysis of the model was performed by running a series of simulations to determine the sensitivity of the model to a variety of different scenarios. In all cases the model performed similarly to other models developed internationally using the same techniques. An interesting feature of this model is the difference in the relative worth of both milk and beef stock in the New Zealand dairy system. The effect of these price differences means that stock currently in the herd are very desirable and that retention over replacement is the most economical option to dairy farmers. Overall replacement rates in DairyMAN user herds was low compared to international figures but appear to be appropriate given the current economic status of the New Zealand dairy industry.

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Dedication

This thesis is dedicated to my husband Colin.

Thank you.

Helen K Crabb 1998

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Introduction

There have been many computer programs developed that investigate the economics of replacement in dairy cattle both internationally and nationally. However none of these programmes have been used commercially by farmer as tools for the selection of replacement animals.

A wealth of information on replacement in dairy cattle has been published in the literature over the last 30 to 40 years yet the risk factors and rates of removal remain essentially the same. With the development of more sophisticated techniques it is possible to extract more useful information about the timing and the effects of removal on the economics of the dairy herd.

While the development of computer programs based on the economics of replacement in New Zealand dairy herds have been fairly abundant there has been no comprehensive analysis of the risk factors and rates of removal in dairy cattle during the last ten years.

This thesis hopes to redress the balance and provide some useful facts and figure about the New Zealand dairy industry in particular aspects of replacement risks reasons and rates. A survey of DairyMAN user herds provided information on which this study was based, and can be considered as a starting point for future research. This information was combined to develop a replacement model that is to be incorporated into DairyWIN in the near future.

Chapter 1.

Literature Review.

Introduction

Culling is the act of removing animals from a livestock production enterprise. In the dairy industry culling involves the removal of both profitable and non-profitable animals from the herd. Animals may be removed by sale for beef, or replacements, and death. The removal of non-profitable animals is a useful method by which an operation can improve its productivity and profitability. The "spaces" left in the herd may be filled with new stock, which offers the opportunity to increase productivity and genetic gain by entering improved genetics into the herd. The removal of profitable animals from the herd imposes a cost to the operation because animals worthy of being kept in the herd are replaced.

The removal of any animal from the herd represents a substantial cost to the producer. Non-profitable cows removed from the herd impose a replacement cost on the producer. Profitable animals removed from the herd impose replacement costs, loss of future production and may cause a decrease in the herd's total production. Replacement animals may be reared by the farming operation or bought onto the farm as either mature or immature replacements. The costs associated with rearing replacement animals have been estimated to be 20% of the overall operating expenses on a dairy in the US [42].

Replacement of a removed cow may occur at differing times throughout the season. It may occur at the same time as the cow is removed or at a later date depending on the farming system and the availability of replacements. In a seasonally operating herds cows are usually culled at the end of the lactation and replacement animals enter the herd at the beginning of the next season. If animals are removed at other times during the lactation replacement animals already in milk have to be purchased because home reared animals are not available for entry into the herd. In contrast to this non-seasonal production systems are able to replace animals at any stage in the lactation because of the continuous calving pattern. An animal may be replaced with a heifer, or another animal of any age and genetic value.

An overall culling policy can have far reaching impact on the performance of a herd or dairy enterprise. It may have dramatic effect in a number of management areas such as capital investment, replacement heifer rearing, mastitis management, disease control programmes, reproductive management, genetic improvement and replacement animal purchases. Changing the replacement policy can have dramatic effects on the factors above and these effects can be both positive and negative.

Increasing replacement rates may have the following effects in a herd with static size [59]:

- Increase the number of replacements entering the herd, therefore increasing the genetic gain as long as animals of improved genetics are used for replacement.
- Allows greater selection of animals from within the herd, and therefore allows removal of a greater number of low producers which may increase the herd productivity.
- Increase the proportion of younger cows within the herd, which may decrease the herd productivity.
- Increase the number of replacements required and therefore increase the costs associated with raising replacements.

General culling policies to improve the productivity in one herd may not be applicable to another herd due to the many variables that influence productivity. For example, an animal culled for low production in one herd may not be culled in another, due to the different levels of production achieved in the two herds. Therefore policies need to be developed that can cater for individual farms specifically.

The selection of an animal to cull has many different facets. There are economic, emotional, and management factors involved in these decisions. It is relatively easy to generate an overall policy for cattle replacements within a herd. The involuntary culls select themselves and there are simple decision trees that can be generated to help decide the fate of an animal that cannot produce any more or has a case of mastitis. What is not easy to decide is which other cows in the herd should be culled. Traditionally the selection of a cull cow has been a mainly subjective process with little objective methodology involved.

Voluntary and Involuntary Culling.

Culling has historically been classified into two categories, voluntary and involuntary.

Voluntary culling is defined as culling animals for production reasons. That is animals are removed from the herd due to poor production performance in the absence of underlying disease or the animals are excessive to requirements and are sold. This implies complete freedom of choice over which animals to remove.

Involuntary culling is the removal of animals because of generally preventable events and age. Animals would be kept by the farmer if the event had been prevented because the cow would have sufficient productive merit to be retained in the herd. Reasons for involuntary culling include reproductive health and fertility, SCC and mastitis, disease or injury, foot/leg problems or lameness, temperament, conformation and other miscellaneous problems. Death is also an involuntary culling reason.

Generally voluntary culling is regarded as desirable and involuntary culling as undesirable. Voluntary culling promotes improvement of the overall herd production by the removal of the low producers or contributes to the herd income by the sale of animals of some genetic merit. Involuntary culls are "forced" upon the producer rather than chosen by him (her). The assumption being that involuntary culls are of financial detriment to the herd.

Fetrow [42] in response to problems with the former classification method has proposed another method for the classification of culling dairy cattle. It is based on three categories of culls:

Emotional culls: Animals culled for essentially emotional reasons, such as temperament, conformation. These culls are rare on most farms.

Forced culls: These are animals which the farmer has no choice but to cull, such as trauma, EBL, squamous cell carcinoma, and on farm deaths. These are often rare events on most farms.

Economic disposal: This includes culling all of the live animals in the herd for economic reasons. This economic analysis is generally done on a very subjective or even unconscious basis. For example the removal of a cow that is not in calf because the cost of keeping her in the herd until she conceives is more costly than replacing her.

The advantage of this system over the previous is that farmers are forces to consider the economic consequences of the culling decision.

Regardless of the definitions of the categories, classification of culls tends to be subjective process. Classification is usually made by the farmer and is subject to considerable bias in reporting. Typically only one "cause" may be allocated to the reason for culling, when there may be a combination of 2 or 3 reasons why an animal may be removed.

Some animals that are classified as voluntary culls and are removed for production reasons may have underlying animal health problems that are affecting their production unknown to the producer. For example the cow with chronic subclinical mastitis which is culled for low production or the lame animal that is culled due infertility. In these situations determining the cause and effect is a very subjective process therefore correct classification of the primary reason for disposal can be very difficult. The difficulty in interpreting the reasons for culling makes research in this area very difficult, as misclassification of reasons can have a significant effect on the results in various studies and models. Eliminating these causes of bias can only be done when strict definitions for culling have been defined prior to the onset of the study.

Due to the complicated nature of the culling process and the wealth of information that has been published on culling the literature review has been divided into the following sections.

1. International Culling

    Culling Rates and Risk factors

        Culling Reasons and Rates

        Risk factors for Removal

    Economics of Dairy Culling Decisions

    Dairy Culling Computer Models

        Marginal Net Revenue

        Dynamic Programming

        Profit Equations

2. New Zealand and Australia Culling

    NZ Culling Rates and Risk factors.

    NZ Dairy Culling Computer Models.

    Australian Culling Rates and Risk factors

International Removal Reasons and Risk Factors

A great deal of research has been dedicated to the analysis of culling in dairy cattle internationally. All the main dairy areas of the world have been covered in the various studies. The investigations into culling can be broadly divided into two areas. 1. Surveys investigating the reasons and rates of culling associated with these factors and 2. Studies that investigated the risk factors associated with culling and their interrelationships. These two groups will be examined separately as they have fundamentally different objectives and study design

Culling Reasons and Rates.

Table 1 summarises the major studies investigating the reasons and rates of removal of dairy cattle. The studies were conducted from the beginning of the 1950's to the late 1990's. Some studies cover a very large time span ranging from 1 to 40 years. Various study types have been used in this research ranging from prospective longitudinal [98 84 44 95 28 45 96 71 3 17], to retrospective studies [1 78 31 43] and cross sectional studies [81 29 19 2]. The most frequently used study methodologies are cross sectional and prospective longitudinal studies.

All studies investigated the reasons for culling and the associated rates of culling for each reason. Some have elaborated on this and look at the different rates of culling by age group or season but make no inference about risks. These studies were mainly performed in the USA and the UK with a few from Australia, NZ and Ireland. Holstein-Friesian cows were the predominant breed investigated, and this is likely to reflect the importance of this breed in the dairy industry internationally. Statistical analysis used in these studies was confined to simple descriptive statistics and the reporting of proportions removed per year, per reason and per lactation. Some included chi-squared [82 28 45 75] and logistic regression [31] analyses, but they were the exception.

Table 1 Summary of studies investigating removal reasons.

Study	Year	Lactations	Herds (Cows)	Sample selection	Data selection	Breed	Analysis	Study type	Production type
UK [98]	1975-1979	4	80 (24800)	Friesian sire daughters	6 monthly	HF	Regression analysis	Prospective longitudinal study	Non Seasonal
UK [2]	1933 –1972		12 (8722)	Institution herds	Routine		Descriptive data analysis	Retrospective observational	Non seasonal
UK [83]	1955-1956	1	11,000 (200,000)	Herd improvement	3 monthly		Descriptive data analysis	Longitudinal	Non seasonal
Ireland [29]	1972-1973	1	274 (3223)	Farm management survey	1		Descriptive data analysis	Cross sectional	Seasonal
USA [44]	1986-1987	1	45	Random stratified sample on herd size	1-2x per month	Mixed	Cumulative incidence, rates of disease	Prospective observational study	Non Seasonal
UK [45]	1973-1975	1	18	Regular	Commercial	HF	Simple descriptive analysis	Cross sectional longitudinal	Non Seasonal
UK [97]	1951-1954	4 yr	163-170 (10863)	Regular	Commercial in 3 counties	All	Simple descriptive analysis	Cross sectional longitudinal	Non Seasonal
USA [78]	1959	40yr	2	USDA herds		HF/jersey	Regression analysis descriptive	Retrospective study	Non Seasonal
USA [19]	1996	1 yr	83.1% US producers, 2,542 herds	NAHMS	Once	All breeds	Simple descriptive stats	Cross sectional study	Non Seasonal
USA [31]	1965-1980		95,322 grade, 104,660 registered	USDA sire summary herds		HF	Log odds regression, descriptive stats	Retrospective study	Non Seasonal
UK [81]	1991	2 wk	2502	Cull cow slaughter survey		HF	Chi square analysis	Cross sectional survey	Non Seasonal
USA [96]	1958-1963	5yr	7317	DHIA herds		HF	Descriptive statistics	Prospective cross sectional study	Non Seasonal
Ireland [28]	1980-1985	6yr	26-35	DairyMIS herds	Regular	HF	Descriptive stats	Prospective longitudinal study	Seasonal
Australia Qsld [2]	1968-1969	1yr	41 (3258)	Dairymilk recording scheme	4x/yr	All	Descriptive stats	Cross sectional longitudinal study	Non Seasonal

Australia NSW [71]	1963-1965	3 yr	44 herds	Commercial	16/3yr	All	Descrpitive stats	Cross sectional longitudinal study	Non Seasonal
NZ [4]	1981-1983	2yr	36 herds (8510)	Commercial	Monthly	All	Descriptive stats	Cross sectional longitudinal	Seasonal
Canada [17]	1967-1968	1 yr	26,651	ROP herds	Monthly	All	Descriptive statistics	Prospective longitudinal study	Non Seasonal
USA [75]	1960-1961	6months	7362	DHIA herds		All	Descriptive statistics	Longitudinal	Non Seasonal
USA [43]	1948-1963		1	Registered herd	Regular	Jersey	Descriptive statistics	Longitudinal	Non Seasonal

There is considerable variation in the classification of removal reasons, which makes it difficult to compare reasons between studies. There is also a huge range in the number of diseases and reasons for culling investigated. Some studies made very specific diagnoses, with or without stated definitions, for culling [78 44 36 96 75 2 3 3 95 98] while others only used very general culling categories [19 84 29 28 45 43 82 72 31].

The reasons for removal of cattle vary with time, as they are a function of the health status of dairy herds, fluctuations in milk and beef markets, demand for breeding stock [17] and other market demands such as milk quality. Data obtained from the UK, using 18 herds, illustrates this point and is shown in the Table 2 below [45].

Table 2 Changes in removal reasons over time.

	1973/74	1974/75	1975/76
Yield	2.7	3.8	3.4
Infertility	8.6	7.6	6.6
Mastitis	2.7	3.2	3.1
Behaviour	0.2	0.5	0.4
Age	0.7	0.7	0.9
Injury/lameness	1.6	1.8	1.6
Death	1.8	1.8	1.2
Other	2.4	3.2	3.2
Total Removed	20.7	22.6	20.4

In the table above it is apparent that the importance of fertility as a removal reason appears to have declined over time while removal for production and mastitis has increased. Many other illustrations of similar changes can be found in the literature. [43 44 68 17 28 97 84]

Reasons for removal have been classified generally into voluntary and involuntary categories as was mentioned previously. Table 3 illustrates the similarities found in the reasons for the removal of cattle around the world. The largest proportions of animals are removed from dairy herds for involuntary reasons rather than voluntary. This feature is the same in all the studies. Infertility, mastitis and age are predominantly the most important reasons for involuntary removals. There does not appear to have been a significant change in reason specific removal rates over time. This is difficult to assess critically due to the different measures used in each study, the herds used are different and the locations of the studies are different. No studies have followed a number of specific herds or an area of herds over a period of time and computed the change in culling reasons.

Between the years 1938 and 1977 the average culling rates (per year) in New Zealand ranged from 17 to 21%.[59], with 29-33% culled for voluntary reasons and 65-67% of animals culled involuntarily. In the US and Canada between the years 1962 to 1986, depending on the area and the reports referred to, culling rates varied between 26.5-49.0% for voluntary removals and 51-73.9% for involuntary removals. The average culling rates per year ranged from 20.1 to 31.5%. [42]

Table 3 Comparison of the reasons for culling.

Reason	[88]	[88]	[13]	[84]	[43]	[68]	[38]	[29]
Low production	20	15.9	19	19.1	26.4	13	13.8	14
Sales				18.1	16.9			
Breeding/infertility	31.1	33.8	31	11	14.5	25	27.2	13.2
Mastitis	10	12.5	10		13.9	18	13.2	7.9
Age	5.8	4.8		6.3	4.2		8.9	10.2
Behaviour		2.6					3.36	
Disease								27.1
Injury/lameness	5	7.4	5	15.3	13.5	8	3.3	3.3
Deaths	1.3			3.5				7.9
Other	26.8	23	35	26.7	10.5	6	30	16.6

As illustrated above most farmers appear to be removing stock involuntarily from the herd, with production as the primary reason for disposal ranging from 13 to 20% of total culls. Greatest production gains are said to occur when culling for production is 3-8% greater than involuntary culling. This will maximise the economic return per cow when the market price for replacement heifers exceeds 150% their value as beef. [1] It appears that there is a lot of room for improvement in both profitability and genetic gain by increasing the proportion of animals culled for productive reasons.

Due to the subjective nature of culling classification the results from various studies often appear be very contradictory yet most show the same overall patterns. Culling for infertility is the primary involuntary reason for culling dairy stock. Whether these animals are sold for slaughter or to other stockmen, this is the biggest cause of loss to the dairy industry. Secondary to this is removal for production and the tertiary reason is removal for disease events. The intensity of culling for various diseases depends on the severity of the disease and the disruption that it causes to the milking process. If an animal is unable to be milked then she is unlikely to be kept in the herd, because there is no reason to keep her there. This is in contrast to animals culled for low production or mastitis. These animals are more likely to be culled late in lactation because while they may be producing lower than other stock they are still contributing to the herd income. It is therefore often more convenient to remove them when they are near the end of the lactation. This makes good economic sense in a seasonal situation where replacement animals are only available at the beginning of the next lactation (season), in the non-seasonal situation replacements are theoretically available at all times.

The most striking feature of the studies is that although great strides in production, diagnosis and treatment of disease has occurred over the last 20-30 years the relative importance of the reasons for removal have not changed significantly. [97 13 84 43 67 38 29] While most studies have looked at the reasons for and risks of removal, none have addressed the issues of how to reduce the proportion of involuntary removals. Improvements in methods for effective early diagnosis, treatment and management of the causes of involuntary removal could be of considerable economic importance to most farmers. Perhaps the involuntary rates of removal for mastitis and infertility are a factor caused by the drive for high production and as such are the cost that farmers have to bear for high production returns.

Risk factors for the removal of cows.

In contrast to the descriptive work above, studies investigating risk factors associated with removal were more sophisticated in their investigative techniques. While the first group of studies were concerned with quantifying and identifying reasons for culling the second group investigated the relationships between the risk factors identified in the first group of studies.

Table 4 shows a summary of the major studies investigating the risk factors associated with culling.

The majority of the studies were concerned with the investigation of the effects of disease on the risk of removal. This was often in association with milk production and reproductive performance. [35 20 17 12 77].

A few studies investigated the interrelationship of the risk factors and the culling events. [74 77 9 72]. All studies were prospective longitudinal giving observational epidemiological type results. All studies reported risks as odds ratios, hazard ratios or relative risks.

North America and Europe are the location of the majority of descriptive studies, with a few performed in Australia and New Zealand. The European studies tended to involve large numbers of animals [17 36 77] but sample sizes varied considerably between the studies. In studies with small numbers of cows and herds [97 21 76 83 20] the incidence of diseases may have been very low. The effects of these low incident diseases on culling would limit the validity of some of the results found.

A summary of the number of diseases and other variables investigated within each of the studies is illustrated in Table 5. There is considerable variation in the number of health disorders were investigated. The number of health variables ranged from 1 [16 7 95] to 22 [35] Most investigated the effect of the common health disorders affecting cattle over the lactation as a risk on culling. Some concentrated only on specific diseases [16 8 95] or diseases occurring at a specific time in lactation such as the peri-parturient period. [76]

A diagnosis of a health disorder could be made by the veterinarian and farmer [87 9 73 35] the farmer alone [68 16], the veterinarian and AI technician [77], or the farmer and trained technician. [9 12 74]

This could lead to potential problems of misdiagnosis and misclassification of diseases. There was no consistent set of definitions for the diagnosis of disease conditions in any of the studies presented. This means that when the incidence of disease was low the potential for misclassification is likely to be reasonably high. Also as diagnosis is subject to human error and judgement, sometimes by less qualified people, some results found may be limited in their interpretation.

Table 4 Summary of studies investigating the risks associated with culling.

Country	Study Period	Lactations	Sample Size	Sample selection		Breed	Analysis	Study Type	Farming System
France [10 12 12]	1986-1990	4	47 (4123)	6 wkly	Commercial herds	HF	Logistic Regression	Prospective longitudinal study	Non Seasonal
USA [39]	1981-1982	1	35	1/mth	University herds		Path analysis, multiple regression, OR	Prospective longitudinal study	Non Seasonal
France [10]	1986-1990	4	47 (3589)	6 wkly	Commercial herds	HF	Survival Analysis	Prospective longitudinal study	Non Seasonal
USA (NY) [73]	1981-1985	1	34 {7763}	4-6 wkly	Non random	HF	Logistic regression	Prospective longitudinal study	Non Seasonal
USA (NY) [74]	1981-1985	1	34{7763}	4-6wkly	Non Random	HF	Simple descriptive, RR, PAP	Prospective longitudinal study	Non Seasonal
USA (NY) [68]	1977-1978	1	18	1/yr	Non Random	HF	Discriminant Analysis	Prospective longitudinal study	Non Seasonal
Sweden [16]	1970-1974	4	950 (21,2166)	1/mth	Stratified	SLB	Cumulative Incidence, RR, Descriptive Stats	Prospective longitudinal study	Non Seasonal
Canada [21]	1969-1977	8	1	Regular		HF	RR, Descriptive stats	Prospective longitudinal study	Non Seasonal
Canada [58]	1972-1981	10	5 (3881)		Commercial	Mixed	Proportional Hazards	Prospective longitudinal study	Non Seasonl
France [37]	1979-1989	10	103,214		Commercial	Normande	Weibull survival analysis	Prospective longitudinal study	Non Seasonal
USA [76]	1976-1977	1	8 (492)	2wkly	Stratified	HF	ANOVA, χ^2 Tests	Prospective longitudinal study	Non Seasonal
Canada [21]	1970-1976	>2	1	Regular			Survival, descriptive stats, Rates	Prospective Longitudinal Study	Non Seasonal
Canada [8]	1967-1968	1	2534	1/mth	Non Random	Ayreshire, Guernsey, HF, Jersey	Multiple Regression	Prospective Longitudinal Study	Non Seasonal
Canada [35]	1979-1981	2	32(2008) {2875}	3 mthly	Purposive	HF	Discriminant analysis, RR, PAP, lifetable analysis	Prospective longitudinal study	Non Seasonal
Sweden [77]	1983-1985	2	69,832, 39,178	UK	UK	SRB, SLB	Multiple logistic regression, path analysis	Prospective longitudinal Study	Non Seasonal
Australia [83 87]	1992-1994	2	8		University herds	HF	descriptive stats, survival analysis	Prospective longitudinal study	Non Seasonal
New Zealand[53]	1985-1986	1	100 herds		Random	Jersey/HF	Logistic regression	Cross sectional study	Seasonal

Only one set of studies investigated the effect of all diseases in the lactation on the length of life [13 9]. Other variables that were investigated included the effect of production [9 12 73 68 35 22], age [21 67 34 21 76], season [9 12 73], lactation state [9 12 73], reproductive status [13 9 35 76] and herd [10 13 73 35] on culling. Age and parity of the cow was often treated as a potential confounder in the analyses because culling is generally found to increase with age. Production was also commonly treated as a potential confounder because of the association between disease and reduced production.

Statistical analysis of the studies gave disease specific relative risks and population attributable risks. [34 16 21 73] Path analysis was used in a few studies to show the relationships between various diseases and culling. [39 76] Odds ratios were reported in many studies to give parity stratified results [39 77 53], while Discriminant analysis [35 68], logistic and multiple regression [73 10 39 9 76 52] were utilised as the main methods of analysis.

In recent years survival analysis has emerged as a useful tool in the analysis of culling data. As culling data is essentially time to event data it is ideally suited this form of data analysis. Censored individuals can be utilised in predicting the probabilities for survival and hence reduce the overestimation of the effects of a disease on survival as is common when using other regression techniques. Several studies employed survival analysis to investigate the risk factors involved in culling. [22 37 9 83 87 20]

Table 6 summarises the risk of removal for the disease conditions investigated in some studies.

Table 5 Summary of the variables used to investigate risks associated with culling.

Study	Diseases	Type	Other variables	Reporting type	Analysis	Data collection
Cobo-Abru (1979)[20]	10	Various	Age, herd	Rates	Life tables	Veterinarian/Farmer
Thysen (1988)[87]	7		Herd	Hazard Ratios	Survival analysis, Descriptive statistics	Farmer/ Veterinarian
Beaudeau (1994)[9]	16	Various	Season, parity, production, reproductive status, herd, year	Hazard ratio	Survival analysis	Farmer / Veterinarian
Beaudeau (1994)[12]	14	Various	Herd, year, parity, season, production reproductive status	Odds ratio	Logistic regression	Farmer / Veterinarian
Milian-Suazo (1989)[73]	14	Various	Season, production, parity, herd, reproductive performance	Odds ratios	Logistic multiple regression	Veterinarian, farmer, trained technician
Martin (1982)[68]	11	Various	Production, age	Odds ratios	Discriminant analysis	Farmer
Bendixen (1989)[16]	1	Mastitis	Parity, stage of lactation	CI, RR	Mantel Haentzel, t-tests	Farmer
Dohoo (1993)[35]	22	Various	Herd, age, production, reproductive status	RR	Life table analysis, risks	Farmer / veterinarian
Cobo-Abru (1979)[21]	10		Age, production, calving interval	OR	t-test, log OR method	
Oltenacu (1990)[77]	8	Mainly peri-parturient	Age, season, herd production, reproduction	OR	Path model analysis, logistic regression	Veterinarian / AI technician
Milian-Suazo (1988)[74]	14	Various	Stage of lactation	RR	Descriptive data analysis	Technician / Farmer.

Table 6 Risk of removal for commonly described diseases.

Risk Factor	Beaudeau et al (1994)[12] OR	Beaudeau et al (1994)[9] HR	Milian-Suazo et al (1989)[73] OR	LIC (NZ)(1994/95)[67] RR	Cobo-Abru et al (1979)[21] OR	Dohoo et al (1993)[35] OR	Oltenacu et al (1990)[77] OR	Milian – Suazo et al (1988)[74] OR
Metritis	0.3-2.3	1.4-1.5			4.11		1.4-1.2	1.2
Mastitis	1.5		0.7-13.5	11	4.95	30.8	1.8	2.0
Early		1.3		5.6-				
Late		1.4						
Dry		0.6-8.7						
Teat injury	6.0	1.7-5.7	49.4			20.1		2.7
Non traumatic udder disorder	2.1-2.6							
SCC			5.5					
Abortion		5.5					1.6-1.7	1.9
Late	75.8							
Early	6.2							
Retained Placenta	1.2				2.33		1.2-1.4	1.6
Ketosis	10.3/17.3	1.7-1.9			1.12		0.8	1.2
Calving Assist		1.2					1.5-1.7	1.5
Infertility	6.6/80.3		2.8	2.0				
Metabolic Disease						18.8		
MF	1.6							
Downer Cow					0.83			
Lameness			14.6	25.0	1.74	19.5		1.5
Pneumonia					2.94	7.8		3.5
Ovarian Cysts					0.70		2.6-3.2	1.7
Anoestrus					1.66		1.3	1.1

The risk of removal has been found to vary considerably with age, time of year, lactation status and the production level of the animal involved. Length of productive life appears to be mediated mainly by calving events, mastitis and reproduction. [9]

Age.

Age appears to have a significant effect on both the timing of removal, the risk of removal for various reasons and the likelihood of a second chance. Dohoo [35] found the greatest risk of removal in 3-3.9 year olds and 7 year olds. The Irish found cow disposals were highest in lactation 1and 2, then decreased with an increase again after 4 lactations. However plenty of work disputes this and shows that the risk of removal generally increases with parity. [17 73 68 18 45] Cows in parity 5 or greater had a significantly higher risk of culling than cows in parity 2. [9] Heifers were removed more often for severe disease situations than older cows, especially dystocia and mastitis. [39] Low production [98 17] was important for removal in parity 1 to 3. However some found that farmers were more tolerant of low producing heifers and were prepared to give them a second chance. [38] Failure to conceive is also an important reason for removal in this age group. [98 18] They were four times as likely to be removed for not conceiving to first service than older cows. [39] The probability of removal for infertility was found to increase with age. [17]

Timing of removal.

Early and late lactation were found to be the main periods for decision making. The timing of culling depends on the age of the animal and the reason for culling. The greatest risk for removal occurs less than 30 days after calving and ≥300-360 days. [35] Cows in the first 60 days were found to have twice the risk of removal as a cow in mid-lactation. [9] The occurrence and timing of disease incidents have an effect on the timing of removal. Culling was found to occur soon after the diagnosis of a disease if at all. [74] Cows with severe health disorders such as teat injury [74], disease or low production was more likely to be culled in early lactation. [10 13] The risk of removal was found to increase again after 150d postpartum and with increasing parity. [74] Cows culled at this stage of lactation were removed for mastitis, reproductive disorders, poor reproductive performance [10 12 74] and low production. [74]

Mastitis.

The risk of removal for mastitis was 13.5 [73] and 11 [9] times greater in animals with a mastitis event than without. Cows with mastitis in the first parity were removed earlier in lactation than older cows with mastitis. Those animals that developed mastitis early in lactation had a greater risk of being removed than animals that developed mastitis late in the season. [16] This was agreed with by Allaire et al[1] who found a higher risk of culling if mastitis occurred in early lactation or the dry period.

Infertility.

Cows with poor reproduction performance were 3 times more likely to be removed than cows with good fertility[73]. As age increased cows were more likely to be removed for infertility[17]. However heifers with poor first service conception were four times as likely to be removed if they also had low production levels[39]. Cows culled for infertility were more likely to be removed at the end of the lactation period. [10 12 74]

Production

Cows with low production were 2.2.times more likely to be removed than cows with good production. [73] Cows with low production were removed at the end of lactation rather than early lactation. [10] Low production at a young age, especially in the 1st to 3rd parities, was a significant risk factor for removal. [98 17] Low production combined with low fertility was found to affect the likelihood of a second chance in heifers. [39] As production increased the risk of removal decreased, and length of productive life increased. [35 12] High production worth was found to have a sparing effect on culling [12], and the expectation of good milk records also protected cows from culling [73].

General Health Events.

Health events in the previous lactation were found to have little influence on the risk of culling in the next lactation. Culling appeared to be related primarily to disease events in the short term rather than the long term [9]. This was not found to be the case by Martin et al[68]. Cows with lameness and dystocia in the previous lactation had an increased risk of removal in the current lactation.

Seasonal vs Non Seasonal production systems.

The reasons for, risks and timing of culling may contrast between seasonal and non-seasonal dairy production systems.

Culling rates and reasons for seasonal and non seasonal dairy production systems are illustrated in Tables 7 and 8. All the work on risk factor investigation has been done in non-seasonal based herds. Therefore comparison of the risk factors between the two farming systems would be inappropriate.

The primary reasons for culling in the Seasonal production system (see Table 7) are production, old age, infertility, mastitis and Brucellosis / Tb. Disease, specifically Brucellosis and Tb, in Seasonal systems appears to be of more importance for removal than in Non-Seasonal production systems. The eradication of Brucellosis and reduction in Tb should reduce the importance of these diseases on culling in NZ, in particular.

In contrast Non-seasonal studies (see Table 8) show fewer removals for old age. Production, infertility, mastitis, and udder disease have greater priority for removal. It is interesting to note the difference in the numbers of animals removed for old age in seasonal farming studies. This is reflected in the higher average herd age in these areas when compared with US herds especially. Removal for other factors first would limit the age at which animals stayed in the herd in Non-seasonal production areas. A higher average herd age and greater proportions of cows removed for production are shown to improve the economic productivity of the farming situation. [80]

Infertility and mastitis appears to be the most important risk factors for the removal of cattle in both farming systems. Mastitis and udder disease is a greater cause of removal in Non-seasonal herds than in seasonal herds. Infertility as a cause of removal appears to fluctuate largely between the studies. There appears to be an increase in the level of removal for infertility with time, however there does not appear to be a significant difference in the rates of removal for infertility between the two farming systems.

Table 7 Culling rates and reasons in seasonal calving herds.

Reason for culling	*1976 Ireland* [29]	*1989 Ireland* [28]	*1957 NZ* [56]	*1973 NZ* [29]	*1985 NZ* [3]
Production	14	22	27.5	34.3	16
Old Age	10.2	2.6	12	3.4	11
Infertility	13.2	25	23	18.1	27.8
Mastitis	7.9	12.5	5	4.1	10
Abortion	5.9	2.8	0.6		
Calving Difficulty	1.3	1.5		0.5	
Udder disease		1.9			
Brucellosis/Tb	19.9	11	2	4.6	27.8
Limb disorders		5			0.8
Injury Death	11.2		9	5.1	3
Other	27.8	14	5	27.3	
Total culling	*12.2*	*17.56*	*19.08*	*21.5*	*22.65*

Table 8 Culling rates and reasons in non-seasonal calving herds.

Reason for culling	*1961-4 NSW* [72]	*Qsld 1973* [2]	*NSW 1996* [87]	*NY 1962* [75]	*USA 1988* [42]	*USA 1996* [19]	*Canada 1971* [17]	*UK 1983* [45]
Production	23.9	16.4	11.76	27-32	25.4	22.4	15.5-27.6	13.6-16.8
Old Age	6	9.4		4				3.2-4.4
Infertility	19.6	16	33	16-19	22.9	26.7	12-16	32.3-43.2
Mastitis	9	11.1	16.89	14-20	15	26.5	3.9-5.4	13.4-15
Abortion		5.2					0.6-1.1	
Calving Difficulty	0.5	3.7	6.07				1.2-1.8	
Udder disease		2.8	11.57				4.9-10.2	
Brucellosis/Tb		2.7		1			1.3-1.5	
Limb disorders		1.1	4.36		1.8	15	1.9-2.6	
Injury Death	5	8.8			13.7			7.7-8.1
Other	29	15.1	14.99		7.5	4.1	3.5-4.8	11.9-15.5
Surplus		7.7	1.52	14-15	13.7			
Total culling	*17.1*	*22.03*	*26*		*20-31.5*	*22-25*		*9-34%*

The work above illustrates the complexity of the culling decisions. The reasons for culling are not easily investigated or follow simple formulae. Disease and production, herd, cow and farmer interact to make the culling decision. The investigation of culling reasons can lead to conflicting results depending on the research methodology and aims. Individual cow factors such as age, stage of lactation, disease, production level, temperament and reproductive performance are taken into account when selecting cows for culling. Herd factors such as replacement costs, the availability of replacements, disease rates, the milk and beef market, as well as genetic and production improvement are also considered when making a culling decision. Culling criteria differ from one farmer to another and they may be sociologically structured. [14] Management styles, social status and production system influence the culling decision. A farmer's combination of strategies, goals and related practices will affect the outcome of a culling decision.

The only way to overcome the subjective nature of the culling decision is to make the process more objective. The calculation of the economic value of an animal, allowing for the inclusion of values for temperament and disease, will allow an objective way to select cows for removal.

The economics of dairy cow replacement decisions.

The single most important aim of the producer, in economic terms, should be to maximise income and profitability on the farm. Culling and replacement has been found to be the least discussed farming decision. [14] Culling is probably one of the least recognised areas where improvement in herd and farm profitability can be achieved. This could be due to the difficulties associated with calculating replacement costs, changing replacement costs and poor understanding of culling methodology. Profitability and improved production can be achieved by improved culling methods. [91]

The studies discussed previously illustrate the importance of disease and reproductive problems on the selection of animals for removal. Subjective economic decisions about an animal's relative worth are commonly made. Ideally culling decisions should be based on objective economic considerations and animals removed for productive rather than involuntary reasons.

Dairy organisations may offer standardised ranking procedures for cattle based on realised production capacity or transmitting ability. In New Zealand standardised ranking's on genetic potential for production, PW (Production Worth), or breeding, BW (Breeding Worth) are calculated for all milk recorded animals and their progeny. Overseas calculations appear to be based on realised production and genetics only. In comparison New Zealand has incorporated economic components into the calculation of individual breeding and production indices.

A number of techniques have been applied to aid the selection of dairy cows for replacement. General guidelines for culling and individual cow culling guides have been developed [34 41]

Culling decisions should be based on anticipated revenues and costs [91] and various methods have been used to determine the optimum replacement policy for dairy cows based on the expected net revenues. These include the marginal net revenue approach, profit equations and dynamic programming.

Marginal Net Revenue approach

The marginal net revenue approach aims to maximise revenues over time. This approach is an extension of the work based on replacement theory started in the early 1960's by Faris [40], Perrin [79] and Burt [18].

Replacement theory is based on maximising the revenues of the current asset before replacement. It is a method by which the calculation of the optimum time for replacement of the current and subsequent assets is maximised with regard to revenue. [18 40 79]

The basic principles behind the marginal net revenue are as follows:

The costs and revenues over time are first calculated. These figures are then used to calculate the net revenue, the marginal cost, the marginal revenue, the marginal net revenue and the average net revenue. These calculations are illustrated in Table 9.

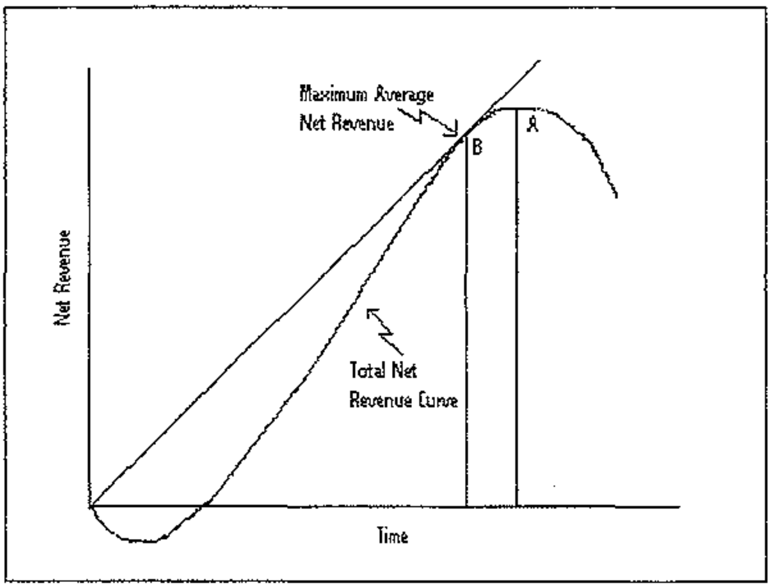
Table 9 Summary of Marginal Net Revenue calculations.

Time	*Total cost*	*Total revenue*	*Net revenue*	*Marginal cost*	*Marginal revenue*	*Marginal net revenue*	*Average net revenue*
n	TC	TR	NR=TR-TC	MC=dTC/dn	MR=dTR/dn	MNR=MR-MC	ANR = NR/n

The net revenue is the total revenue minus total costs. The marginal revenue is the change in revenue divided by the change in time, as is the marginal cost. The marginal net revenue is therefore the marginal revenue minus the marginal costs. It is a calculation of the change in revenue over time. The average net revenue is the net revenue over the change in time. To illustrate the optimum time for replacement the total net revenue over time is graphed in Figure 1.

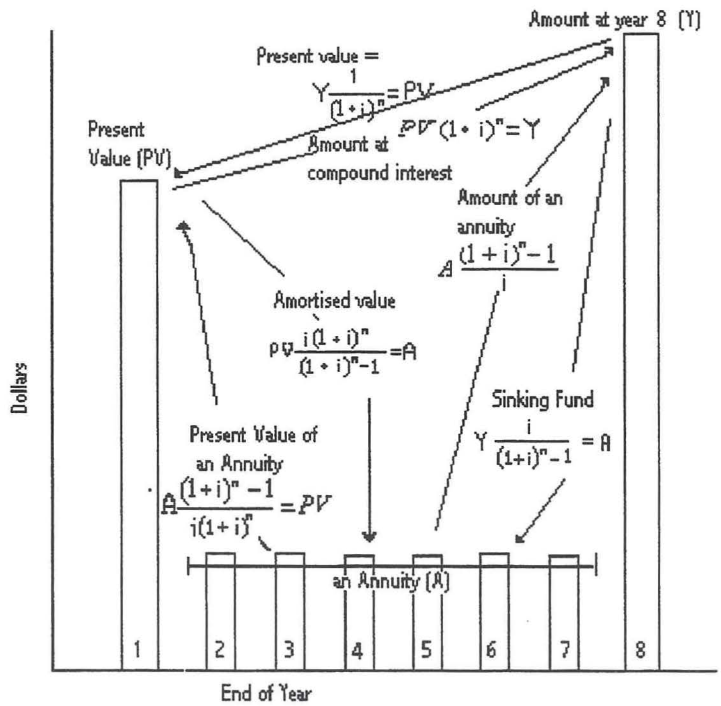
Point A is the Maximum net revenue. The maximum average net revenue occurs at point B. Point B is the place where the marginal net revenue is equal to the average net revenue. The outcome in a situation where the revenue from an asset is realised by the sale of that asset then the optimum point of replacement should only occur to the point where the marginal net revenue equals the maximum average net revenue anticipated from the subsequent lot.

Figure 1 Marginal Net Revenue Curve



The dairy cow replacement issue is more complicated than this simple issue. It can be considered as a long production period with revenues being realised throughout the life of the asset. The complications arise because of uncertainty in costs, prices and time preference. To deal with this issue discounting is applied. Discounting to account for time preference works as follows: A sum of money received or paid now is worth more at the present time than at some time in the future. The further into time that the sum is to be received or paid the less the present value placed upon the sum. The relationships between the present value and the future value are illustrated in Figure 2. The arrows indicate the direction of the movement between different points in time. When taking into account discounting of future returns the point of optimum replacement is when the marginal net revenue from the present asset equals the maximum present value of the net revenues from the subsequent asset.

Figure 2 Relationships between present and future values [40]



Burt [18] elaborated this work on replacement and considered replacement under risk. The risk of failure or involuntary replacement was considered. His model assumed that an infinite planning horizon was considered and the revenue, cost and probability parameters do not change over time. This ensured that the optimal replacement age is constant for all assets throughout the infinite chain of events. However the planned replacement age and the actual replacement age were allowed to differ.

The optimal replacement policy under risk is to hold the current asset until the expected marginal net is less than the weighted average net revenue from the potential replacement. The weights are the products of the discount factor and the probability of survival for each age. [18]

Work done by Perrin [79] showed that the previous calculations could be applied to the problem of replacement with an improved asset. The net returns of the current asset are compared with the present value of the subsequent asset at each point in time. If the net returns from the current asset are larger than the subsequent asset then it will be retained for another year. The effect of the discounting rate on the age of replacement depends on the asset characteristics such as the marginal net revenue, interest and costs to the replacement age. These factors will result in earlier or later discounting. [79]

In summary the optimum time for the replacement of an asset depends on:

- The shape of the total net revenue curve,
- The characteristics of subsequent assets,
- The discount rate
- Involuntary replacement.

The application of this theory to dairy cattle has been considered to have the following constraints. Firstly, dairy cattle cash flows are irregular within the lactation. The time for planned replacement of present and subsequent cows have to be varied. All subsequent cows are identical with respect to net revenues, in this instance therefore it is impossible to account for continuous genetic improvement. If there are seasonal differences in the net revenues it is not possible to account for the fact that subsequent cows will likely be replaced in different seasons. With periods shorter than a constant calving interval, the optimum time for replacement may differ between cows. All replacements have the same optimum time for replacement because they are assumed to be identical replacements. [91]

However these constraints are not applicable if using the replacement theory as outlined by Perrin, Faris, and Burt. [79 40 18] In the seasonal situation cash flows can be controlled so that they are regular throughout the lactation. The calculations only require values at a point in time so cash flows can be smoothed to cover these periods. The time for replacement can vary with time as we are only considering a point of optimum replacement, based on the current revenue streams of the assets. This in turn means that seasonal effects can be modelled successfully. All animals are not the same with respect to revenues and these can be adjusted for the individual. This also means that improved assets can be included in the calculations successfully.

Dairy Cattle Culling Computer Models.

Marginal Net Revenue

Zeddies applied the marginal net revenue approach developed by Burt et al [18 40 79] to the dairy cow replacement problem in the early 1970's. This was followed by a series of studies by Renkema and Stelwagen 1979 [80], Korver and Renkema 1979 [62], Dijkhuizen, Stelwagen and Renkema 1984/85 [33 32] that investigated the application of marginal net revenues to the replacement of dairy cattle.

Renkema and Stelwagen, and Korver and Renkema addressed two questions: What is the economic significance of improved health permitting a longer herd life? [80], and Which cows should be removed from the herd during the first lactation in view of their milk yield? [62]

The economic criterion of replacement was stated as follows: "A cow of a particular age should be kept in the herd as long as her expected marginal profit is higher than the expected average profit during a replacements life". The marginal profit equals the profit in one productive year including the change in slaughter value. The average profit equals the sum of profits in the whole productive life divided by the number of productive years. If the sum of expected differences (the marginal future profit of the present cow weighted against the average profit of a replacement young cow) is positive then the cow is kept, otherwise it is replaced.

Milk production and value, calf production and value, slaughter value, feed costs and the probability of disposal, for each age/parity group, were used to calculate the marginal net revenue. It is assumed that all replacements are purchased so the cost of a two year old replacement prior to calving is also required. The probability of disposal in each productive year due to production and other causes, most likely disease, was taken into account. Replacement was assumed to occur 365d after calving and calculations could only be performed at the end of the lactation.

To determine the effect of forced replacement comparison was made with and without removal due to ill health. A decrease in forced replacement rate was found to be of major economic importance because it resulted in an increase in the average herd age. With an increase in average herd age there was an increase in average herd income. The long term effects of increasing herd age were slightly reduced when a 1% annual increase in genetic gain was include in the calculations. The calculations are sensitive to price changes, with a change in milk price being 6 times greater in importance than the same relative change in slaughter value.

Korver and Renkema[62] extended this model to consider the selection of cows during the first lactation. Four herd culling policies were evaluated and compared on the basis of average earned income per cow per annum over the average productive lifetime. The production level below which it was considered uneconomic to keep an individual animal was also calculated.

The culling policies were as follows:

1. Ill health or insufficient production was reason for disposal. 58% replacement rate
2. Culling is not based on production, only ill health. 51% replacement rate.
3. Production based culling during first lactation. All animals used for replacement production.
4. Production based culling during first lactation. Animals culled for production not used to breed replacements.

In this model a cow could be replaced every month of the first lactation, 30.4d, and then every 245 days in lactation in the following lactations. Probabilities of disposal due to ill health only were used for the present cow, so that disposal due to production could be determined, the replacement cow had all probabilities of disposal used. The decision to replace an individual should be made before she is inseminated therefore calculations for the predicted milk yield based on the current lactation yield were developed. Critical levels of production were calculated for each month of the first lactation, below which a cow should be removed. Calculations showed that in almost every case there is no advantage of keeping a first lactation cow any longer when the decision to replace her had been made. Overall the rate of genetic improvement in the herd was considered to be hardly influenced by the intensity of culling for production. Culling policy one was considered to be the most profitable followed by policy two.

Djikhuizen, Stelwagen and Renkema [33] further extended this model in 1984/85. This work extended the previous calculations to investigate the financial loss at farm level due to reproductive failure and to evaluate the value of various insemination policies. The point at which it became uneconomical to continue insemination was determined. Ten calving intervals, increasing at 20-day intervals from 345 to 525 days were defined. Each lactation was divided into periods of 25 days immediately after calving, followed by periods of 20 days. In the current lactation replacement was possible at the end of each period but in subsequent lactations only at 225 days after calving. Discounting and the probabilities of disposal were included in the calculations. The average profit per year (annuity) was calculated as in the previous work. The extra income of retention over replacement was calculated, and was called the norm-loss per cow. The length of the calving interval with the highest yearly income was defined as optimal. On average an optimum calving interval of 1 year or less was established with an increase in cost per day open. Total loss due to reproductive failure was estimated to average 2% of the gross production value or 10% of an average farmer's income. Considerable difference in losses between farms was also found.

This model was then used to investigate the optimum time to replace animals with reproductive failure [32]. The sum of expected differences (SED) was used as the criterion on which to replace an individual. This is the equivalent to the norm-loss per culled cow presented by Djikhuizen et al. [33]

The replacement criterion was: A cow should be kept in the herd as long as the sum of the expected differences (SED) in profits between her and the replacement cow exceeds zero. In deciding whether to replace the cow for reproductive failure immediately or not, as long as the expected income in the current lactation of an empty cow is more than the average income of the replacement cow then it is worthwhile to postpone replacement to the end of the lactation. Therefore at each heat the criterion of the decision is: A cow should be inseminated again if the SED in profits during her remaining expected life, in the case of pregnancy compared with replacement at the optimal stage of the current lactation, still exceeds zero.[32] All the criteria of the calculations for the previous model were used for this investigation. In this study it was found that it was still profitable to continue inseminating young cows, with an average or above-average production level, with poor fertility for a long time. Factors influencing this were persistence of milk production per lactation and repeatability of a longer calving interval of the cow concerned.

Dynamic Programming.

Dynamic programming is a mathematical technique useful in situations where a sequence of decisions has to be made. A dynamic programming model policy is defined by a number of decisions taken at different stages. Each stage in the system can be defined by a series of states defining the possible conditions at that stage. The action to be taken at each stage has a probability of occurrence associated with it. The dynamic program runs by finding the optimum solution to the model. The optimal policy at the last stage is calculated first before calculating backwards through each of the stages until reaching the optimal policy at the initial stage. At each step in the matrix the optimum decision for that state is determined. A starting variable such as a cow is defined in a state e.g. milking, lactation 1, in calf etc the transition variables from this state to the next state are also defined. This is called the transition matrix. Each transition state has to be defined and may have various stochastic possibilities therefore enabling many various conditions to be accounted for.

This technique can be used to determine the optimum time for replacement based on net revenues. The advantage of this system is that it puts no restriction on the nature of the marginal net revenue or other functions used to specify the structure of the system. Continuous genetic improvement can be accounted for. The effect of season and year can be incorporated into the model as well as variation within traits. The possibilities of variables to be included are limitless but are in reality limited by the ability of the process to be computed. With faster computer processors the size of the model can become very large but is still limited by technology and time to process the data.

The development of dynamic programmes devoted to culling decisions occurred earlier than the computationally simple MNR models developed previously. They also continue to be the main method by which people have researched the economics of culling decisions. The advantage of dynamic programming is that it allows the developer to include stochastic processes into the model and hence try to re-create reality as closely as possible. The disadvantage is that every state in the model has to be specified and this poses limitations both in the knowledge of how the interactions work and computing time. However the limitations due to processing time are quickly being eroded with modern computers. Currently models with 1,000,000 different states are being worked. Another limitation with these models is that we stop talking about real animals and instead are talking about optimal animals that fit the requirements of the model developed. This may bring answers to questions that do not fit with reality.

A summary of the major dynamic programming models is illustrated in Table 10. This table describes the range of models that have been developed and the number of states and variables that have been included in the development. Age and Milk production variables were considered in all models. Stage of lactation was included in two models [90], [30], calving interval and timing in three models [63 30 56], and Fat percent [86 85], Body Weight [86 85] and Mastitis [60] in one model. The number of states modelled ranged from 9 [61] to 151,200 [30]. Six out of ten models accounted for genetic improvement. [90 86 85 49 30 56]

Table 10 Summary of key features of some Dynamic Programming models.

Characteristics	Van Arendonk 1985[90]	Stewart 1976[86] and 1978[85]	Kristensen 1987[63]	Ben Ari 1983[15]	Kennedy 1993[60]	Gartner 1979[49]	Killen 1978[61]	De Lorenzo 1992[30]	McArthur 1973[70]	Harris 1986[56]
State Variable										
Age/lactation number	12	7	15	√	12	10	9	12	7	10
Stage of lactation	12							12		
Calving Interval/date			8					7		5
Milk Production	15	11	15	√	5	5		12	80	52
Fat Percentage		7								
Mastitis					2					
Body Weight		5		√						
Number of States	29880	2695	60,000		120		9	151,200	560	2600
Length of each stage	12m	12m	8 wk	12m	12m	12m	12m	30d	12m	12m
Genetic Improvement	Yes	Yes	Yes	No	No	Yes	No	Yes	No	Yes
Length of planning horizon	15yr	10yr	∝	∝	?	15yr	20yr	20yr	20yr	20yr

Much of the Dynamic programming work can be attributed to the four main dairying areas of the world, the UK, Europe, New Zealand and U.S. The following section will outline the major work and its derivative's in chronological and author sequence. All work relating to that done in New Zealand is included in the section dealing specifically with Australia and New Zealand.

The first work on dynamic programming for the dairy cow replacement problem was started in the early 60's. It was based on the maximisation of net returns. [55] It consisted of 12 states based on lactation number with the length of each stage equalling 12 months, and a planning horizon of 12 years. This work was based on Bellman's work on dynamic programming. [91 55]

In 1976 Stewart [86] published a replacement model for Holsteins considering the age, milk yield, milk fat %, and body weight. The optimal culling decision was defined as one that maximised the present value of returns from milk and beef sales. The sensitivity of the model to prices, interest and feeding costs were considered. Replacement was considered to be with an average heifer in first lactation. Culling decisions occurred at 60 days post calving prior to mating. A ten year planning horizon was used which when decreased to five caused more intensive culling to occur. Optimal policies for replacement was dependent on lactation number, body weight and prices. Areas requiring more investigation were identified. These included relationships between age and body weight, milk components and future returns, economic costs of milking speed and temperament and the interaction between reproductive performance, lactation number, milk yield and body weight.

This model was extended in 1978 [85] to consider the effect of using a probability distribution for replacement heifers rather than an "average" and to include the effects of all breeds. They found that the specification of an average replacement tends to underestimate the replacement value and hence the decision to replace or keep.

De Lorenzo [61] published a model in 1978 to define the optimum replacement policy for a seasonal calving herd with culling in autumn. Their model was a retrospective one in which they compared the replacement pattern that occurred naturally with the optimal pattern produced by the model. One state variable, lactation number, was used in the model. They also considered replacement with an average heifer. Not included within the model were costs of production with age, calf value, or the salvage value of a cull. The probability of survival was calculated and included in the model. If a cow failed the value of a failure was not included in the model as it was calculated to be equal to zero profit. The conclusion was that the optimal rate for culling was 17 to 20%. To improve yield the proportion of cows culled voluntarily would have to increase and disease levels reduce. The implications of this on culling strategies could then be traced using the model developed.

Gartner [49] developed a model to investigate culling in dairy animals competing for grassland in 1979. This model was developed to determine the effects of different replacement rates on genetic improvement in yield per cow, milk output farm profit and husbandry. The cows weren't modelled as individuals but rather as a herd policy. Un-predicted culls were determined deterministically and predicted culls stochastically. The salvage values were not variable. A constant calving interval and age at first calving was included in the model. They found that the "profitability falls as the replacement rate increased because the number of animals able to be milked and maturity of the herd overrides gains in milk yield per cow due to genetic improvement by culling and use of genetically improved sires".

This work was used as the basis of a series of work that modelled an experimental herd with which they could explore the effects of their findings in the original model. This model described the entire dairy production system rather than a specific goal such as culling. All aspects of the farming system were included in the model [46]. Testing of this model and experimentation with the working hypothesis above was performed and outlined in the second paper in the series [47]. Quantitative effects of different replacement rates on profitability and herd improvement were discussed. The effects of changes in management showed that increasing health and premium bull use significantly increased yield per cow. Reduction in the age at first calving decreased yield per cow. Further investigation lead to the discovery that the major influence of profitability in the grassland situation was the number of cows in the herd. [48] Increased replacement rate or yield per cow was not always associated with a decrease or increase respectively, in profitability. The difficulty in modelling the process was the method by which to validate the model. In trying to predict the components of the system further understanding of the range of responses to the experimental situations in "real" terms gave enlightened understanding of the objectives the farmer faces.

In 1983 Ben-Ari et al [15] developed a Markovian decision model based on the expected economic value of keeping a cow in the herd to aid in the optimisation of replacement decisions. It was based on the assumption that there is a limited supply of replacements on the farm, such as the situation where all replacements are reared on the farm. For each animal the economic value of keeping it in the herd was calculated. Animals were ranked by a "keep value" and the cow was replaced when the expected value of the cow was lower than that of an inferior heifer. Survival was not taken into account in this model.

Congleton began a series of work spanning the period from 1983 to 1988 [24]. A dynamic model that simulated the biological and economic components of the dairy cow was presented. This first model was structured in a modular fashion that allowed for the variables modelled to be easily modified and contained detailed estimates of relationships between age, production and costs of production. For validation output was compared to survey information. Extending herd life resulted in more days open, lower annual milk yield per cow, decreased replacement cost and cull cow income, and increased cow health cost. The profitability of extending herd life was insensitive to increased feed price, poor management and decreased salvage value. High salvage value and low feed price significantly decreased the profitability of extending herd life.

Congleton published further work on the culling issue in 1985 and 1988 [26]. It was based on an income projection 6 months into the next lactation. Rather than continue solely using dynamic programming approaches the work was extended to use profit type equations. Two indexes were used for culling. One was a short-term index based on the predicted monthly returns, which were the predicted profitability of the remainder of the current lactation and the following next 6 months of the next lactation. The second index was the maximum average monthly return index which calculated the average returns for planning horizons including each future month in the present lactation to 10 months into the next lactation and was used to rank the cows on the maximum average value. These calculations were used to predict the effect of culling decisions on the future herd income and evaluate herds with different planning horizons. This economic model was based on calculation of the net present value of the herd income. Lengthening the planning horizon increased long-term income more than short-term income. Culling on Net Present Value resulted in a cow average herd life (4.084) close to the average herd life expected to maximise herd income.

This model was extended in 1988 [25] to investigate the development of a cow culling technique using an initial screening of the herd based on a short term income prediction and then selection of the final cull from the long term income. It also aimed to describe the patterns of culling and predict the income resulting from application of this technique. Culling on both income projections found it advantageous because it took advantage of the benefits of both. Highest long-term income was found to occur in lactations 1 to 5, with most of the voluntary culling occurring in the middle of the calving interval.

Further extension of the model to evaluate the effect of herd genetic merit and projected herd income based on the use of the MaxANR and UAF calculations was performed.[22] The influence of the culling decisions on the herd profitability was investigated. The overall finding was that the timing and criterion of culling had significant influence on herd income but that culling explained only 14.67% of the factors affecting income. Culling solely on projected income decreased the genetic gain of the herd over time for production. The final study aimed to determine the effect of anticipated changes in the milk price to compare income streams for cows that differ in age. [23] They also evaluated the application of statistical decision theory techniques to culling when there is uncertainty in the culling decision altered by a likely change in the milk price. This model involved application of decision-making theory with the inclusion of Bayes theorem and Markov chains. The information required to predict the future income was found to be more important than the price changes in the milk.

Between 1984 and 1990 Van Arendonk [91] published a series of studies using a dynamic programming model to estimate the optimum replacement policy for Dutch herds. [90 92 93 89 81 30] This work was an extension of the marginal net revenue work started by [33 32]. The first model was used to estimate the course of performance, revenues and cost of individual cows with different levels of production and number of days open. [90] Three major components of the system included milk revenues, production, body weight, carcass value, calf value, feed costs, and sundry costs. In this model no accounting for genetic improvement was given. The model found that the relative level of milk production had a large influence on the average monthly net revenues during the lactation period. A prolonged calving interval resulted in a decline in the average monthly net revenue during that period, due to decreased revenues from calf and milk sales. The financial loss from increasing the length of the calving interval was curvilinear, with losses accounted from 1 to 5 Dfl per day open. A difference in revenue due to season was noted. Highest average net revenues occurred in winter calving cows and lowest in spring calving cows. These changes were due to seasonal fluctuations in milk production and composition. The effect of calving interval on average daily net revenue is bigger for winter calving cows than for cows during the grazing season.

This model was then used to study the influence of changes in production and prices on the optimum policy of replacement [92]. The variables modelled were lactation number, stage of lactation, milk production in the previous lactation and milk production in the present lactation. In total a possible 29,800 states were possible. Net revenues were calculated from milk revenues, calf revenues, feed costs, sundry costs, culled cow revenue and replacement heifer costs. The probability of disposal was included in the model as was genetic improvement. Genetic improvement was modelled as a 1% increase in production with each group of incoming heifers. Discounting was applied to convert the net revenue into the present net revenue and a transition from one lactation level to another within the lactation was possible. Voluntary replacement occurred at 205 days but could range from 61 to 275 days into lactation. Heifers and second parity cows could be removed only at 135 and 205 days into lactation. If there was an increase in beef price and a decrease in heifer replacement price then a shorter optimum herd life and an increased replacement rate was the optimal decision. A change in milk price, calves, feed price, and production level did not affect the optimum herd life. Heifer price and beef prices were the variables that had most affect on the optimum replacement rate. Greater genetic improvement causes a decrease in the optimum herd life, which may not necessarily be apparent in the short term. The calculation of the optimum herd life at a given level of involuntary replacement lies close to the average observed in practice. A reduction in involuntary replacement rates allows a higher level of voluntary replacements. This increases the financial advantage but reduces the effect on average herd life. Management and breeding should be directed towards reduction of involuntary disposal rather than maximisation of the average herd life of cows.

This work was further continued [93] with optimisation extended to take into account the variation in the time of conception. Inseminations could occur for 2 to 7 months after calving at monthly intervals. An open cow could stay in the herd for a maximum of 16 months after calving. If a cow remained open then the decision to remove the cow or inseminate the cow is based on the level of milk production at the time. At two months if the cow produced less than 84% of the rest of cows then replacement was the preferred option and at seven months this level was 94%. The optimum situation was determined to be an average calving interval of 371 days and an average herd life of 44 months with an annual replacement rate of 27%. Cow production was considered independent of conception time, therefore greater profitability occurred with early rather than late conception. Insemination was allowed to continue for longer periods of time in cows with average or higher production. The optimum policy was greatly affected by changes in the replacement heifer price.

This was followed by work on the effects of seasonal variation in performance and prices [94]. The model was as for the previous studies with the parameters for the variables changed to reflect the seasonal changes in these factors. Seasonal effects were calculated for prices of milk, calf value, salvage value, milk production, conception rate and replacement cost. It was found that the season of calving influences the production of milk, fat and protein, the probability of conception, feed costs, the price of milk, calves and culled cows. Seasonal effects on the above variables result in different optimal times for removal than if seasonal effects are not taken into account.

In 1987 this model was further used to develop management guides for insemination and replacement decisions [89]. By showing which factors influence the future profitability of cows the development of management decisions based on future returns and not just realised potential was illustrated to be of benefit to farmers. Milk production, lactation number and stage of lactation affect the management guides. Management guides not only indicate optimum decisions relating to a cow but also allow a farmer to weight additional information on the cow or herd.

The original model developed by Van Arendonk and Djikhuizen was taken to the US and adapted to model the US dairying system. [81] The objective in these studies was to determine if the differences in production systems between the US and Holland were sufficiently different to affect the nature of the model. They found that optimum yearly culling rate in the US was around 25% and as such some farmers could benefit by reducing on farm costs associated with extensive culling. Increased culling to improve milk yield may not be justified due to the increased replacements required. Feed costs represent a large proportion of the farmers' costs and affect the optimum culling rate especially if replacement heifer costs decline with lower feed cost. While the absolute values were different the nature of the model was not affected.

In 1992 the model was further extended to optimise the insemination and replacement decisions for a specific region incorporating US seasonality effects into the model [30]. This model was then used to predict future productive lifespan, insemination and replacement at profit maximising times. Herd structure, calving patterns, culling, milk production and income was able to be optimised using the model output. Overall this study demonstrated the usefulness of the model to aid in management decisions in large dairy herds of 1000 cows or more. The model was modified to accept individual herd data to tailor specific applications to the herd. "What if?" runs were performed to test the effects of various policies on the performance of the herd.

Kristensen [63] developed the original work of Van Arendonk [90], in 1987, using a Markovian Hierarchic process, which consists of a number of sub processes that are collated to form a main process. Optimality is based on the maximisation of the expected present value of the total future rewards under the infinite planning horizon. The sub processes consisted of two options, one to replace the cow with a heifer and the other to keep the cow. The main process ends and a new one begins when a cow is replaced. Therefore the length of the stage is equal to the expected lifespan of the individual cow. The only state variable of importance in this process was based on the genetic value of the cow's sire. This was considered to affect the production ability of the dam. Ranking of the cows on the future profitability is possible with the least profitable cow being replaced if a heifer is available. Low yield cows were replaced but if the cows calving interval was short then a lower milk yield is accepted before the cow is replaced. Current yield was the most important factor in determining the profitability of the cow. The influence of genetic class showed that cows with higher genetic merit had improved survival times when compared with stock of lower genetic value.

In 1993 Kristensen [64] extended this work to incorporate the use of a Markov chain process with Bayesian updating. The model was mainly concerned with the correct definition and measurement of animal traits in order to give the best possible prediction of the future revenues from an animal considered for replacement. A method was developed by which the temporary and permanent characteristic traits could be measured and utilised in a model to predict the future revenues. Differentiation of production variation between animals and over time for the same animal is important and directly influences the expectations of future net returns from the animal.

In 1993 Kennedy [60] created an adaptive dynamic programming model with the objective of maximising the present value of the expected net return form a cow currently in the herd and future replacements, across all decisions with a limitless planning horizon. The decision moment occurred at yearly intervals at the beginning of the lactation. The options available were to keep the animal, replace the animal or cull with no replacement. The state variables include lactation number, yield potential and mastitis status, which gave a total of 120 possible states at each decision stage. Mastitis was included as a variable to take into account involuntary replacement decisions. A Bayesian estimate of the yield potential in each lactation was calculated using a repeatability of 0.48 for milk records. The optimal decision for a given historical record of milk yields was highly sensitive to the estimate of repeatability, which is dependent on the year and season and herd production. An allowance was made to include the quota variable in the decision process. The key parameters which affected the calculations were estimated to be the variances between the cow and the within cow variances to determine the repeatability of the milk production. Key parameters, which aid in the culling decision, were between-cow and within-cow yield performance. This work showed that while optimal replacement policy by yield class may not be sensitive to repeatability, the optimal policy by historical record yield may be very sensitive. Investigating the relationship between milk yield within herds was identified as an area requiring more work.

Lehenbauer [65] developed a decision support system based on a recursive stochastic programming approach. The aim was to model individual cows to establish preferred culling decisions for each animal. State variables for milk production, reproductive status and mastitis were used to describe cow performance. Using the recursive stochastic programming model allows the modelling of individual animals rather than relying on fixed herd sizes to ensure optimality as other programmes do. Cows are modelled from the present state to the 10^{th} lactation where they will be replaced with a heifer. Involuntary replacement by death and forced sale is taken into account over the ten lactations. Ranking of the cows is possible based on present values obtained from marginal net revenues.

Profit Equations

Profit equations have been developed which reflect the realised profitability of cows. The profit equation includes revenues and costs during a specified period or the total herd life of the cow. It is often used to determine the relative importance of longevity to the profitability of cows. They are also used to compare the relative efficiency of indexes for improving profitability.

Simply put profit equations are economic measures of an animal's total profit, profit per day, profit per unit of investment or cost per unit of production. In essence they are calculations of income and expenses. Van Arendonk in 1984 stated "A profit equation should be equal to the profit until disposal of the cow and it is necessary to take the opportunity cost of postponed replacement into account. If this is not done then the effect of herd life and associated variables such as stayability on profitability will be over estimated". [91]

Andrus and McGillard [4] using methods from plant breeding developed economic weights for milk production, mastitis, milk fat, herd life body weigh, number of calvings and milking time. A profit function which ranked cows using the derived economic weights had considerable agreement with actual profit. These indexes predicted the profit more accurately than the actual or mature equivalent milk production and were concluded to be of benefit to the formation of useful economic selection weights.

In 1975 Gill and Allaire [52] produced a series of studies on profit equations. They determined the relationship between first lactation milk production and lifetime production to determine the economic return of increasing the first lactation production. [52] First lactation yield accounted for 1.7 to 11.4% of variation in lifetime traits and 31.4 to 62.3% of the variation in milk/day of life and profit/day of life. Maximum total or daily lifetime performance occurred in the range of 19 to 22kg milk/day during the first lactation.

Genetic and phenotypic relationships were estimated in a profit function for profit per day of herd life [50]. Production, reproduction and body weight were included in the equation. Genetic and phenotypic correlations between first lactation or lifetime records per day of herd life and profit were 0.93, 0.74 and 0.79 and 0.65 respectively. They found that genetic gain expected in profit per day of life from selection based on profit per day first lactation was 24% more efficient than milk per day of first lactation, and concluded that this may be a more profitable method of selection.

The relationships of breeding and management factors to economic return were studied using a profit function. [51] The profit function was defined using reproductive performance, milk production, body weight, herd life and prices for milk, calves, salvage value, fixed costs, feed. (Fixed costs probably shouldn't have been used in this case as they are all the same for each animal) It was found that a maximum of 31 days open and 10.5 days dry were optimal for profit per day of herd life. (However these figures may be a little difficult to achieve practically!) Maximum profit per day was expected for cows 25 months of age at first calving, 124 days open and 42 days dry while maximising milk per day and herd life. Again it was concluded that estimated profit functions per day could be more descriptive of economic worth than milk per day and serve as a useful cow selection/culling method.

The selection of cattle on milk yield, selection indices and regression indices and profitability traits were compared for gains in expected profit. [66] Milk, fat percentage, days in milk, number of matings, and age at first calving were combined to form indices. Genetic gain was found to be 13-14% greater when selection was based on profit to 42 months than on first lactation milk yield. Selection on traits of estimated profit were 2 to 14% more efficient for genetic gain in total profit than using milk yield or selection indexes. Heritabilities for profit to the end of the first lactation exceeded milk traits by 15 to 27%. The benefit of the use of profit as a selection tool rather than absolute cow characteristics cannot be emphasised enough.

Balaine et al [5] in a series of studies looked at profit functions in dairy cattle and the effect of measures of efficiency and prices in the ranking of cattle. Four profit functions were computed from the income and expense of each cow. Milk, fat and protein yield, live calf weight and ending weight were included in income. Expenses were Age difference, weight gain, feed energy, mastitis treatment, services and herd life. Changes in relative prices had little effect on the rank of cows. Income variables milk, protein, and fat yield had the highest simple correlations with profit per day. Feed intake, mastitis treatments and herd life had the highest correlations with the profit function and are therefore the most important costs involved in maintaining profitability. Increased longevity caused an increase in the profitability, which showed the benefit of retaining animals for as long as possible.

A second study [6] investigated the repeatability of net economic efficiency and predictors of this efficiency. Net profitability was measured as total profit, profit per day of herd life and profit per unit of investment. First lactation total income, value of product, fat and protein, feed, mastitis and service costs were the most important predictors of lifetime traits. The correlations of most economic variables with herd life were low. Improved reproduction was considered to be economically beneficial. In contrast to the work above it was found that the repeatability of net profitability in this profit function was generally lower than the repeatability of standardised milk yield. However it was large enough to be considered as a possible selection tool for improved net economic efficiency.

New Zealand and Australian Culling

New Zealand and some parts of Australia have unique dairy production systems compared to the rest of the world. Dairy production is predominantly seasonal with pasture being the main feed source. Because of this dairy production is timed to synchronise with the annual production of pasture. Housing of cattle during the winter is non-existent in both countries. Culling of cattle provides not only a way of improving productivity and profitability within the herd in terms of milk production and genetic value but also a way for farmers to manage their pasture surpluses and deficits.

In seasonal calving areas cows calve in the spring period, late June to September, and are dried off the following year in the autumn, April/May, with a typical lactation length of 270 to 305 days. Calving is concentrated to an optimum pattern of 6-8 weeks around the peak of the spring flush of grass growth to maximise milk production in the early part of the season. Culling is generally concentrated at the end of the lactation to lower the stocking rate on the farm for the winter period and bring in new replacements for the next season. Replacements are commonly home reared and may be grazed on or off the home farm. Grazing off the young stock is becoming an increasingly popular method of increasing production on the home unit by milking more cows. Culling is utilised as a pasture management tool during times of feed deficits.

In New Zealand nearly all supplements are made on the farm and are predominantly grass based such as hay and grass silage, which is made from the surplus grass during the milking season. Alternative supplements such as concentrates, maize silage or crops are becoming more popular feed sources but their use is limited by high costs and pressure to maintain maximum profit per hectare. This is however changing. In Australia the utilisation of concentrates for supplementary feeding is much more common due to the low costs of grain and the more extreme seasons causing greater feed deficit situations than is experienced in New Zealand.

Victoria is the only state to have a similar dairy production system to that of New Zealand so it is difficult to compare the Australian culling literature directly with that of New Zealand.

Descriptive culling analysis in Australia and New Zealand.

Descriptive data analysis on the reasons for culling has been sparse in Australia. Culling work in Australia has been limited to descriptive data analysis with a small amount of work done on the investigation into the risk factors for culling using survival analysis. [72 2 83 87] Previously no work on risk factors had been done in Australia. Only one study investigating risk factors for removal in New Zealand has been published. [53]

New Zealand work on culling has been more prolific with annual reports of wastage published by the New Zealand Dairy Board from the 1950's until the late 1970's [59]. This data collection was continued by the LIC in the early 1980's. [67] Due to their concern over the quality and accuracy of the data collected reports on herd wastage ceased. (pers comm LIC)

A number of dynamic programming models for the simulation of optimum culling in New Zealand herds have been developed [70 71 54 69 10 55 56 27], and these will be discussed in a separate section. The one limiting factor to New Zealand culling research has been the lack of studies on culling risk factors similar to the recent work done in Australia. Table 11 illustrates the main findings of the descriptive culling analysis published in New Zealand and Australia.

Table 11 Summary of culling reasons in New Zealand and Australia.

Reason	NZDB 1977 [3]	RPD 1985 New Zealand [3]	1963-65 Vic [72]	1973 Qslnd [2]	NSW 1996 [87]
Low Production	5.05	3.7	4.1	3.61	3.12
Sold	4.48	5.2	0.77	1.69	0.52
Infertility	3.19	6.3	3.33	3.53	8.58
Mastitis	0.95	2.3	1.53	2.46	7.28
Age	0.6		1.03	2.07	
Behaviour	0.55	0.4	0.36	0.54	
Disease	1.68	2.35	0.83	2.08	
Injury/Lameness	0.35	0.4	0.83	1.22	1.04
Deaths	0.3	0.5	1.8	1.57	
Other	0.24	1.5	3.97	1.27	5.46
Total	17.35	22.65	17.13	22.03	26.0

Culling practices appear to be very similar between the two countries with culling rates appearing to increase with time in both New Zealand and Australia. Low production may have been the single highest reason for removal but infertility and mastitis quickly replaced this. Even though there is improved treatment options and management tools available for the management of mastitis it appears that second to infertility it is the most significant reason for disposal in the Australian herd, at least in NSW. Culling for production reasons alone is less than a third of the reasons for culling. It indicates that there is considerable work required to improve the productivity of herds within both New Zealand and Australia in terms of management of stock and culling practices.

New Zealand rates of removal and risk factors.

Reports on the wastage of cattle had been published annually by the NZDB up until the early 1980's. [67] However this data was the result of annual data collected from farms using Dairy Board farm extension services and artificial insemination. Initially the results were subject to a fair amount of selection bias due to the small proportions of farms using dairy board services. With time however as greater numbers of producers used their services the results were likely to be more representative of the New Zealand dairy industry but the reliability of the data was still questionable. This role was taken over by the Livestock Improvement Corporation in the early 1980's [67] and these figures are not published any more due to the paucity of information and lack of reliability of the data. (Pers comm LIC)

A NZ survey [3] on culling rates was published in 1985 as part of a Veterinary practice initiative to investigate causes of cattle wastage in the practice area. The findings were remarkably similar in nature to those reported in the literature from around the world. An annual replacement rate of around 22.6% was found. 50% of the cows to be culled were removed in the last quarter of the lactation. Lameness culling occurred more often in early lactation, if the injury was caused by peri-parturient disease, and late lactation if injury was of a chronic nature. Mastitis cases were culled early if acute, and late if chronic as were high SCC cows.

In 1989 Harris [53] published a paper on the reasons for dairy cow removal and survival rate. Logistic regression was performed to calculate the risk factors important in determining an animal's probability of surviving, being culled involuntarily, or dying in the 1985-86 season. Poor fertility, mastitis and other diseases increased culling with age. Culling and deaths from bloat and metabolic diseases were low and independent of age, except for bloat. Deaths from bloat decreased with age. There was no age related cause of death. The frequency of removal for low production was found to decrease from 1st to 4th lactation and then increase with lactation number. The risk of removal for sale increased remarkably with age.

The herd was found to have a significant effect on the risks for removal for involuntary culling and survival. The level of production, age and calving date were found to be the most significant factors affecting an animals probability of survival and involuntary culling. So the higher the production, the younger the cow and the closer the cow was to due to the planned start of calving the greater the probability of survival and the smaller the risk of involuntary removal.

New Zealand modelling of replacement theory.

In 1973 ATG Mac Arthur [69] developed a stochastic dynamic programming model for AB Jersey replacements, which determined optimum replacement decisions. It was based on age and production of cows and contained 80 production states with up to 10 records [11]. The decision of whether a cow should be retained or replaced was based on the current history of production. The planning horizon for the programme was set at 15 years. The programme was based on a Monte Carlo stochastic simulation model with the lowest 20% of the herd removed, ie those with the lowest genetic potential for production. This was equivalent to approximately five percent of the culls after enforced culling was accounted for. The conclusion from the model was that optimisation of culling rules developed by dynamic programming to maximise profit did not increase the gains from culling. Therefore the culling rules based on dynamic programming were unlikely to supersede genetic value as the criterion for culling. It must be noted that this model did not take into account net present value of an animal as many other programme approaches did.

This model was extended to in 1975 [70] the purpose of which was to devise procedures for making optimal replacement decisions based on age and previous performance and determine the value of recording animal performance for use in replacement models. It was based on the economic principles generated about replacement decisions proposed by Burt, Faris and Perrin. [18 40 79] In contrast to the previous model the average performance of an animal was predicted from all its previous records and an increasing genetic value was taken into account. All animals that failed were to be replaced with a 2 year old heifer of average production. The calculation of genetic value assumed no selection of replacements from the best cows but only improvement from the use of AB sires. The calculations were similar to above with a maximum herd life of 10 years with 11 record classes and a planning horizon of 20 years. The culling criteria was set as the average production below which an animal with a given lactation performance and number of records should be culled. It did not involve an individual animal calculation. The results found that culling tended to occur in the oldest cows with the greatest number of records. A high replacement rate was optimal due to the increased genetic value of a decreased generation interval. It was concluded that to make the best use of herd testing information all age groups must be culled heavily and large numbers of replacements should be reared. The optimum model consisted of high culling and high replacements.

In 1985 McArthur [71] published a simulation model of a dairy herd which aimed to calculate the optimum level of culling for production and the economic value of making the best use of herd testing information. The model was not discussed in any great detail but was based on a gross margin, which was expressed as the present value using 10% discounting. Again the model only included culling based on age and production. The calculations estimated the effect of different culling levels on the herd production of milk fat in each year.

In 1986 Harris [56 54] produced a dynamic programming model also. It included the estimation of future milk fat production based on a BLUP model from Henderson [57]. The costs and revenues and calving date were used to calculate the expected net revenue. He produced three models:

1. An Annuity model that was not a dynamic programming model
2. A dynamic programming model to calculate NPV of cash flows up to a fixed planning horizon.
3. A second dynamic programming model as above but cows only removed for age (10^{th} lactation), or death or failure (ie no removal for production reasons). APV was used to rank cows.

The programme was used to rank cows on future profitability to enable the selection of replacement cows. It was not constrained by the number of stock reared or purchased or the herd size. In comparison to the models of ATG McArthur [71 70 69] this model included the effect of calving date on economic value. It included cow appreciation and interest on the capital value of the cow. [Discounting is applied in the model so the addition of these variables result in double accounting therefore should not be included in the calculations.] The probability of involuntary removal and death was also included in the model. Again the model assumed replacement with a 2 year old heifer with a fixed level of milk fat production. The overall results were similar to that found in the previous literature. Changing milk price had little effect on ranking of animals with the price of beef and replacement animal costs having the most significant effect.

In 1990 Harris published a recursive programming model [55] to predict the future profitability of various income streams. Included in this model were extra variables from the first model including milk volume, milk protein and breed. The average present value (APV) of each cow in the present state is calculated and then the net present value (NPV) of cash flows for each state up to a fixed planning horizon is calculated.

Cows with the lowest APV in the present stage are candidates for culling. Comparison of culling based on APV with production index showed that the two were uncorrelated hence would result in different cows being culled from the herd. When the two were compared in terms of the rate of increase in the NPV per 1% of animals culled within the herd it showed that selection based on Production Index increased the NPV by 0.70c and $1.8 when using APV.

Crequer continued the work of McArthur and published the most recent model in 1996 [27]. The model addresses the question of when should dairy cows be replaced. It is also based on a stochastic dynamic programming model to determine the optimum replacement policies for cows. The cow state was modelled by performance level, calving date and lactation number. The probability of death was constant over all ages and based on the bivariate distribution. The policy generated an optimal decision for an animal in any state. The overall conclusion was that any culling based on performance should be focused on the first lactation performance.

Australia rates of removal and risk factors.

In comparison to the work that has been done on culling in New Zealand the work done in Australia has consisted of only a few studies on culling reasons and risk factors. In 1968 a survey was published on the disease wastage of herds in New South Wales [72]. The survey covered three years from 1963 to 1965 and was mainly concerned with the incidence of disease on the farm. Herd wastage appeared to have increased since the previous surveys. Diseases of reproduction and lactation were the most important in adult cattle with parasitism, malnutrition and gastroenteritis the most important in young stock.

In 1973 a report was published on dairy herd wastage in South Eastern Queensland [2]. A survey of 41 herds was undertaken with data collected on management, breed and herd demographic information and the reasons for disposal of each cow. The most important causes of culling were low production, infertility, mastitis, old age and type. The absolute rates of culling for involuntary reasons appeared not to have changed significantly over time.

Stevenson [87 83] extended this work in 1995 with the publication of a prospective observational study on eight herds over two seasons, using survival analysis.

The risk of removal was found to be four times greater in the first 20 days of lactation, than from 20 days onwards. 83% of removals occurred during lactation with the rest occurring during the dry period. Cows were removed from the herd sooner in lactation than heifers. (Heifers were given a second chance.) The risk of removal increased with increasing parity and depended on the level of production. Heifers were not removed for low production in the first lactation. The farm of origin had a significant effect on the probability of removal for infertility. There appeared to be no influence of production level on the risk of removal for failure to conceive.

Conclusion.

Overall it is interesting to note that in the last 40 years since the recording of wastage in dairy herds has occurred there has been little change in the most important causes of wastage. Mastitis and infertility are the most important causes of dairy herd wastage. It would appear that mastitis and infertility are functions of dairy herd management and productivity. Veterinary input would appear to have solved very few of these problems or reduced the relative numbers of animals removed for these reasons. The push for higher quality products will most likely ensure that "mastitis" becomes a more significant reason for removal, in New Zealand dairy herds at least.

The little change in the removal rates for mastitis and infertility could reflect the efficiency with which farmers are managing these problems. The benefits farmers gain from removal may be greater than persisting with more expensive options to keep these animals in the herd.

An abundance of modelling studies have been generated over the last 30 years concerning the development of culling policy in cattle yet very few models have been developed that are in use to make culling decisions in the field. Many models determine an optimum herd culling policy and ways to maximise profitability, some models provide a means of ranking cows such that the lowest earners be removed and replaced with economically better animals. Copious work shows the benefit of culling based on future net revenues and that it is advantageous over simple genetic parameters for decision making yet no-one uses it.

It would appear that while most work has focussed on the why of animal replacement and the optimum replacement policy, little work has been directed at constructive demonstrations of the benefits of optimal timing of the removal of animals and aiding in the decision making process of this task. Rather than determining an optimal policy of culling for a herd it would appear that helping farmers make good decisions about the timing of removal of an animal, or when to stop treating an animal, could be of far more economic benefit than deciding should she be culled.

The aim of my work is to develop a model based on the Dutch work of Marginal Net Revenues that can be integrated into a commonly used dairy herd management programme in New Zealand for use by farmers to assist in culling decisions. My aim is a model that is simple in its overall design such that it will estimate the future net revenues and rank cows based on their future returns. By keeping the model simple this allows additional variables to be include in the model, with time, without it becoming too labour intensive and time consuming to calculate. Instead of working with "modelled" cows the information will be based on actual data and hence the limitations of these processes will be encountered. Hopefully the model will answer the question's of whom to remove and when.

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Chapter 2

Descriptive data analysis of the DairyMAN database.

Introduction.

The demographic profile of the national New Zealand dairy herd has been published annually since the Livestock Improvement Corporation (LIC) took over this function from the New Zealand Dairy Board in 1983/84 [7]. These reports use the demographic information of herds with more than 10 cows, from dairy company records and those utilising the LIC services.

Prior to this a summary of key features of the dairy industry was published annually in the Dairy Board Production Report, from the early 1950's. This summary was based on an annual census of farmers that utilised artificial insemination services provided by the Dairy Board. [6 7]

Very little information has been published detailing farm management practices for a large group of New Zealand farmers. One such group of farmers includes those that utilise the services of the DairyMAN programme. DairyMAN is a farm management programme developed by Massey University in collaboration with the LIC for collection of farm records. It manages information input by the farmer, and downloaded from the LIC, at a cow level and is able to generate management, production and reproduction reports and analyses.

Very little work has been published in New Zealand regarding the incidence of disease and culling on dairy farms. The most recent report of disease incidence was published in 1985. The Dairy Board reported culling rates and associated reasons annually until the 1980's but this was stopped by the LIC due to the poor quality of the data received, and the paucity of the information recorded (LIC statistics department pers communication).

The purpose of the data analysis in this and the following chapters includes the following:

1. A description of the demographic and management characteristics of DairyMAN herds.
2. Estimation of the production performance of DairyMAN herds and comparison with national figures.
3. Identification of recorded animal health disorders and quantification of their importance.
4. Description of the timing and frequency of culling.
5. Investigation into risk factors for culling.
6. Use of the information gained above in the development of a computer model for culling decisions.

Materials and methods

Materials.

A database in ACCESS 97 [9] format was utilised for the analysis below and in the subsequent chapters. A previous study collected data from a survey of seasonal farming DairyMAN [8] users, and this data was used for the study reported here. It was drawn from DairyMAN users who were willing to provide a copy of their herd data. The methods and reasons for collecting this data are described elsewhere [4]. Data available in the database included records for individual cows identifiable via a unique identification number (lifetime ID), owner, location and herd. Information for cows belonging to one herd comprises the animal register for that herd. Data from the DairyMAN herds include this herd register information as well as data input by the farmer, such as management groups, condition score, weight, and animal health events and treatments. Data available in the database for each animal includes the information shown in Table 12.

Table 12 Data available for DairyMAN herds

Record	*Description*
Cow Key	Unique National Identifier
Tag	Unique Herd tag number
Location	Geographical herd location
Herd ID	Unique herd identifier
Birth date	Day, month and year of cow birth
Breed	Breed classification
Breeding and Production Indices	Genetic capacity for production and breeding indices.
Calving Date	Day, month and year of last calving
Mating Details	All matings, including date, technician and semen
Milk production and Somatic cell counts	Herd test figures for four herd tests includes date, litres of milk, fat, protein, lactation to date estimate and SCC.
Removal Date	Day, month and year of removal
Fate	Fate of cow that is removed, sold, culled, lost, died.
Animal Health Events	Animal health events including date, possible treatment. May include events such as lameness, mastitis, metabolic events.
Calf data	Last calving information, includes calf sex, fate, twin information.
Management Events	Included pregnancy testing information, heat recording pre-mating, and dates of these events. Planned start of mating and planned start of calving dates, estimated future calving date.

Methods.

The DairyMAN files for the 1993/94 season were converted from a data file in dBASE format to an ACCESS97 [8] database. Data manipulation and summary calculations were performed in Excel 97 [10] while descriptive statistics, Chi square and t-tests were generated in Minitab v11.21 [11]

Data validation

Data contained within the database had already been screened for data integrity and errors prior to this analysis. A description of this data cleaning process and the criteria used for exclusion of herds from the original database file is described elsewhere [4]. Herds with unusable data for various reasons were deleted leaving 146 herds suitable for the analysis. All 146 herds contained within the DairyMAN database were used for the initial descriptive data screen and validation of the data contained within the database. For the purposes of the following analyses, data was further checked and validated as follows. An assessment of data quality was made by initially checking the information that is most easily collected by the farmer about the animals within his herd. Herd register information is collected and stored by the LIC and all DairyMAN herds should have this data present for all members of the herd. All herds had cow identifiers, herd numbers, birth dates, calving dates and location information. Mating and production information may be collected as a download from the LIC, or input by the farmer, and should be the second most complete data obtainable. It is possible to collect this information from the LIC at any time during the lactation therefore may be incomplete. One hundred and twenty nine herds from a total of 146 had production information recorded, however only 4 of the 17 herds that did not record production information had no animal health event information available. At this point, it was decided that rather than exclude herds based on an overall level of completeness, during each analysis a decision would be made about the herds to be included in the respective analysis. With respect to demographic information, such as herd size and region, all herds had this type of data recorded and therefore all herds could be included in the analyses. With respect to production data, 129 herds with complete herd testing information in the database were included in the analyses.

For the analysis of animal health and culling information it was decided to exclude any herds in further analysis that had no production or animal health data, as the validity of this data was questionable. A total of 142 herds with animal health information remained in the analysis. The original data was not collected with the specific aim of collecting animal health information, and therefore may be of poor quality. Possible reasons for an unrecorded animal health event included that the animal health event did not occur or that it had not been recorded. All 142 herds remaining in the database recorded at least one animal health event in one category. For each of the sections relating to animal health events only herds that recorded an event in this category were included in the analysis. Farms without any record of animal health events in a particular category were excluded from the analysis to reduce the potential of biased estimates resulting from under reporting. The likely consequence of this analysis strategy is that the true occurrence of animal health events was over-estimated, because there are no null event herds in each group. As the analysis focused on the timing of disease events and incidence of disease in herds with these events, this effect was assumed not to influence the results too strongly. Rather than analyse the level of disease within each herd, analysis was performed looking at the DairyMAN herds as a population of animals and the levels of disease recorded in each of these groups is reported.

Analyses.

Demographic information was collated using all 146 herds in the database. Where appropriate, comparison of the DairyMAN data with that of the national Dairy Statistics for the 1993/94 season is conducted using chi square tests t-tests and one way ANOVA.

Average herd size was calculated for the 146 DairyMAN herds within each region. A single sample t-test was used to compare the average herd size in each region with that of the dairy statistics for each region

One hundred and twenty six herds that recorded production were used to calculate average milk, fat and protein production per cow. Production by herd test and total production to the end of the lactation were summarised for national and regional comparison. Comparison of the average production per cow by region and nationally was performed using single sample t tests. Statistical comparison of the average production between each region was performed using a one -way ANOVA.

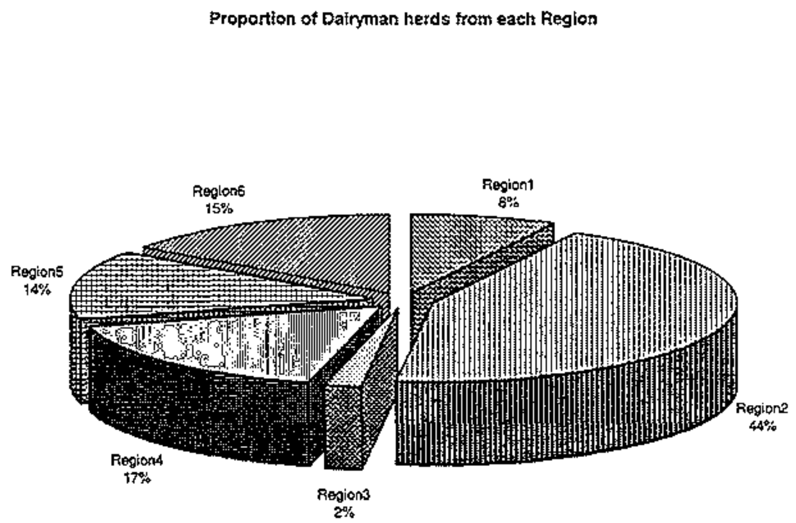
All animals present in the 146 herds were grouped according to Breeding Index and breed and stratified by region. Due to the enormous range of breed combinations within the herd register, breeds were reclassified according to the dominant breed. The following classes were used: Ayreshire (A), Ayreshire cross (Ax), Friesian (F), Friesian cross (Fx), Jersey, Jersey cross (Jx) and other. The "other" group included a selection of breeds ranging from Guernsey and milking Shorthorn to Angus and Hereford.

Comparison was made between the national and DairyMAN herds using chi square tests for distributions. For all animal health events the number of animals at risk was considered to be the number of animals present in the herds that recorded the event in question. For example, if lameness events were considered then the group at risk was the 16396 cows present in the 65 herds that recorded lameness events. The risk of an animal health event was calculated as a cumulative incidence according to the method of calculation for cumulative incidence described in Kleinbaum [8]. The risk (cumulative incidence) was calculated as follows: The denominator was the number of calved cows present in the herds with a specific animal health event recorded minus the removals in those herds. The numerator was equal to the number of calved cows with the animal health event. Risk was calculated on a monthly basis and summarised graphically using a series of charts indicating the periods of greatest risk.

Demographic analysis of the DairyMAN herds.

The DairyMAN farms were located in all of the 6 major dairying regions within New Zealand. These regions are as follows: Northland=1, Auckland=2, BOP/East Coast=3, Taranaki=4, Wellington/Hawkes Bay=5 and South Island=6. Figure 3 presents the proportion of farms included in the survey, stratified by region. Forty four percent of the farms were located in region 2. Regions 1 and 3 were slightly under represented with region 2 and 6 being slightly over-represented. There is no statistically significant difference between the sample of farms used in the survey and the national herd distribution with respect to regional representation ($\chi^2 = 6.989$, df = 5, p>0.1).

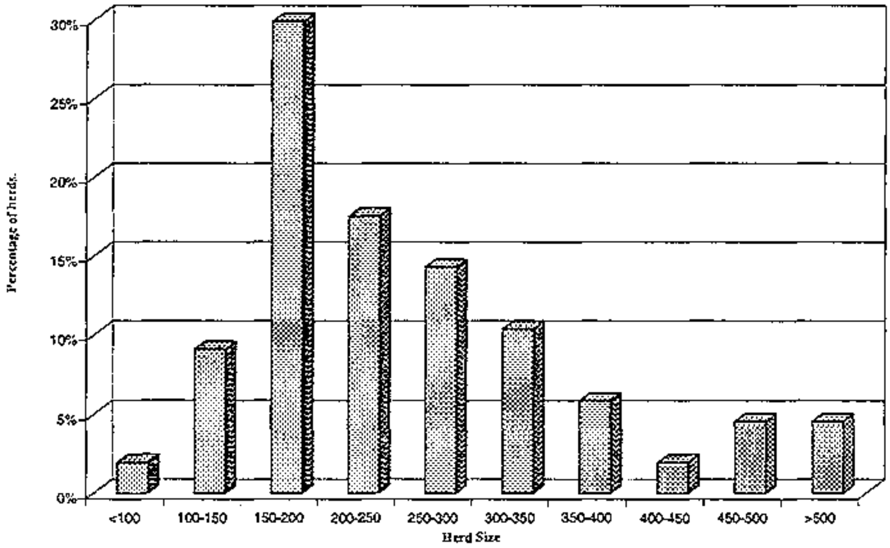
Figure 3: Pie chart of the proportion of DairyMAN herds by region.



Herd Size

A histogram of the herd size distribution for DairyMAN users is presented in Figure 4. The average herd size in the sample was 225 cows. The herds ranged in size from 89 to 862 cows. The average herd size is significantly larger than the national average of 193 cows per herd ($\chi^2 = 5.3$, df =1, p<0.05).

Figure 4: Histogram of herd size distribution of DairyMAN herds.



There was a significantly higher proportion of large herds (>250 cows) in the DairyMAN sample of farmers than represented in the national herd size distribution (χ^2= 62.64, df = 9, p<0.001).

Summary figures of the average herd size stratified by region are shown in Table 13.

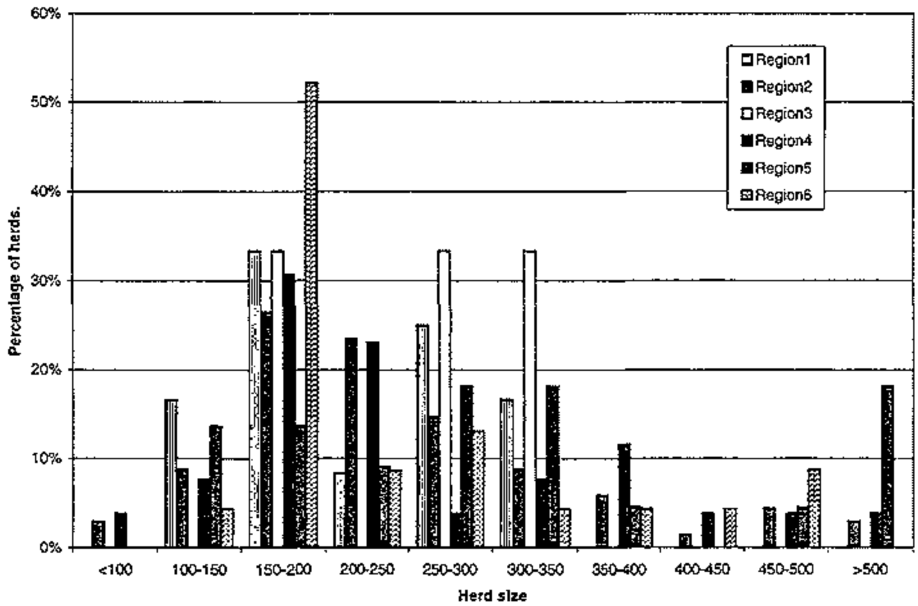
Table 13 Average herd size by region.

Region	National Mean	DairyMAN Mean	95% CI	T-test	p-value
1	164	218.9	170.2-267.7	2.48	0.031
2	176	253.8	222.3-285.3	4.93	0.000
3	206	251	55.9-446.1	0.99	0.43
4	176	254	205.2-302.8	3.29	0.003
5	199	321	245.3-396.8	3.34	0.003
6	249	242.3	197.1-287.5	-0.31	0.76

All regions except for 3 and 6 had significantly larger herd sizes than the national average for that region. The small sample size in region 3 is likely to have contributed to its insignificance.

The distribution of herds within each region is shown in Figure 5. Region 5 has mainly large herds while region 2 has a wide range of herd sizes represented in the database.

Figure 5 Average herd size in DairyMAN herds stratified by region.

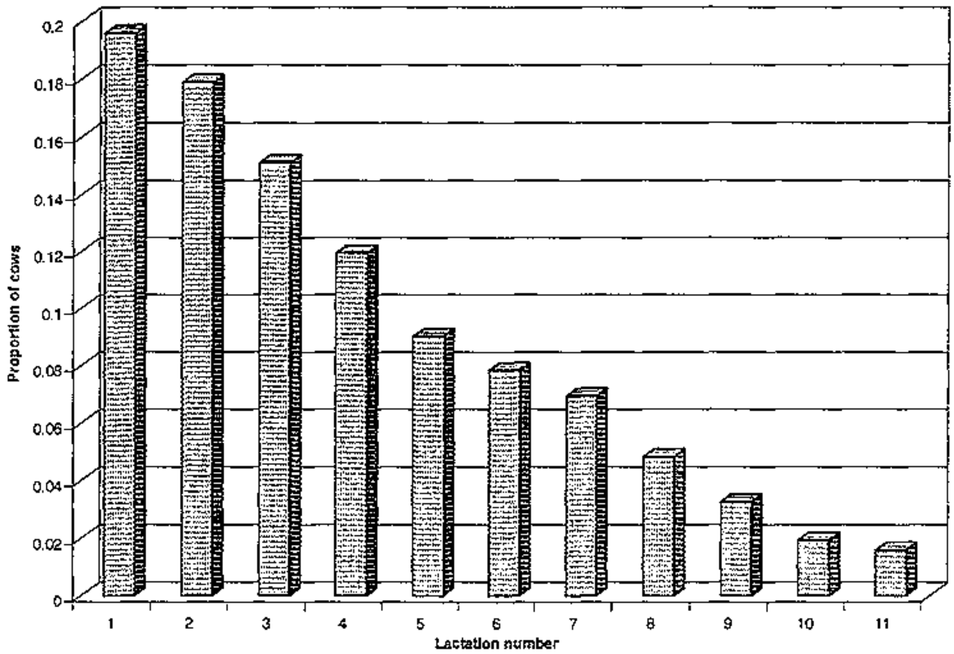


Herd Age.

The distribution of the cows by age (illustrated as parity, the average age of a cow in lactation 1 is 2 years) is illustrated in Figure 6. The age distribution of DairyMAN herds is significantly different to the age distribution of the national herd (χ^2= 267.65, df=8, p<0.0000). DairyMAN herds have a statistically significant lower average herd age of 4.94 years compared with the national herd age of 5.12.(t-test = -89.42, df=1, p<0.01). DairyMAN cows were kept from 1 to 14 lactations during the 1993/94 season.

Young stock is reared and enters the herd as rising 2-year-olds. They may then be kept for an average of 3.36 lactations or 4.94 years of age. The average number of lactation 1 animals in the national herd is 17% [9], compared to around 19% in DairyMAN herds.

Figure 6 Distribution of cows in DairyMAN herds stratified by parity



The average herd ages for regions 1 to 6 are 4.95, 5.05, 4.79, 4.95, 4.69, and 4.93 respectively. There was no significant difference in herd age between the six regions.

Region 2 has the highest average herd age at 5.05 and region 5 has the lowest average herd age at 4.69 years.

Planned start of calving and mating.

The mean onset of calving is the 30/7/93 ± 2 days. Summary figures for the planned start of calving are outlined in Table 14.

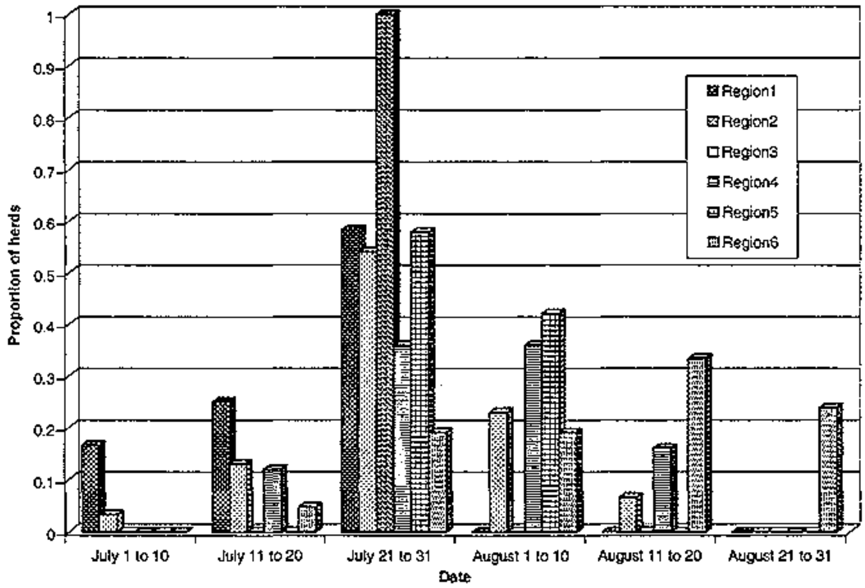
Table 14 Planned start of calving for DairyMAN herds

Mean	Standard Deviation	Minimum	Maximum	95% CI	Range
30/7/93	10	2/7/93	1/9/93	28/7/93-1/8/93	61 days

The pattern and timing of the onset of calving for each region is illustrated in the Figure 7.

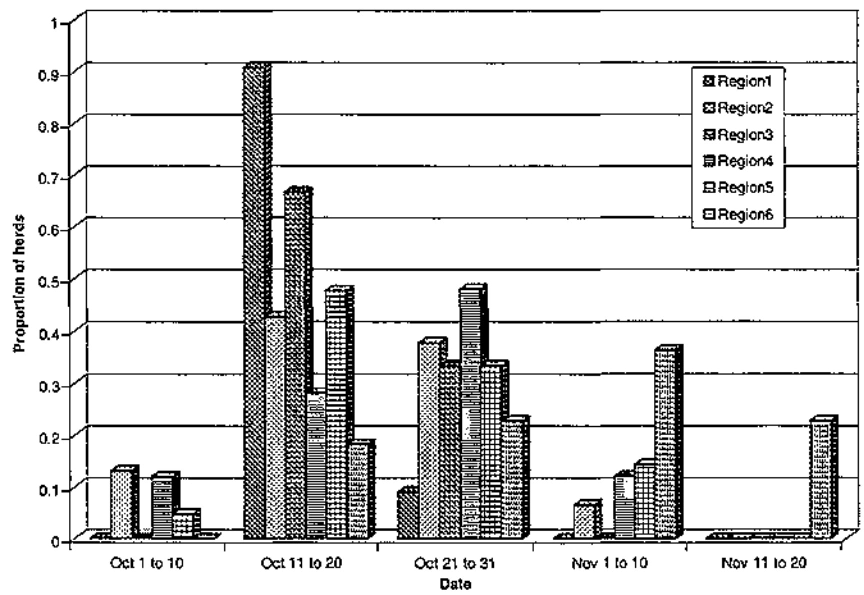
The pattern of planned start of calving is distinctly different between regions. Calving starts in early July in region 1 and 2 and late July in region 3 and 5. Region 3 has a small number of herds represented so may not be very accurate. In region 1 calving is concentrated to start during July with all farms calving this month. In region 6 calving starts in mid to late July and all farms are calving by the end of August. The planned start of calving dates are very similar to those reported in the Dairy Statistics for 1993/94. [9]

Figure 7 Planned start of calving for DairyMAN herds stratified by region



The pattern of mating is very similar to the calving pattern above as is shown in Figure 8.

Figure 8 Planned start of mating in DairyMAN herds stratified by region



The mean onset of mating begins on the 21/10/93 ± 2 days. Mating dates are summarised in Table 15.

Table 15 Planned start of mating for DairyMAN herds

Mean	Standard Deviation	Minimum	Maximum	95% CI	Range
21/10/93	18 days	12/9/93	10/12/93	16/10/93-22/10/93	89 days

Region 6 has a delayed onset of mating compared with the rest of the regions. Region 1 and 3 have a fairly compacted mating spread while regions 2, 4, and 5 have a spread onset of mating.

Production.

National average milk production per cow and region is shown in Table 16. Average lactation to date milk production (litres) in DairyMAN herds is summarised in Table 17.

Table 16 National average milk production per cow [9]

Region	Milk (litres)	Milkfat (kg)	Protein (kg)
1	2,812	129	100
2	3,371	159	122
3	3,486	161	123
4	3,185	164	122
5	2,994	136	107
6	3,328	149	118
New Zealand	3,253	154	118

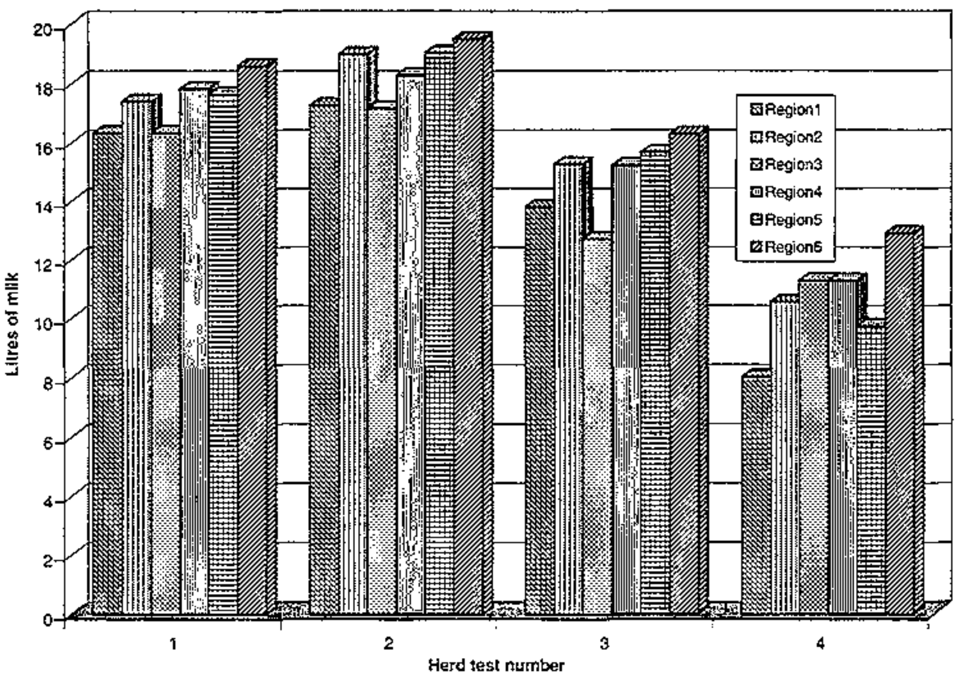
Average milk production, in litres, is significantly higher in DairyMAN herds than the national average and when stratified by region.

Table 17 Average lactation to date production (L) for DairyMAN herds

Region	Milk (litres)	Std Deviation	Range	T-test	P value	95% CI
1	3,515	398	2713-3963	5.3	0.0000	3,209, 3,821
2	3,755.5	546.8	2530-4831	4.92	0.0000	3,598.5, 3,912.6
3	3,517	776	2901-4388	0.07	0.95	1,589, 5,444
4	3,769.8	431.1	2352-4348	6.92	0.003	3,595, 3,944
5	3,498	646	1409-4284	3.4	0.000	3,187, 3810
6	4,012	563	3074-4933	5.29	0.000	3,741, 3,810
New Zealand	3,735.4	552.5	1409-4933	9.76	0.000	3,637.6, 3,833.2

Milk production reaches a maximum around the second herd test as seen in Figure 9. Peak milk across all cows in this survey averaged 19.5 litres. There was a statistically significant difference in the average milk production per cow per region.

Figure 9 Average production (L) per herd test in DairyMAN herds.



Average milk fat production by region is summarised in Table 18. All regions have significantly higher milk fat production than the national and regional averages for the 1994/95 season.

Table 18 Average milk fat production (kg) for DairyMAN herds by region

Region	Milk_fat (kg)	Std Dev	Range	t-test	p-value	95%CI
1	165.82	16.83	134.2-180.14	6.56	0.000	152.88, 178.76
2	186.74	19.04	142.42-221.87	9.66	0.000	180.75, 192.53
3	172.2	27.1	146-200.2	0.72	0.55	104.8, 239.7
4	200.87	18.9	161.92-231.35	8.94	0.000	192.25, 209.47
5	178.75	19.32	137.42-213.28	7.66	0.000	166.47, 191.02
6	190.80	21.4	158.9-231.74	8.05	0.000	179.8, 201.8
New Zealand	187.10	21.32	134.2-231.74	15.99	0.000	182.99, 191.20

Region 6 outperformed on litres of milk produced but Region 4 outperformed on total fat produced per cow to the end of the lactation.

Average total protein production in DairyMAN herds is summarised in Table 19. Average protein production per cow is significantly higher in DairyMAN herds compared with the national and regional average.

Table 19 Average protein production (kg) for DairyMAN herds by region

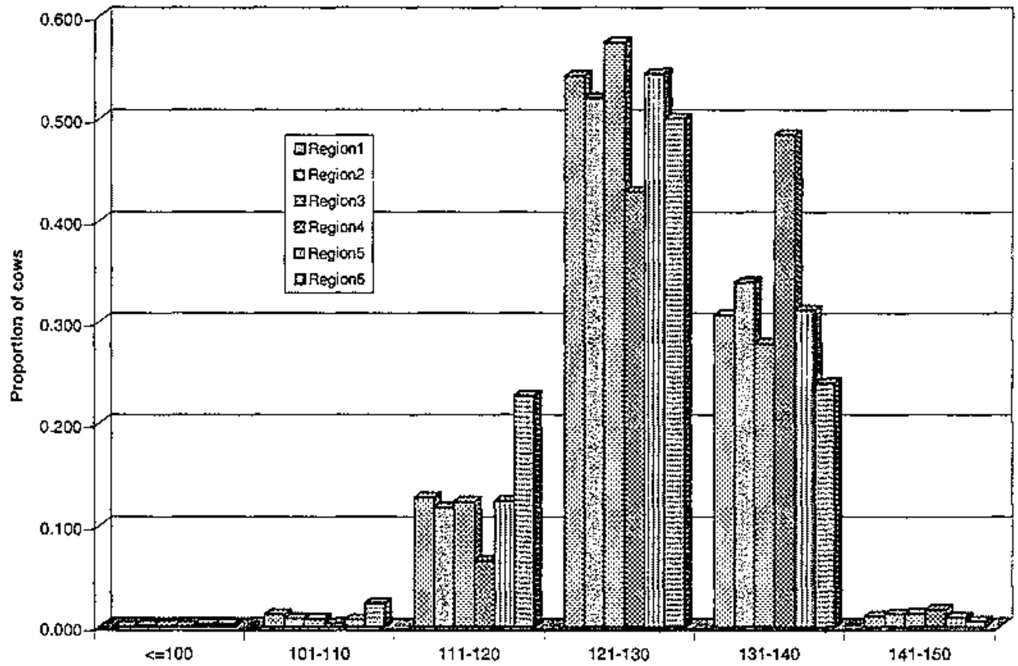
Region	Protein (kg)	Std Dev	Range	t-test	p-value	95% CI
1	128.23	13.44	105.73-143.04	6.3	0.000	117.89, 138.56
2	142.26	15.08	108.74-170.5	8.91	0.000	137.67, 146.84
3	131.00	19.5	117.8-153.4	0.71	0.55	82.6, 179.4
4	152.00	11.77	129.96-169.68	11.69	0.000	146.65, 157.36
5	137.45	12.89	113.06-160.65	8.18	0.000	129.26, 145.64
6	147.91	19.19	116.62-182.47	6.42	0.000	138.04, 157.77
New Zealand	143.00	16.15	105.73-182.47	15.97	0.000	139.93, 146.15

Breeding Indices.

Breeding Indices (BI) stratified by region are presented in Figure 10. There is no statistically significant difference between the average BI of cows in the DairyMAN herds and the national average BI (t-test = 0.003, df = 38743, $p<0.5$).

In all regions except for region 4 BI peaks in the 121 to 130 range. Region 4 peaks in the BI range 131 to 140. The spread and shape of the BI distribution is very similar to the national BI distribution. [7]

Figure 10 Breeding Indices stratified by region for DairyMAN herds

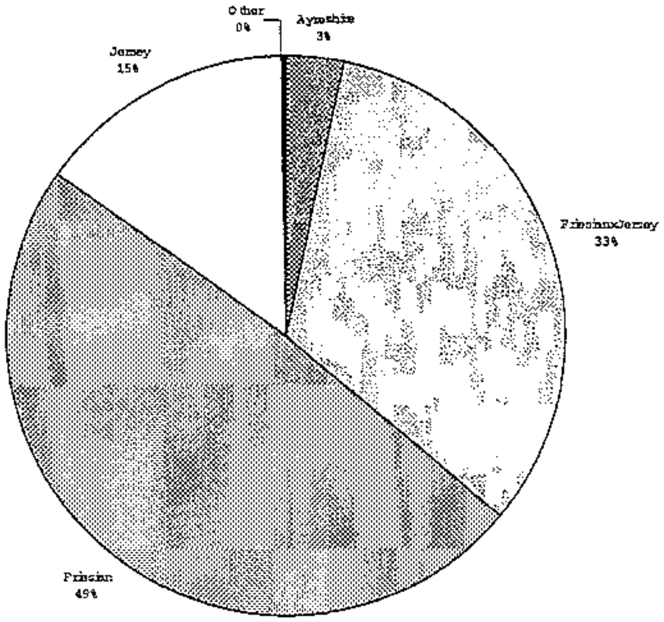


Breed of cows.

The proportion of cows in each breed category, based on DairyMAN herds, is illustrated in Figure 11.

Friesian and Friesian/Jersey Cross breeds are the most popular breeds. There is a significant difference in the breed distribution between the national and DairyMAN herds (χ^2= 42.36, df = 4, p<0.0001).

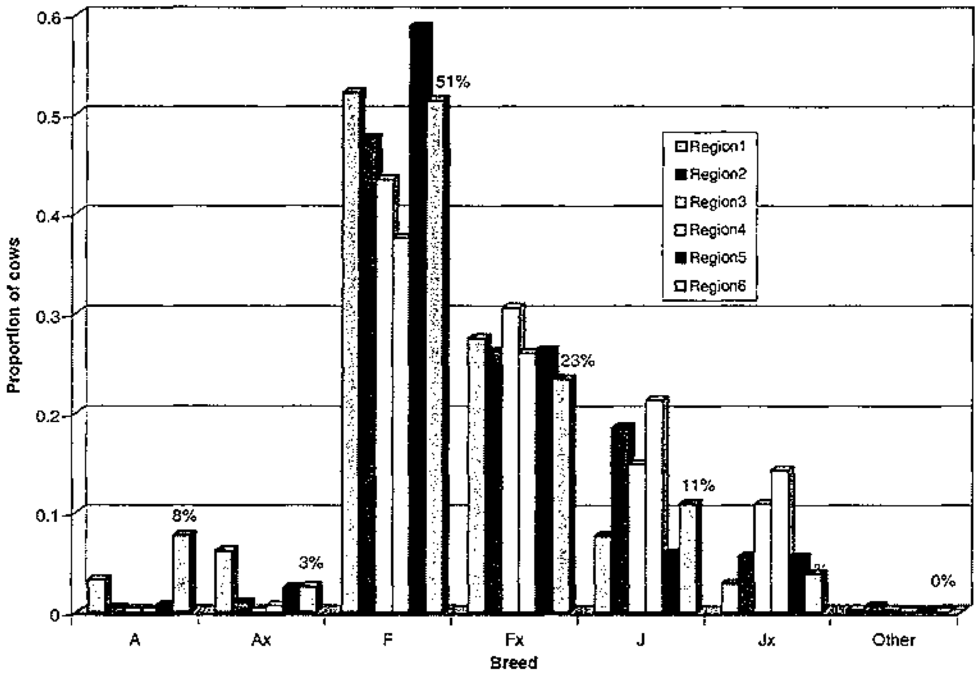
Figure 11 Proportion of breeds in DairyMAN herds.



The DairyMAN herds in this survey have fewer Friesian, similar numbers of Jersey and a greater amount of Friesian/Jersey Cross animals. In the 1994/95 season the national breed distribution was as follows; Friesian 57%, Jersey 18%, and Friesian/Jersey Cross 16%, Ayreshire 2% and other breeds 7%.

Comparison of the breeds across the regions is illustrated in Figure 12. Regionally the Friesian and Friesian-cross animal is the most common. All the regions differ from the national breed averages for their region. The herds using DairyMAN appear to have more crossbreds on average in their herds than would be suggested on the basis of the overall summary. Region 4 has the lowest proportion of Friesian cattle and the highest proportion of Jersey cattle, which is consistent with the region population demographics.

Figure 12 Breed summary stratified by region for DairyMAN herds



Animal Health and Management.

Assuming that calving is the start of the milking season the following results are structured in chronological order, to describe the management and animal health problems that occur over the milking year.

Calving.

There were 35,535 calvings recorded in the database. Of these calvings 90.5% were normal. 3072 cows or 8.6% of cows were induced to calve (Induction of calving is an important management tool farmers use to maintain a tight calving pattern). Abortion occurred in 0.3% of cases and premature calves occurred in 0.6% of cows. Calves are either sold as beef, to be reared for the bull beef market, or sold as heifer calves for rearing. Four-day-old calves are sold as bobbies to be processed as veal or calves are kept for rearing on the farm. Both heifer and bull calves are kept for rearing on the home farm. The fate of all 31624 calves recorded in the database is summarised in Table 20.

Table 20 Calf fate in DairyMAN herds

Calf Fate	*N*	*%*
Reared	11104	35
Bobbied	10350	33
Sold	5545	18
Died	3385	11
Unknown	1240	4
Total	31624	100

There were 332 twin calvings recorded in the database. The rate of twinning was 1.1%. There was a significant difference in the fate of the calves depending on the sex and twin status. $\chi^2 = 314.9$, df = 4, p<0.000 The fates of the calves stratified by sex and twin status are summarised in Table 21.

Table 21 Fate of single and twin calves born in DairyMAN herds.

	Single Calves				**Twin Calves**			
	Male		*Female*		*Male*		*Female*	
Fate	N	%	N	%	N	%	N	%
Reared	1472	8.9	9554	64.5	19	8.9	59	49.6
Bobby	7958	48.3	2267	15.3	102	47.9	23	19.3
Sold	4180	25.4	1327	9.0	29	13.6	9	7.6
Died	1918	11.6	1384	9.3	57	26.8	26	21.8
Unknown	948	5.8	284	1.9	6	2.8	2	1.7
Total	16476	52.6	14816	47.3	213	64	119	36

64.5% of all single female calves were reared while only 49.6% of twin female calves were reared. Nearly 50% of all male calves, both twins and singles, were bobbied. 25% of single males and 13.6% of twin males were sold. 47.9% of male twin calves were bobbied.

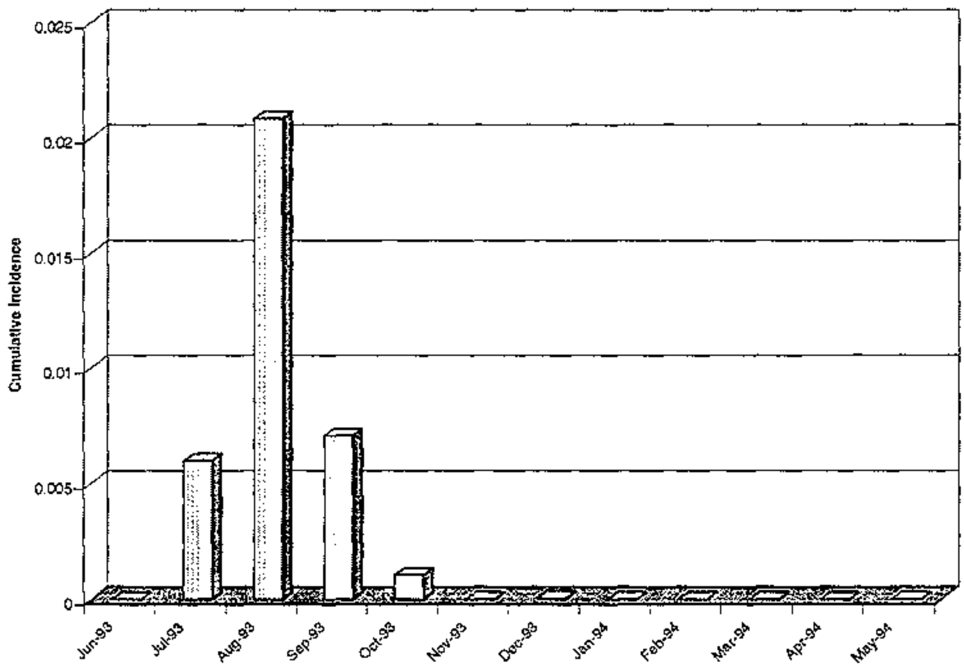
There was a significant difference in the mortality rate of male and female twin calves compared with single calves ($\chi^2 = 71.7$, df = 1, $p < 0.000$). 11.6% of single males and 9.3% of single female calves died, in contrast to the 26.8% of male twins and 21.8% of female twins that died.

Calving Assistance.

Seven hundred cows required calving assistance during the calving period. On the 77 farms that recorded calving assistance, there was a cumulative incidence of 3.6%. This means that about four cows in 100 appear to require some form of help during the calving period. 14.7% of those animals that required assistance were culled at the end of the season. A further 3.6% of these cows died. The cause of death was not given.

The period of the year during which calving assistance is most likely to be required is presented in Figure 13.

Figure 13 Period of risk for calving assistance in DairyMAN herds



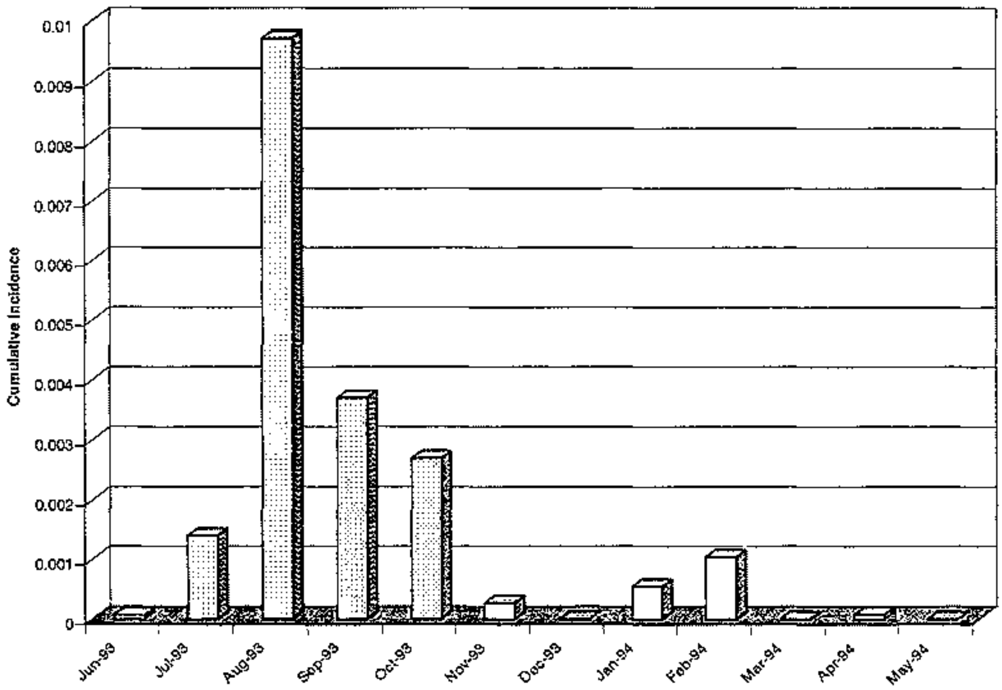
As the majority of calvings occurred during July to September the period of greatest risk was also at this time.

Metabolic events

Fifty-eight farms recorded metabolic events with a total of 295 individual metabolic events recorded. Metabolic events usually occur during the spring (September to October) and include milk fever (hypocalcaemia) and grass staggers (hypomagnesaemia). Specific causes of metabolic event were not recorded in the database. It was therefore not possible to calculate the incidence of each cause. The cumulative incidence of metabolic disease was 2.0%. 5.4% of cases experienced two metabolic events and 0.7% had three metabolic events. More than 20% of the cows that suffered a metabolic event were culled compared with 10% of cows that did not suffer a metabolic event.

The period of risk for metabolic events is shown in Figure 14. The period of risk for developing a metabolic event shows a bimodal pattern. Cumulative incidence reaches a peak in August and again in January/February.

Figure 14 Period of risk for metabolic events in DairyMAN herds



Mating

Mating occurs approximately two months after the onset of calving. Nationally, about 80% of cows were bred using artificial insemination [7] in the 1993/94 season[9]. In the DairyMAN user herds 95% of cows were inseminated by AI for the first mating, 74% for the second mating and 32% for the third mating. Bulls were used in 5% of the first matings and 68% of the third matings.

Reproductive disorders.

Forty-five herds recorded reproductive disorders with a cumulative total of 365 reproductive events. The most important reproductive events are summarised in Table 22.

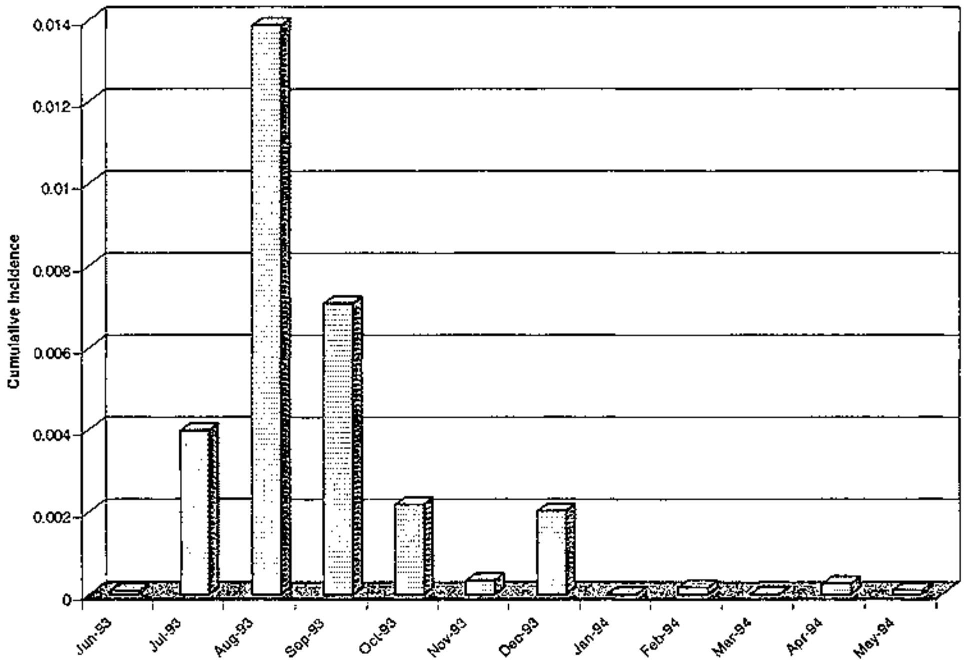
Table 22 Summary of reproductive disorders

Cause	*Number of cases*	*Proportion of all cases*
Discharge	49	13.4%
Prolapsed Vagina	195	53.4%
Retained membranes	84	23%
Non Cycling Cows	21	5.7%
Other	16	4.3%

For all reproductive events there was a cumulative incidence of 3.1%. Of these cows 16.6% were culled at a subsequent date. In comparison 10.4% of cows, from the same herds, without a reproductive event were culled. Vaginal prolapse had the highest risk of the reproductive events accounting for 53.4% of all the reproductive cases recorded. Very few non-cycling cows were recorded and it is therefore unlikely to fairly represent the number of cases truly y treated on any of the farms.

The risk of developing a reproductive disease is shown in Figure 15. The highest risk of developing reproductive diseases such as retained membranes, discharges and uterine infections is likely to be around calving, as indicated. An increase in risk for reproductive disorders due to non-cycling occurred between October and December.

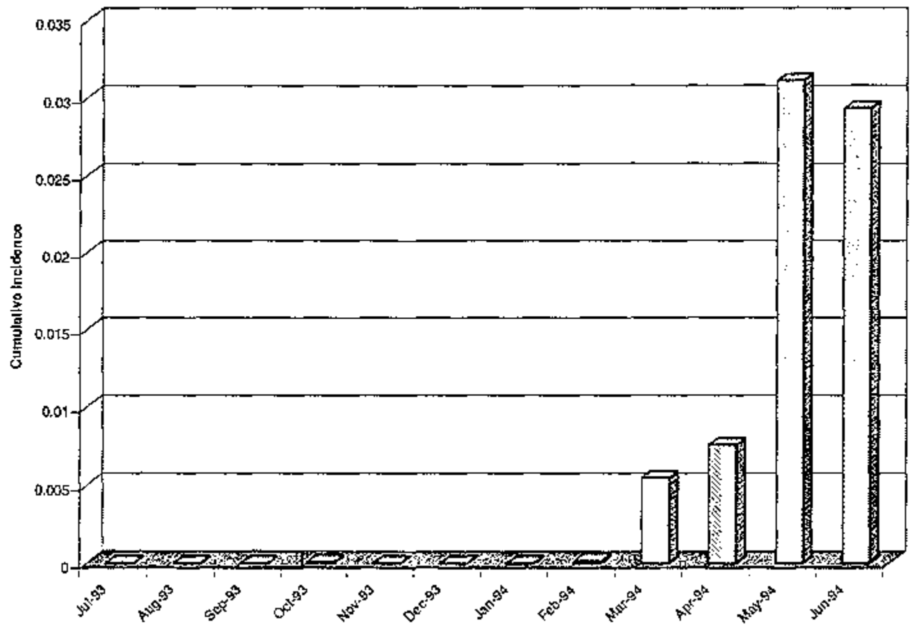
Figure 15 Period of risk for a reproductive event in DairyMAN herds



Pregnancy testing.

Fifty-two herds performed whole herd pregnancy testing, while 37 herds pregnancy tested selected cows during the 1993/94 lactation. There were 1215 empty cows in a total of 13614 cows which had their pregnancy status recorded in the database. This results in an empty rate of 8.9%. 45.2% of cows that were recorded empty were removed from the herd. As pregnancy testing is not performed until February/March, the maximum risk of removal will not occur until after this point in time. The timing and the risk of removal is illustrated in Figure 16.

Figure 16 Period of risk for removal of empty cows in DairyMAN herds

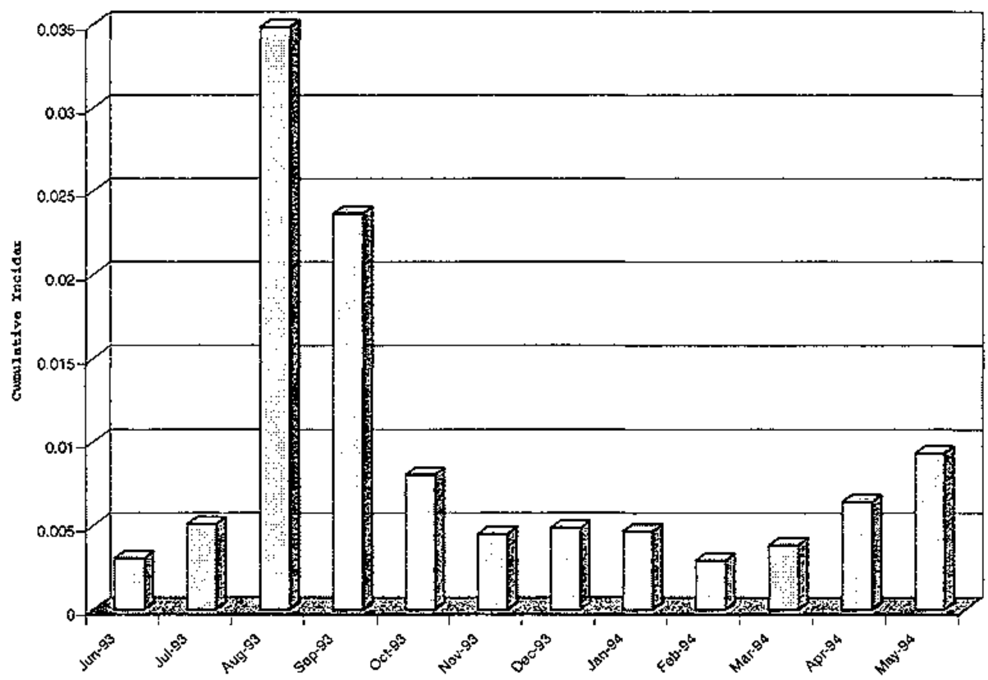


Mastitis.

Eighty-one herds recorded mastitis events with 2201 cows out of 20164 animals recorded having a mastitis event in the 1993/94 season. There was a cumulative incidence of 10.9%. 19.7% of cows had two mastitis events during the season and 5.5% of cows had three mastitis events. It could not be determined whether the multiple events of mastitis were new cases of mastitis or repeat treatments. 14.6% of cows with mastitis events were culled at some time during the season.

The pattern of risk for a mastitis event is illustrated in Figure 17. The period of highest risk occurs in August and September, however the risk of mastitis is moderate throughout the remaining lactation period and increases towards drying off.

Figure 17 Period of risk for a mastitis event in DairyMAN herds

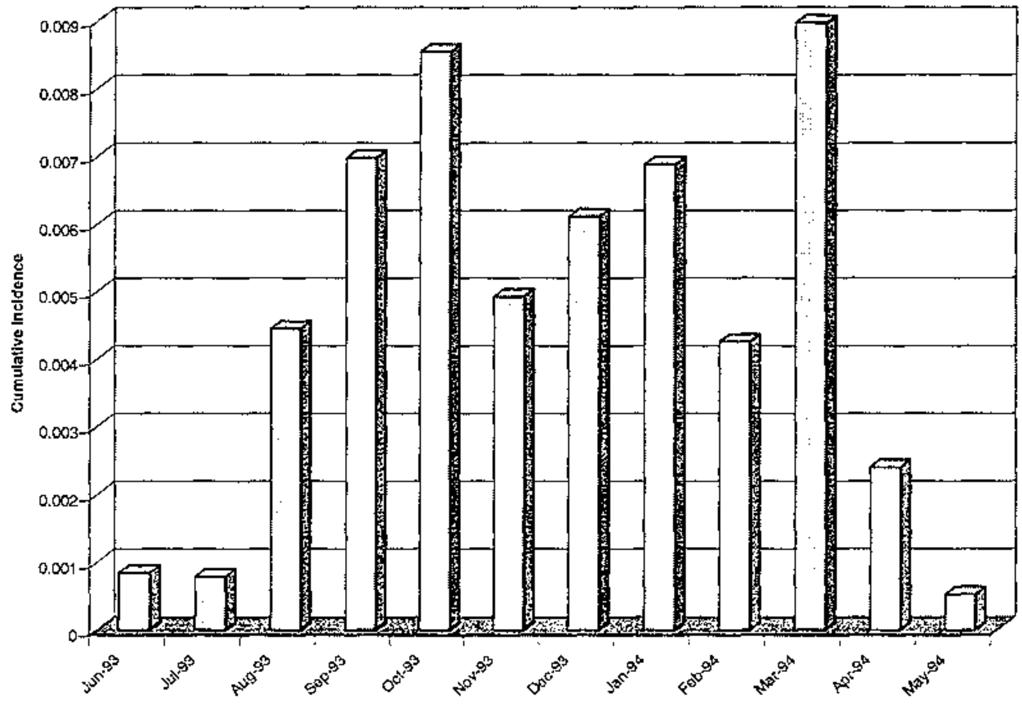


Lameness.

Sixty-five herds recorded 897 lameness cases out of 15519 cows in the herds that recorded lameness events. The cumulative incidence of lameness events was 5.8%. 18.2% of cows with a lameness event had 2 events and 3.7% had 3 events.

The periods of risk for developing a lameness event are outlined in Figure 18. The distribution of lameness events shows a bimodal pattern with two peaks in October and March. Lameness around the mating period related to cow's heat behaviour is a common cause of lameness during October. The risk of developing a lameness event is highest between August and April.

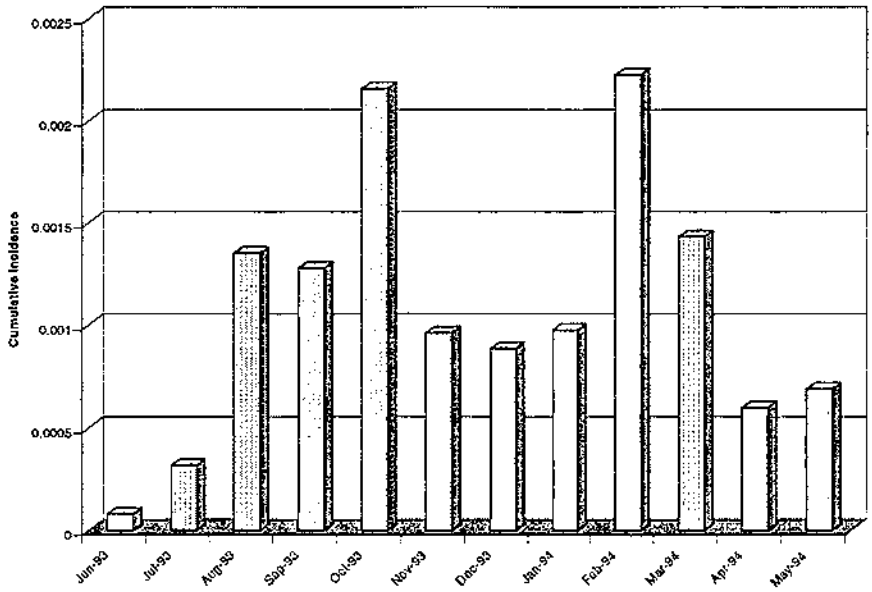
Figure 18 Period of risk for a lameness event in DairyMAN herds



Sickness.

Forty-five herds recorded 159 sickness events out of 12497 cows in the herds with sickness events recorded. The cumulative incidence of a sickness event was 1.3%. Sickness events can range from gastrointestinal disease to pneumonia or abscesses. There was no further classification for any of the sickness events. 11.3% of cows with a sickness event died compared with 1.4% of cows without a sickness event. The periods of risk for the development of a sickness event are shown in Figure 19.

Figure 19 Period of risk for a sickness event in DairyMAN herds.

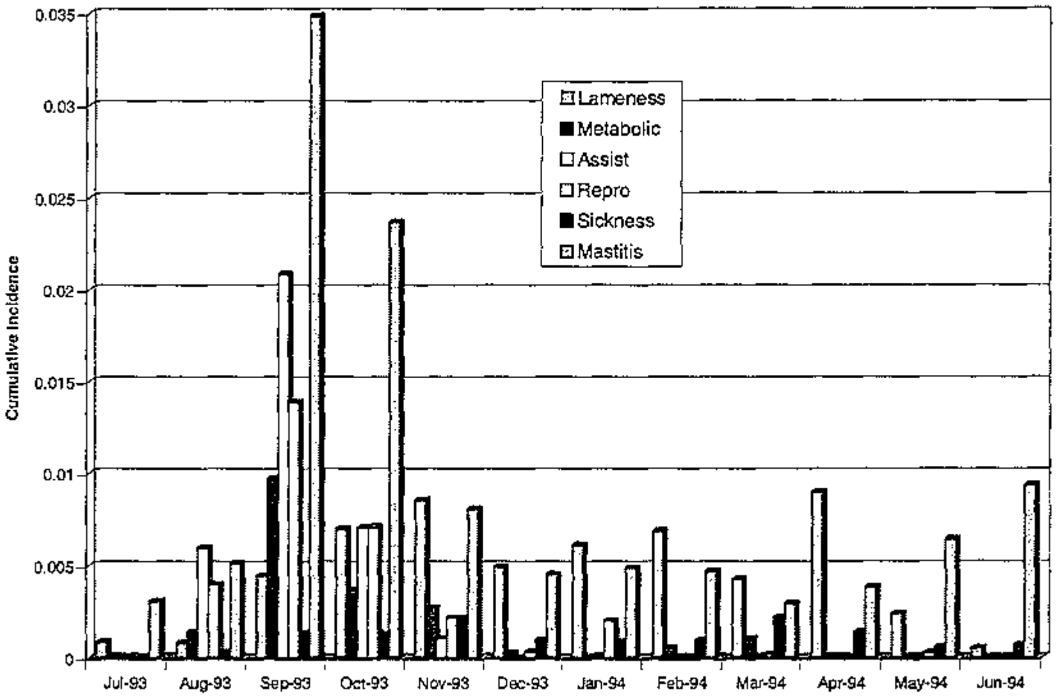


The risk of a sickness event during the entire lactation was low, with the highest incidence of sickness events occurring during October and February.

Summary

The risk and timing of an animal health event is shown in Figure 20. The greatest risk period for an animal health event to occur is around the calving period. Mastitis, calving assistance and reproductive events are most likely to occur over the spring period August to October. Lameness and metabolic events are the most likely events to occur over the remainder of the lactation period with the risk of mastitis increasing towards the end of lactation. Lameness events peak around mating in October and November and remain at a constant level for the remainder of the lactation.

Figure 20 Comparison of the periods of risk for all animal health events in DairyMAN herds



The risks of developing an animal health event are summarised in Table 23.

Table 23 Summary of the risk of animal health events in DairyMAN herds

	Cumulative incidence of disease events per month (x 10^{-3})					
Month	Lameness	Metabolic	Assist	Repro	Sickness	Mastitis
Jul-93	0.85	0.067	0.0	0.083	0.079	3.1
Aug-93	0.79	1.4	6.0	4.0	0.32	5.1
Sep-93	4.46	9.7	21.0	14.0	1.4	35.0
Oct-93	6.98	3.7	7.1	7.1	1.3	24.0
Nov-93	8.55	2.7	1.1	2.2	2.2	8.1
Dec-93	4.93	0.27	0.0	0.34	0.96	4.5
Jan-94	6.12	0.0	0.051	2.0	0.89	4.9
Feb-94	6.89	0.55	0.	0.0	0.98	4.7
Mar-94	4.26	1.0	0.0	0.17	2.2	2.9
Apr-94	8.97	0.0	0.0	0.0	1.4	3.9
May-94	2.41	0.072	0.0	0.26	0.6	6.4
Jun-94	0.53	0.0	0.0	0.09	0.69	9.3

Discussion

General.

The dairy production system described above is limited to a few areas of the world. Other dairying areas are constrained by milk quotas, environmental issues and climate, which makes the New Zealand dairy production system unique. Dairying in New Zealand is managed around a seasonal pasture growth system. Cows typically calve once per year in the spring. Some farms operate a continuous type operation but this also has a seasonal component to it. Calving may occur only twice a year (in autumn and spring) and not continuously throughout. Factory supply farms such as these are few in numbers compared with the seasonal farms. Only spring calving herds were utilised for the data analysis presented above.

Herds using DairyMAN represent a subsection of the dairying community and are not representative of all New Zealand dairy farmers. The DairyMAN users sampled have larger herd sizes than average dairy herds in the different regions and as a group. Thirty percent of DairyMAN users had between 150 and 200 cows compared with 23% of NZ dairy herds.

The proportion of lactation one animals present in the DairyMAN herds is around 19%. If it is assumed that all animals are replaced with lactation 1 animals then the average replacement rate for DairyMAN herds is around 19%. This also approximately indicates the number of replacements that are reared on each farm. The average age for cattle from DairyMAN herds is 4.94, which is younger than the national average age of 5.12. This would indicate that culling and replacement rates are slightly higher in DairyMAN herds.

Due to the seasonal pastoral nature of farming it is important to match the production of grass with the calving of cows. As a result of the seasonal growth pattern of pasture, different areas of the country have peak pasture growth at different times, which in turn means that different regions and areas within these regions will have different times for the start of calving and mating.

The manipulation of the calving date and mating date are important parameters in the management of a New Zealand dairy herd. The calving date is adjusted to coincide with the peak of pasture growth. Because all cows must calve annually in the spring, they have to get in calf within a small time frame. The start of mating generally starts approximately 80 days after the start of calving. The ideal is to have a compact calving spread allowing all cows adequate time for recovery prior to mating.

The mean onset of calving and mating for the DairyMAN herds are similar to the national herd. This indicates that the management of the DairyMAN farms in terms of calving and mating onset is representative of the regional and national averages.

The LIC [7] performs regular herd testing and artificial insemination, and provides breeding values for stock. Herd testing measures daily milk production (L), fat (kgMF) and protein production (kgP) and somatic cell counts for each animal lactating in the herd. A farmer may request from 1 to 8 herd tests over the lactation period. A minimum of four herd tests are required for an estimate of an animal's total lactation production to be calculated. Most commonly farmers choose between 3 and 4 herd tests over the lactation period. The daily yield is used to produce an estimate of the cow's current lactation to date production and end of season adjusted 305day lactation yield. This estimate of production is based on a BLUP model as described by Henderson [5]. The first herd test tends to occur within the first 60 days of the start of lactation. The following herd tests are then evenly spaced throughout the lactation until drying off. Drying off occurs around April and May (autumn) each year depending on both the season and the region the farm is located in.

At the first herd test some cows may have only been in the herd for 1 or 2 days compared with other cows that may have been in the herd for 60 to 70 days. An over or, more likely, underestimate of average production would result from using these figures to estimate production levels.

The herd test figures are combined with breeding and genetic information and used to calculate breeding and production indices for each animal. These standardised figures are used for breeding, mating and culling decisions.

Breeding indices are a measure of a cow's value for breeding purposes. The indices are based on production of milk, milk fat and protein, ancestry information, genetics and the ability to pass these qualities on to offspring. These indices were not comparable between herds and breeds although they were commonly interpreted as such. For this reason these indices were replaced in 1996 with new indices, Breeding Worth, which measure a cow's breeding value in economic terms per unit of feed consumed.

The Breeding Indices for the DairyMAN herds approximate the national average figures. The level of production attained by the DairyMAN herds is unlikely to be attributable to better than average breeding of animals. Management rather than breeding is likely to be of greater influence on the productive ability of these herds.

It is common practise to use AI for one or two rounds of mating (6 weeks) and then to put bulls out to serve the remaining cows that do not get in calf to AI. Bulls are more likely to be used for cows that are older or less productive and will be culled at the end of the season if they do not get in calf. When the cost of insemination starts at around $10 per straw the cost of AI can become prohibitive very quickly. In 1993/94 the average number of inseminations per cow was estimated at 1.294 [7]. The cost of inseminating 100 cows once would be around $1294. When a bull costs between $500 and $1000, depending on breed, it is easy to understand why bulls are used to run with the rest of the herd after around 6 weeks. Ideally after a 6-week mating period, with good submission rates, enough cows should be in calf to AI so that sufficient calves could be reared as replacements.

DairyMAN herds have higher numbers of Jersey x Friesian crossbred cattle than the national herd. Jersey x Friesian crossbred animals are noted for the combination of the desirable traits of their respective breeds. The more prolific milk fat, litres and protein production of crossbred animals may explain some of the higher milk production levels in the DairyMAN herds. Milk prices are structured to reflect the increased value of milk fat and protein. The more fat and protein produced the higher the profit generated. There has been a steady swing towards paying for milk solids, with protein having a price advantage compared with fat. This means the crossbred animal, which combines the best of both the Friesian protein and milk production with the Jersey fat production is likely to be the breed of the future.

Thirty five thousand calvings were recorded in the database, with 1.1% of the calvings involving twin calves. Female calves are more likely to be reared than male calves as indicated by the small number sold or bobbied. Male calves are more likely to be bobbied and sold and a small number are reared. There appears to be a significant difference in the number of deaths in male calves compared with females. The difference in death rate between males and females may be attributed to two factors. One may be the increased probability of male calves causing dystocia, due to increased size, and therefore greater likelihood of death. The second reason is that female calves are more desirable as replacements and more attention may be given to keeping them alive. There are a smaller number of twin calves sold and reared in both sexes. It is likely that the lower number of twin males sold is due to the size of a twin calf at the time of sale. Twins are usually smaller and therefore less desirable to purchasers especially at four days of age. There is a large difference in the mortality rate of twin calves and single calves. A 10-12% mortality rate in single calves may be indicative of the number of inductions present in the population. If 8.6% of cows are induced then at least this many calves will be born prematurely and have very poor survival chances. This means that the true mortality rate would be closer to 0.7% and 3% for female and male calves respectively. Twin calves are nearly twice as likely to die than single calves. The difference in survival between the twins and single calves is probably due to the small size and the increased probability of dystocia in twin calvings.

Animal Health Events.

Very little work has been published on the incidence of disease in New Zealand dairy herds.[1 3] It is difficult to determine the accuracy of the reporting of the disease events in this database especially as the farmers were not asked specifically to record these events. One method for assessing the validity of the results is to compare the results found in the work above with previously published work. On such study published the results of a survey conducted in the Bay of Plenty in 1981-83 [1]. Levels of disease incidence reported in that study compared with this work are shown in Table 24.

Table 24 Comparison of current work with previous reported disease incidence

Disease	Incidence 1981/83 [1]	Incidence 1993/4
Calving Assistance	1.7	3.6
Metabolic	4.6	2.0
Mastitis	18.7	10.9
Lameness	3.6	5.5
Illness	2.9	1.3
Reproductive	Not recorded	3.1

The results from this current study are very similar to that of the previous study, which increases confidence in the results from this work. Metabolic disease, mastitis, lameness events have seasonal and annual components to them. This means that the incidence of disease may change from season to season depending on the conditions, the amount of pasture available and rainfall. Farm management also influences disease incidence. The study in the Bay of Plenty was restricted to one area of the dairy industry and as such may not be representative of the whole country as each region has quite different incidences of certain diseases due to the nature of the farming environment in each area. One disease in particular that is commonly quoted is the high incidence of lameness events in Taranaki. [2] It would be desirable, if it were possible, to assume that the decrease in the level of mastitis over the period from 1983 to 1993 was associated with improved treatment and management of this disease.

Animal health events overall have a low cumulative incidence in the DairyMAN herds. Mastitis has the highest cumulative incidence, 10.9%, of all animal health disorders. Lameness, reproductive events, metabolic cases and sickness events had a cumulative incidence of 5.5%, 3.1%, 2.0% and 1.3% respectively.

The greatest risk period for metabolic events is during the spring period when hypomagnesaemia and hypocalcaemia are fairly common. The rise in risk of metabolic disease during January and February may be due to two events. Firstly, treatment with zinc products for the prevention of facial eczema occurs at this time. Zinc may interact with calcium and prevent calcium uptake. Cows that are being dosed with large amounts of zinc may succumb to milk fever. The second cause for metabolic cases may be the misdiagnosis of ryegrass staggers for hypomagnesaemia. There appears to be a degree of misunderstanding about the cause of ryegrass staggers in the farming industry and often cows are treated with magnesium when it is not indicated.

The time of greatest risk for the development of mastitis is commonly regarded as spring and immediately prior to or after calving. Poor drying-off techniques commonly cause an increase in mastitis at drying off.

In late summer, from the end of February until drying off in May, cows are pregnancy tested. If pregnancy testing is performed early, it can provide an effective management tool for de-stocking if the weather becomes dry in the summer. Empty cows are typically not removed from the herd until the end of the lactation. This is commonly because the cow is still producing, therefore earning money and it makes economic sense to remove her from the herd at the end of the lactation.

A considerable amount of epidemiological work has been performed on lameness in the NZ dairy industry.[9 15 2 12 13 14] There is a well-defined pattern and series of risk factors that cause lameness over the lactation period [2]. The periods of risk for lameness events outlined previously coincide well with the published literature regarding the timing of lameness events.

In conclusion, DairyMAN herds appear to be a subgroup of the national herd. They tend to have larger than average herd sizes with higher per cow production than the national herd. DairyMAN herds have more Jersey x Friesian crossbred cattle in their herds than the national average. Calving and mating dates are similar to the national herd, as are the breeding indices. This indicates that farm management rather than cow breeding plays a significant role in the better than average performance levels of the DairyMAN herds. The levels of disease recorded in the database are similar to other studies [1 2 14] in different regions of New Zealand. The overall disease incidence is low for all diseases except mastitis, which had an incidence of 10.9%. There has been very little information published in the literature regarding the disease incidence in New Zealand herds. More research is required to continually assess the levels of disease and changes over time.

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Chapter 3.

Descriptive analysis of culling data.

Introduction

Descriptive statistics on culling in dairy cattle have been reported annually in the New Zealand literature since the 1950's until the mid 1980's.[2 21] Since then there have been no published reports on the rates and reasons for culling in New Zealand dairy herds.

The objectives of this chapter are as follows:

1. To investigate the risks of removal in DairyMAN herds.
2. Identification and quantification of risk factors for removal in DairyMAN herds.
3. Identification of risk periods and the timing of removal in DairyMAN herds.
4. Quantification of the effect of animal health events on the risk and timing of removal.

Materials and Methods.

Culling information was extracted from the Access 97 [23] database described fully in Chapter 2 and manipulated in Excel 97 [24]. Relative risks, odds ratios and their 95% confidence intervals were calculated using the appropriate formulas in an Excel 97 spreadsheet. Charts were drawn in Excel 97 and Minitab V11.21 [26]. Statistical analysis, single sample t-tests, chi square analysis were performed using Minitab V11.21 and NCSS 97 [19].

Of the 154 herds in the database 23 herds did not record any culling events. All statistics reported are from the remaining 131 herds that recorded culling events. It is not possible to differentiate between the farms that recorded no culling events and those that performed no culling. It is assumed for the purposes of these analyses that the herds without culling events recorded reflected poor recording by the farmer, and therefore were excluded from analysis to prevent any reporting bias.

No reasons for culling were given in the database. Removal date and the fate of removed cows were recorded. Cows were either culled (C), died (D), lost (L) and or were sold (S). Risk of removal was estimated for each month of the 1993/94 lactation. The monthly removal risk for calved cows was calculated as a cumulative incidence. All animals from herds that recorded any specific health events (and performed culling) were used as the population at risk. The denominator was the total number of calved animals at risk minus the withdrawals. [20] The numerator was the number of animals associated with a specific health event which were removed each month. For each health disorder a time-plot of the cumulative incidence of disease and removal is shown. Timing of removal was recorded as month in the current lactation.

Chi square analysis was performed to compare the distribution of removal in cows with an animal health event with that of cows without an animal health event. Cross-tabulations of count data for the disease positive and negative groups, stratified by fate were constructed. Expected values for the disease group were calculated from the distribution of removals in the non-diseased group. These expected values were then compared to the observed removal distribution in the diseased group and a chi square value was computed.

The relative risks and their 95% confidence intervals comparing risk of removal between animals with and without a particular animal health event were calculated using the following procedure. A contingency table was set up with the number of disease positive and negative cattle grouped by removed or not removed as shown in Table 25.

Table 25 Data tabulation for relative risk calculation

	Removed	*Not Removed*	
Disease Positive	A	B	A+B
Disease Negative	C	D	C+D
Sum	A+C	B+D	A+B+C+D

The relative risk of removal comparing between disease categories is based on the ratio of removal incidence in diseased animals and the incidence of removal in non-diseased animals ($RR= A/(A+B)/C/(C+D)$). The odds ratio is calculated similarly from the ratio of the odds that a diseased animal is being removed and the odds of a non-diseased animal is being removed ($OR = A*D/B*C$).

The monthly-accumulated risk of removal was calculated for all calved cows, stratified by parity. The monthly risk of removal was quantified as a cumulative incidence (CI). The CI was calculated as the number of cows removed divided by the number of cows at risk of removal. The number of cows at risk of removal was equal to the total number of cows present (from 131 herds with recorded removals) each month minus the number of previously removed cows, stratified by parity. The monthly-accumulated risk of removal was calculated by combining each monthly incidence of removal using the formula of Elveback

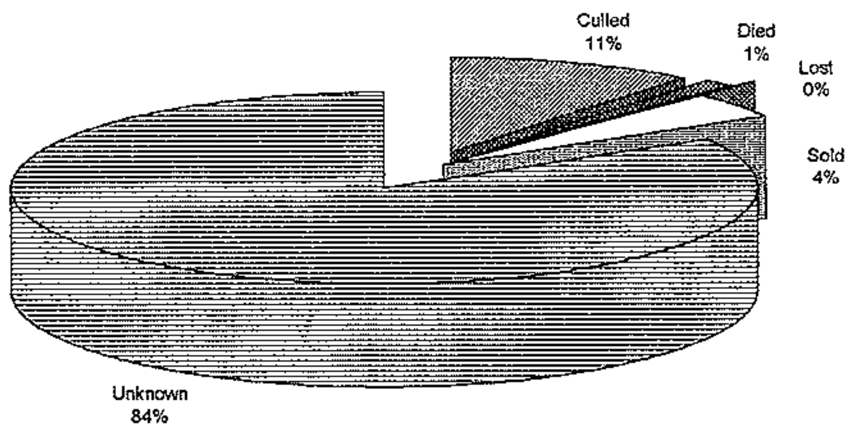
Results.

Risk factors for removal.

Risk of removal.

A total of 5559 (16.58%) cows were removed from a population of 33520 cows that had culling information recorded in the 1993/94 season. 10.7% were culled, 1.5% died, 0.1% were lost, 4.3% sold, and 83.4% were retained. The fate of DairyMAN cows is summarised in Figure 21.

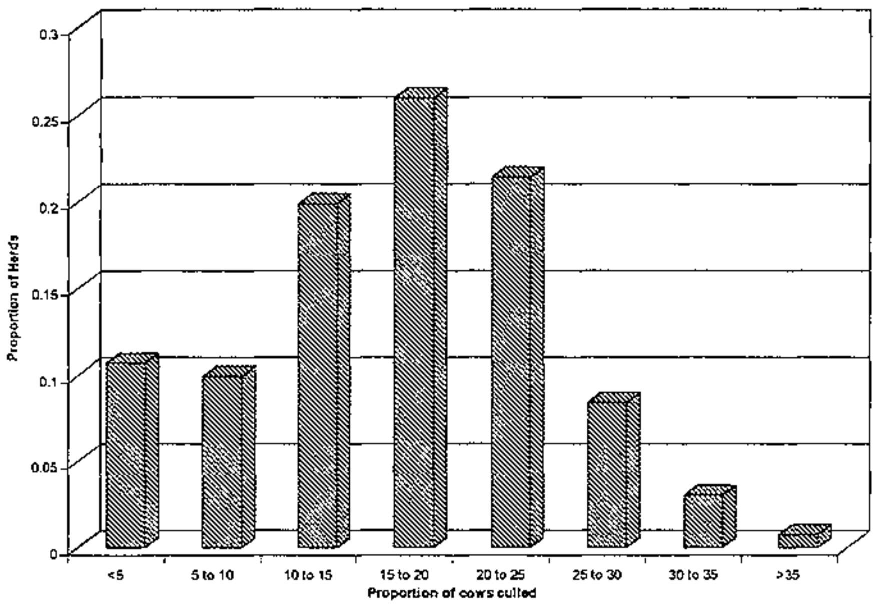
Figure 21 Fate of cows from DairyMAN herds.



Culling risks for the DairyMAN herds in the 1993/94 season ranged from 0.003 to 0.52 cows removed per year. The average culling risk in the 131 herds for which culling data was available was 16.58%. 67% of farms recorded a removal risk of 10 to 25%, with a removal risk of 15 to 20% in 25% of the herds. A summary chart presenting the distribution of culling rates for DairyMAN herds is shown in Figure 22.

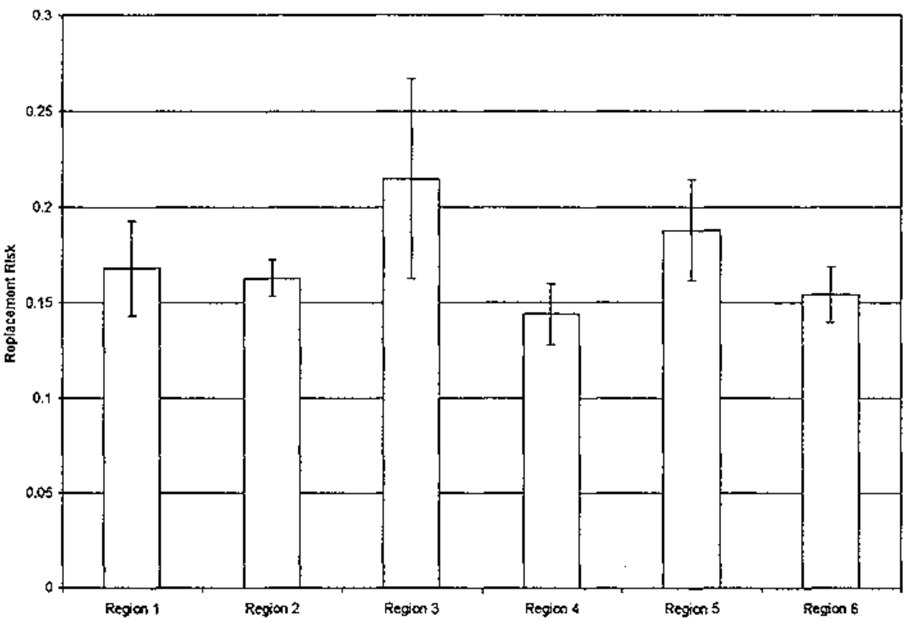
Comparison of the culling risk by region showed there was no statistical difference in the culling risks ($F=0.94$, $df = 5$, $p = 0.459$). Visually the average culling rates appear to be different as shown in Figure 23.

Figure 22 Distribution of removal risk in DairyMAN herds.



Region 3 had the highest average removal risk at 20.1% with Region 4 having the smallest average removal risk of 14.4%. The other 4 regions had similar removal risks of around 15 to 18%.

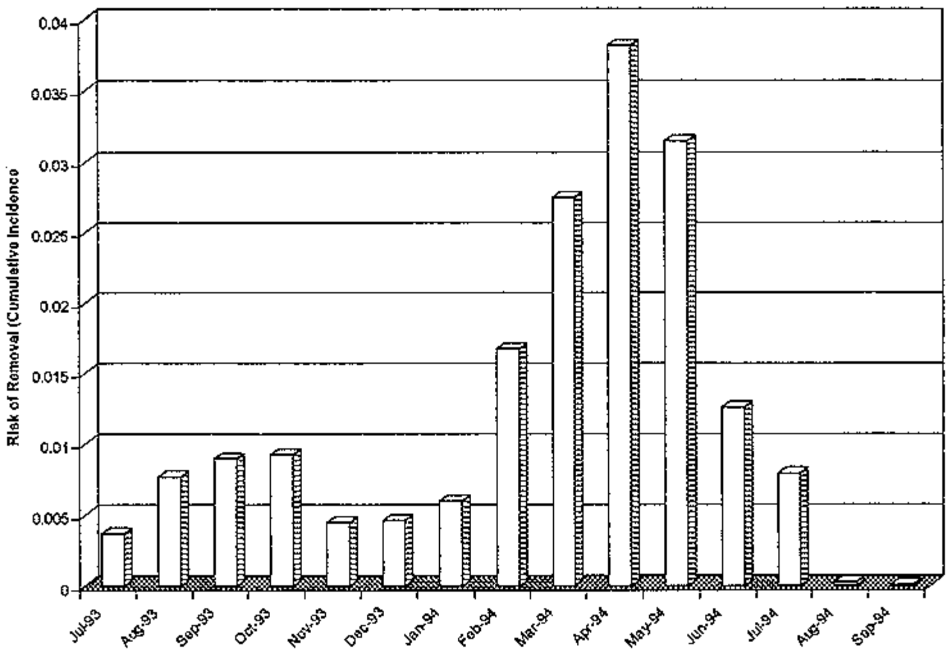
Figure 23 Average replacement risk in DairyMAN herds stratified by region, including standard errors.



Timing of Removal.

The temporal pattern of removal is bimodal. This is illustrated in Figure 24. There is a small risk of removal in early lactation, August through to October, which reaches a maximum at the end of the lactation, February to June.

Figure 24 Temporal pattern of cow removal risk during the 1993/94 Season



Fate of removed cows.

The timing and risk of removal stratified by fate is presented in Figure 25. Cows have a lower risk of death or removal due to sale during the lactation than removal by culling.

The risk of death is highest during early lactation in August, September and October with a small peak again in April while remaining low during the remaining part of the lactation. A summary chart of deaths in cows with recorded animal health events is shown in Figure 26. Seventeen percent of cows that died had an animal health event recorded.

Figure 25 Risk and timing of removal stratified by fate for the 1993/94 season.

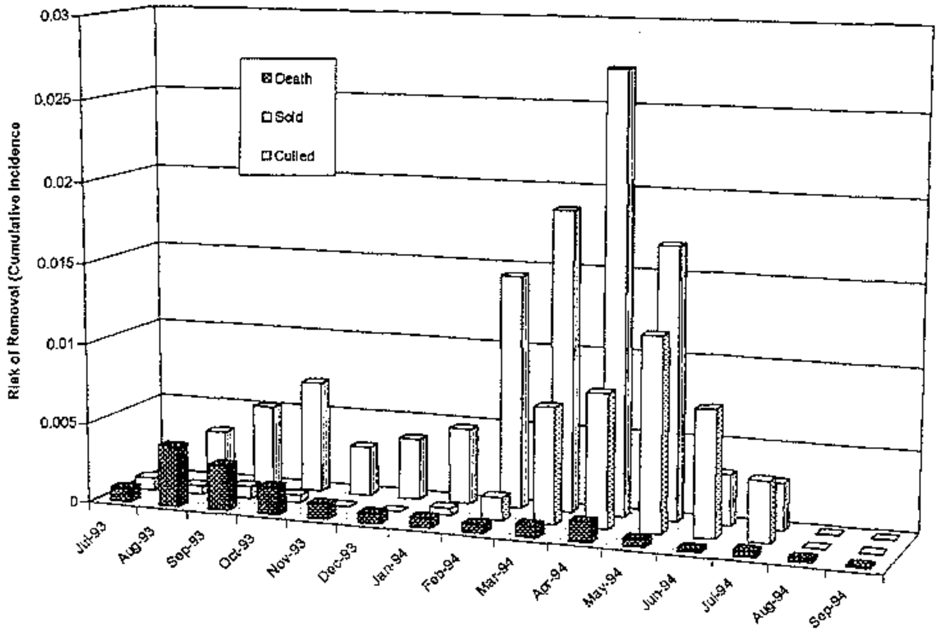
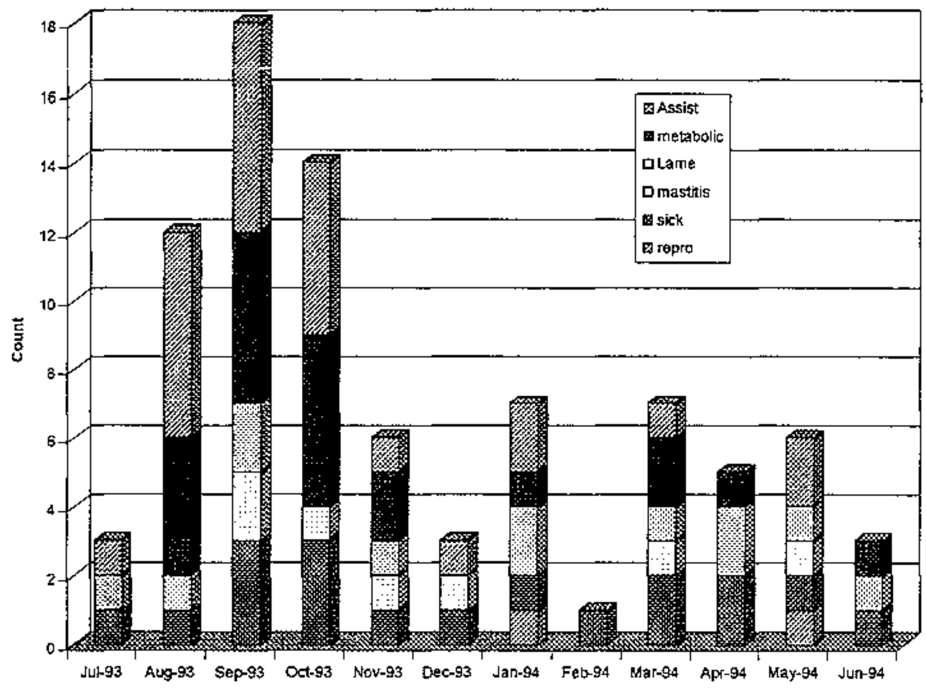


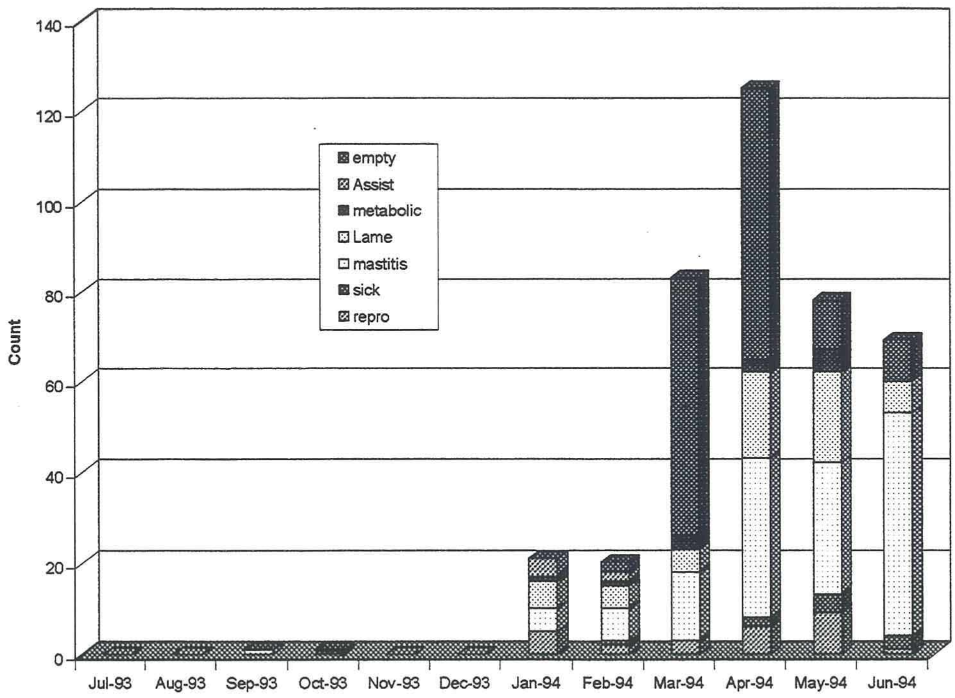
Figure 26 Animal health events recorded in cows which died, stratified by month, 1993/94



The risk of removal by sale is low during the early lactation and then peaks in May, with the majority of sales occurring from March to July. Twenty six percent of animals that were sold had an animal health event recorded. The number of animals sold stratified by animal health event is shown in Figure 27.

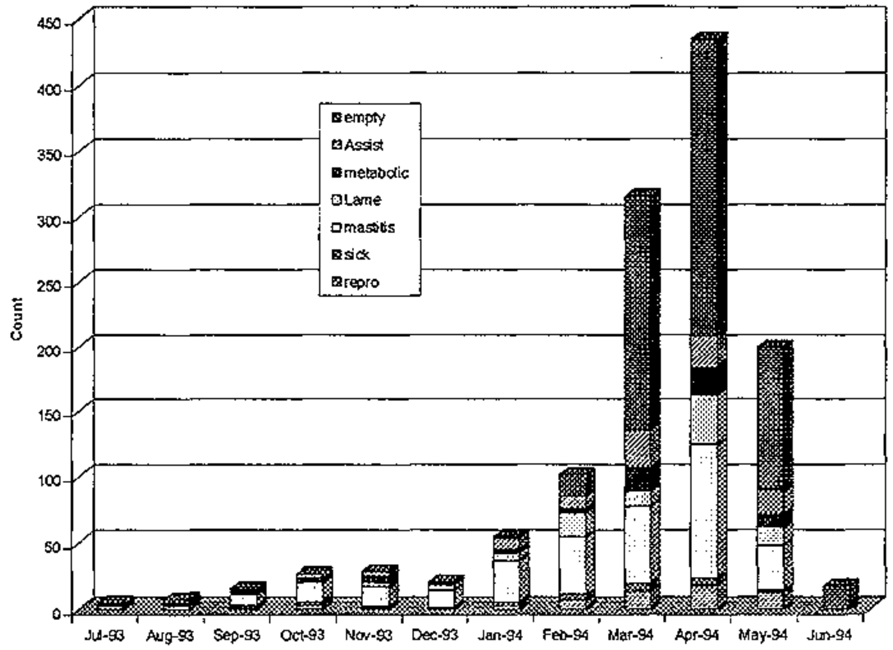
Animals with a health event tend to be sold at the end of the lactation. Empty cows represent the largest proportion of sales, followed by cows that had a mastitis or lameness event.

Figure 27 Animal health events recorded in cows removed by sale, stratified by month 1993/94.



The proportion of cows removed by culling, with an animal health event recorded, is summarised in Figure 28. Thirty four percent of cows that were culled recorded an animal health event. During the early lactation, cows are more likely to be removed from the herd by culling than either sale or death. (See Figure 25) Cows culled in the early lactation period consisted largely of animals that had a mastitis event recorded. The greatest risk of culling occurs from February to May. Cows culled in late lactation were empty, had mastitis, lameness, reproductive and metabolic events recorded.

Figure 28 Animal health events recorded in cows removed by culling stratified by month, 1993/94.



Risk of removal and age.

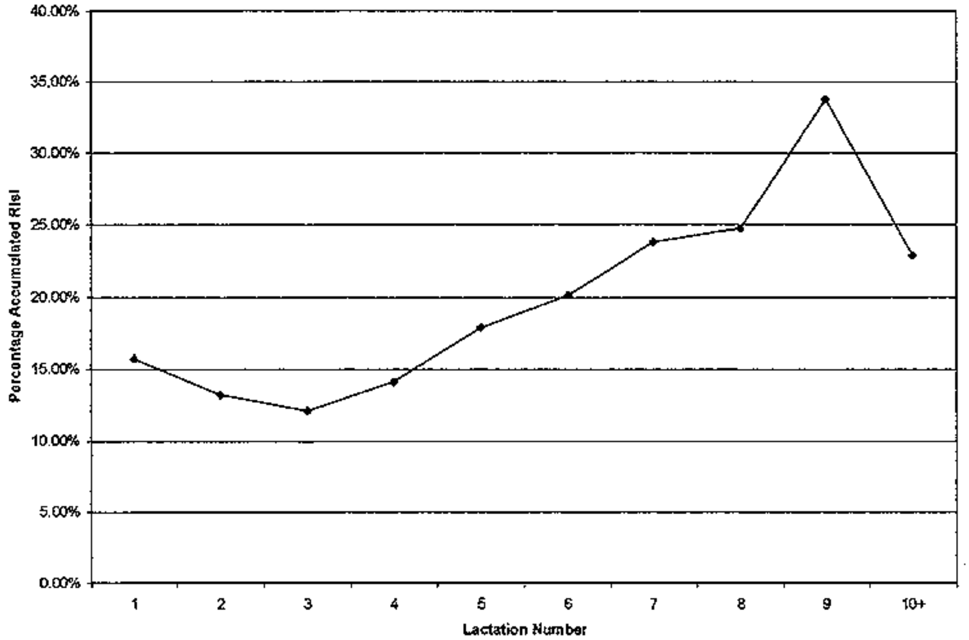
The monthly risk of removal, for calved cows, stratified by parity was calculated as described in the materials and methods . The monthly percentage-accumulated risk of removal is presented in Table 26.

Table 26 Monthly percentage-accumulated risk of removal stratified by parity

	Parity									
	1 N=7583	2 N=6429	3 N=5483	4 N=4376	5 N=3923	6 N=2670	7 N=1659	8 N=767	9 N=421	10+ N=320
Jul-93	0.41%	0.33%	0.33%	0.44%	0.43%	0.38%	0.42%	0.13%	0.00%	0.00%
Aug-93	1.18%	0.97%	0.88%	1.17%	1.33%	1.28%	1.45%	1.05%	1.92%	0.00%
Sep-93	1.99%	1.57%	1.48%	2.10%	2.42%	2.55%	2.84%	1.57%	5.02%	0.94%
Oct-93	3.08%	2.39%	2.10%	2.83%	3.46%	3.52%	4.15%	2.22%	5.49%	2.51%
Nov-93	3.50%	2.75%	2.35%	3.28%	3.96%	4.14%	4.45%	3.38%	5.95%	3.13%
Dec-93	3.87%	3.02%	2.60%	3.71%	4.56%	4.66%	5.16%	4.15%	7.34%	4.37%
Jan-94	4.55%	3.39%	3.03%	3.91%	5.24%	5.36%	6.64%	4.80%	8.03%	5.60%
Feb-94	5.70%	4.62%	3.99%	4.99%	7.14%	7.90%	9.41%	7.64%	14.63%	10.90%
Mar-94	8.25%	6.70%	5.98%	6.90%	10.09%	11.04%	13.40%	13.85%	17.75%	12.09%
Apr-94	11.01%	9.58%	8.28%	10.22%	14.14%	15.35%	19.25%	19.46%	24.93%	17.52%
May-94	13.79%	11.63%	10.55%	12.68%	17.16%	18.50%	22.27%	22.06%	29.56%	19.52%
Jun-94	15.11%	12.65%	11.26%	13.39%	17.53%	19.65%	23.07%	24.16%	32.80%	21.50%
Jul-94	15.72%	13.19%	12.08%	14.09%	17.86%	20.06%	23.76%	24.61%	33.78%	22.89%
Aug-94	15.74%	13.21%	12.10%	14.11%	17.88%	20.09%	23.76%	24.72%	33.78%	22.89%
Sep-94	15.74%	13.21%	12.12%	14.11%	17.88%	20.12%	23.81%	24.72%	33.78%	22.89%

The risk of removal for cows from parity 1 to 10 ranges between 12.12% and 33.78%. Cows in lactation 9 had the highest risk of removal at 33.78%. Cows in lactation 10+ had a 22.9% risk of removal. The percentage-accumulated risk of removal was high in lactation 1, declined in lactations 2 to 4, and then increased with parity from lactation 5 to 10. This pattern is shown in Figure 29.

Figure 29 Percentage-accumulated risk of removal for each parity.



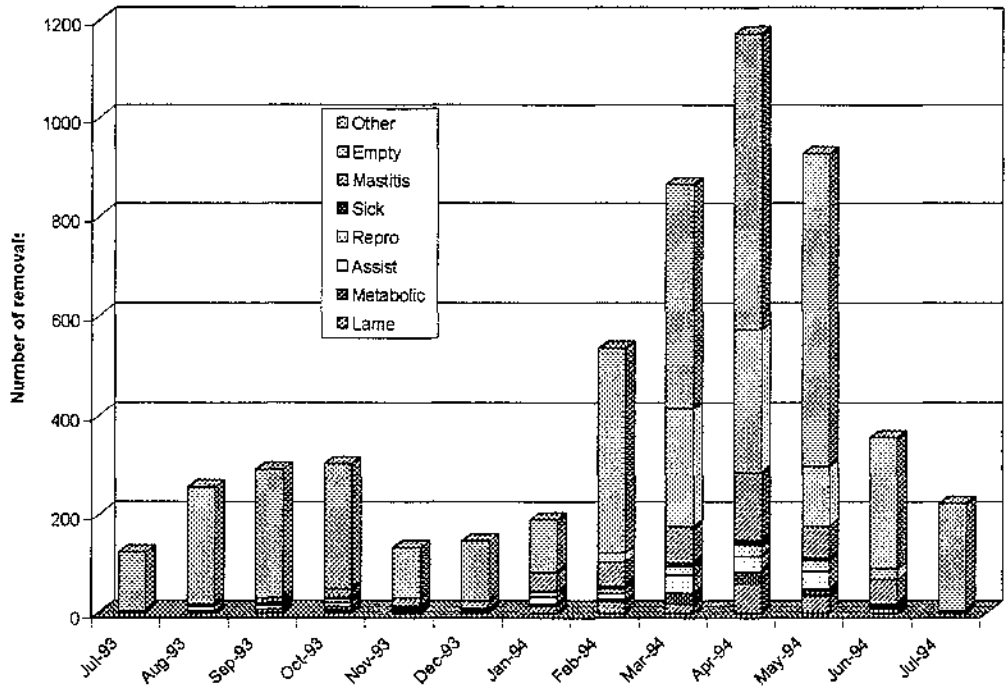
Cows in lactation 5 to 9 tend to be removed earlier in the lactation than cows in lactation 1 to 4. Cows in lactation 10 are removed slowly in the first 6 months of lactation but are removed more rapidly after this.

Animal health events and removal.

Animal health disorders and their effect on removal investigated in this study included reproductive, mastitis, lameness, metabolic, calving and sickness events. One thousand and forty seven cows, or 18.6% of removed animals, recorded an animal health during the 1993/94 lactation.

The contribution of specific animal health disorders to the number of animals removed is illustrated in Figure 30. Events or reasons other than the animal health events recorded in the database contributed the greatest numbers of animals culled at all times of the year. The "other" cows removed had no record of an animal health event. This does not however rule out animal health as a reason for removal. Possible reasons for removal in this group include production, age, temperament, and breeding value. Very few cows with an animal health event recorded were removed at the beginning of the lactation. The numbers of cows removed with an animal health event recorded increased from January to a peak in April and declined until June.

Figure 30 Contribution of various animal health events to the removal pattern.



Empty cows comprised 12.5% (692 cows) of cows culled. No cows that were recorded empty were culled prior to December 1994. Cows with a mastitis or lameness event recorded also comprised a large number of animals removed at the end of the lactation.

The calculation for the relative risk of removal for animals, which recorded an animal health event, is described fully in the materials and methods section. Using lame cows as an example, the risk of removal was calculated comparing the ratio of removals in the lame group with the number of removals in the non-lame group. The relative risk of removal, and confidence limits, for each of the animal health disorders is summarised in Table 27.

Table 27 Relative risk of removal for cows with an animal health event

Animal Health Disorder	Relative Risk	95% CI
Lame Case	1.115	0.98, 1.29
Metabolic Case	2.026	1.71, 2.39
Assistance Case	1.622	1.41, 1.86
Reproductive Case	1.531	1.29, 1.82
Prolapsed Vagina	1.493	1.48, 2.30
Discharge	1.900	1.25, 2.88
Retained Membrane	1.060	0.56, 1.98
Sick Case	1.984	1.59, 2.46
Mastitis Case	1.341	1.23, 1.46
Empty Cow	6.963	6.44, 7.57

Lame cows (1.15, 95%CI 0.98, 1.29) and cows with a retained membrane event (1.06, 95%CI 0.56, 1.98) appear to be at no greater risk of removal than cows without these events. As the confidence interval of the relative risk for these groups includes one, cows without retained membranes or a lameness event do not seem to have an increased risk of removal compared with cows that do not have these conditions.

Empty cows have the greatest risk of removal compared with all other recorded animal health events and are 6.9 (95% CI 6.44, 7.57) times more likely to be removed than pregnant cows. All other animal health events had a similar magnitude of removal risk. The risk of removal for the other animal health events in descending order is as follows: Metabolic > Sick > Discharge > Assist > Reproductive > Prolapse > Mastitis event.

The distribution of removals, in the herds which recorded removals, was found to be 10.7% removed by culling, 1.49% died, 0.11% lost, 4.28% sold and 83.42% were retained, giving a total removal risk of 16.57%. There is a significant difference in the removal pattern for pregnant cows compared with animals with an animal health event recorded. χ^2=798.3, 3df and $p<0.000$.

The distribution of removals in pregnant cows was 3.68% culled, 0.25% died, 4.24% died and 91.8% were kept. The removal rate for pregnant cows being 8.2%.

Comparison was made of the different fates (sale, death, or culling) of cows that had an animal health event recorded. The fate of a cow with an animal health event was significantly different to that of a cow without an animal health event. The results are summarised in Table 28.

Table 28 Chi Square analysis of the fate distribution for specific animal health events

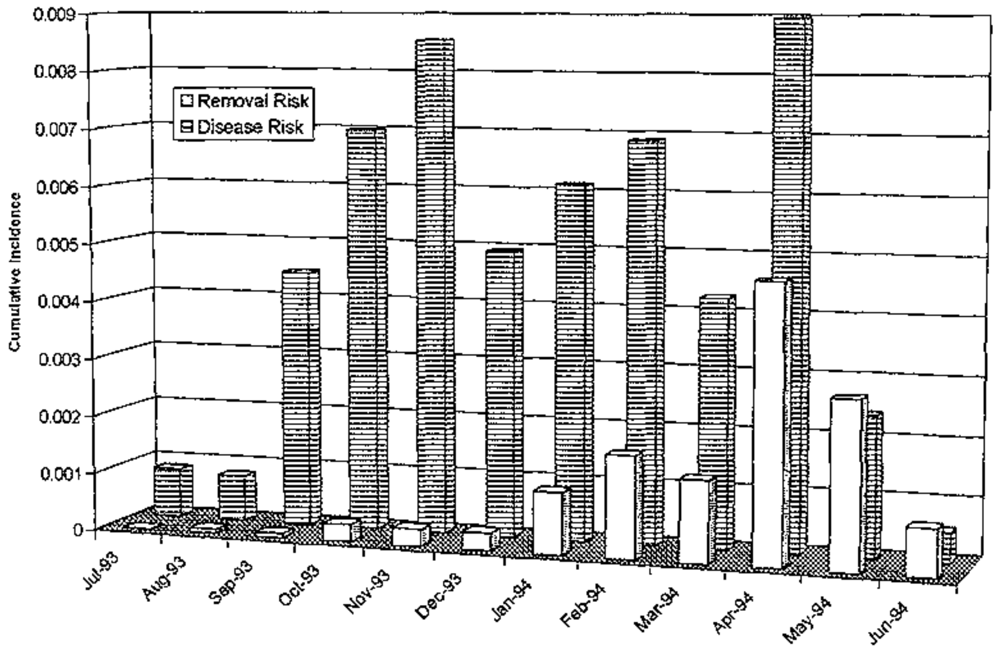
Risk factor	Chi Square Value	Degrees of Freedom	P value
Empty	6157.9	3	0.000
Lameness	8.17	3	0.050
Metabolic	129.64	3	0.000
Assistance	80.81	3	0.000
Reproduction	26.078	3	0.000
Sick	126.6	3	0.000
Mastitis	90.34	3	0.000

Empty cows were more likely to be culled or sold than pregnant cows. Lame cows were more likely to be sold rather than culled compared with non-lame cows. Cows with a metabolic event, requiring calving assistance or a sickness event were more likely to die or be culled than cows without a metabolic, calving assistance or sickness event. Cows with a reproductive event were more likely to be culled or die than cows without a reproductive event. Cows with a mastitis event during the lactation were more likely to be culled, sold or die than cows without a mastitis event during the lactation.

Lameness Events.

Figure 31 illustrates the timing of lameness events and removal of animals with a lameness event recorded.

Figure 31 Time plot for comparison of the risk of removal and incidence of lameness events

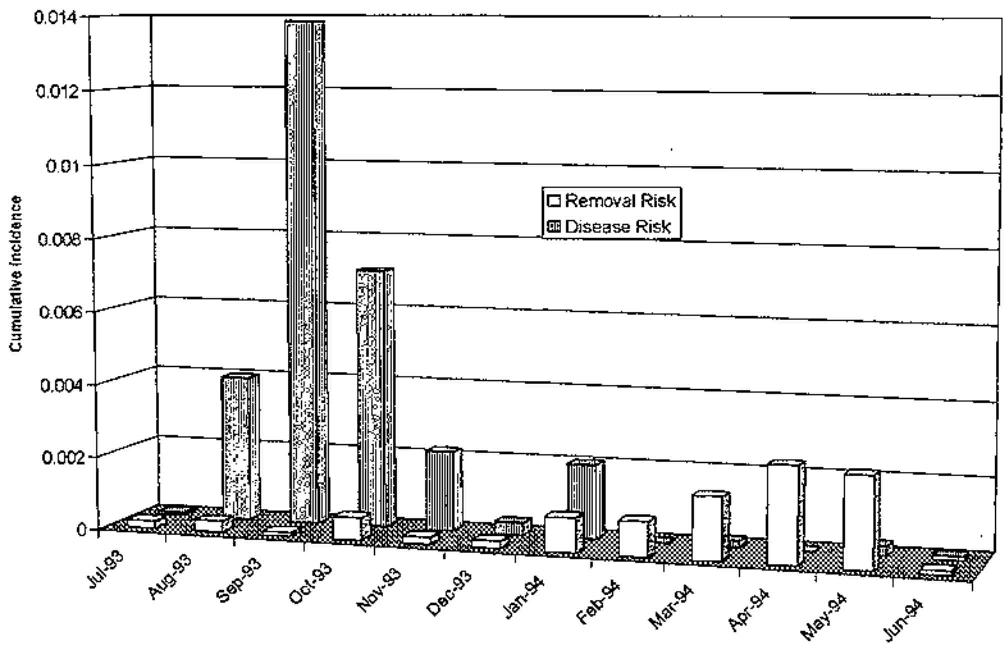


Few animals with a lameness event are removed during the beginning of the lactation. Removal risk rises to a peak during April and declines until June. The removal risk and cumulative incidence of lameness is very low for animals with a lameness event, ranging between 0.073 x 10^{-3} and 4.7 x 10^{-3} of cows removed per month.

Reproductive Events

The timing of reproductive events and period of removal is shown in Figure 32. The peak occurrence of reproductive disorders occurs in September with the peak of removal occurring in April and May. There is a much smaller peak risk of removal in cows with a reproductive disorder when compared with cows with a lameness event. Risk of removal per month ranges from 0.11 x 10^{-3} to 2.6 x 10^{-3}.

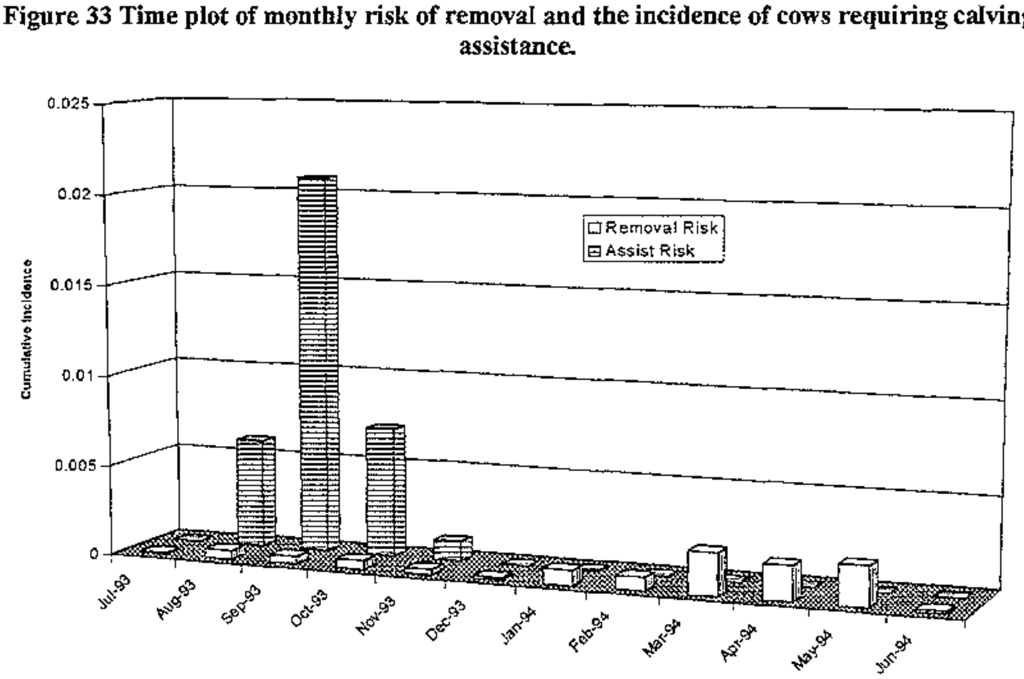
Figure 32 Time plot for comparison of the risk of removal and incidence of reproductive events.



Calving Assistance.

The timing of removal and incidence of calving assisted cows is shown in Figure 33. The risk for calving assistance is highest between August and October, when the majority of calvings are likely to occur. There is a small risk of removal early in the lactation, August through to November, with the peak of removal occurring March to May. Removal risk ranges from 0.058 x 10^{-3} in July 93 to a peak of 2.2 x 10^{-3} in May 94.

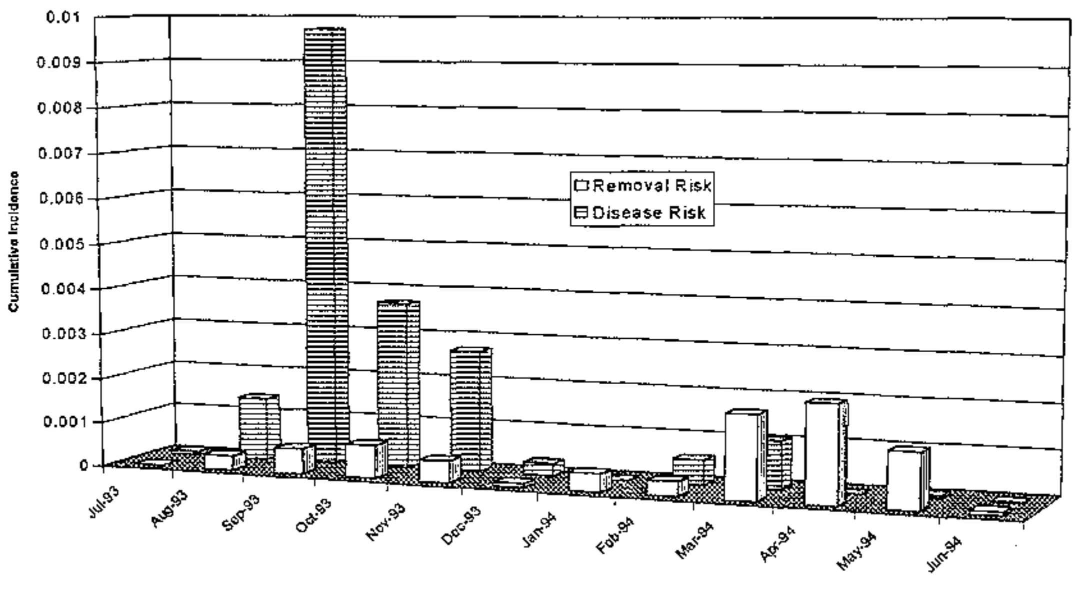
Figure 33 Time plot of monthly risk of removal and the incidence of cows requiring calving assistance.



Metabolic Events.

The monthly cumulative incidence and risk of removal for cows with a metabolic event is shown in Figure 34.

Figure 34 Time plot of monthly risk of removal and cumulative incidence of metabolic events

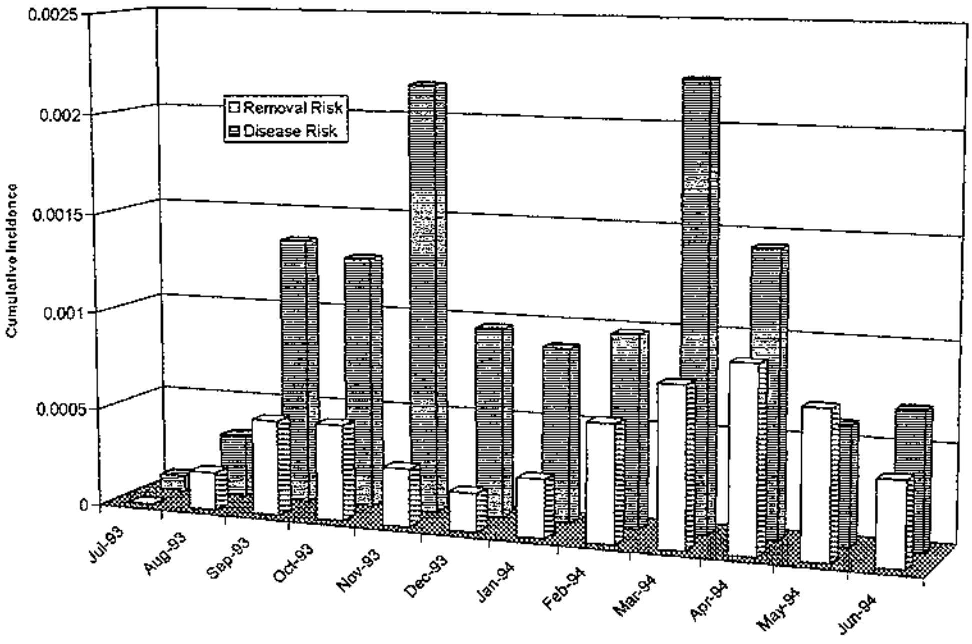


The risk of removal during the spring, August to November ranged from 0.32 x 10^{-3} to 0.73 x 10^{-3}. The risk of removal in cows, which recorded a metabolic event, during the spring months is low when compared with the risk of removal during March and April. The risk of removal ranges from 0.08 x 10^{-3} in December to 2.16 x 10^{-3} in April.

Sickness Events.

The timing of removal and incidence of disease in animals with a sickness event is shown in Figure 35.

Figure 35 Time plot of monthly removal risk and cumulative incidence of sickness events.



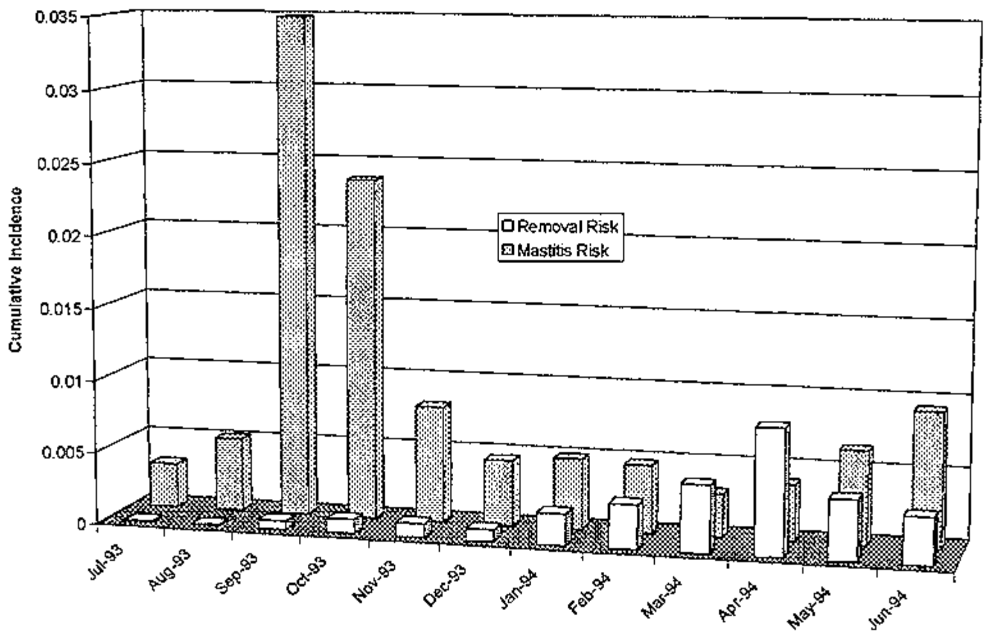
The incidence and removal risks are much lower in sickness cases compared with the other animal health disorders. There is a bimodal pattern in the distribution of removals, with removal risk in September and October showing a small peak that declines and then increases to a peak in April.

The risk of removal for a sickness event is very small ranging from 0.19 x 10^{-3} in July 93 to a peak of 0.81 x 10^{-3} in April. Animals with a sickness event early and late in lactation are at greater risk of removal than at any other time of the lactation.

Mastitis Events.

Mastitis case incidence and timing of removal are illustrated in Figure 36. There is a small risk of removal during early lactation in cows that have had a mastitis event. Removal risk steadily increases throughout the lactation to peak in April and then declines. The risk of removal for mastitis is greater than in any of the other animal health events ranging from 0.059 x 10^{-3} in July 93 to a peak of 8.7 x 10^{-3} in April.

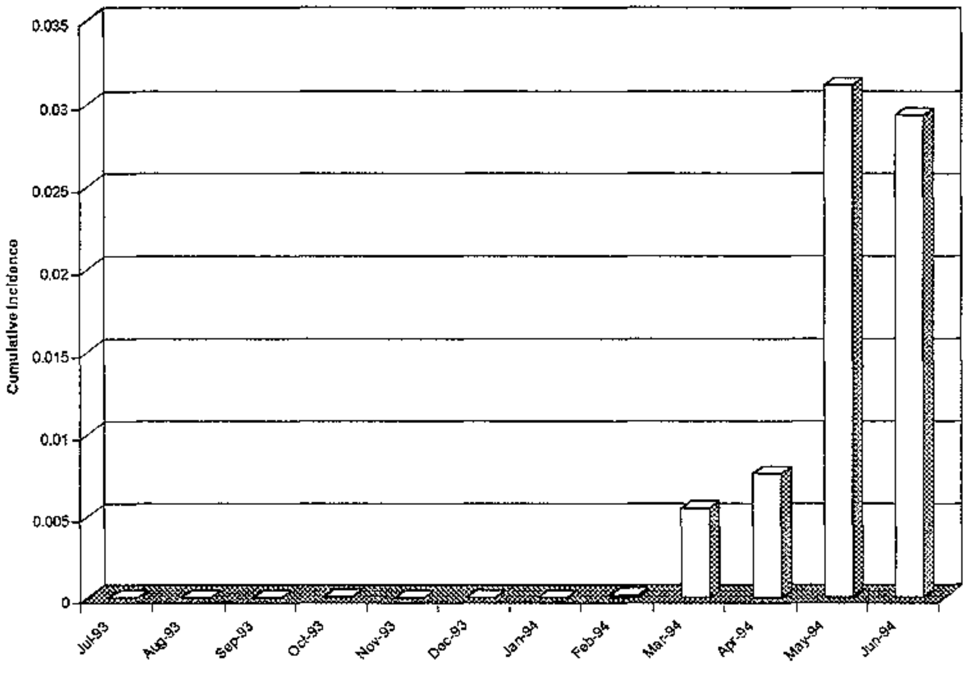
Figure 36 Time plot of monthly removal risk and cumulative incidence of mastitis events



Empty Cows.

Empty cows are more likely to be removed at the end of the lactation than animals affected by any other recorded animal health event. No empty cows were removed prior to January 1994. The removal risk for cows recorded as empty is illustrated in Figure 37.

Figure 37 Time plot of monthly removal risk for cows recorded as empty.



The risk of removal increased from 0.17 x 10^{-3} in February to 31.11 x 10^{-3} in May. The risk of removal in empty cows is much greater than removal for any animal health event that was recorded.

Discussion.

The annual culling risk is approximately 16.58% which is low by international comparison [14 18 15 31 3 29 12] and lower than the most recent study [2] published in New Zealand. This level of culling is comparable with NZ culling risks described in the late 1970's and early 1980's[2]. The most recent Australian study found a culling risk of 26% in non-seasonal herds. [30]

A large amount of work has focussed on the economics of different levels of culling. [8 9 8 10 17 28] Optimum culling levels vary depending on the aims of the producer. In order to improve the herd genetic base, higher levels of culling may be optimal. But to maximise profit, then lower levels of culling may be preferable from an economic perspective. [28 9 18 13] The highest gains in production are said to occur when culling for production is 3-8% greater than involuntary culling. [1]

The reason why culling risks appear to be so low in these farms is subject to speculation. Culling risks around this level may be the most economical "natural" level that farmers can utilise to maximise profit. One study found that the current farm culling policy generated the most profit. [28] So the culling levels being used by DairyMAN farmers may be the most economical.

Cows may be removed as a result of sale, death or culling during the lactation. Deaths occur in early and late lactation, sales occur predominantly at the end of the lactation and culling may occur in small numbers at the beginning of lactation with a peak during late lactation.

The peak of deaths in early lactation may be attributed to metabolic, calving and sickness cases. Deaths in late lactation appear to be mainly attributed to sickness events, such as facial eczema, and metabolic events, possibly due to zinc treatment.

Sale of stock may occur at the end of the lactation for three reasons. Firstly, stock is often not wanted by purchasers until the beginning of June. Secondly sale stock can be grazed longer to be in the best condition possible for sale to get the best price. Thirdly, herd and stock sales do not usually occur until the end of the season when cows are close to drying off, so that farmers can obtain maximum income from them.

The risk of removal by parity is lower and shows a different pattern than the findings of another New Zealand study. [16] In this study the risk of removal was high in parity 1, declined in parities 2 to 4 and then increased from parity 5 to 10+. In Ireland, a high risk of removal was reported for lactations 1and 2, which then declined until lactation 4 and then increased. [7] Dohoo found an increased risk of removal in 3-3.9 and

7 year olds.[11] Other studies found that removal risk generally increased with age.[4 22 5 25 15 6 30] The risk of removal of parity one animals in this study is comparable[27 25 11], higher[6 30] and lower[6 27 25] than the findings of other studies.

Animal health may account for 20% of the reasons for disposal of stock, with empty cows another 12.5%, leaving 65% of the reasons for disposal unexplained in this database. Alternative reasons for disposal include age, production and breeding.

Pregnant cows have a different removal distribution to the overall removal pattern with 3.68% culled, 4.24% sold, 0.25% died and 91.8% retained. It is interesting to consider why the pattern of removals in pregnant cows should be so different from that of the rest of the dairy cows. The timing of conception is very important to management and empty cows would represent the largest cost to farmers in terms of replacements required. Therefore pregnant cows are a very valuable commodity and as such may be retained in preference to all empties.

Empty cows have the greatest removal risk with 45% culled and 11% sold. An interesting research question that should be addressed is what happens to the 44% of remaining empty cows. If these cows are retained in the herd as holdovers what are the criteria by which they are retained, what are the economics of this retention and what are the production and reproduction levels of cows that have been retained in this

In conclusion, the risk of removal is strongly influenced by parity and the type of animal health event recorded. As parity increases the risk of removal increases in animals that have recorded an animal health event. In all cattle the risk of removal is greater in parity 1 and parity 5 to 10 animals than in parities 2 to 4. Empty cows are more likely to be culled than pregnant animals. Removal by sale occurs predominantly at the beginning and the end of lactation. Death occurs primarily in the early part of the lactation, and removal by culling occurs mainly at the end of the lactation period.

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Chapter 4

Risk factors associated with culling

Introduction.

An Access97 [16] database containing information obtained from DairyMAN users about their dairy herds was analysed. This database contained breeding, production, reproduction and animal health information for a single lactation, 1993 to 1994, on 39878 cows in 154 herds. Descriptive data about these 154 farms and the investigation into risk factors for culling is described in Chapters 2 and 3.

One hundred and fifty four farms were used in the descriptive culling analysis discussed in Chapter 3. Of these herds 23 performed no culling or had no records of animals culled. It is possible that some herds did not perform culling but it is unlikely that 15% of the herds did not perform any culling during this lactation period. This absence of culling information may reflect either a difficulty in the farmer entering this information into DairyMAN or may indicate the importance (or lack of) that these farmers placed on the recording of culling events. These 23 herds were not used for analysis of removal risks because the animal event information was likely to bias the findings. Cows with health events from these herds would lower the removal rates due to the risk factors and so result in possible misclassification bias, as we do not know their true fate.

Risk factors for removal of dairy cows have been studied extensively in the literature. The most common removal reasons given are production, animal health events and old age. The animal health events of most importance are infertility and mastitis. (See literature review.) Based on these assumptions the database was examined for the possible relationships between animal health events and production to determine the risk factors associated with removal. Additional risk factors for removal such as the timing of conception, future calving date and pregnancy status, which are important management features were also investigated.

Of the remaining 132 herds with culling events recorded 5559 cows were culled out of 33721 cows giving an average annual replacement rate of 16.58%. In these 132 herds 64% of removed cows were culled to the meat works, 26% were sold as dairy replacements, 9% of the cows died and 1% were lost from the herd. This is summarised in Figure 21, Chapter 3. The distribution of herd replacement rates is illustrated in Chapter 3, Figure 22. Recorded herd replacement rates ranged from <1% to 52% of the herd. The median herd replacement rate is 17%.

There was no correlation between the herd replacement rate and the herd size. (r^2= 0.033) That is the replacement rate did not increase as the herd size increased.

Culling is a very subjective business depending on the motivations of the farmer and the reason given for culling may have nothing to do with why the animal was actually culled. [3]

Introduction to survival analysis.

Survival analysis is a statistical method useful for the analysis of time to event data. The outcome variable is usually the measure of time elapsed from a starting point until an event occurs. This event may be infection with a disease, death or removal from a herd or response to a treatment. Survival data is not amenable to standard data analysis because of two specific features about it. Firstly the data is not symmetrical and is commonly positively skewed and therefore normality cannot be assumed. This may be easily overcome with power transformations or possibly using alternative distributional models. The second feature about the survival analysis is that you can take into account the values of *censored* variables. Data is censored when the end point of interest, such as culling or death, has not been observed prior to the end of the study. Alternatively individuals' data may be not be known at the time of analysis because they have been *lost to follow up*. That is individuals' data has not been able to be collected for they may have been lost to the study. Censoring also occurs when another event occurs prior to the event of interest i.e. death due to another cause. In the examples above censoring occurs after the individuals have entered the study and is therefore termed *right censoring*. *Left censoring* is when the event of interest occurs prior to the start of the follow up period. These events happen very rarely.

Partial information about the individual up until the time of censoring can be used in the analysis. This has the advantage that we are able to obtain as much information as possible about the group we are studying at all times in the study even if subjects are lost to the final analysis. Unlike other forms of analysis where these subjects would be lost and their data discarded as incomplete. If right censored subjects are not included in the analyses this has the result of underestimating the true probability of survival in the population under study. Similarly the exclusion of left censored subjects will overestimate the survival probability.

The aims of this chapter are as follows:

- To describe and quantify the risk factors for culling identified in Chapter 3 using univariate survival and hazard analysis.
- To use the risk factors for culling identified using univariate survival analysis to develop a multivariable model that describes the inter-relationship between these risk factors.

This chapter is structured into two sections one dealing with univariate survival analysis and the other with multivariable survival analysis. Each section will contain materials, methods and results relevant to the section. This is followed by a general discussion pertaining to both sections.

Univariate survival analysis

Introduction.

To summarise survival data the survivor function and the hazard function are used. They are based on the survival probability density function shown in Equation 1:

Equation 1 Survival probability density function.

$$F(t) = P(T < t) = \int_0^t f(u)du$$

This describes the relationship of the actual survival time of an individual, *t*, with the random variable *T* associated with survival time. The distribution function of *T* represents the probability that the survival time is less than some value *t*.

The survivor function, *S(t)*, is the probability that the survival time is greater than or equal to *t* :

Equation 2 Survivor function.

$$S(t) = P(T \geq t) = 1 - F(t)$$

The survivor function represents the probability that an individual survives from the time origin to some time beyond *t*.

The hazard function, *h(t)* is the probability that an individual fails at time *t*, conditional on surviving until that time. This therefore represents the instantaneous failure rate for an individual surviving to time *t*. The hazard function is defined using the probability density function of *T* as shown below:

Equation 3 Hazard function.

$$h(t) = \frac{f(t)}{S(t)}$$

As can be seen it is possible to obtain the survivor function and the hazard function from each other. Both the survivor function and the hazard function are estimated from the observed survival times.

Univariate analysis of a set of survival data begins with the numerical and graphical summaries of the survival times for individuals in each group. A summary is given by estimates of the survivor function and the hazard function. These methods are non-parametric because they do not require specific assumptions to be made about the underlying distribution of the survival times.

Estimates of the survivor function can be performed using life table type estimates that divide the period of observations into time intervals and calculate the average number of individuals at risk during each interval. Similar estimation is made for the hazard function except that the number of events per unit of time over each interval are described. That is the observed number of events in the interval divided by the average time survived in the interval.

The Kaplan-Meier estimate of the survivor function is similar to the above. A series of time intervals is formed so that each event time is contained within the interval, and the event occurs at the start of the interval. The calculation is therefore the probability of surviving through the intervals until failure. The estimation of the hazard function takes the ratio of the number of events at a given event time to the number of individuals at risk at that time. As long as the hazard per unit time is constant between successive event times then further division of the time interval can find the hazard per unit time.

Statistical comparison of two groups of survival data involves using the log-rank test (also known as the Cox Mantel, Peto Gehen tests) or Wilcoxon test. The log rank test is more suitable when the assumption of proportional hazards is true for the two groups. That is the hazard of an event at any given time for a subject in one group is proportional to the hazard at that time for a similar individual in the other group. The log rank test places more emphasis on longer intervals to outcome than the Wilcoxon test.

The Wilcoxon test is best used if the assumption of proportional hazards can not be assumed between the two groups. This test gives more weight to smaller intervals to outcome than the log-rank test.

One method to check the assumption of proportional hazards is correct is a simple visual appraisal of a plot of the survivor functions for each strata. If the hazard functions are proportional then the survivor functions for each strata do not cross. If the survivor functions cross then the assumption may not be valid. But care should be made to ensure that interpretation is correct if the survivor estimates are based on samples. Another method for determining proportional hazards is to plot the negative logarithm of the estimated survivor function against the logarithm of the survival time. This will yield parallel curves if the hazards are proportional across all groups.

Materials

A database in Access 97 [16] containing records on 39000 cows in 123 herds was utilised for the univariate analysis. The criterion for inclusion in the analysis has been described in detail in Chapter 3. All univariate survival analysis was performed using NCSS 97. [14] Odds ratios, relative risks and their confidence intervals were calculated in an Excel 97 [17] spreadsheet. Survival plots were drawn using Minitab V11.21. [20]

Methods.

General

Descriptive analysis of the risk factors for culling discussed in Chapter 3 identified three areas of risk to the survival of cattle within the dairy herd. They were production, animal health and management practices. These risk factors identified by descriptive data analysis were further analysed using univariate survival analysis.

In this analysis the outcome of interest was the length of the current lactation, defined as the interval in days between the date of the most recent calving and the time to removal from the herd. Right censoring was considered to occur if a cow was not removed from the herd 365 days after the last calving. For most removal factors investigated small numbers of animals (less than 50%) with a risk event were removed from the herd. This meant that 50% or median survival times could not be reported. As the time to removal from the date of last calving is the outcome of interest and most farmers perform culling at the end of the lactation, survival to 270 or 305 days after calving was determined as an appropriate measure of the survival experience.

The cumulative hazard was calculated for cows by parity and for those cows with an animal health disorder recorded. The outcome of interest was the length of the current lactation as described above. For the cumulative hazard analysis by parity, the removal times (days from last calving) for 1000 cows in each parity were compared. Cows were censored if they were not removed during the lactation period. An unknown fate and a removal date in 1999 were used to identify the censored cows. If 1000 cows were not present in a particular parity then all cows present were used. The cumulative hazard analysis for cows with an animal health disorder recorded was performed as follows. All animals with an animal health disorder recorded, from the 132 herds used, were included in the cumulative hazard analysis. Cows were considered censored if they were not removed during the lactation period. An unknown fate and a removal date in 1999 was used to identify the censored cows. Calculation of the cumulative hazard by parity for cows that recorded an animal health event was also performed. The censored and non censored data used in the cumulative hazard analysis was used to calculate the cumulative hazard by parity for each animal health disorder. Hazard analysis was performed using the Minitab V11.21 [20], Survival and Hazard function analysis module. Log rank tests comparing survival curves was performed using NCSS 97. [14]

Production.

Production, specifically milk (L) and fat (kg), was considered as a risk factor affecting the survival of dairy cattle. For the production analysis 107 herds were used. 25 herds were not used for this analysis because there was no milk production information collected.

Comparison was made of the survival experience of cows with above and below average herd milk production. Descriptive data analysis indicated that the milk and fat production closely approximated a normal distribution. Using the final lactation to date production figures, calculated from herd testing, the average herd production was estimated at the time of the fourth herd test. The average herd production was calculated from each individuals total lactation production and averaged against all the cows present in the herd. This average herd production was measured in both litres and milk fat. Each cow within the herd was compared with the average herd production. The cows were then classified according to production levels as either above or below average producers for that season. One thousand cows with above and 1000 with below average production were selected randomly from the 107 herds, used for production analysis, and their survival experience compared.

A common target for a "good" cow is to achieve 200kg milk fat over lactation. The average milk fat production per cow in New Zealand for the 1994/95 season was 154kg milk fat ranging from 129 to 164 kg milk fat depending on region. It is assumed that a cow that achieves at least this level of production will remain in the herd for a longer period than a lower producing cow. Cows in the 107 herds with milk production recorded were grouped according to the level of milk fat produced by the 4^{th} herd test into those that performed greater than or less than 200kg milk fat for the season. One thousand cows from each group were randomly selected and the survival experience of cows producing greater than 200kg fat by the 4^{th} herd test was compared with cows that produced less than 200kg milk fat by the 4^{th} herd test.

Animal Health Disorders.

Five animal health categories were recorded in the DairyMAN database. They were lameness, metabolic, reproductive, sickness and mastitis cases. As all data entered into DairyMAN is often based on farmer diagnosis and input, there was inadequate information available to define an animal health event with any greater precision than DairyMAN coding allowed. Only the reproductive events were categorised more fully. Owing to this deficit in the data it is only possible to compare the animals on the basis of the simplest diagnostic criteria. But given this criticism it is also these diagnoses by which a farmer will make his/her decisions about keeping or removing an animal. So while the diagnosis may not be very sophisticated or accurate and may suffer from misclassification this may be the most accurate animal health information available to the farmer for culling purposes.

For each of the animal health disorders univariate survival analysis and relative risk data was estimated. Using the group of animals with a lameness event as an example the relative risk of culling was calculated as follows. The cumulative incidence of the removal for a lameness event was calculated for both the lame and the non-lame cow groups. The numerator was the number of animals removed with a lameness event over the denominator, which was the total number of lameness cases at risk of removal. This was repeated for the non-lame group. The ratio of the two cumulative incidences gives the relative risk of the culling event for animals with a lameness event during the total lactation period. A more detailed description is given in Chapter 3.

Lameness

Cows with and without a lameness event were compared and the timing of a lameness event during the lactation period was investigated. Six hundred and sixty three cows with lameness events and 12278 cows without a lameness event were available for survival analysis. The survival experience of all cows with a lameness event recorded was compared with the survival of 1000 randomly selected cows, without a lameness event recorded, from those herds that recorded lameness events. Comparison of the effect of the timing of the timing of a lameness event on the survival experience was conducted. The lactation was divided into 3 time periods: Less than 100 days, 100 to 200 days and greater than 200 days. Three hundred and fifteen cows, 246 and 68 cows were used in groups one to three respectively. The survival experience of the cows in each group was plotted and compared.

Metabolic events.

There was no distinction made in the database between types of metabolic events, so a metabolic event could indicate any sort of incident where a cow was down or treated with a metabolic treatment. Therefore it could include hypocalcaemia, hypomagnaesia or downer cow syndrome. Hypocalcaemia and downer cows tend to occur during the first few weeks of lactation. Calcium responsive downer cows may occasionally be seen between the months of January and April. This is due to interference with the mobilisation of calcium when zinc is used at high doses for the prevention of facial eczema. Hypomagnesaemia may occur into the second month after calving if magnesium levels are low and animals have not been treated early enough prior to calving. The severity of some cases can lead to the culling of these animals or self-selection due to death.

Cows with and without a metabolic event were compared and the influence of the timing of a metabolic event was considered. The survival of 209 cows with a metabolic event was compared with the survival of 1000 cows without a metabolic event. The cows without a metabolic event were randomly selected from herds that recorded metabolic event. The timing of a metabolic event was considered as a risk factor to removal and three time periods were selected as follows, 1 to 5 days post calving, 6 to 30 days post calving and greater than 30 days post calving. One hundred and forty eight, 29 and 30 cows were used in groups 1 to 3 respectively.

Mastitis events.

There was no definition made between the types of mastitic events, the cause, diagnosis of disease and severity of disease. There was no indication of the quarters involved or the type of treatment given. Two thousand two hundred and 2209 cows with a mastitis event were recorded in the database. One thousand cows with a mastitis event were randomly selected from the 2209 cows and compared with 1000 randomly selected cows, from herds that recorded mastitis events, without a mastitis event. The effect of the timing of a mastitis event during the lactation period was investigated by stratifying the lactation into four time periods as follows: The dry period, between 1 to 40 days, 40 to 100 days and 100 to 300 days after calving. Cows with a mastitis event falling into one of the time periods were grouped and their survival curves compared.

Sickness events.

Sickness events are coded in DairyMAN as miscellaneous events that could account for any type of illness that is not coded anywhere else. These events can include abscesses, pneumonia, facial eczema or digestive disorders. Basically any event that is not involved with legs, the udder, a metabolic disease or the reproductive system is classified as a sickness event.

The survival curve of 119 cows with a sickness event recorded was compared with the survival curve of 1000 randomly selected cows, from herds that recorded sickness events, without sickness events.

Reproductive events.

This was the only animal health event that was categorised more specifically. Reproductive disorders were recorded for 811 cows. They included calving assistance, uterine prolapse, vaginal prolapse, discharge, retained membranes, and non-cycling cows. Calving assistance and reproductive cases were analysed separately.

- Calving assistance.

There was no definition of the reason calving assistance was required. It is presumed that the calving assistance was any cow that required help calving regardless of the degree of difficulty. Five hundred and twenty five cows requiring calving assistance were compared with 1000 randomly selected cows not requiring calving assistance. All cows were used from herds that recorded calving assistance.

- Reproductive events.

Two hundred and eighty six cows with a reproductive event, defined as cows with a uterine prolapse, vaginal prolapse, discharge, retained membranes, and non-cycling cows recorded were assessed. The survival of all 286 cows with a reproductive event recorded were compared with 1000 randomly selected cows, from herds that recorded reproductive events, without a reproductive event. Reproductive events were further analysed by specific disease events. Animals with a discharge, prolapsed vagina or retained membrane event were grouped and their survival and risk of removal calculated. Forty five, 170 and 43 animals were used in each group respectively.

Management

Empty cows.

The survival times of 984 empty cows and 1000 pregnant cows randomly selected from herds that pregnancy tested cows within the herd were compared.

Calving dates

It is important for good grass management that calving is concentrated into a small window to match the grass supply. A calving pattern of 6 to 8 weeks is ideal for good pasture management in the spring. Cows that are in calf later than 8 weeks after the start of calving are at risk of early removal to maintain a good calving pattern. Cows are considered to be late calving if their calving date is after this 6 to 8 week period and may be induced to maintain a tight calving pattern. To investigate the importance of future calving dates and early and late calving the planned start of calving for each herd was used as the base figure. Each cow with a future calving date recorded was compared to the planned start of calving date for its respective herd. A cow was defined as early calving if its calving date was less than 8 weeks after the planned start of calving and late calving if it had an estimated calving date after this time. The survival times of 1000 cows with early calving dates and 1000 cows with late calving dates randomly selected from all cows with future calving dates recorded were compared. To further quantify the influence of the future calving date on cow survival, cows were grouped into three based on their anticipated calving date as follows: Calving date <6weeks, 6 to 8 weeks, 8 to 10 weeks and >10 weeks after the planned start of calving. One thousand, 786, 457 and 1000 cows were used in each of the four groups respectively and their survival curves compared.

Breeding Indices.

Breeding Indices (BI) supplied by the Livestock Improvement Corporation give a method by which farmers can select cows of higher genetic merit. To investigate the influence of BI on removal and survival in the herd the average BI value was calculated for all the herds. Each individual BI was compared with the average herd BI. Animals were categorised as above or below the herd BI. Nine hundred and ninety four cows with above average BI and 996 cows with below average BI were randomly selected from the herds that contained BI information. The survival curves for these two groups were compared.

Results.

Production

Table 29 summarises the results of the univariate survival analysis investigating the effect of production on the survival of cows in DairyMAN herds.

Table 29 Summary of univariate survival analysis comparing production levels.

Variable	Survival probability		χ^2	Df	p-value
	270 days	305 days			
Production					
Litres> average	0.945	0.926			
Litres <average	0.892	0.874	14.86	1	0.00011
Fat >200kg	0.97	0.96			
Fat <200kg	0.90	0.881	43.29	1	0.0000

Comparison of production levels above and below the herd average.

A survival plot was constructed to compare the survival of cows with above or below average milk (L) production. One thousand cows were used in each group. This is illustrated in Figure 38

Figure 38: Timing of removal for cows with milk (L) production above or below the herd average.

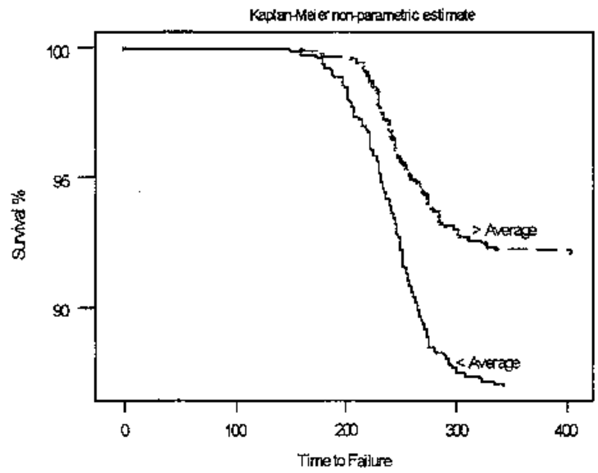
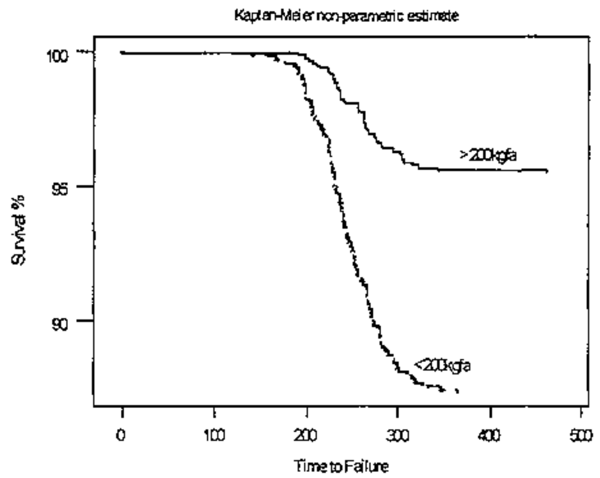


Figure 38 shows that those cows with less than average milk (L) production had lower survival times than cows with above average milk (L) production. The survival function for cows with above average milk (L) production to 270 and 305 days post calving was S(t)=0.945 and S(t) = 0.926 compared with S(t) =0.8925 and S(t)= 0.8735 for cows with below average production in litres. There was a significant difference between the two curves with the log rank test χ^2 = 14.86, df=1 and p=0.00016. Cows with less than average milk production are 1.76 times as likely to be removed than cows with greater than average milk (L) production. OR = 1.76 95% CI (1.31 to 2.36)

Cows producing greater or less than 200kg milk fat.

Cows achieving >=200kg milk fat by the end of the 4th herd test were compared with cows that achieved less than this production to the 4th herd test. 1000 cows were compared in each group. The survival experience of cows producing less than or greater than 200kg milk fat is shown in Figure 39. The log rank test comparing the two groups indicates the statistical significance of the difference between these two groups. χ^2 = 43.29, df = 1 and p=0.0000. The survival function for cows with greater than 200kg fat per cow production for 270 and 305 days into lactation was S(t)= 0.97 and S(t) = 0.96 respectively compared with S(t) = 0.904 and S(t) = 0.881 for cows with less than 200kg fat production.

Figure 39 Timing of removal for cows producing less than or greater than 200kg milk fat.



Between three and four percent of cows producing greater than 200kg of fat to the 4th herd test were removed from the herd compared with ten to thirteen percent of the animals producing less than 200 kg fat to the 4th herd test. Cows that produced less than 200kg fat were 3.09 times more likely to be removed than cows with greater than 200kg fat production. (OR = 3.09 95% CI 2.17 to 4.39)

Animal Health Disorders.

Table 30 summarises the results of the univariate survival analysis comparing the survival experience of cows with an animal health disorder to those without an animal health disorder. A full description of the analysis for each animal health disorder is given in the following sections.

Table 30 Summary of univariate survival analysis for animal health disorders

Variable	Survival probability 270 days	305 days	χ^2	Df	p-value
Lameness					
Yes	0.833	0.808			
No	0.85	0.827	1.10	1	0.29
<100 days	0.806	0.77			
100 to 200 days	0.84	0.82			
>200 days	0.906	0.906	8.08	2	0.017
Metabolic Event					
Yes	0.64	0.622			
No	0.86	0.83	46023	1	0.0000
1 to 5 days	0.61				
6 to 30 days	0.62				
>30 days	0.80		3.22	1	0.20
Mastitis Event					
Yes	0.808	0.77			
No	0.877	0.857	20.17	1	0.000
Dry Period	0.84	0.73			
<40 days	0.77	0.75			
40 to 100 days	0.71	0.67			
100 to 300days	0.89	0.86	28.07	1	0.000
Sickness Event					
Yes	0.66	0.63			
No	0.86	0.833	32.54	1	0.000
Reproductive Events					
Yes	0.72	0.69			
No	0.87	0.85	32.54	1	0.000
Calving Assistance					
Yes	0.78	0.75			
No	0.86	0.84	18.39	1	0.000

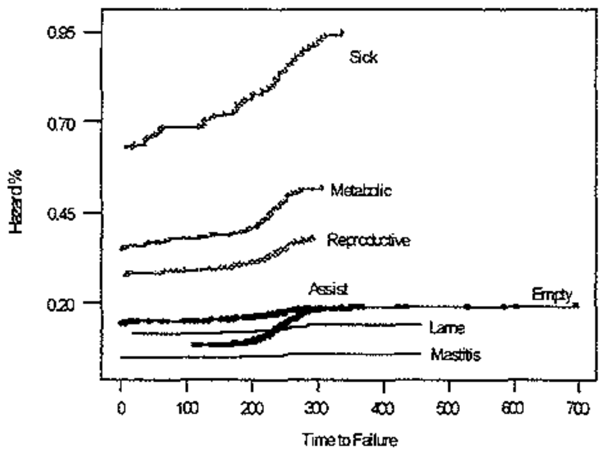
Table 31 summarises the cumulative hazard for removal of cows with various animal health events stratified by parity. In all cases the removal hazard increases with parity. A full description of these results is given in the following sections.

Table 31 Cumulative hazard for removal of cows with an animal health disorder stratified by parity.

Parity	Lameness	Metabolic	Mastitis	Reproductive	Sickness	Empty	Assist
1	0.11	-	0.047	0.29	0.68	0.095	0.16
2	0.15	0.36	0.057	0.40	0.93	0.13	0.26
3	0.17	0.39	0.069	0.56	1.30	0.17	0.35
4	0.22	0.43	0.087	0.71	2.08	0.22	0.45
5	0.30	0.54	0.12	1.06	2.78	0.31	0.65
6	0.46	0.83	0.19	1.59	4.17	0.52	1.04
7	0.79	1.63	0.34	2.50	7.69	1.06	2.00
8	1.45	3.57	0.709	5.26	14.29	1.75	4.17
9	3.33	5.55	1.22	9.09	100.00	4.54	7.14
10	10.0	12.5	3.57	14.28	-	11.11	14.29
11	-	-	12.5	-	-	-	-
12	-	-	50.00	50.00	-	-	-

The cumulative hazard of cows with an animal health event is shown for each specific animal health event in the following sections. Figure 40 summarises the cumulative hazard for each of the animal health disorders on one chart. This illustrates the effect of the different animal disorders on the hazard of removal. Cows with a sickness, metabolic or reproductive events have a higher cumulative hazard of removal during the lactation than cows with a lameness, mastitis or reproductive event. There was a statistically significant difference in the cumulative hazard curves for each of the animal health disorders. (Log rank test $\chi^2 = 535.7$, Df = 6, P=0.000)

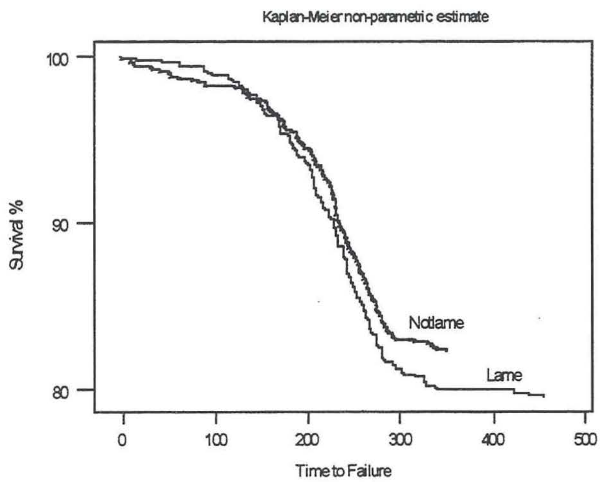
Figure 40 Cumulative hazard of cows with an animal health event during the lactation.



Lameness.

The cumulative incidence of lameness events was 5.8%. The relative risk of an animal being culled for lameness was 1.115 (95% CI 0.98 to 1.29), which indicates that an animal with a lameness event may be more likely to be removed than an animal without a lameness event. Comparison of the survival experience for cows with and without a lameness event is shown Figure 41.

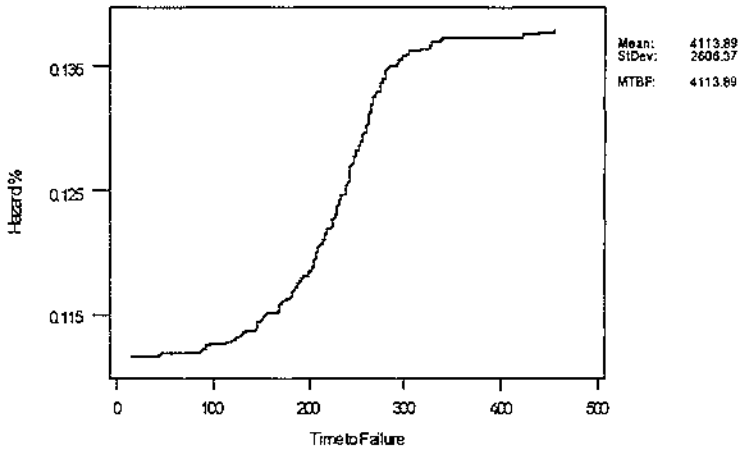
Figure 41 Time to removal for cows with or without a lameness event.



Those cows with a lameness event appear to be culled sooner than cows without a lameness event. Culling of animals in both lameness groups began from a very early date in the lactation. Compare this survival plot with that of the production data where the survival plot is flat until the middle of the lactation period before animals are removed from the herd. In the lameness survival plot the two survival lines cross therefore proportional hazards cannot be assumed. The Wilcoxon test is best used in this situation for comparing the survival probabilities. The results were as follows, $\chi^2 = 1.10$, df =1 and p= 0.29. The two survival curves were not statistically different. Survival time to 270 and 305 days in lame cows was S(t) 0.833 and S(t) 0.808. For non lame cows survival was S(t) 0.85 and S(t) 0.827 respectively. While the survival curves were not significantly different lame cows appear to be removed sooner than non-lame cows.

The cumulative hazard function for removal of animals with a lameness event is illustrated in Figure 42. The hazard is small and increases only slightly during the first 100 days of lactation, it then increases exponentially to peak at 0.135 around 300 days into the lactation.

Figure 42 Cumulative hazard function plot for removal of cows with a lameness event during the lactation.

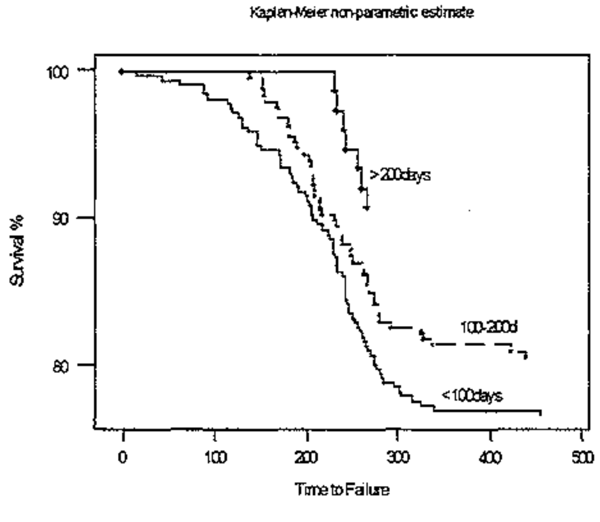


The cumulative hazard, by parity, for cows with a lameness event are summarised in Table 31. The risk of removal for cows with a lameness event increased with parity. Cows in parity 1 to 7 had a low risk of removal compared with cows in parity 8 to 10. Cows in parity 10 with a lameness event were 10 times more likely to be removed than cows in parity 1.

- *Timing of a lameness event.*

Cows were stratified into three groups based on the timing of the lameness event. Group 1 was any lameness event less than 100 days into the lactation, group 2 was a lameness event between 100 and 200 days of the lactation and group 3 was a lameness event greater than 200 days of the lactation. Three hundred and fifteen cows were used in group 1, 246 cows in group 2 and 68 cows in group 3. The survival of cows in each of the respective groups is illustrated in Figure 43.

Figure 43 Survival of cows with a lameness event stratified by timing of the event.



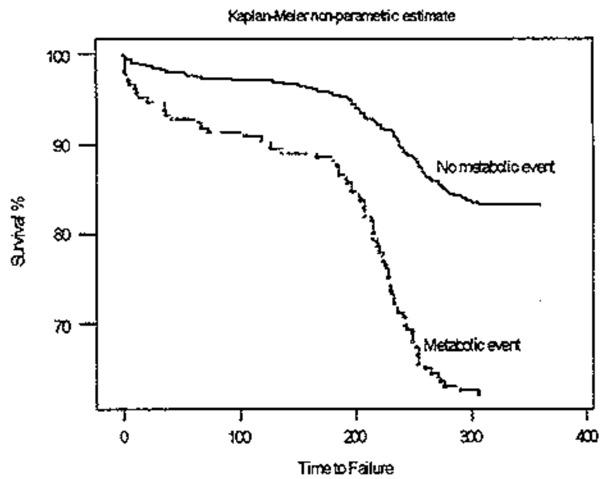
There was a significant difference in the survival times of all three groups. The log rank test is used because the survival curves do not cross. The results were as follows; χ^2 = 8.08, df =2 and p= 0.017. The survivor function to 270 days post calving was S(t) = 0.806, S(t) = 0.84, and S(t) = 0.906 for cows in group 1 to 3 respectively.

Animals with a lameness event in the first 100 days have a decreased survival time compared with animals with a lameness event from 100 days onwards. Only a small number of lameness events occurred after 200 days into lactation so this curve may be exaggerated due to small numbers present. The survival time for cows with a lameness event in late lactation is better than a lameness event in early lactation.

Metabolic Events

The cumulative incidence of metabolic events in the herds that recorded metabolic events was 0.019. This indicates that 2 cows in 100 experienced a metabolic event. The risk of removal was 2.03 times greater among cows with a metabolic event than without a metabolic event. (RR = 2.03, 95% CI 1.71 to 2.39) The survival plot for cows with a metabolic event is shown in Figure 44.

Figure 44 Time to removal for cows with or without a metabolic event.

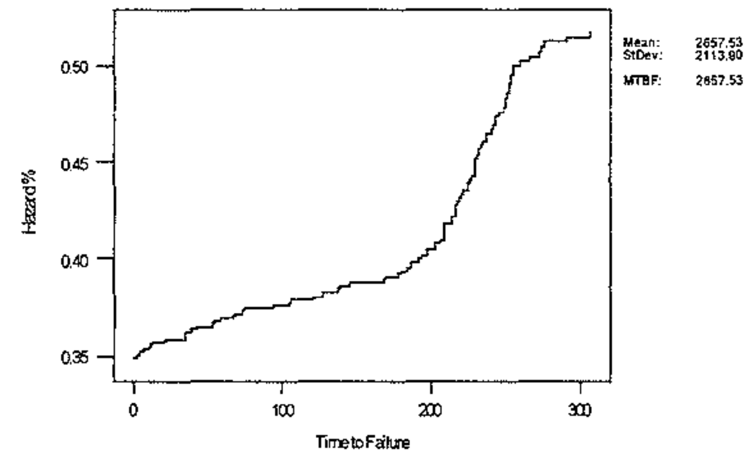


The survival curve for cows with a metabolic event declines rapidly from time zero for the first month of the lactation. It then shows a steady decline until around 200 days when the survival curve drops very steeply to around 300 days. 10% of the cows with a metabolic event are culled before 200 days in the lactation with the remainder being culled quickly before the end of the lactation, between 200 and 300 days. 30 to 40% of cows with a metabolic event during the lactation compared to 15% of cows without a metabolic event were removed. Removal times between cows with and without a metabolic event were statistically different. Log rank test $\chi^2 = 46.23$, df=1 and p=0.0000. The survival function to 270 and 305 days post calving for cows with a metabolic event was S(t)= 0.64 and S(t) = 0.622 compared to S(t) = 0.858 and S(t) = 0.833 for cows without a metabolic event.

The cumulative hazard function for removal of cows that recorded a metabolic event is presented in Figure 45. The risk of removal increases in a curvilinear fashion from calving until the end of the lactation. For the first 200 days in the lactation the risk of removal increases steadily. From 200 days the risk of removal increases rapidly until 300 days.

The cumulative hazard of removal for cows, which recorded a metabolic event stratified by parity, is shown in Table 31. The risk of removal increased with parity. No cows in parity one recorded a metabolic event therefore the risk of removal was zero. Cows in parity 7 to 10 were at greater risk of removal than cows in parity 2 to 6.

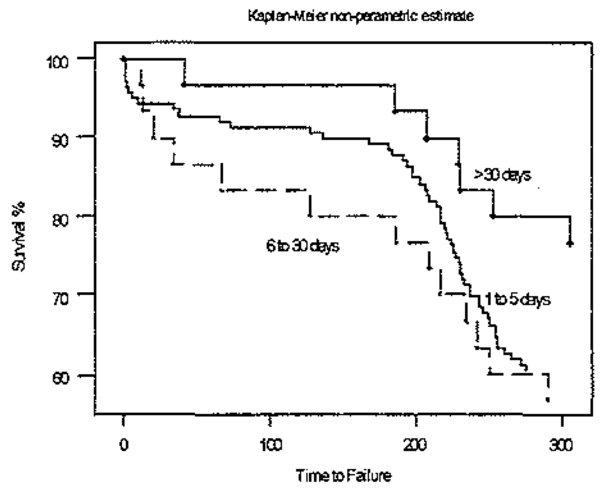
Figure 45 Cumulative hazard function for removal of cows with a metabolic event during the lactation.



- *Timing of a metabolic event.*

The influence of the timing of a metabolic event on the survival of a cow used the following time periods. One to five days' post calving, 6 to 30 days post calving and greater than 30 days post calving. One hundred and forty eight cows were used in group 1, 29 cows in group 2 and 30 cows in group 3. The survival curve illustrating the effect of the timing of a metabolic event on survival is shown in Figure 46.

Figure 46 Survival plot of cows with a metabolic event stratified by timing of the event.



Cows with a metabolic event between 6 and 30 days into the lactation were removed earlier than cows that had a metabolic event in the first 5 days of lactation. In both of these groups 40% of the animals were removed during the lactation. In the group with a metabolic event greater than 30 days into lactation their survival appeared longer than the previous two groups. Only 25% of these animals were culled during the lactation period. There was no statistical difference between the timing of the metabolic event and the removal time. χ^2= 3.22, df=2 and p= 0.20. Even though it appears that there may be some difference between the timing of disease and removal there is unlikely to be enough cows in each group to show this difference statistically.

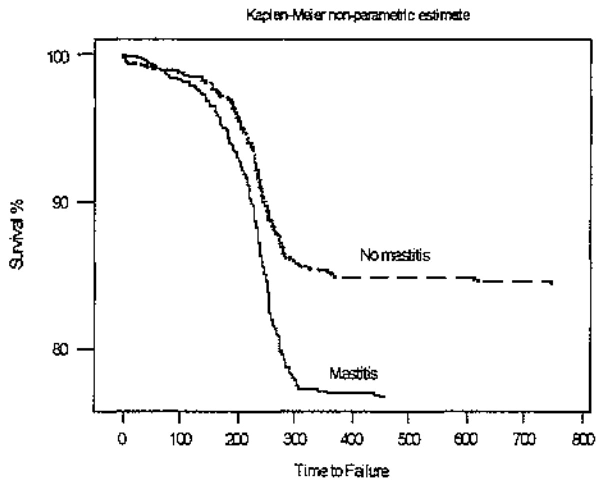
Mastitis Events.

A mastitis event was recorded for 2201 cows with a cumulative incidence of 0.109 during the lactation, in the herds that recorded mastitis events. Around 11 cows in 100 experienced a mastitis event. Culling was 1.34 times as likely to occur in those cows with a mastitis event than those without a mastitis event (RR =1.34, 95%CI 1.23 to 1.46). The effect of a mastitis event on the survival of animals during the lactation period is shown in the Figure 47

The survival curve for cows with a mastitis event shows a very small decline over the first 200 days of the lactation, which then increases, dramatically from 200 days until the end of the lactation.

There was a statistically significant difference between the survival times of cows with and without a mastitis event. The Wilcoxon test results were as follows; χ^2=20.17, df=1, p=0.0000. Cows with a mastitis event had a lower survival rate at 270 and 305 days S(t) = 0.808 and S(t)= 0.77 than cows without a mastits event S(t) = 0.877 and S(t) = 0.857. 25% of cows with a mastits event were culled during the lactation compared to 15% of the population without a mastitis event.

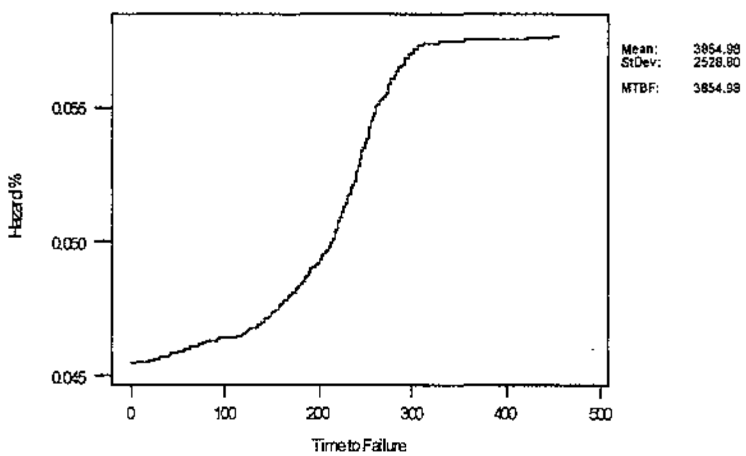
Figure 47 Time to removal for cows with or without a mastitis event.



The cumulative hazard function for removal of cows with a mastitis event is shown in Figure 48. The cumulative hazard increased slowly for the first 100 days of the lactation then increased rapidly until 300 days when the risk plateaus.

The cumulative hazard for removal, by parity, of cows with a mastitis event recorded is summarised in Table 31. The hazard for removal is low until parity 9 when the risk of removal increases. Cows in parity 10 to 12 have the greatest risk of removal compared to cows in earlier parities.

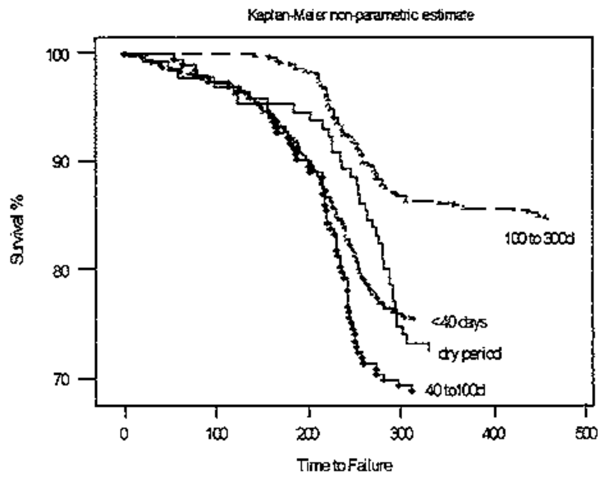
Figure 48 Cumulative hazard function for removal of cows with a mastitis event during the lactation



- *Timing of a mastitis event.*

Mastitis events were stratified into those occurring in the dry period, between 1 to 40 days, 40 to 100 days and 100 to 300 days after calving. There was 36 cows in group 1, 238 cows in group 2, 60 cows in group 3 and 69 cows in group 4. A graphical summary of the effect of the timing of a mastitis event on survival is illustrated in Figure 49.

Figure 49 Survival of cows with a mastitis event stratified by timing of the event.



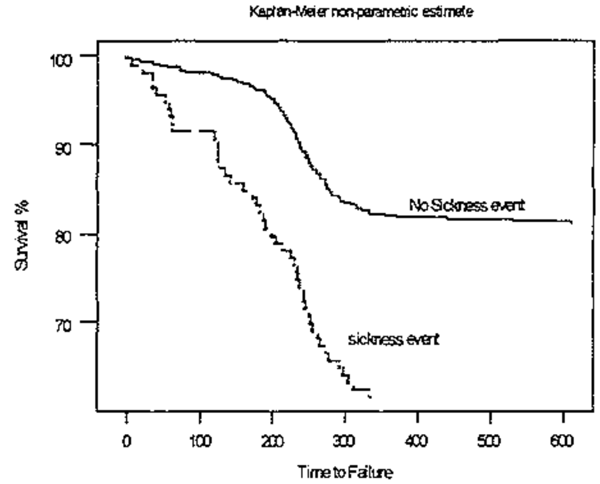
Cows with mastitis during the dry period were removed later in the lactation than cows with mastitis in the first 100 days. Cows with mastitis after the first 100 days had a longer survival time and they were not removed until the end of the lactation period. This is in contrast to the other groups that were removed at all stages throughout the lactation. There was a significant difference in the survival curves between the four groups. The Wilcoxon test was used because the survival curves crossed. Results were χ^2 = 30.82, df=3, p=0.0000.

The survival functions for these groups 270 and 305 days after calving are as follows; group 1 S(t) = 0.84 and S(t) = 0.73, group 2 S(t) = 0.77and S(t)= 0.75, group 3 S(t) = 0.71 and S(t) = 0.67 and group 4 S(t) = 0.89 and S(t) = 0.86. 30% of cows with a mastitis event in less than 100 days into lactation were removed from the herd compared to only 15% of cows with a mastitis event after 100 days.

Sickness Events.

One hundred and nineteen sickness events were recorded in the database. The cumulative incidence of sickness events was 0.012 or 1 cow in 100 in the herds that recorded sickness events. Cows with a sickness event had a relative risk of 1.98 of being removed than cows without a sickness event. (RR = 1.98, 95%CI 1.59, 2.46) The effect of a sickness event on survival is shown in Figure 50.

Figure 50 Time to removal for cows with and without a sickness event.

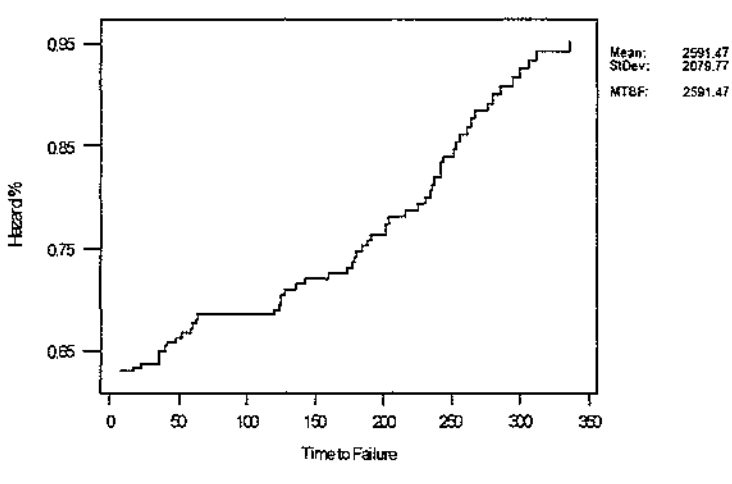


The survival curve for cows with a sickness event declines in a straight line to around 80 days post calving. There is a plateau from this point until around 150 days and then a steep decline until 300 days post calving. The risk of removal was almost constant throughout the whole lactation in cows that had a sickness event.

The survival of cows with and without a sickness event was statistically different. Log rank test χ^2= 28.07, df =1 and p=0.0000. The survival function for cows with a sickness event to 270 and 305 days was S(t) = 0.66 and S(t) = 0.63 compared with S(t) = 0.86 and S(t) = 0.833 in cows without a sickness event.

The cumulative hazard function for removal of cows with a sickness event during the lactation is shown in Figure 51.

Figure 51 Cumulative hazard function for removal of cows with a sickness event during the lactation.



The cumulative hazard for removal increases rapidly until 50 days post calving. The hazard remains flat from 50 to 125 days when in rises linearly until 300+ days. The hazard of removal, for cows with a sickness event recorded, for each parity is summarised in Table 31. There is an increase in the hazard of removal with parity. Cows in parity 8 and 9, with a sickness event are 14 and 100 times as likely to be removed than any other parity.

Reproductive Events.

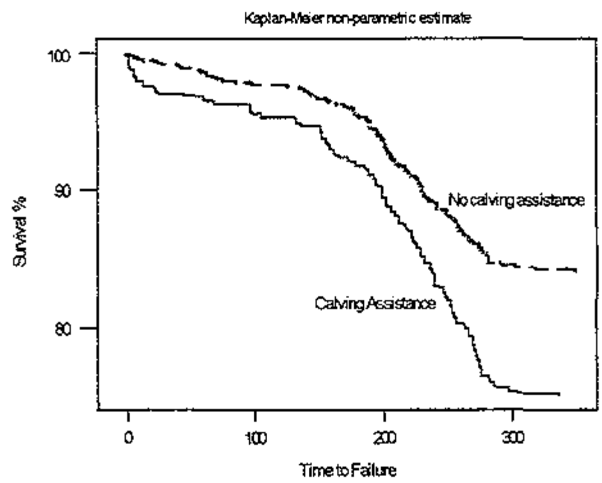
This was the only animal health event that was categorised more specifically. Reproductive disorders were recorded for 811 cows. They included calving assistance, uterine prolapse, vaginal prolapse, discharge, retained membranes, and non-cycling cows. Calving assistance and reproductive cases were analysed separately.

- *Calving Assistance.*

525 cows required calving assistance, with a cumulative incidence of 0.034 or 3.4 cows in 100. The risk of removal in cows requiring calving assistance was 1.62 times greater than in cows not requiring calving assistance. (RR = 1.62, 95%CI 1.41, 1.86) 20 to 30% of the cows requiring assistance were removed from the herd compared with 15% of cows without assistance.

The effect of calving assistance on the survival of animals during the lactation is illustrated in Figure 52.

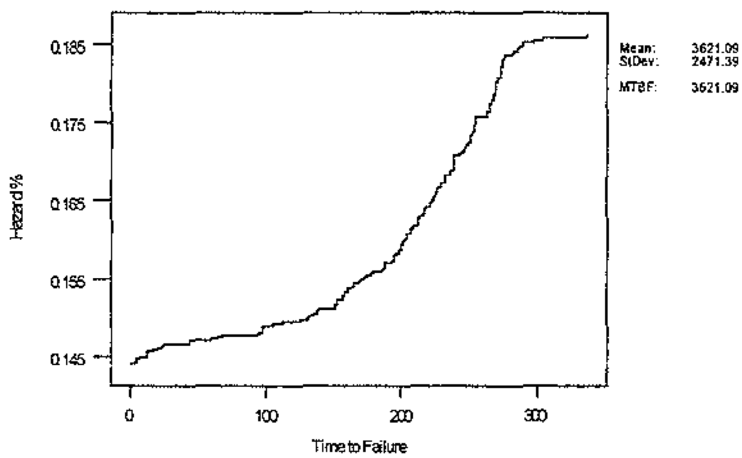
Figure 52 Time to removal for cows with and without calving assistance.



The survival curve of cows requiring calving assistance shows a quick decline in the first few days around calving which then slows to a more gradual decline until 200 days into the lactation from which removal increases rapidly until 300 days. Cows requiring calving assistance have a reduced survival time in the herd compared with cows that do not require calving assistance. There was a statistically significant difference between the two groups. The log rank test was as follows; χ^2 = 18.39, df=1, p=0.0000. The survivor function to 270 and 305 days in cows requiring assistance was S(t) = 0.78 and S(t) = 0.75 compared with S(t) = 0.86 and S(t) = 0.844 in cows not requiring assistance.

The cumulative hazard function for removal of cows requiring calving assistance is shown in Figure 53. The hazard increases suddenly at the beginning of the lactation to climb exponentially until around 200 to 300 days when the risk plateaus.

Figure 53 Cumulative hazard function for removal of cows requiring calving assistance during the lactation.



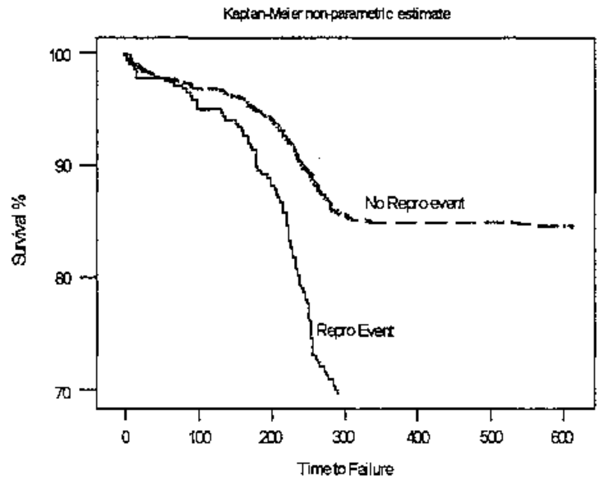
The cumulative hazard of removal for cows requiring calving assistance stratified by parity is summarised in Table 31. The hazard of removal increases with parity.

- *Reproductive events.*

Reproductive events in general occurred in 286 cows with an incidence of 0.03 in herds that recorded reproductive events. 3 cows in 100 were recorded as having a reproductive event in those herds that recorded these events. The risk of removal for reproductive events was 1.53 greater in those cows with a reproductive event. (RR = 1.53, 95%CI 1.29, 1.82) The survival pattern for cows with and without reproductive events is shown in Figure 54.

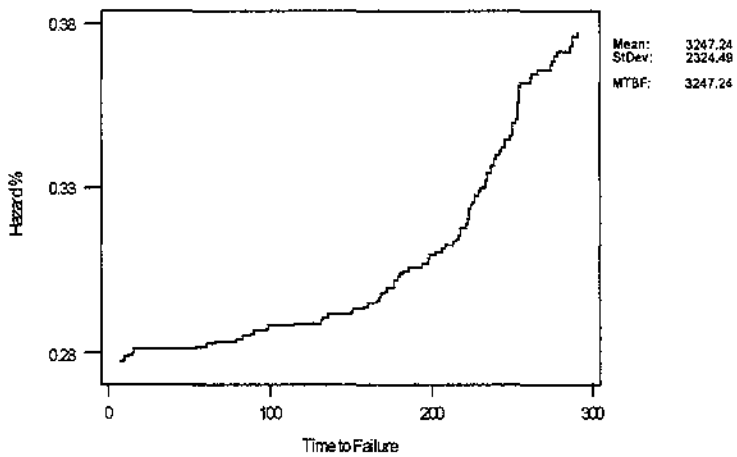
The survival curve of cows with a reproductive event recorded show a steady decline for the first 200 days of the lactation that increases rapidly until 300 days. There is a statistically significant difference between the removal times of both groups. Wilcoxon test results, due to survival curves crossing, were as follows; χ^2 = 32.54, df =1, p=0.0000. Cows with a reproductive event were removed earlier in the lactation than cows without a reproductive event and the survivor function of the respective groups to 270 days post calving was S(t) = 0.72 and S(t) = 0.87. 15% of cows were removed that required no calving assistance compared to 30+% of cows that required calving assistance.

Figure 54 Survival of cows with and without a reproductive event.



The cumulative hazard function for removal of cows with a reproductive event is summarised in Figure 55. The cumulative hazard increased from 0.27 at the beginning of the lactation to 0.38 at 300 days after calving. The hazard increased rapidly during the first 30 days then plateaus around 57 days post calving when the risk of removal increases to a peak at 300 days.

Figure 55 Cumulative hazard function for removal of cows with a reproductive event during the lactation.



The cumulative hazard for cows with a reproductive event stratified by parity is shown in Table 31. The hazard of removal increases with parity. Cows in parity 1 to 5 that recorded a reproductive event have a small risk of removal compared with those in parity 1 to 12.

i. Retained membranes

Forty-three cases of retained membranes were recorded with a cumulative incidence of 0.004 or 1 in 250 cows. Cows with retained membranes had a slightly greater risk of removal compared to cows that did not suffer from this event. The relative risk of removal was 1.06. (95%CI 0.56,1.98). As the confidence interval includes one it is likely that the risk of removal for cows with retained membranes was no different from cows without retained membranes.

ii. Vaginal prolapse.

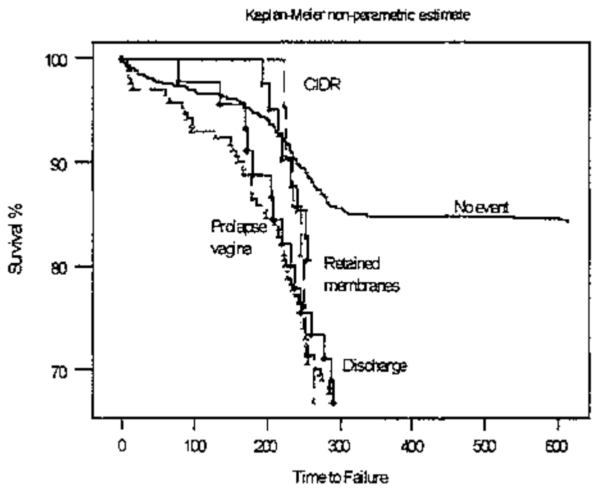
There were 170 cases of vaginal prolapse recorded with a cumulative incidence of 0.017 in herds that recorded this event. The risk of removal for cows with a vaginal prolapse was 1.84 times greater than in cows that did not have this event. (RR = 1.84, 95%CI 1.48, 2.3)

iii. Discharge.

Forty-five cows were recorded as having a discharge with a cumulative incidence of 0.0046 or 1 cow in 250 in the herds that recorded this event. The risk of removal in cows with a discharge was 1.90 times as likely than for cows that did not record a discharge event. (RR = 1.90, 95%CI 1.25,2.88).

To determine if any specific reproductive events had an influence on survival during the lactation the three groups above were plotted in Figure 56.

Figure 56 Survival of cows stratified by type of reproductive event.



Cows with a non-cycling or retained membrane event are maintained in the herd for a longer period before removal than are cows with a discharge or vaginal prolapse. Vaginal prolapse cases are removed earlier in the lactation than the discharge cases. There was no statistical difference in the survival curves between the four reproductive disorders. Wilcoxon test results were χ^2= 3.27, df=3 and p=0.35. Small numbers in all of these groups may exaggerate the effects shown above.

Management

Table 32 summarises the survival analysis results of the management factors that may affect the survival of cattle in DairyMAN farms. A full description of the findings of each of the management factors is given in the following sections.

Table 32 Summary of univariate survival analysis results for management factors

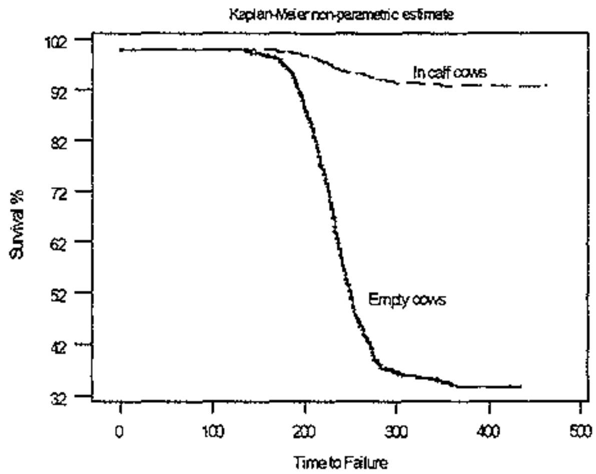
Variable	Survival probability		χ^2	Df	p-value
	270 days	305 days			
Empty Cows					
Yes	0.43	0.36			
No	0.74	0.93	732.61	1	0.0000
Calving Date					
Early	0.95	0.94			
Late	0.89	0.87	48.27	1	0.000
BI					
>average	0.94	0.92			
<average	0.82	0.79	69.91	1	0.000

- *Calving*

    i. *Empty cows*

The cumulative incidence of removal was 0.089 or 9 cows in 100 removed due to non-pregnancy. A survival plot comparing the removal times of in calf and empty cows is shown in Figure 57.

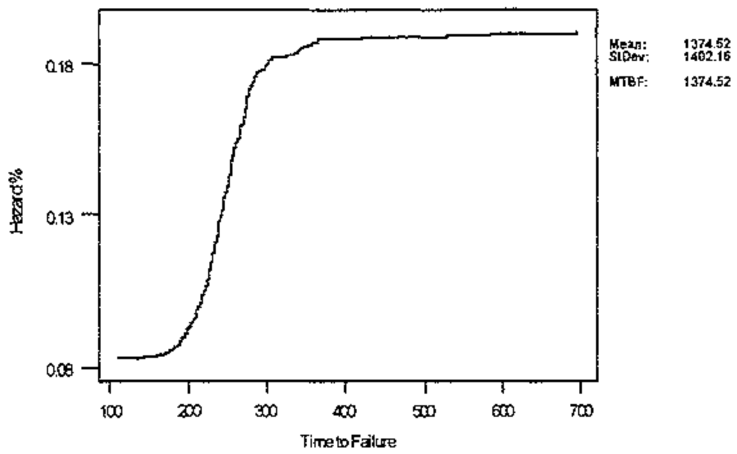
Figure 57: Survival plot of non-pregnant versus pregnant cows.



The survival curve for empty cows is flat until 200 days into the lactation when the curve declines steeply to plateau around 350 days in the lactation. Empty cows are removed at the end of the lactation and have a much higher removal rate than pregnant cows. The risk of removal in empty cows is 6.96 times greater than pregnant cows. (RR = 6.96, 95%CI 6.44, 7.51) There is a highly significant difference between the removal pattern of empty cows compared to pregnant cows. χ^2= 732.61, df=1, p=0.0000. The survivor function for empty cows from 270 to 305 days is S(t) = 0.43 and S(t) = 0.36 compared with S(t) = 0.94 and S(t) = 0.93 for pregnant cows.

The cumulative hazard function for removal of cows recorded as empty is shown in Figure 58. The cumulative hazard is flat for the first 100 days of the lactation then increases slowly to 200 days. From 200 days in lactation the cumulative hazard for empty cows increases dramatically until 300 days post calving where it remains high until nearly 700 days post calving.

Figure 58 Cumulative hazard function for removal of non-pregnant cows.

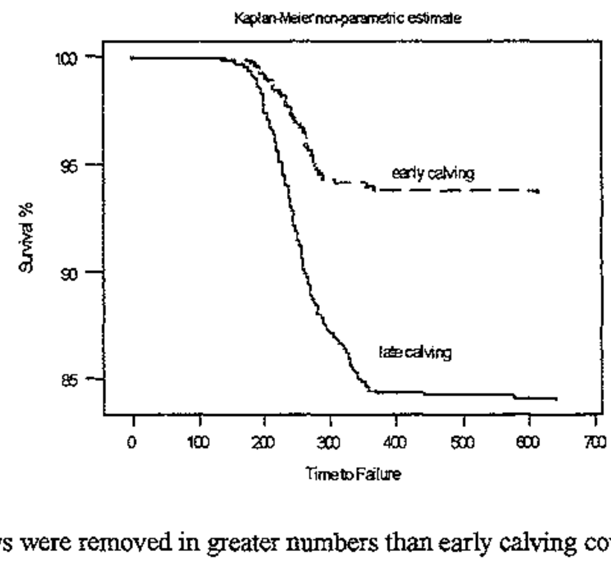


The hazard of removal for empty cows in each parity is summarised in Table 31. Cows in parity 7 to 10 are more likely to be removed than cows in parity 1 to 6.

ii. Calving date.

12.6 cows out of 100 with late calving dates were removed from the herds that had future calving dates recorded. The influence of calving date on survival time is illustrated in Figure 59.

Figure 59 Survival plot of cows with early and late calving dates.



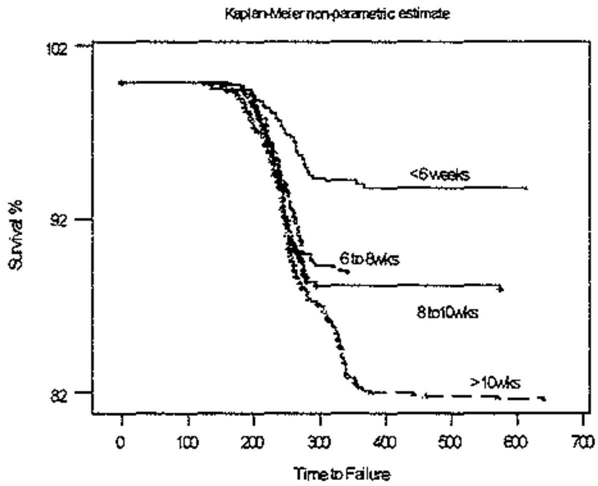
Late calving cows were removed in greater numbers than early calving cows. Cows with both early and late calving dates had a very low risk of removal in the first 200 days of lactation. From 200 days the survival curves declines rapidly until around 350 days when the survival plateaus. The survival of late and early calving cows was statistically different in the survival of cows that were late and early calvers. Log rank test results χ^2 = 48.27, df = 1, p= 0.0000. Late calving cows were 2.85 times more likely to be removed than cows with an early calving date. (OR = 2.85, 95%CI 2.10,3.87) The survivor function for late calvers to 270 and 305 days was S(t) =0.892 and S(t) = 0.87 compared to S(t) = 0.95 and S(t) = 0.94 for early calvers.

Cows that are late calving have a much lower survival rate than those cows that are early calving. Around 7% of early calvers are removed from the herd compared to 15% of late calvers.

iii. Timing of future calving date.

To quantify the effects of an anticipated future calving date on a cows survival time the future calving date was further stratified into <6weeks, 6 to 8 weeks, 8 to 10 weeks and >10 weeks from the planned start of calving. There were 1000, 786, 457 and 1000 cows in each of the four groups respectively. The survival times for the four groups are shown in Figure 60.

Figure 60 Survival of cows stratified by future calving date.



Cows with a calving date less than 6 weeks after the planned start of calving had the highest survival rate. Cows with a calving date between 6 and 10 weeks after the planned start of calving had similar survival curves and survival rates. Cows with a calving date greater than 10 weeks after the planned start of calving had the lowest survival rates. Regardless of anticipated calving date removal from the herd does not occur until the second half of the lactation with the majority of cows being removed between 200 and 300 days of lactation.

There was a statistical difference in the survival pattern of cows stratified by calving date after planned start of calving. Wilcoxon test results χ^2 = 22.42, df=3, p=0.0000.

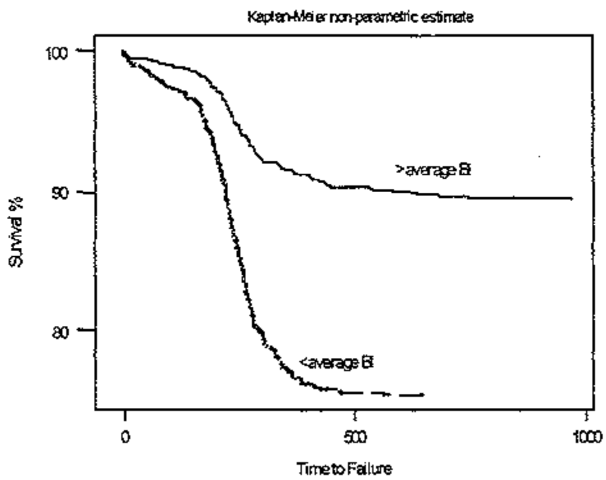
The survival functions are very similar at 270 and 305 days after calving S(t) = 0.89, 0.90, 0.89, 0.88 and S(t) = 0.88, 0.89, 0.88 and 0.86 for each group respectively. The significance of this result may influenced by the large difference in survival curves between the early and late calvers.

Breeding Indices

The survival of 994 cows with an above average BI was compared with 996 cows with a below average BI. The risk of removal in cows with a below average BI is 2.78 times greater than for cows with an above average BI. (OR = 2.78, 95%CI 2.16,3.55) The comparison of the effect of BI on the survival of cattle is illustrated in Figure 61.

There is a slow decline in the survival of cows with a lower than average BI in the first 200 days of the lactation. From 200 days to 500 days post-calving the survival rates decline much more rapidly. There was a statistical difference in the survival curves between the two groups. $\chi^2 = 69.91$, df =1, p= 0.0000. The survivor function for each of these groups to 270 and 305 days post calving is S(t) = 0.94 and S(t) = 0.92 for cows with greater than average BI and S(t) = 0.82 and S(t) = 0.792 for cows with less than average BI.

Figure 61 Survival plot for cows with above and below average Breeding Indices (BI)



25% of cows with a below average BI were removed from the herd compared with 10% of cows with a high BI.

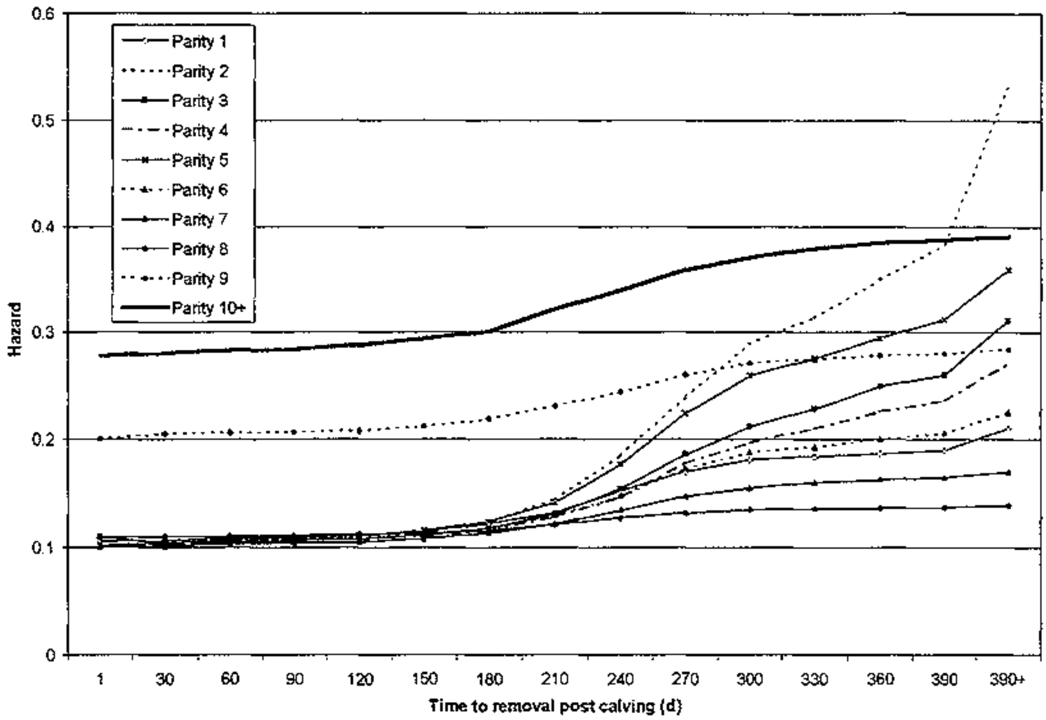
Parity.

The cumulative hazard, every 30 days, for cows stratified by parity is described in Table 33. A graphical presentation of the cumulative hazard function for each parity is shown in Figure 62. The cumulative hazard of removal is similar for each of parities 1 to 8 during the first 210 days of the lactation. At this point in the lactation period the cumulative hazard changes for each parity. By the end of the lactation the cumulative hazard indicates that the risk of removal increases for each parity in the following order. Parity 8 < 7 < 1 < 6 < 4 < 9< 3< 10 < 2. Cows in parity eight, seven and one have the lowest risk of removal compared with cows in parity three, ten and two. In contrast cows in parities nine and ten have a higher cumulative hazard in the early lactation which then climbs slowly to a peak after 210 days in lactation. There is a significant difference in the cumulative hazard curves between the ten parities. Log Rank test χ^2= 1092.61, Df=9, p =0.0000

Table 33 Cumulative hazard for removal of cows during the lactation stratified by parity.

Time	Parity									
(d)	1	2	3	4	5	6	7	8	9	10
1	0.105	0.101	0.109	0.101	0.101	0.101	0.100	0.108	0.200	0.278
30	0.106	0.104	0.103	0.102	0.103	0.103	0.101	0.109	0.204	0.280
60	0.108	0.107	0.105	0.105	0.106	0.105	0.102	0.11	0.206	0.283
90	0.109	0.109	0.106	0.106	0.108	0.107	0.103	0.110	0.206	0.284
120	0.111	0.111	0.107	0.107	0.11	0.109	0.104	0.111	0.208	0.288
150	0.114	0.114	0.111	0.110	0.115	0.111	0.107	0.112	0.211	0.294
180	0.121	0.123	0.117	0.115	0.123	0.116	0.112	0.114	0.219	0.301
210	0.131	0.144	0.130	0.127	0.141	0.129	0.120	0.119	0.231	0.322
240	0.152	0.185	0.154	0.146	0.177	0.147	0.133	0.126	0.244	0.34
270	0.170	0.239	0.186	0.178	0.224	0.173	0.146	0.131	0.260	0.359
300	0.181	0.289	0.211	0.197	0.259	0.188	0.154	0.134	0.271	0.371
330	0.184	0.314	0.228	0.210	0.275	0.193	0.159	0.135	0.274	0.379
360	0.187	0.350	0.249	0.226	0.294	0.200	0.162	0.136	0.278	0.385
390	0.19	0.383	0.260	0.236	0.312	0.206	0.164	0.136	0.280	0.387
390+	0.21	0.532	0.311	0.271	0.359	0.225	0.169	0.137	0.284	0.390

Figure 62 Cumulative hazard function for removal of cows during the lactation by parity



Multivariable Survival Analysis.

Introduction

Modelling of survival data using multiple explanatory variables is possible and in some cases more desirable than simple univariate analysis. More complex relationships and interactions between variables may be investigated when modelling the data. It is unlikely in reality that single factors are responsible for the outcome of an event. Therefore the inclusion of likely factors that influence an event may help better understanding of the problem at hand.

The main method used for the multivariable modelling of survival data is a semi-parametric model called the proportional hazards model or the Cox proportional hazards model [7, 9]. This model is semi-parametric because no specific form of probability distribution is assumed for the survival times. This is ideally suited to survival data because it can rarely be defined into a specific distribution easily. The model is defined thus:

Equation 4 Cox proportional hazards model.

$$h_N(t) = \psi h_S(t)$$

Assume the value $h_N(t)$ and $h_S(t)$ are the hazards of an event at time t for group N and group S respectively. The value of ψ is the ratio of the hazards of events at any time for an individual in group one relative to an individual in group two, and so is known as the relative hazard or hazard ratio. If $\psi<1$, the hazard for an event at t is smaller for an individual in group N relative to group S. If $\psi>1$ then the converse is true. The hazard of an event at time t is greater for an individual in group N relative to group S. [7]

The major advantage for the use of this model is also its major limitation. Because a specific distribution is not defined the Cox model can only provide comparisons between subjects and cannot provide absolute probabilities on the occurrence of an event. As the model is not restricted to a specific functional form, the model has flexibility and widespread applicability. Depending on the situation this may or may not be an important limiting factor. [13] If the assumption of a particular probability distribution for the data is valid inferences based on this assumption will be more precise. The estimates of relative hazards and median survival times will have smaller standard errors than in the absence of a distribution assumption. An exponential probability distribution is appropriate if the hazard is constant over time, or if the hazard increases or decreases monotonically over time then a Weibull distribution model is appropriate.

The aim of the multivariable survival analysis was to use the risk factors identified, using univariate survival analysis, to describe the inter-relationship of these factors on the survival experience of cattle in DairyMAN herds. A model with a minimum number of risk factors that satisfactorily explained the variation in the dependent variable was desirable.

Materials.

Screening using the univariate survival analysis allowed identification of risk factors that potentially affect the survival of dairy cattle in dairy herds. The Access 97 [16] database was screened for cows that had complete data for all management criterion including, calving to conception information (CCI), production (FAT, LITRES), breeding and lactation indices (BI, LI), somatic cell count (SCC) and parity. As long as all management data was present then cows could be considered for modelling. Animal health information was considered as optional for the screening process however it was preferred that at least half of all cows had some form of animal health disorder present. One thousand three hundred and eleven cows fitted the selection criteria and were used to develop the Cox proportional hazards model.

Methods

A Cox Proportional Hazard model was developed using NCSS97. [14]. The outcome of interest was length of lactation, defined as the interval in days since the last calving and the time to removal from the herd for sale, culling or death, prior to the next lactation.

Variable description.

The univariate survival analysis summarised in the section above was used to assess the association between a prognostic variable and the length of lactation. The variables that showed an association with length of lactation ($p<0.1$) were considered for inclusion into the multivariable model. For all variables considered for inclusion into the model the assumption of proportional hazards was verified visually, using the crossing of the survival curves as an indication of non-proportional hazards. [7]

Binary explanatory variables included in the model were mastitis events (MASTITIS), sickness events (SICK), reproductive events (REPRO), calving assistance events (ASISST), metabolic events (MET), lameness events (LAME) and pregnancy status (EMPTY). An event was coded 1 if it occurred and zero if it did not. (EMPTY was coded 0 for pregnant, 1 for empty.) In case specific animal health events were not significant due to small numbers, or more than one animal health event occurred for an animal, a combination variable ANH was created that indicated if an animal event had occurred. It was coded zero for no events, 1 for one event, 2 for two events and 3 for three events.

Current lactation total milk (LITRE) and fat [11] yield, cow breeding index (BI), cow lactation index (LI), somatic cell count at the last herd test (SCC), and calving to conception interval (CCI) were considered as continuous explanatory variables. CCI is the calving to conception interval taken from the most recent calving date to the last mating. It is an estimated conception date based on data collected by the LIC. This figure was used an indicator of the importance of the future calving date.

When a variable with a large range of values is to be modelled the assumption of linearity in this variable was considered. Transformations of variables with wide ranges or skewed data may be appropriate or the inclusion of an indicator variable may be more appropriate. To determine if a variable should be transformed then a polynomial term can be included in the model and the effect on the value of –2logL determined. If the change in –2logL is significant then the transformed term should be included in the model. The same process applies to indicator variables. Comparison of the model –2logL statistic with the original variable and an indicator variable with the appropriate degrees of freedom will determine the necessity of the indicator variable.

NCSS97 did not require the use of indicator variables for the modelling of survival data therefore modelling variables with several levels could be simple, as indicator variables did not have to be defined. However the effect of non-linearity for each of the variables was examined as they entered the model. If non-linearity was considered to be a problem then a dummy variable was used for this variable or a transformation was considered. Parity, BI, LITRE, FAT, ANH, LI, SCC and CCI were checked for non-linearity as they entered the model. Parity had a non-linear effect in the model and was modelled as a dummy variable. SCC also had non-linear effects in the model and so the reciprocal SCC was entered into the model. BI, LITRE, FAT, ANH, LI and CCI showed a linear effect on entering the model so required no transformation.

Variable Selection.

The first stage of the modelling process is to determine the significance of each of the main effects compared with the null model. The size of the effect of the explanatory variable compared with the null model is used to determine the order each variable will enter the model. Those with largest effect enter the model first. The value –2logL is a summary measure, which measures the extent to which the model fits the data. It is not used on its own as a measure of model adequacy but is useful for comparing between models[7]. Subtraction of the –2logL value of the regression model including the parameter of interest from the –2logL of the null model results in a value approximating the χ^2 distribution. Those variables significantly different, at 1 df, from the null model indicated by an asterisk in Table 5 were considered for inclusion into the model. The only variable that indicated non-proportional hazards was the SICK variable. As it was not significantly different from the null model it was decided not to include this variable in the modelling process. ANH, CCI and EMPTY were not statistically significant variables when in the model as the only explanatory variables but were considered at the latter stage of the model building process.

Model Building.

Model building was conducted using the Proportional Hazards Template in NCSS97.[14] Options for modelling include user defined models, forward and backward stepwise models. The advantage of using the forward and backward stepwise models is that variable selection is automatic. The disadvantage of these methods is that you have little control over the model itself. I chose to develop the model manually, by selecting the most significant variables to enter the model one at a time. The first variable to enter the model was the one with the largest difference from the null model. This was followed by the next significant variable. As variables were added to the model other variables became insignificant. If the model with the new variable was not significantly different from the previous model the variable was not included. The p-value for entry was 0.05 and 0.1 for removal. Interaction variables were considered for variables that were included as main effects in the model. If the addition of an interaction term in the model resulted in a significant benefit (change in $-2\log L$) to the model fit it was added to the model. At later stages in the model all variables that were not added earlier were tested again to ensure that they did not improve the model. Modelling continued in forward and backward stepwise fashion until all variables and combinations were tried and a satisfactory model was built.

The regression coefficient β can be converted into a hazard ratio by exponentiation. ($HR=\exp(\beta)$) The hazard ratio gives the change in hazard (conditional failure rate) associated with an increase of one unit in the risk factor. Using the hazard ratio it is possible to assess the risk of removal from the herd associated with each variable included in the model.

Results.

A summary of the effect of each of the variables in comparison with the null model is shown in Table 34. The variables considered for inclusion in the model, in descending order, were as follows: LI, BI, FAT, PARITY, SCC, MASTITIS, EMPTY, CCI and ANH.

Table 34 Variables considered for inclusion in the model.

Variables in the model	-2logL	Difference from null model
None	8580.164	
ANH*	8576.992	3.172
PARITY*	8543.888	36.284
BI*	8405.38	174.78
FAT*	8408.09	172.074
LITRE*	8503.644	76.52
LI*	8396.202	183.962
SCC*	8510.626	69.538
EMPTY*	8573.176	6.988
LAME	8578.96	1.204
MET	8579.994	0.17
ASSIST	8580.114	0.05
REPRO	8578.14	2.02
SICK	8578.434	1.73
CCI*	8575.53	4.634
MASTITIS*	8567.14	13.024

A summary of the variables included at each step of the model building process is shown in Table 35.

Table 35 Summary table of the variables included in the model at each step.

Variables in the model	-2logL
Null model	8547.546
LI	8396.202
LI+BI	8324.056
LI+BI+FAT	8276.382
LI+BI+FAT+LIXFAT	8248.194
LI+BI+FAT+BIXFAT	8267.892
LI+BI+FAT+LITRES	8271.624
LI+BI+FAT+LITRES+FATXLITRE	8255.86
LI+BI+FAT+LIXFAT+SCC	8198.492
LI+BI+FAT+LIXFAT+SCC+PARITY	8164.704
LI+BI+FAT+LIXFAT+SCC+PARITY+MASTITIS	8160.21
LI+BI+FAT+LIXFAT+SCC+PARITY+MASTITIS + EMPTY	8152.04
LI+BI+FAT+LIXFAT+SCC+PARITY+MASTITIS + EMPTY +CCI	8152.122
LI+BI+FAT+LIXFAT+SCC+PARITY+MASTITIS + EMPTY +CCI+REPRO	8149.518
LI+BI+FAT+LIXFAT+SCC+PARITY+MASTITIS + EMPTY +CCI+REPRO+ANH	8131.38

The final model contained the following variables: ANH, PARITY, CCI, BI, FAT, SCC, EMPTY, REPRO and MASTITIS. The regression coefficients of the variables included in the final model are summarised in Table 36.

Table 36 Regression coefficients for variables included in the final model.

Variable	β	s.e.(β)	P value
PAR10	1.417525	0.298035	0.0000
PAR9	1.26441	0.270834	0.0000
PAR8	0.509218	0.259426	0.04966
PAR7	0.785001	0.176611	0.0000
PAR6	0.594548	0.179267	0.0009
PAR5	0.614102	0.162274	0.0001
PAR4	0.344267	0.16489	0.0368
PAR3	0.248263	0.155413	0.11016
PAR2	0.294242	0.137993	0.03298
ANH	-0.52539	0.181521	0.0003
CCI	0.004011	0.001121	0.0003
BI	-0.03661	0.00627	0.0000
FAT	-0.01437	0.001065	0.0000
EMPTY	-0.82249	0.271051	0.0027
REPRO	1.027195	0.363042	0.00466
MASTITIS	0.931834	0.225101	0.0000
SCC(RECIP)	3.661422	0.813918	0.0000
Model -2Log Likelihood	8101.026		
χ^2	403.50	17df	0.0000
Pseudo R^2	0.256		

The summary hazard ratios and 95% confidence intervals for each variable in the model are listed in Table 37.

Table 37 Summary hazard ratios and confidence intervals for each variable in the model.

Variable	Hazard Ratio	95% Confidence Interval
PAR10	4.13	2.30 to7.40
PAR9	3.54	2.08 to 6.02
PAR8	1.66	1.00 to2.77
PAR7	2.19	1.55 to 3.10
PAR6	1.81	1.28 to 2.58
PAR5	1.85	1.34 to 2.54
PAR4	1.41	1.02 to 1.95
PAR3	1.28	0.95 to 1.74
PAR2	1.34	1.02 to 1.76
ANH	0.59	0.41 to 0.84
CCI	1.004	1.002 to 1.006
BI	0.96	0.95 to 0.98
FAT	0.99	0.98 to 0.99
EMPTY	0.44	0.26 to 0.75
REPRO	2.79	1.37 to 5.69
MASTITIS	2.54	1.63 to 3.95
SCC(RECIP)	38.92	7.89 to 191.85

The hazard ratio indicates the size of the risk associated with removal due to that variable. Cows with a high SCC, aged 9 or 10, with a reproductive or mastitis event were at increased risk of removal than cows without these characteristics. As the SCC increases by 1 ('000's) (-1/sqrt(SCC)) the risk of removal increases 38 times. Similarly for cows with a reproductive or mastitis event the risk of removal is 2.79 and 2.54 times more likely than in cows without these events. Empty cows are 2.27 times as likely to be removed than pregnant cows. As the number of health events increases by one the risk of removal increases by 1.69.

When the calving to conception interval (CCI) increases by one day there is a 0.04% increase in the hazard rate, so for every 10 day period there is an increased risk of removal of 0.4%.

As parity increases the hazard of removal increases linearly compared to the baseline cow in parity one. Cows in parity 8 appear to be different from the trend with a slightly lower risk. As one is included in the confidence interval the risk of removal in this group may similar to that of the baseline cow.

In comparison the risk of removal decreases with each unit increase in FAT and BI. As FAT production increases the removal rate decreases by 1.1% so for every 10kg of extra fat produced the risk of removal is reduced 11%. Breeding Index also influences the removal rate and the higher the BI the lower the risk of removal. For every one-unit increase in BI there is a 1.4% decrease in the hazard rate.

This model explains only 25% of the variation in the removal rates of the 1311 cows in the model. As the specific reasons for removal of any of the animals in the model are not known the results of this model appears satisfactory in explaining some of the risk factors involved in making culling decisions.

Discussion.

Selecting cows for removal is a subjective process that involves a multivariable decision making approach. Animal health events, production and breeding values as well as management features are used in combination to determine the fate of an individual animal. Farmer personality, cow temperament and behaviour has some effect on the decision making process[3]. A great deal of work has been done on investigating the individual risk factors for removal [10 6 4 2 21], but very little work has concentrated on the combination of risk factors involved in the decision process and their relative worth [19 21 1 18]. Until this subjective decision making process itself is properly understood and the factors and processes involved in making the decision are included in research objectives research investigating only risk factors for removal the same research is likely to be perpetuated and never resolved.

Management decisions about the stock to keep on the farm are influenced by production goals and matching stock production with grass production. New Zealand dairying is a predominantly seasonally based production system reliant on the conversion of home-grown pasture into milk. Therefore to match milk supply and feed growth, cows must calve annually. This means that cows have a limited time to get in calf each year to maintain this management goal. Cows that do not make these criteria may either be culled if they do not get in calf, removed if they get in calf late or have calving induced so that they calve in time.

This work has investigated putative risk factors for removal identified and reported by other researchers as well as using an understanding of farming goals in New Zealand. Most studies concentrate on specific removal reasons and the associated risk factors for these, rather than the risk factors for removal in general. With the restrictions of the data available there been no way to assess the risk factors associated with removal for specific reasons due to the absence of given reasons. Putative risk factors for removal such as animal health events, calving to conception intervals, breeding indices and production were identified using univariate survival analysis as having significant effects on the timing of removal in cattle.

Cows producing over 200kg fat per season had the highest probability of survival to 270 days followed by cows with an early calving date, a greater than average breeding index and cows doing better than herd average production.

Cows diagnosed as empty had the lowest survival rate to 270 days followed by cows with a sickness event, reproductive event, calving event, mastitis event, low BI, lameness event or late calving date. Cows with a non-cycling or retained membrane event are maintained in the herd for a longer period before removal than were cows with a discharge or vaginal prolapse. Vaginal prolapse cases are removed earlier in the lactation than the discharge cases, which would indicate that for the discharge, retained membrane and non-cycling animals there is more incentive to keep them in the herd before removal. The hazard of removal for cows with an animal health event recorded increases with parity. Cows with a mastitis event and empty in the first parity are less likely to be removed than parity one animals with any other animal health event. Cows in parity 8 to 10+ with any animal health event have a greater hazard of removal than cows in parity 1 to 7.

There appears to be a considerable delay in the time that some cows are removed from the herd after their last calving. Some animals were not removed until nearly 600 days after their last calving. There are four likely possibilities for this. One is that the removal date was incorrectly recorded, secondly the next calving date was not accurately recorded. The third possibility is that an incorrect pregnancy diagnosis was made and the cow was kept until her due calving date before being removed. Finally a cow may be kept as a holdover to be mated in the following season. If she did not get in calf at this mating then she may be removed at this time. Keeping animals on to the next year is a common management practice on many farms that has been little investigated and it is worthy of investigation into the merits and costs of such an arrangement.

The cumulative hazard for removal of cows with an animal health event recorded increases with parity. Cows with a mastitis event and empty in the first parity are less likely to be removed than parity one animals with another animal health event. Cows in parity 8 to 10+ with any animal health event have a greater hazard of removal than cows in parity 1 to 7.

In conclusion, the risk of removal is strongly influenced by parity and the type of animal health event recorded. As parity increases the risk of removal increases in animals that have recorded an animal health event. In contrast to the findings in Chapter 3 that the risk of removal is greater in parity 1 and parity 5 to 10 animals than in parities 2 to 4, using hazard analysis the hazard for removal was found to be different. Cows in parities one to ten had a deceasing risk of removal as follows: Parity 2 > 10 > 3 > 9 > 4 > 6 > 1 > 7 > 8. Parity 2 animals had the greatest probability of removal compared with all other parities. Interestingly parities 1, 7 and 8 had the lowest hazard of removal. This would indicate that cows in parity 1 have a good chance of survival, but if they don't make the grade by the end of the 2nd lactation then they are likely to be removed. Older cows in parities 9 and 10 are not kept if any other adverse event occurs to them during the lactation. Cows in parities 6, 7 and 8 are presumably good cows to have initially got to this stage and a perhaps less likely to suffer problems that would have removed them at an earlier parity and so are kept in preference to all other cows. These different results highlight the effects of different methods of analysis on the outcome to the same question. Even though exactly the same data has been used to generate this information the results that are given are very different. Survival analysis appears to be the preferred method by which to analyse censored data such as this and given the results above can highlight deficiencies in other forms of analysis.

The risk factors identified using survival analysis were combined into a multivariable model to determine the contribution of these variables to the overall timing of removal. The variables found to most significantly affect the timing of removal were the calving to conception interval CCI, pregnancy status, fat production, breeding indices, parity and animal health disorders specifically reproductive and mastitic disorders. The survival experience of a cow with a mastitis reproductive or multiple animal health events is different to an animal without these events. If the level of fat production and breeding index (BI) are low combined with increased calving to conception interval the risk of removal increases. Removal risk was found to increase linearly with parity. This finding is in agreement with many other studies, which found removal risk increased with parity. [4 18 15 5 12 1] .It is in contrast to the Irish [8] findings, who found decreased risk of removal in lactation 3 and 4 and increased risk after this time. Pregnancy status and somatic cell counts also influence the timing of removal.

The variables included in the model explained only 25% of the variation in the time to failure. This may indicate that the model is not very good or that there are other factors that influence the timing of removal that were not included in the model. As mentioned previously culling is a subjective process determined by psychological, sociological production and management goals. The decision to cull animals may be influenced by season and time of the year and other factors that have not been measured. Future research aimed at understanding the relative importance of each of the management, production and animal health disorders on culling would be recommended.

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Chapter 5
Model Development.

Introduction.

The economics of farming decisions have become one of the most important issues in modern dairy farming. With increasing costs and decreasing margins the biggest factor for maintaining sustainability of a farming enterprise is the profit generated. This is no different from the situation 50 years ago. With rising costs of production and a static price per kg of milk that has changed minimally with inflation it becomes more difficult to generate profit without taking into account the economics of various management options. Due to the seasonal and pastoral nature of dairy farming in New Zealand it is essential to maximise profit per hectare and per cow. One aspect of maximising the profit per cow is to ensure that the good producing cows remain in the herd as long as possible and poor producers are removed as soon as possible. This is the basic premise of replacement theory.

The aims of this chapter are as follows:

1. To describe the development of a spreadsheet model based on Marginal Net Revenue for the New Zealand Dairy industry
2. To summarise the findings of this model.
3. To describe the results of the sensitivity analysis of the model.

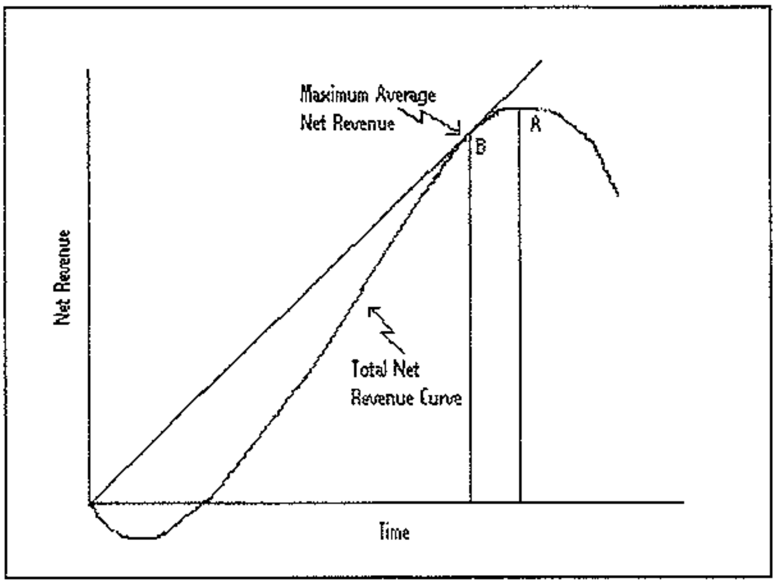
Marginal net revenue approach to replacement theory.

In the early 1960's Faris [5], Burt [1] and Perrin [14] developed the replacement theory concept. It is based on the marginal net revenue curve and the optimum time for replacement of an asset. Originally, it was used to evaluate the replacement of mechanical components, but was later adapted for use in dairy and pig production. [15 11 3 4 2]

The objective of the marginal net revenue approach to replacement decisions is to maximise revenues over time. The aim is to maximise the revenues from the current asset before its replacement. The optimum time for the replacement of the current and subsequent assets is maximised with regard to revenue flows.

The costs and revenues over time are first calculated. The total net revenue (TNR) is calculated by subtracting the total costs from total revenues. The total net revenue is then plotted against time to generate the Total Net Revenue Curve illustrated in Figure 63.

Figure 63. Total and maximum average net revenue curve.



The Maximum Average Net Revenue (MaxANR) is the point on the curve (B) where a line from the origin touching tangentially with the curve has maximum slope. It is also the point where the Marginal Net Revenue (MNR) is equal to the Average Net Revenue [16]. Point A is the point of Maximum Net Revenue (MaxNR). This is the point on the curve where further increases in time result in no additional increase in Net Revenue (NR).

From the Net Revenue the Marginal Costs (MC) and Revenues (MR) can be calculated. The marginal costs are the change in total costs per unit of time (usually expressed as the change in one unit per unit time) and the marginal revenues are the change in total revenues per unit time. The marginal net revenue is therefore the marginal revenue minus the marginal costs. The average net revenue is the net revenue divided by the total change in time. These calculations are summarised in Table 38:

Table 38 Summary of the cost and returns calculations. [5]

Time	Total Cost	Total Revenue	Net Revenue	Marginal Cost	Marginal Revenue	Marginal Net Revenue	Average Net Revenue
n	TC	TR	NR=TR-TC	MC=dTC/dn	MR=dTR/dn	MNR=MR-MC	ANR=NR/n

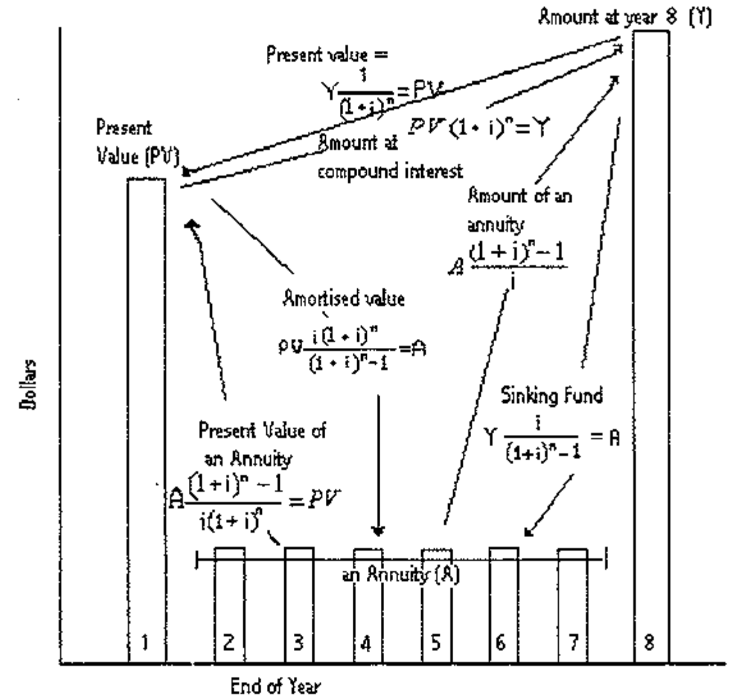
There are three types of replacement considered using replacement theory. Type 1: A short production period with revenue being realised by the sale of the asset. Type 2: A long production period with revenue being realised by the sale of the asset. Type 3: A long production period with revenues being realised throughout the life of the asset. [5]

A bull-beef dry-lot finisher operation may illustrate the first type of asset replacement. The aim in this operation is to maximise the average net revenue over time. The question is when should the stock be sold and replaced. The overall aim here is to keep the present lot until the MNR from it equals the ANR anticipated from the subsequent lot. The optimum time of replacement is equal to point B as illustrated in Figure 63.

The second type of asset replacement may be illustrated by the bull-beef finisher operation from rearing to sale. Here there is uncertainty regarding pricing and values due to the length of the production cycle. This requires the use of discounting of returns and compounding of costs to ensure that any future returns are compared with today's values. The relationships between the streams of net revenue and costs are illustrated in Figure 64. With this type of production system the optimum time to replace is when the marginal net revenue from the present enterprise is equal to the highest present value of anticipated net revenues from the enterprise immediately following.

Replacement of dairy cattle can be used as an example of the third type of asset replacement. The calculations are the same as for the beef situation except that the method for handling establishment and annual costs is different. The optimum point of replacement is when the ANR from the present asset is equal to the present value of the net value from the following asset. Essentially, fixed costs can be deleted from the cost calculations without changing the optimum replacement time because annuity calculations and amortised present returns cancel each other out. [5, 14]

Figure 64 Relationships between a stream of net revenue and costs. [5]



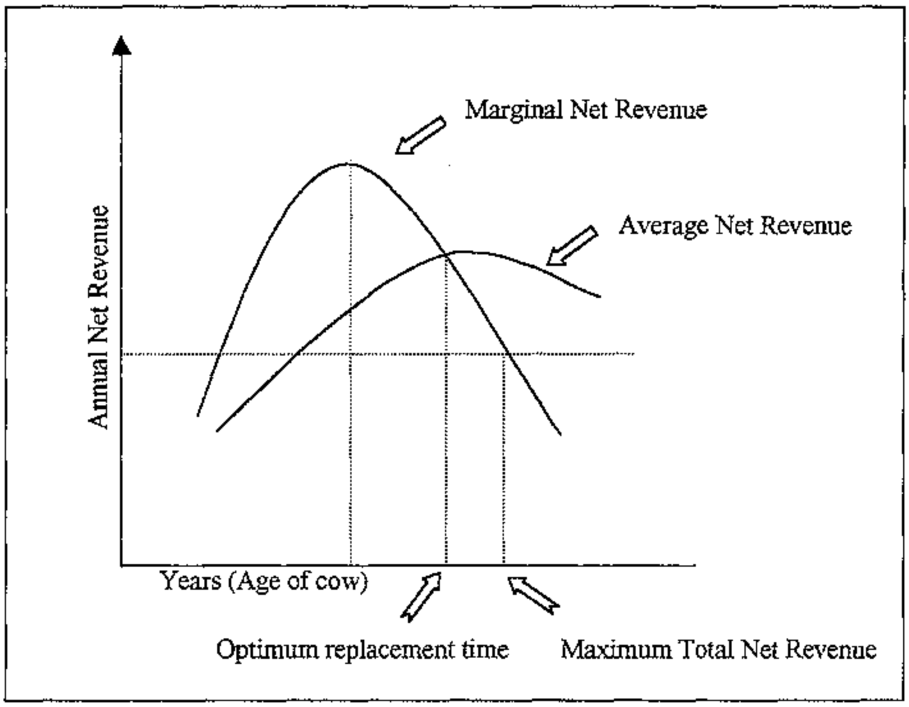
Dairy Cattle Replacement Policy Development.

The MNR approach was adapted by Dutch researchers to model the dairy replacement problem and led to the extension of the work described above.

In the dairy herd, at the end of each lactation, a decision has to be made with respect to whether each animal in the herd should be kept or disposed of. The economic approach to this, in a herd of constant size, is to compare the marginal future net revenue of the present cow with the average net revenue of a replacement young cow. The economic criterion of replacement is: A cow should be kept in the herd as long as her expected marginal net revenue is higher than the expected average profit during the replacement cows life. [15]

The point of optimal replacement using the marginal net revenue curve is illustrated in Figure 65.

Figure 65 Optimal point of replacement using the marginal net revenue curve.



The point of optimum replacement occurs when the MNR of the asset is equal to the ANR of the replacement animal. In this case optimal replacement is prior to the point of maximum total net revenue from the asset.

To make the replacement decision as realistic as possible the probability of involuntary replacement is included in the calculations. The calculations involve the comparison of the MNR of the current asset with the ANR of the future asset at the end of each time period taking into account the probability of disposal at each of these time points. The optimal moment for replacement is the last period with a positive difference between the MNR and ANR. Once the optimum lifespan is determined the total extra profit from trying to retain a cow until the optimum, compared with immediate replacement, is calculated. The resulting figure is called the sum of expected difference or Retention Pay-off (RPO). It can be considered as the opportunity cost of postponed replacement. The RPO is an economic index with which it is possible to rank cows on their future profitability. The higher the RPO the more valuable the animal. It represents the amount of money that can be spent in trying to keep the animal in the herd. However if the estimated cost of retention is equal to her RPO value then replacement is a better choice. An RPO value below zero means that replacement is the most profitable choice. [9]

Model Development.

Model Objective

The objective of this project was the development of a simple spreadsheet model (CowCHOP) giving RPO values customised for the New Zealand production system. The structure of the resulting model will be used to develop an additional module for the DairyWIN software. [13]

The initial model was based on the calculations included in the PigCHOP model [2] and then adapted for dairy cows with specific additions to account for the New Zealand production system.

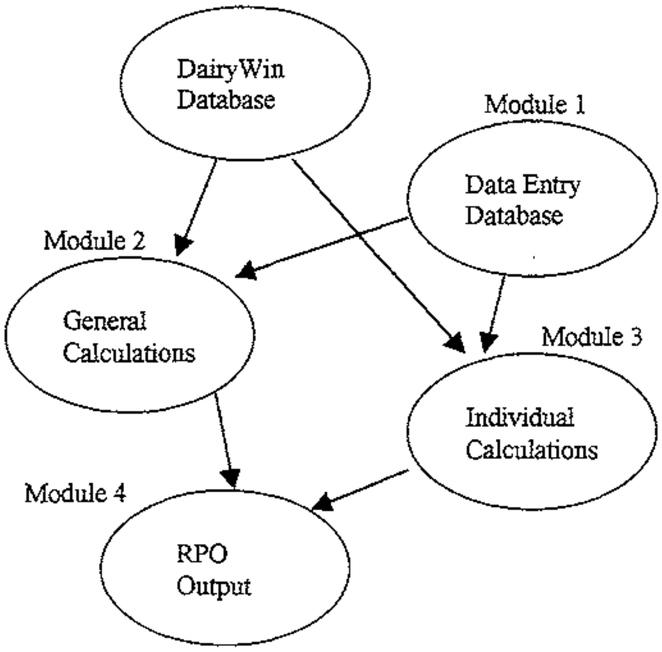
Model Structure

The CowCHOP model is a simple spreadsheet structured into four modules. Module 1 is used for data input, Module 2 for general calculations, Module 3 for individual calculations and Module 4 for the output. The model is designed so that it will interact fully with the DairyWIN software, which functions as the main database containing all the information required for the operation of the model. Any data that is optional or is farm specific that is not contained in DairyWIN can be entered at the data entry module.

This data is then combined in the calculation module where general animal values are calculated for the model. Information from the database and the data entry module are also combined to calculate individual calculations for module 4. The individual calculations and general calculations are combined and the RPO value is determined for each animal. This RPO value in descending order with cow identification is then presented in the output module.

The model structure and flow diagram is illustrated in Figure 66.

Figure 66 CowCHOP model structure and information flow diagram.



To determine the optimum lifespan for individual cows, CowCHOP first calculates the lifetime average income from a replacement heifer. This is done in the general calculation module and combines information from DairyWIN with information supplied by the data entry module. The average income minus feed costs for each of the different parities is used assuming this is the best estimate of future performance of heifers entering the herd. The average values for each parity are combined as a weighted average using the probability of survival for each parity and taking a discount factor into account. Discounting ensures that future incomes are comparable in time. The figure calculated is the average net revenue for each lactation of a replacement heifer.

Next the lifetime performance is calculated for each cow in the herd. This calculation is performed in the individual calculation module, and is exactly the same as the one for the average net revenue of a replacement heifer. But instead of the average net revenue, the marginal net revenue is calculated for each cow.

Finally, the Retention Payoff value is estimated in the individual module for each cow. The difference between marginal net revenue of the individual and the average net revenue from a replacement heifer is calculated, for each parity. The optimum economic lifespan for a cow is the last parity with a positive difference between the MNR of the individual and ANR of the replacement heifer.

After the optimum lifespan is calculated the total extra profit that could be obtained by keeping the cow until this optimum point compared with immediate replacement is determined. This total extra profit is called the Retention Pay off (RPO).

The Output module lists all the cows in the herd with their current age, RPO value and optimum lifespan. An indicator value for the ranking of cows is also estimated on the basis of dividing the RPO by the remaining expected lifespan. Cows can then be sorted in order of ranking value.

DairyWIN farm management system

The DairyWIN [13] information system has been developed to support the management of dairy cattle health and production by Massey University in collaboration with the Livestock Improvement Corporation (LIC). [13]. Production and mating information is collected by the LIC as part of their herd testing and Artificial Insemination programmes and can be imported into DairyWIN from the LIC database or farmers may enter this data manually if desired. Animal health and management data must be entered manually by the farmer. All individual ancestry, breeding, production and animal health data is stored in DairyWIN in an ACCESS database in separate tables for easy retrieval and analysis. A series of reports has been designed and set up to allow analysis of calving and mating patterns, production information and culling guides. Farmers, veterinarians and consultants can readily use these guides, for identification of reproductive or animal health problems. Recommended targets are set for specific levels of animal health or submission patterns that enable quick diagnosis of problems.

Information that is required for the CowCHOP model can be retrieved from the DairyWIN database. The following data about the herd is required for the model calculations: Individual production fat, protein as well as litres production for the current and previous lactations. Current age or parity and weight, calving history, calf sex fate and breed are also required. This information is extracted from the appropriate tables in DairyWIN and entered into the Individual and General calculation modules.

CowCHOP Model.

Module 1: Data Entry.

Data that is not available in the DairyWIN database can be entered for the model at this point. This section is designed as a checkbox question and answer sheet. Information about prices for calves, milk prices, slaughter values, supplementary feed costs and replacement heifer costs are entered here.

a) **Milk production values.** Prices paid to the farmer for milk fat, milk protein, milk litres and milk solids are entered here. Each dairy company has its own calculation for determining the price paid to suppliers for product supplied. A check box option is available for farmers to give their company payment calculation. This may be a difficult section to answer due to the complicated methods by which farmers are paid for their products. The Dairy Board sets a base price per kilogram of milk solids for the coming season. The Company to which the farmer supplies milk products provides an estimated payout advance based on the final company payout. Therefore the farmer income is based on the Dairy Board price plus additional payments from the company. As these prices change due to market fluctuations the farmer will not know the final payout until the end of the current season. This income is spread out, by the company, over the entire year to give a balanced cash flow throughout the year rather than peaks and lows associated with the milking season. To achieve this, a system of payments is set up for each month of the year for products supplied. An example based on this payment system is presented in Table 39.

Table 39 Payment system for milk products supplied by the farmer to the milk company. [10]

Supply date and Payment Timing	C/kg Milksolids	C/kg Milksolids
June paid July		224
July paid August		224
August paid September		224
September paid October		224
October paid November		224
November paid December		224
December paid January		224
January paid February		224
February paid March	4	228
March paid April	7	235
April paid May	11	246
May paid June	22	268
June paid July	28	296
July paid August	27	323
August paid September	17	340

For each month of supply, the farmer is paid by the set price of the advance as outlined in column 2. At the end of the season when income is decreasing due to lower production and supply, the balance of the payment is given to maintain the income at a set level over the season. These figures are provided in column 1. This payment is for the total solids produced up to the time of payment. These figures will vary depending on how good the season has been. If the Dairy Board base price drops then this price will drop and vice versa. Likewise if the company payout increases then these payments will also increase.

b) **Calf values.** This is the current market price paid to farmers for bobbied stock, calves sold for beef, calves sold as replacements and slink calves. These prices vary according to the markets that farmers choose to sell their calves to. The value of bobby calves depends highly on the buyer. Beef calf value is better for male Hereford or Angus calves over any other breed. A smaller number of farmers will sell calves as replacements if they have all the replacements they require. These are commonly sold on the basis of breeding value, and calves with breeding values above a certain market level are most desirable. Slink calves are dead calves sold to the tanneries for their skins. Under this system the tanneries provide farmers with cash at the gate in return for dead calves. These prices are very low and depend on the size of the carcass.

c) **Slaughter values.** Cows are slaughtered for a cull cow market value per kilogram. Cull cows are usually marketed as manufacturing beef of various grades depending on the carcass back fat depth and weight. The criteria for grading vary between companies purchasing the cow and their markets. Unless the weight and condition of the animal is known prior to slaughter then this figure will only be an estimate of the actual price to be received by the farmer at slaughter.

d) **Supplementary feed costs.** All feed costs in the model are considered fixed, because in the NZ dairy system the main feed supply is pasture. As animals are group fed specific intakes of individual animals is difficult, if not impossible, to estimate. This entry section has been included in the data entry module of CowCHOP to allow for those farmers that may be preferentially feeding groups of stock supplements other than grass. Supplementary feeds are becoming more commonly used as more farmers aim towards improved production per cow. Only supplements that are given to separate groups and that can be calculated on a per cow basis over and above the base diet should be recorded. The cost of additional supplements per cow during the lactation is recorded in this data entry section.

e) **Additional costs of a removed cow:** This section allows for the inclusion of the average costs associated with removal. This can include transport, treatment or grazing costs as well as losses associated with decreased production due to premature removal.

f) **Replacement cost.** The current market value of a replacement heifer is to be recorded in this data entry section. As the majority of farmers rear their own replacements it becomes difficult to value a replacement animal. It was therefore decided to use the market value of a replacement heifer instead.. Alternatively if a farmer has a set price at which a heifer would be purchased, or if a mature cow is considered as a replacement option then the market value for a purchased cow or set purchase price may be inserted here.

g) **Discount Rate.** The discount rate is set at a default figure of 5%, which is the current market value. However, if the farmer believes this to be different then the value can be altered.

h) **Survival probabilities.** For each lactation group/parity the probability of removal/survival has been calculated elsewhere and is stored as default values on this sheet. These values are critical for the calculation of the RPO value and cannot be changed by the farmer. Survival information has been generated from estimates of removal calculated in another chapter. (See chapter 3)

Module 2: General Calculations.

This section combines data from DairyWIN and the Data Input sheet for the calculation of the expected average income margin per parity for a replacement animal. The following information is used during the first phase of the RPO calculation.

a) **Life expectancy of a replacement heifer.** For each parity, the probability of removal and survival is used to generate the parity structure of the herd, parity structure of the removed cows and the average parity of the calved cows. The formulae for these calculations are reciprocal so if the values of one are present then the others may be calculated as shown in Table 40.

   Survival can either be given directly or can be calculated from the removal probability (hazard). The calculation for the probability of survival for each parity is shown in Equation 5:

Equation 5 Survival calculation

$$S_n = S_{n-1} - (H_{n-1} \times S_{n-1})$$

The probability of survival in parity 2 (S_{ii}), is equal to the probability of survival in parity 1 (S_i), minus the probability of removal (hazard) in parity 1 (H_I), multiplied by the probability of survival in parity 1 (S_i).

Summation of the survival probabilities for each parity gives the value of the average herd age (HA), shown in Equation 6. This value can be used to compare the life expectancy of the present asset with the expected average age of the replacement asset.

Equation 6 Average herd age (HA)

$$HA = \sum_{i=1}^{n} S_i + S_{ii} \ldots + S_n$$

The herd parity structure, PS is calculated using the survival probability for each parity and the average herd age is shown in Equation 7.

Equation 7 Herd parity structure (PS)

$$PS_n = S_n / HA$$

The division of the survival probability in parity$_i$, (S_i) by the average herd age (HA) calculates the proportion of animals in each parity. These values can be used to evaluate the effect of changing the survival probabilities of animals in the herd on the change in herd structure.

The parity structure of the removed cows (or the proportion of cows removed in each parity), PSR is calculated by multiplying the probability of survival by the probability of removal in each parity (See Equation 8).

Equation 8 Parity structure of removed cows (PSR)

$$PSR_n = H_n \times S_n$$

The average parity of calved cows, AP is the final calculation. This is the summation of the parity structure multiplied by the parity (See Equation 9).

Equation 9 Average parity of calved cows (AP)

$$AP = \sum_{i=1}^{n} P_i x PS_i + \ldots + P_n \times PS_n$$

This value is used as an indicator variable during the calculations and for determining the effects of changing the herd survival characteristics on the herd structure. It is not essential for the RPO calculations but is used for model validation, verification and sensitivity analysis.

Table 40 Calculation of the hazard and survival values for the CowCHOP model

Parity	Removal Probability	Cumulative Survival Probability	Herd Parity structure	Removed cow Parity structure	Average parity of calved cows
1	0.08	1.00	0.16	0.08	0.16
2	0.08	0.93	0.15	0.07	0.30
3	0.08	0.85	0.14	0.07	0.42
4	0.13	0.78	0.13	0.10	0.51
5	0.17	0.68	0.11	0.11	0.55
6	0.20	0.57	0.09	0.11	0.55
7	0.21	0.45	0.07	0.09	0.51
8	0.31	0.36	0.06	0.11	0.47
9	0.30	0.25	0.04	0.07	0.36
10	0.68	0.17	0.03	0.12	0.28
11	0.22	0.06	0.01	0.01	0.10
12	0.36	0.04	0.01	0.02	0.08
13	1.00	0.03	0.00	0.03	0.06
		6.17	1.00	1.00	4.35

b) **Expected production per parity.** Data on average milk production per parity is imported from DairyWIN and combined with the price values from the data entry module is used to estimate the gross income from milk. See Table 41.

Table 41 Calculation of the gross revenue from milk per parity.

Parity	Litres of Milk produced	Fat kg	Protein kg	Milksolids	Gross return on milk produced
1	2854.00	143.00	101.00	244.00	$866.77
2	3159.00	162.00	121.00	283.00	$1,022.93
3	3362.00	175.00	128.00	303.00	$1,091.38
4	3633.00	179.00	137.00	316.00	$1,143.65
5	2872.00	161.00	116.00	277.00	$1,002.74
6	2990.00	155.00	114.00	269.00	$969.79
7	2927.00	151.00	113.00	264.00	$955.42
8	2742.00	145.00	112.00	257.00	$940.37
9	2814.00	140.00	105.00	245.00	$883.15
10	2262.00	128.67	100.31	228.97	$846.62
11	2073.00	117.92	83.69	201.62	$728.33
12	2000.00	110.00	78.00	188.00	$676.34

The calculation for gross income from milk (GMI) per parity is based on the average lactation to date [12] herd testing figures for each parity which are inserted into Equation 10.

Equation 10 Gross milk income (GMI)

$$GrossMilkIncome(GMI)_n = (\$fat * kgfat_n + \$protein * kgprotein_n) - \$litres * litres_n$$

c) **Income from calves.** The average income from calves is calculated for each parity. (See Table 42) The fate of calves is summarised by parity using standard reporting functions in the DairyWIN information system. This data is combined with the calf value from the Data entry module to provide an average income per cow from calves. The reason for this calculation is related to the different mating preferences and therefore differing values of calves from different cow parities. For example, heifers may be exposed to a bull for beef calves in one herd or use AI. Each mating strategy will result in different calf returns per parity.

Table 42 Calculation of the average revenue from calves per parity.

Parity	Ave income per lactation	Bobbies	Slinks	Beef	Dairying	Total Value per lactation
1	$36.11	$50.00	$6.66	$50.00	$110.00	$216.66
2	$14.17	$50.00	$6.66	$0.00	$0.00	$56.66
3	$33.33	$50.00	$6.66	$0.00	$110.00	$166.66
4	$14.17	$50.00	$6.66	$0.00	$0.00	$56.66
5	$21.33	$50.00	$6.66	$50.00	$0.00	$106.66
6	$14.17	$50.00	$6.66	$0.00	$0.00	$56.66
7	$14.17	$50.00	$6.66	$0.00	$0.00	$56.66
8	$14.17	$50.00	$6.66	$0.00	$0.00	$56.66
9	$21.33	$50.00	$6.66	$50.00	$0.00	$106.66
10	$14.17	$50.00	$6.66	$0.00	$0.00	$56.66
11	$25.00	$50.00	$0.00	$0.00	$0.00	$50.00
12	$46.25	$75.00	$0.00	$0.00	$110.00	$185.00

The total value of calf returns is equal to the value of the calves by fate for each parity divided by the number of calves born in the parity. The formula for the Gross Calf income (GCI) is shown in Equation 11.

Equation 11 Gross calf income (GCI)

$$GCI_n = (\sum Bobby\$ * Bobby + Slink\$ * Slink + \mathrm{Rear}\$ * \mathrm{Rear} + Beef\$ * Beef) / Totalcalves$$

d) **Expected slaughter value.** The expected slaughter value [17] of cows requires the live-weight (CW) of cows from DairyWIN, the estimated killing out percentage (DO%) and the current slaughter value per kg ($kgCarcass) from the data entry sheet. Killing out percentage varies with carcass condition, live-weight and breed. It is assumed that for dairy breeds a killing out percentage of around 45 to 50% was used. [18] Price for carcasses depends on the grade classification. Cull cows are graded into 6 fatness grades, M, P, K, G, T and E. Carcasses are paid based on hot weight immediately after slaughter at grading. A summary of the cow classes is shown in Table 43.

Table 43 Summary of carcass grading classification.

Fat Class		Weight Range
M	To 1mm	<145 to >200kg
P	4mm to 7mm	160 to >270kg
K	8mm to 12mm	160 to >270kg
G	13mm to 18mm	160 to >270kg
T	19mm to 24mm	160 to 270 kg
E	>24mm	>295kg

Most dairy stock fall into to the M grade class. The price ranges for carcasses in this category for two different companies are presented in Table 44.

Table 44 Comparison of the carcass weight category values from two companies.

Carcass Wight	Price per Kg	
	A	B
130 to 145kg	$0.85c	$1.01
145 to 170kg	$0.95	$1.22
170 to 195kg	$1.05	$1.26
195 to 220kg	$1.15	$1.31
>220kg	$1.20	$1.34
Premium per Kg	$0.60	$0.34
Average per kg	$1.64	$1.56

However, carcass value estimates can be difficult to obtain because processing premiums per kilogram are added and various levies are removed from the carcass value. Levies include the New Zealand Meat Processing Board levy amounting to 1.18% of carcass value, Disease Eradication levy at 2.45%, and the meat inspection charge at $11.00 per carcass. Processing premiums are determined by the company and are set at a base rate which vary according to time of the year, cattle supply and demand, area purchased from, seller, purchaser and animal health and cow condition factors. Therefore the premium paid will vary between farms. The average carcass value is likely to range from $1.50 to $1.70 per kilogram depending on the producer and the purchaser.

Calculation of the average slaughter value per parity is shown in Equation 12.

Equation 12 Slaughter value

$$SV_n = (CW_n * DO\%) * \$kgCarcass$$

e) **Supplementary feed costs.** Supplementary feed costs as described above are feeds in addition to the basic ration (grass). They are additional to the fixed costs of feeding because these animals are being preferentially fed compared with other groups. The cost is estimated on a per cow basis. For example, if parity 1 cows were fed a ration of 1kg grain per day for the first month of calving then the total cost is calculated and divided by the number of cows fed. See Equation 13.

Equation 13 Supplementary feed costs (SF)

$$SF_n = (\$Feed * QuantityFeed) / NumberFed$$

f) **Additional costs in case of removal.** The additional costs in case of removal are calculated as described previously. These extra costs may be the cost of transport, animal health treatment or grazing costs. They are averaged for each lactation group which are then multiplied by the hazard of removal to provide the additional cost of removal per parity. This calculation is illustrated in Table 45

Table 45 Calculation of the additional costs in case of removal per parity.

Parity	Extra cost per removed cow	Expected removal per parity	Expected extra cost per parity ($)
1	20.59	0.08	1.54
2	20.59	0.08	1.60
3	20.59	0.08	1.74
4	20.59	0.13	2.63
5	20.59	0.17	3.45
6	20.59	0.20	4.10
7	20.59	0.21	4.25
8	20.59	0.31	6.45
9	20.59	0.30	6.13
10	20.59	0.68	14.01
11	20.59	0.22	4.57
12	20.59	0.36	7.48

As the probability of removal increases the average costs of removal will increase per parity. Using the hazard (H) probability from the general calculations module and the costs of removal (rc) from the data entry module the additional estimated cost of removal (RC) per parity is calculated using Equation 14.

Equation 14 Additional cost of removal (RC)

$$RC_n = H_n * rc$$

g) **Marginal profit per parity.** The Marginal Net Revenue (MNR) per parity, or the marginal profit, is calculated at this stage. This is the total income minus the costs for each parity as shown in Equation 15.

Equation 15 Marginal net revenue (MNR)

$$MNR_n = GMI_n + GCI_n + (SV_n - RV_{n-1}) - SF_n - RC_n$$

Marginal net revenue is estimated as the sum of gross milk income, the gross calf income and the change in slaughter value minus the supplementary feed costs and the removal costs. The change in slaughter value is equal to the replacement cost minus the slaughter value in parity one and then the difference between slaughter values in parity 2 and 3 and so on for each parity.

The next calculation involves taking into account discounting and the survival probability for each time unit. The calculation is set up in this manner so that this stage of the decision process can be separated into its smallest possible time units. However, due to limitations in the estimation of production we are currently limited to the prediction of RPO for a single time unit of one year.

The Marginal Net Revenue including discounting is calculated using Equation 16.

Equation 16 Marginal net revenue including discounting.

$$MNR_n inclDiscounting = MNR_n / 1.0d^{(t_n - t_I)}$$

Where:

MNR_n = Marginal Net Revenue per period.

1.0d = discount rate (d=5)

I = moment of decision; for the first time occurs at the age of 2 prior to first calving. (I=0)

n = period at the end of which a cow can be replaced

t_n-t_I = time difference in years between initial decision moment and period at which cow can be replaced. (In this model 1 year time units)

Taking into account the survival probability for each parity involves multiplying each MNR including discounting with the probability of survival in each parity, as shown in Equation 17.

Equation 17 Marginal net revenue including discounting and survival

$$MNRtot_n = S_n * MNR_n / 1.0d^{(t_n - t_I)}$$

The effect of discounting and including the probability of survival on the marginal net revenue is demonstrated in Table 46. Discounting allows future returns to be valued in present monetary terms. The further the time interval for which the return is calculated leads into the future, the smaller the estimated return in present value. Survival probability estimates are used in the calculation to weight the estimated gross margin by the chance of removal in each parity. Discounting and the introduction of survival estimates into the calculation ensure that returns are not over-estimated.

Table 46 Calculation of the expected marginal net revenue including discounting and survival

Parity	Probability of survival	Expected margin (not discounted)	Expected margin (discounted)	Expected margin (discounted) weighted by survival.
1	1.00	$201.64	$192.04	$192.04
2	0.93	$1,046.21	$948.95	$877.78
3	0.85	$1,133.69	$979.33	$835.31
4	0.78	$1,155.18	$950.37	$742.03
5	0.68	$1,020.62	$799.68	$544.33
6	0.57	$979.85	$731.18	$414.29
7	0.45	$965.33	$686.04	$311.13
8	0.36	$948.07	$641.69	$230.89
9	0.25	$898.35	$579.08	$143.00
10	0.17	$846.76	$519.84	$90.13
11	0.06	$748.75	$437.78	$24.22
12	0.04	$715.10	$398.20	$17.14
		$9,944.45	$7,465.97	$4,422.27

h) **Average net revenue per year.** The average net revenue per year is calculated using the Equation 18.

Equation 18 Average net revenue per year

$$ANR = \frac{\sum_{n=i+1}^{j} S_n * MNR_n / 1.0d^{(t_{nj}-t_i)}}{\sum_{n=i+1}^{j} S_n * l_n / 1.0d^{(t_n-t_i)}}$$

Where:

l_n = length of Period n in years.

J = final period at the end of which a cow can be replaced: in the present model at the end of 12 lactations.

All other symbols have been explained in the Equation 16. The sum of Equation 17 for each parity gives the results for the top line of Equation 18. Calculation of the bottom line of Equation 18 is illustrated in Table 47.

Table 47 Calculation of the average net revenue per year.

Parity	Cumulative Length period j in years	Survival X Length period j in years	Discount rate to power of decision interval (1.0d(tj-ti))	lj/(1.0d(tj-ti))	Annuity survival x lj/(1.0d(tj-ti))
1	1	1.00	1.05	0.95	0.95
2	2	0.93	1.10	0.91	0.84
3	3	0.85	1.16	0.86	0.74
4	4	0.78	1.22	0.82	0.64
5	5	0.68	1.28	0.78	0.53
6	6	0.57	1.34	0.75	0.42
7	7	0.45	1.41	0.71	0.32
8	8	0.36	1.48	0.68	0.24
9	9	0.25	1.55	0.64	0.16
10	10	0.17	1.63	0.61	0.11
11	11	0.06	1.71	0.58	0.03
12	12	0.04	1.80	0.56	0.02
					5.01

The Average Net Profit per parity is then equal to the following:

$4,422.27/5.01 = $881.91

The general calculations are now completed. The objective of these calculations is to determine the level of production that an average replacement cow is likely to achieve in the current herd. Animals that are reared from home stock are likely to produce within the same range as stock that are currently on the farm because farm-specific environmental characteristics are likely to modify the phenotypic production potential of the cows.

Module 3: Individual calculations.

The individual calculations are now performed for each animal in the herd. They are identical to the general calculations except for the method of estimating milk production. The aim of the individual calculations is to calculate the Marginal Net Return for each lactation of the cow in question.

As the calculations are identical to those described in the general calculation module section they will not be repeated in detail. Estimation of milk production is the only component that differs in respect to its calculation and explanation.

The reliability of the model depends on the ability to accurately estimate the income from all cows in the herd. The most limiting factor in all models for predicting the economic value of cows is the method used for the estimation and prediction of current and future milk production. This model is no different to any other models in its limitation to accurately predict the future and current production for individual animals.

Current lactation yield estimates are calculated using a BLUP model developed by the LIC. [8] This model uses the herd test day milk, fat and protein yield figures to produce a straight line estimation of the predicted lactation yield. However, prediction of a total lactation yield will only be performed if four herd tests are conducted during the lactation. As the model is to be included in DairyWIN it was decided that milk yield predictions should be consistent with the LIC predictions and therefore these estimates would be used for this part of the model. Access to the formulae on which these predictions are based was not made possible by LIC. It is therefore not possible to comment on their accuracy or predictive ability.

a) **Predicted gross income from milk.** For the calculation of an individuals GMI, all previous lactation yield totals, the current lactation yield and the predicted future lactation yields are used. An illustration of the gross return on milk produced using all the information required as described is shown in Table 48.

Table 48 Illustration of the gross return on milk produced for an individual cow.

Cow ID	Parity	Litres of Milk produced	Fat kg	Protein kg	Milksolids	Gross return on milk produced
10	1	3425.00	172.00	121.00	293.00	$ 1,040.07
	2	3791.00	194.00	145.00	339.00	$ 1,225.24
	3	4034.00	210.00	154.00	364.00	$ 1,311.98
	4	4359.00	215.00	164.00	379.00	$ 1,370.65
	5	3446.00	193.00	139.00	332.00	$ 1,201.59
	6	3588.00	186.00	137.00	323.00	$ 1,164.90
	7	3512.00	181.00	136.00	317.00	$ 1,148.27
	8	3290.00	174.00	134.00	308.00	$ 1,126.15
	9	3374.00	168.00	126.00	294.00	$ 1,059.89
	10	2714.00	155.00	120.00	275.00	$ 1,015.50
	11	2474.00	150.00	120.00	270.00	$ 1,011.21
	12	2200.00	140.00	115.00	255.00	$ 965.49

b) **Gross estimated calf income.** For each parity the fate of any calves born is extracted from DairyWIN and combined with the calf value to estimate the calf income. See Table 49

Table 49 Calculation of the gross estimated calf income

	Lactation	Ave income per lactation
Cow 10	1	$ 25.00
	2	$ 110.00
	3	$ 50.00
	4	$ 3.33
	5	$ 110.00
	6	$ 25.00
	7	$ 50.00
	8	$ 110.00
	9	$ 50.00
	10	$ 110.00
	11	$ 25.00
	12	$ 25.00

c) **Slaughter value.** An estimate of the individuals slaughter value is made using her live weight records extracted from DairyWIN and the current market value. This estimate is made for each of the future and previous parities. The future value of a cow remains the same once the mature body size is reached in the 3rd parity. See Table 50

Table 50 Calculation of the gross income from slaughter

	Parity	Live weight(kg)	Slaughter weight	Slaughter value
Cow 10	1	440	220	$ 314.60
	2	450	225	$ 321.75
	3	480	240	$ 343.20
	4	480	240	$ 343.20
	5	480	240	$ 343.20
	6	480	240	$ 343.20
	7	480	240	$ 343.20
	8	480	240	$ 343.20
	9	480	240	$ 343.20
	10	480	240	$ 343.20
	11	480	240	$ 343.20
	12	480	240	$ 343.20

d) **Feed costs.** Any additional feed costs as described in the previous section are calculated on an individual cow basis. They can be extracted from the DairyWIN database and combined with the feed value to provide the total cost of feed supplements given over each lactation. Estimates of future requirements after the current lactation will be based on the average requirements in the general section.

e) **Additional costs of removal.** Any specific extra costs associated with this cow such as treatment for disease, dry cow or injury in each lactation, is recorded in DairyWIN. This information is extracted and used in this section. If there is no information or the information is not recorded then the default value of zero is used.

f) **Marginal Net Revenue.** Finally the Marginal Net Return for the previous, current and future lactations are calculated, using Equation 15. See Table 51. At this point discounting and survival are not taken into account, as they will be calculated in the next phase of the RPO calculations.

Table 51 Calculation of the marginal net revenue (no discounting) for an individual animal

	Parity	Expected margin (no discount)
Cow 10	1	$ 379.67
	2	$ 1,342.39
	3	$ 1,383.43
	4	$ 1,366.29
	5	$ 1,311.59
	6	$ 1,189.90
	7	$ 1,198.27
	8	$ 1,236.15
	9	$ 1,109.89
	10	$ 1,125.50
	11	$ 1,036.21
	12	$ 990.49

This completes the Individual calculation module. At this point the MNR for individuals and the ANR for a replacement animal has been calculated for each lactation interval. These two values are combined and the RPO can then be calculated.

Module 4: Output.

This is the final calculation in the model. The RPO is calculated using Equation 19.

Equation 19 Retention payoff (RPO)

$$RPO_i = \sum_{n=i+1}^{r} \frac{S_n * (MNR_n - ANR)}{1.0d^{(t_n - t_i)}}$$

Where:

RPO_i = Retention pay off of a current herd member compared to a replacement.

r = Optimum moment for replacement.

The optimum moment for replacement is determined as the last lactation where the Marginal Net Revenue from the current cow minus the Average Net Revenue from the replacement cow becomes positive. The RPO for each lactation is then calculated to the point of optimum replacement. For example: A second lactation cow is considered for replacement. Her point of optimum replacement is determined as the end of lactation 10. The value (RPO) of keeping her until this point is estimated for all the lactations until the optimum removal point. In Table 52 it can be seen that the total extra profit of trying to keep this 2 year old animal until the optimum removal time is $1,101.28, when compared with immediate replacement.

Table 52 Calculation of the RPO for an individual animal

Cow ID	Lactation Number	Survival	MNR	ANR	RPO
10	0				$151.46
	1	1.00	$390.55	$466.31	$1,127.82
	2	0.93	$1,531.78	$926.90	$1,101.28
	3	0.85	$1,597.36	$1,103.34	$965.13
	4	0.78	$1,668.90	$1,234.69	$779.08
	5	0.68	$1,772.92	$1,314.96	$473.44
	6	0.57	$1,601.73	$1,365.89	$314.20
	7	0.45	$1,556.35	$1,379.40	$179.66
	8	0.34	$1,505.12	$1,378.09	$72.43
	9	0.23	$1,441.83	$1,373.24	$3.93
	10	0.16	$1,372.80	$1,368.68	
	11	0.12	$1,329.39	$1,364.99	

This means that if this cow is retained until the optimum removal time of 10 lactations she will generate an extra $1,101.28 over the remaining lifespan or an extra $137.66 per remaining lactation compared to an average replacement heifer.

Once the RPO is calculated for all cows the remaining expected lifespan can be estimated and the cows can be ranked by their RPO values. The ratio between the RPO and the remaining lifespan provides a method by which the cows can be ranked. The cows with an RPO of less than zero should be replaced. The cows in order of RPO gives the relative ranking of the animals and those at the bottom end should be removed rather than the cows at the top of the ranking.

Results from the CowCHOP model simulation runs.

The CowCHOP model was run using a set of default parameters to mimic the values of a commercial dairy herd. The default price parameters used in the model are described in Table 53.

Table 53 Default price parameters used in CowCHOP simulation runs

Parameter	Value
Milk Fat/kg	$2.78
Milk Protein/kg	$5.78
Milk Litres/L	$0.04
Bobby calf	$25.00
Sold for rearing calf	$110.00
Sold for beef Calf	$50.00
Dead Calf (Slink)	$3.33
Slaughter Value/kg	$1.35
Replacement Heifer	$1,000
Extra Costs	$320.59
Discount Rate	5%

All prices listed are current for the 1996/97 milking season, and were obtained from discussion with dairy farmers, stock buyers and personal experience.

Parity specific information was generated to calculate the marginal profit per lactation for the average animal. A herd with which I was familiar and had complete data, was selected as an example for the model. The parity specific default values are illustrated in Table 54.

Table 54 Parity specific default values used for the CowCHOP simulation runs

	Lactation										
	1	2	3	4	5	6	7	8	9	10	11
Milk Yield (L)	3789	4416	4630	4860	4536	5078	4505	4389	4274	4120	3945
Fat Percent (%)	4.88	4.80	4.84	4.84	5.40	4.79	5.24	5.13	5.01	5.10	5.07
Protein Percent (%)	3.67	3.76	3.74	3.74	3.95	3.78	3.86	3.85	3.84	3.88	3.80
Milk Income ($)[1]	1166.16	1372.20	1437.46	1510.86	1534.28	1582.18	1481.6	1426.76	1371.88	1343.8	1265.2
Calf Sales ($)[2]	26.11	46.11	46.11	46.11	46.11	46.11	46.11	47.08	47.08	47.08	47.08
Gross Revenue[3]	1192.27	1418.31	1483.57	1556.97	1580.39	1628.29	1527.71	1473.84	1418.96	1390.88	1312.28
Feed Costs[4]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Extra Costs[5]	24.04	24.97	27.12	41.10	53.73	63.99	78.87	100.57	95.50	96.18	71.24
Total Costs	24.04	24.97	27.12	41.10	53.73	63.99	78.87	100.57	95.50	96.18	71.24
Margin	1168.23	1393.34	1456.45	1515.87	1526.66	1564.30	1448.84	1373.27	1323.46	1294.71	1241.05
Heifer Price[6]	1,000										
Carcass Weight	220.8	230.4	235.2	240	249.6	247.2	244.8	242.4	240	237.6	235.2
Slaughter Value	596.16	622.08	635.04	648	673.92	667.44	660.96	654.48	648	641.52	635.04
Risk of removal[7]	0.08	0.08	0.08	0.13	0.17	0.20	0.25	0.31	0.30	0.30	0.22
Marginal Profit[8]	764.39	1419.26	1469.41	1528.83	1552.58	1557.82	1442.36	1366.79	1316.98	1288.23	1234.57

[1]The price of milk is calculated as $2.78 per Milk Fat (kg) plus $5.78 per Milk Protein (Kg) minus $0.04 per Milk Litres (L).

[2]Calf value was calculated taking into account the sex and breed of the calf produced.

[3]Gross revenue excluding the slaughter value.

[4]Feed costs are calculated as those fed in excess of the normal ration for all animals. In the NZ case this value is usually zero because all animals are fed the same.

[5]Extra costs are those due to premature disposal of an animal multiplied by the probability of disposal in that lactation.

[6]Current average purchase price of a heifer before entering the herd. This price is used to give an estimate of the approximate value of a reared replacement, as this is the opportunity cost of rearing an animal.

[7]Risk of removal is the probability that an animal will be disposed of in that lactation.

[8]Marginal profit is the margin plus the change in slaughter value. In the case of a lactation 1 animal this is the slaughter value at the end of lactation 1minus the cost of a replacement heifer. In the other lactations this is the margin plus the slaughter value at the end of lactation n, minus the slaughter value at the end of lactation n-1.

The parity specific estimates of the marginal net revenue are used as an estimate of the value of the average replacing animal. A group of seven cows representing a "herd" was used to examine the effectiveness of the model, in determining the optimum replacement time. These seven cows were animals that had records for at least 8 complete lactations. Prediction of the remaining production up to the eleventh lactation was calculated using a computer model, Twopoint. [6 7] The seven cows had production levels ranging from 70 to 130% of the average. For each animal the life expectancy and RPO values were calculated.

In a herd with average production and an average herd life of 6.26 years the effect of a reduction in the replacement rate is of economic importance at the farm level. The income earned during the second lactation of a cow with average production is approximately $480 higher than the average earned income per year over a herd life of 6.29 years. See column 1, Table 55.

Maximum profit is generated between the 2nd and 5th lactation in an average producing cow and optimal removal should occur after the 7th lactation.

Table 55 Net profit generated by an average (prod. level 100) or above average (prod. level 120) producing cow.

	Net Profit with the risk of disposal	
Production Level	100	120
Lactation	Expected Net Profit $	
1	0.00	550.96
2	479.40	979.60
3	359.59	841.75
4	287.66	796.93
5	224.66	805.32
6	195.17	822.46
7	66.20	686.95
8	-8.06	647.81
9	-53.03	582.01
10	-77.21	527.98

In contrast the economic consequences of a long productive life of for cows with above average production is shown in column 2, Table 55. Profit generated by a high producer is maintained for the length of its productive life. The longer the cow is kept in the herd, the longer the farmer may take advantage of the additional profits generated by a high producing animal.

The gain per lifetime in terms of additional lactations and profit that may be realised when a cow is saved from premature removal is illustrated in Table 56.

Table 56 Net profit generated at different milk producing capacities. (Average prod. level set at 100)

	Milk yield as a percentage of the herd average.						
Completed Lactations	70	80	90	100	110	120	130
	Retention Payoff (RPO) $						
0	$(739.21)	$(716.43)	$(424.48)	$ 163.79	$1,043.58	$1,668.33	2775.139
1	$ 69.89	$ 102.56	$ 423.42	$1,139.67	$1,748.30	$2,466.82	3357.314
2	$ 107.32	$ 121.11	$ 490.28	$1,114.36	$1,649.18	$2,280.37	3043.994
3	$ 77.18	$ 106.76	$ 503.04	$ 978.77	$1,447.95	$2,026.84	2761.118
4	$ 2.71	$ 89.30	$ 433.64	$ 794.03	$1,246.39	$1,805.94	2437.992
5		$ 5.99	$ 339.28	$ 490.66	$ 898.46	$1,459.09	2063.766
6			$ 259.56	$ 334.96	$ 634.20	$1,163.73	1597.735
7			$ 104.13	$ 180.97	$ 178.01	$ 483.76	741.498
8				$ 73.46	$ 259.30	$ 704.76	1080.281
9				$ 4.54	$ 128.96	$ 465.25	776.0418
10					$ 29.14	$ 248.57	439.2021
11							
Life expectancy	5	6	7	9	11	11	11

The economic importance of a cow with an above average level of production is shown in Table 56. As the level of production increases the life expectancy of an animal increases, as does the profit generated during each additional lactation. Negative values indicate that an animal is better replaced than kept. In the case of an animal that has less than average production (which is not known until the first lactation) the optimal life expectancy is much reduced. The life expectancy for an average producing animal is about 9 lactations compared with 11 for animals with above average production and 7 to 5 lactations for cows with less than average production.

To demonstrate the economic effects of an extended average herd life, the profits of the additional lactation are spread over the whole productive lifespan. This is illustrated in Table 57.

Table 57 Effect of extended average herd life on the profits generated per cow

Milk Yield of the herd (as % of average)	Average Herd Life (yrs)	Average annual earned income per cow ($)	Average earned income minus average earned income at 6.26 yrs.
80	3.29	1113.03	-141.09
	5.25	1231.62	-22.5
	6.26	1254.12	-
	7.27	1268.74	14.62
	12.88	1309.05	54.93
100	3.29	1178.61	-176.73
	5.25	1329.91	-25.43
	6.26	1355.34	-
	7.27	1369.62	14.28
	12.88	1400.39	45.05
120	3.29	1717.45	-229.78
	5.25	1906.79	-40.44
	6.26	1947.23	-
	7.27	1973.42	26.19
	12.88	2038.17	90.94

In a herd showing average production, the annual income per cow increases by $176.73 if the average herd life increases from 3.29 to 6.26 years. If the average herd life is increased from 6.26 to 7.21 then there is an increase of $14.28. Therefore a farm with 100 cows and an average herd life of 7.21 years will earn approximately $3900 more income each year than a similar farm with an average herd life of 5.25 years.

Sensitivity analysis.

A sensitivity analysis was conducted to analyse the behaviour of the model and the sensitivity of the results to changes in major price and production parameters. Table 58 illustrates the effect of changes to the price of beef, milk and replacements on the optimal herd life.

The economic importance of herd life was more significant in animals with an average or less than average level of production. The length of herd life for this group of cows is very dependent on the price of milk and beef. If the price of beef increased by more than 5 times the current price then the life expectancy decreased. It was more profitable to remove low producing cows earlier than to retain them. On the other hand, if the price of beef decreased or increased by up to 100% there was little change in the optimum time of replacement. This is most likely due to the low salvage value of cattle in the New Zealand market.

Table 58 Effect of a change in the base price on the optimal life expectancy.

	Production Level (as % of herd average)						
Change in Base Prices	70	80	90	100	110	120	130
	Life Expectancy						
Base Level	5	6	8	10	11	11	11
Inc Beef x5	0	0	0	7	9	11	11
Dec Beef x5	5	6	9	10	11	11	11
Inc Milk 50%	4	5	8	9	11	11	11
Dec Milk 50%	5	7	11	11	11	11	11

The effect of a change in the price of milk had a more significant effect on the life expectancy of a cow than the beef value. If the price of milk increases then it is more profitable to keep high producing cattle longer and to remove low producing cattle earlier. As the price of milk decreases it is important to keep the lower producing cattle for a longer period of time. These effects are illustrated in Table 58.

Table 59 Effect of a combined change in two price variables on the optimal life expectancy

	Production Level (as % of herd average)						
Change in value from base.	70	80	90	100	110	120	130
	Life Expectancy						
Base	5	6	8	9	11	11	11
Inc Milk Inc Beef	4	5	6	9	10	11	11
Dec Milk Dec Beef	5	7	11	11	11	11	11
Inc Milk Dec Beef	4	5	7	9	10	11	11
Dec Milk Inc Beef	5	6	6	9	11	11	11

As the prices for milk and beef change relative to each other the following effects were noticed. (See Table 59) With an increase in the prices for beef and milk it is more desirable to remove low producing cows at an earlier age than is presently the case. As the prices for milk and beef decline the optimum herd life increases in all cows except for those producing less than 70% of the herd average. If the price of milk increases and the price of beef declines the optimum herd life is decreased in all cows except for those performing 120 to 130% of the average. If there is a decrease in the price of milk and an increase in the price of beef then the optimum herd life remains essentially the same as the original model. This indicates the dependence of the optimum herd life on the price of milk.

An analysis of the effect of the replacement heifer costs was undertaken. An increase in the price of a heifer resulted in an increase in the optimum time to removal. A decrease in the optimum time to removal occurred when the price of a heifer decreased. Therefore, the decision to replace cattle depends significantly on the price of a replacement. However, this will only depend on the level of production of the cow to be replaced. If the original cow is producing 10 to 20% better than average it is still advantageous to retain the cow rather than replace her even if the cost of a replacement is low. An increase or decrease in the price of milk has a little effect on the optimum time to replacement with a high milk price indicating it is better to replace early if the cost of replacements is low. On the other hand if the cost of a replacement is high it is better to retain animals longer if the price of milk changes. With an increase in milk price, optimum removal times decrease and with a decrease in milk price optimum life expectancy increases. The optimum life expectancy is greatest in all production groups when the price of milk declines and heifer prices increase. These effects are illustrated in Table 60.

Table 60 Effect of a change in the price of a replacement on the optimal life expectancy

	Production Level (as a % of average herd level)						
Change from	70	80	90	100	110	120	130
Base cow.	Lifetime expectancy						
Base Cow	5	6	7	9	11	11	11
Dec Heifer value	4	5	6	9	10	11	11
Inc Heifer value	5	6	9	10	11	11	11
Dec Heifer value +							
Inc Milk	4	5	6	9	10	11	11
Dec Milk	4	6	9	9	11	11	11
Inc Beef	3	3	5	8	10	11	11
Dec Beef	4	5	6	9	11	11	11
Inc Heifer value +							
Inc Milk	4	5	8	10	11	11	11
Dec Milk	5	7	11	11	11	11	11
Inc Beef	5	5	9	9	11	11	11
Dec Beef	5	6	9	11	11	11	11

The price of beef has its greatest effect on optimum life expectancy when the price of a replacement is low. If the price of beef increases when the price of replacements is low then the optimum herd life is reduced in all groups except those producing 10 to 20% above average. As beef value declines the optimum herd life remains similar to that of the base cow.

If the price for a heifer increases, and beef value declines then the herd life increases in all groups except for cows producing 70% of average.

Overall, the biggest effects of beef and milk value depend on whether the price of a heifer increases or decreases. If the price of a heifer increases then a decrease in the price of milk has the biggest effect on increasing the optimal life expectancy. If the price of a heifer increases then an increase in the price of beef has the biggest effect on decreasing the optimal life expectancy. Table 61 illustrates the effect of changes in prices on the average net revenue.

Table 61 Effect of changes in price on the average net revenue

Change in Prices	Average Net Revenue ($)
Base value	1355.34
Inc Milk value	2961.81
Dec Milk Value	552.11
Inc Beef	1381.04
Decrease Beef	1,342.49
Inc Milk, Inc Beef	2987.51
Inc Milk, Dec Beef	2,948.96
Dec Milk, Inc Beef	529.26
Dec Milk, Dec Beef	577.81

The change in milk price has the most significant effect on the average net revenue. A change in beef price has virtually no effect on the average net revenue. This effect is caused by the relative difference in income received from beef compared with milk. For a change in beef price to approximate a similar effect on average net revenue as the current change in milk price, the current price of beef would have to increase approximately 5 times. At this level the effect of a change in beef value on the average income would be more significant than it is at present.

Discussion.

The above spreadsheet model has been described in detail with respect to the development process and data required for its operation. This model is to be developed further and implemented as a module of the DairyWIN information system available for use by New Zealand farmers.

Operation of the model in its current form has demonstrated the benefits from retaining animals in the herd as long as possible to maximise the net revenue from each cow. It is economically advantageous for a farmer to increase the average herd life of cows within a herd. Increasing the herd life from 3.29 to 5.25 years in an average producing herd will increase the average profit in a herd of 100 cows by $15,000 per year. This represents a huge benefit to farmers in the current economic situation where the production costs are rising and it becomes more difficult to generate profits.

The optimum herd life depends on the price of milk and beef. Milk prices have a more significant influence on the timing of removal than beef prices alone. This is most likely due to the low price of beef in comparison with that reported overseas. [2 15] The influence of the price of replacements on the timing of removal depends on the relative increase or decrease of both milk and beef. If replacement prices are low then the price of beef has a significant influence on the timing of removal. If the replacement prices are high then the price of milk has a more significant influence on the optimum herd life.

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Chapter 6.

Conclusion.

Introduction

The aim of this thesis has been to investigate the reasons and risk factors for culling in New Zealand dairy herds, with the objective of using this information to develop a simple culling model that could be added to the DairyWIN [12] farm management programme. Information on culling was derived from a previous study which investigated the reproductive and management features of NZ dairy herds in order to develop DairyFIX, an expert system for investigating herd reproductive problems that is also to be included in the DairyWIN programme. [11] There were some limitations in using this data for the analysis of culling rates and reasons due mainly to the paucity and the reliability of the information available. As the previous study was concerned mainly with the collection of reproductive information, the culling information collected was a lower priority.

The thesis is divided into several sections that appear to diverge from the overall aim of the thesis. This was necessary to provide an overview of the data analysed and illustrate the differences in management and production that are evident in the DairyWIN herds that sets them apart from the rest of the national herd. All the information derived from the data analysis was used in some form to provide a complete understanding of the management issues that were necessary for the development of the CowCHOP model.

Animal health and culling in New Zealand dairy herds.

Reports on replacement in New Zealand dairy herds have been published infrequently in the last 10 years. No major studies on the reasons or risks of removal have been done since the late 1980's. [1 7] Very little work has been published on the incidence of common animal health disorders affecting dairy cattle in New Zealand. The most recent report on the incidence of several common animal health disorders was published in 1985.[1] Since then a small amount of work on animal health disorders has been published, specifically lameness in dairy cattle [19 3 20 21 18 17] but none on overall rates of disease. This work hoped to quantify the incidence of commonly recorded diseases due its paucity in the literature but also to quantify the effects of disease on culling so that at some point in time the influence of various disease conditions on cow survival may be included in the CowCHOP model.

All the work on animal health disorders has been summarised fully in Chapter 2. As discussed previously DairyWIN herds are a subgroup of the national herd. The herd size is generally larger, 225 versus 193 cows, and there is generally more larger herds using the DairyWIN programme. The average herd age is younger than the national herd, 4.94 years versus 5.12 years, with a higher proportion of lactation 1 animals 19% versus 17% in the national herd. This indicates that DairyWIN herds tend to have higher levels of culling and replacement rates than the national herd. Production levels in DairyWIN herds are significantly higher than the national average with the average milk, fat and protein production 3,735l, 187kg and 143 kg versus 3253l, 154kg and 118kg. The influence of management on the differing levels of performance between the national herd and DairyWIN users cannot be emphasised more by the fact that the Breeding Indices and the planned start of calving and mating dates in the DairyWIN herds are the same as the national herd. There was a significant higher proportion of Friesian cross Jersey cows present in DairyWIN herds than in the national herd, which may partly explain the difference in production levels in these herds, but is unlikely to explain all the differences seen between the two herds. A full description of the differences between the DairyWIN and national herd has been described elsewhere. [11]

A brief summary of the cumulative incidence of animal health disorders is shown in Table 62.

Table 62 Cumulative incidence of common animal health disorders.

Animal health disorder	Cumulative Incidence		Timing of disorder
Calving assistance	0.036	4/100	
Metabolic events	0.02	2/100	Sept/Oct, Jan/Feb
Reproductive events	0.031	3/100	Jun, Oct/Nov
Mastitis events	0.11	11/100	Calving, Drying off
Lameness events	0.058	6/100	Oct, Mar
Sickness events	0.013	1/100	Calving, Feb/Mar
Empty rate	0.89	9/100	

The cumulative incidence of all animal health disorders is low and appears to be similar to the most recent report of disease incidence. [1] This gives confidence to the quality of the data that was contained in the database and enhances the validity and relevance of the information to not only the DairyWIN users but also the rest of the New Zealand dairy industry.

The culling information available in the DairyWIN database was limited to the fate after culling, herd, animal, age and date of removal. No information was supplied in the database giving the reason for culling. This meant that it was impossible to investigate directly the risks and reasons for culling as defined by the farmer. Also the records supplied by some farmers were incomplete. 131 farms out of 154 had culling information recorded in the DairyWIN database. However some of the farms had very small numbers of animals recorded as removed. This meant that the validity of the data and its interpretation may be questionable. However to overcome the problem of incomplete data various methods of data screening and checking were instigated as is described in full detail in Chapter 2.

The culling rates varied from 0.03 to 0.52 in the herds that remained in the database after all herds with no culling were excluded. The overall culling rate was 16.58%. The fate of cows removed from the DairyWIN herds is shown in Table 63.

Table 63 Proportion of animals removed stratified by fate.

Fate	%
Culled	10.7
Died	1.5
Lost	0.1
Sold	4.3
Unknown	83.4

The removal pattern showed a bimodal pattern with a small amount of culling occurring from August to October while the majority of culling occurs from February to June with a peak in April. There is a specific pattern to the timing of removal depending on the fate of the animal. Deaths occurred most commonly in August/September/October, while sales occur mainly from March to July. Culling occurred in small amounts in early lactation August/September but mainly from February to May.

As the age of animals increased the risk of removal increased from 0.12 to 0.34 in lactations 1 to 10. Cows in lactation 9 had the greatest risk of removal. There was an increased risk of removal in lactation one animals, which declined in lactations 2 to 4 but then increased again in lactations 5 to 10. Cows in lactations 5 to 9 were removed earlier in the lactation period than animals in lactations 1 to 4. Overall this indicates that cows in lactations 2 to 4 were kept in preference to all other lactations so that if a cow in lactation 1 made it into lactation 2 she is likely to remain in the herd for at least 3 more lactations. Younger cows were also given more time to perform over the lactation than older cows, which were removed sooner in the lactation.

18.6% of all cows that were removed from the DairyWIN herds had an animal health event recorded. 17% of deaths, 26% of sales and 34% of culls had an animal health event recorded. Cows that were sold were likely to be empty or have a mastitis, or lameness event during the lactation. Cows that were culled in early lactation were likely to have a mastitis event recorded. If they were culled at the end of the lactation animals could be empty, have had a mastitis, lameness, reproductive or metabolic event during the lactation.

The fate of animals with an animal health disorder is significantly different to the fate of all animals removed from the DairyWIN herds. The proportion of animals removed with each animal health event stratified by fate is shown in Table 64.

Table 64 Proportion of animals removed with each animal health event stratified by fate.

	Culled	Died	Sold	Total removed	Unknown
All removals	10.7	1.49	4.28	*16.5*	83.42
Empty	45.2	0.4	11.4	*57.0*	43.0
Pregnant	3.7	0.3	4.2	*8.2*	91.8
Lame	10.9	1.3	7.0	*19.2*	80.7
Metabolic	21.4	7.1	4.7	*33.2*	66.8
Reproductive	16.6	3.0	7.2	*26.8*	73.2
Sick	17.0	11.3	6.3	*34.6*	65.4
Assist	14.7	3.6	5.0	*23.3*	76.7
Mastitis	14.6	0.3	6.4	*21.3*	78.7

Cows with a mastitis event or empty were more likely to be culled or sold than all removals. Cows with a lameness event are more likely to be sold than all removals. Cows with a metabolic or sickness event were more likely to be culled, die or be sold than all removals. Cows requiring calving assistance or with a reproductive event are more likely to be culled, sold or die than all removals. Pregnant cows are less likely to be sold or die than all removals.

The relative risk of removal in animals with an animal health disorder is listed in descending order as follows: Empty > Metabolic > Sick > Discharge > Assist > Reproductive > Prolapse > Mastitis > Lameness > Retained membranes.

Survival analysis was used to investigate the effect of various risk factors on the timing of removal. Production, future calving date, Breeding Indices and animal health events were assessed as possible risk factors to affect the survival of cows within DairyWIN herds. In all cases except for cows with a lameness event animals with an animal health event recorded had lower survival times than animals without an animal health event recorded. Cows that produced less than the herd average milk or produced less than 200kg milk fat to the end of the season were removed from the herd sooner than cows that produced better than this. Cows that had a late predicted calving date for the next season were also removed from the herd sooner than cows with an early calving date.

All the risk factors assessed using univariate survival analysis were included into a multivariable survival model to further understand the relationship between the risk factors. A Cox proportional model was built including parity, animal health events including reproductive and mastitis events, calving to conception interval, breeding index, fat production, pregnancy status and somatic cell count as variables. Cows with a high somatic cell count, in lactation 9 and 10, with a reproductive or mastitis event were at increased risk of removal. High milk fat production and breeding indices, or pregnancy increased the survival probability of cows in the DairyWIN herd.

All the risk factors and analysis performed using the data available from the DairyWIN herds confirmed the findings of similar research performed internationally. The risk factors for removal in New Zealand herds are similar to those found in other dairying countries. This is not surprising, as the same factors for the selection of cattle for herd improvement are universal. The only differences are likely to be the relative importance of production and animal health disorders in the selection of cows to remove. As mentioned in the literature review it would appear that the removal rates for seasonal and non-seasonal herds are very similar except for the proportion of animals removed for animal health events. (See Literature review)

Computer modelling

A simple spreadsheet model that allows the selection of cows to be removed from the herd based on economic criteria has been developed. Using the general farm management information and the survival calculations a spreadsheet modelled on the marginal net revenue approach to culling was created. [6 2 15 16 5 4] The objective of the model is to predict the future income of each cow within a herd and compare her future income with that of a replacement animal. Using a series of economic calculations to compare these income streams, a value that gives the predicted amount of extra income each cow is expected to provide in the future lactations if she is kept in the herd is calculated. This value the retention payoff (RPO) is used to rank the cows within the herd on future profitability. Those cows with a high RPO are more desirable than cows with a low RPO, which should be removed from the herd first.

Differences in production between the New Zealand dairy system and the Dutch dairy system that affected the development of the model were very few and it did not require much work to convert the Dutch model into one that would fit the New Zealand system.

The primary limitation to the model was the estimation of future and current production. This limitation is common with all models that attempt to predict the future revenue of cows within a dairy herd. (Personal communication A. A. Djikhuizen) In the case of this model a simple lactation curve model [10] was used to estimate future production and it is hoped in the future that the prediction model used by the Livestock Improvement Corporation (LIC) will be used for this part of the model. This is to ensure that the current and future production estimates are in line with the current measures of performance used by the LIC.

In the future the spreadsheet model will be developed into a module of the DairyWIN programme [12] which will automate all the calculations not able to be automated in the spreadsheet model. This will enable faster and more efficient sensitivity analysis of the model to be performed. It is hoped that the model will provide a useful tool that farmers may use to assist in their culling decisions.

Directions for future research

The work performed on modelling the culling issues in New Zealand dairy herds have been fairly prolific over the last twenty years, which is surprising given the paucity of published work investigating culling rates and reasons. [9 13 14 8]

More detailed work collecting data on the incidence of disease in specific areas and the importance of these diseases on production and farm management in NZ needs to be pursued and followed up over time. As well more detailed investigation into the risks and reasons for culling in New Zealand herds need to be performed. Good culling information combined with the effects of animal health disorders on cow survival should be pursued. This information may then be used to modify the current culling model to include the effects of animal health on survival to make the model even more useful than it is in its current form.

Cross sectional studies provide information on the reasons for culling or the prevalence of animal health disorders at a point in time. They are useful in that they are quick to perform and can provide a lot of information in a short time. However they are limited in that it is not possible to follow groups of animals over periods of time and assess changes in risk factors. Longitudinal studies are a more useful tool to investigate culling and animal health events. Basically they are studies that collect data over a period of time so that a series of snapshots can be combined to create an overall picture of the dynamics of disease and culling. By combining the two epidemiological approaches to investigate animal health and culling it will be possible to assess that incidence of disease and the seasonal effects over a period of time and these effects on culling policy. It is also possible to assess potential changes or shifts in reasons for culling that may be related to season or financial changes over time. DairyWIN users are not a representative group of dairy farmers within New Zealand, however their use of DairyWIN provides an opportunity for the collection of information that would otherwise be very difficult and costly to obtain. A coordinated approach by researchers and the users of DairyWIN to follow groups of farmers around the country over periods of time combined with other studies surveying other farmers would provide useful information on the incidence of animal health disorders and culling.

Work not only needs to be instigated to investigate the rates and reasons for culling but a more coordinated approach to understand the nature of the culling process of farmers also needs to be addressed. The risk factors for culling have been well researched and are understood by many but what is not well understood is the culling decision process and the methods by which farmers select animals for removal. Until the way in which culling is performed is understood it is impossible to make recommendations to advise farmers on how to improve their culling policy.

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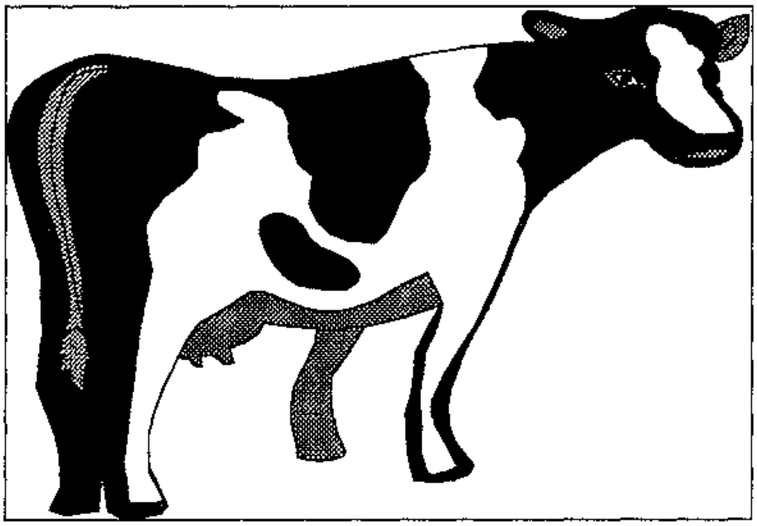
Appendix

Appendix 1.

CowCHOP spreadsheet model.

Welcome to Dairychop.



Module 1: Input Data.

In this section you are required to input data that is not easily obtained from the DairyWIN programme. This information is used to calculate the economic parameters required for the calculation of the RPO of your cattle. Please input the data as accurately as possible. If you do not know the value then accept the default value already calculated. The data you are required to input is coloured red.
To go to the first section click this button
If you wish to return to the Title Page or the Output page click the appropriate button below.

1. Probability of removal for each parity.

Parity	Probability of removal per parity (hazard)
1	0.075
2	0.078
3	0.085
4	0.128
5	0.168
6	0.200
7	0.207
8	0.314
9	0.298
10	0.681
11	0.222
12	0.364
13	1.000

2. Milk Production Value

Please input the market price of the following milk products as you receive them from the dairy company.

Milkfat /kg	$2.78
Milkprotein/kg	$5.78
Milk litres	$(0.04)

3. Calf value per parity

How many calves did you produce this year and what happened to them? Please enter the number of calves that fall into each of the following categories below:
If this information has already been entered into dairyman then please ignore this section.

Parity	Bobbied	Slinks	Sold for Beef	Sold for Dairying	Total
1	2	2	1	1	6
2	2	2	0	0	4
3	2	2	0	1	5
4	2	2	0	0	4
5	2	2	1	0	5
6	2	2	0	0	4
7	2	2	0	0	4
8	2	2	0	0	4
9	2	2	1	0	5
10	2	2	0	0	4
11	2	0	0	0	2
12	3	0	0	1	4

Please input current market values for each of these groups.

Price	Bobby	$25.00
	Sold for Dairying	$110.00
	Sold for beef	$50.00
	Slink	$3.33

4. Slaughter value of removed cows

Market price	heifer	$1.43 $/kg
	mature cow	$1.43 $/kg

5. Supplementary Feed costs per cow per lactation.

If you are feeding groups of cows extra supplements in addition to grass then please record the cost per cow per lactation below. For example if parity one cows are being fed 1kg meal per day for the first 6 weeks.
If all animals are being fed the same then please ignore this section.

Parity	Feed cost per cow per lactation
1	$ 0.00
2	$ 0.00
3	$ 0.00
4	$ 0.00
5	$ 0.00
6	$ 0.00
7	$ 0.00
8	$ 0.00
9	$ 0.00
10	$ 0.00
11	$ 0.00
12	$ 0.00

5. Extra costs per removed cow.

Please put in costs associated with the removal of your cattle, this includes transport costs, treatment costs and other miscellaneous costs associated with removal.

Transport	$20.59
Treatment	$00.00
Other	$00.00
Total	$20.59

6. Costs of a replacement heifer

Input the current market value of your replacement heifers and any other costs incurred when purchasing replacements eg grazing costs, until mixed with the herd

Market price at selection	$1,000.00
Other costs	$0.00
Total	$1,000.00

7. Discount Rate

5

You have now finished this section.

To see the results of your input go to the Output page now.

To return to the Title page click the go to page now.

If you wish to return to the beginning of the Input page click the go to button now.

Module 2: General Calculations.

To return to any of the previous pages click on the appropriate button above.
To view the whole section of each calculation scroll downwards.

1. Life expectancy of a replacement heifer.
The hazard values (probability of removal) for each parity have been calculated elsewhere and input below. Cumulative survival has then been calculated from the hazard data for the probability of survival column.

Parity	Removal probability per parity	Probability of survival
1	0.08	1.00
2	0.08	0.93
3	0.08	0.85
4	0.13	0.78
5	0.17	0.68
6	0.20	0.57
7	0.21	0.45
8	0.31	0.36
9	0.30	0.25
10	0.68	0.17
11	0.22	0.06
12	0.36	0.04
13	1.00	0.03

2. Expected production per parity
Calculation of milk value (income) average/parity = (fat + protein)- volume charge or alternatively milksolids*value for MS

Parity	Litres of milk produced (L)	Fat (kg)	Protein (kg)	Milk solids (kgMS)	Gross return on milk produced
1	2854.00	143.00	101.00	244.00	$866.77
2	3159.00	162.00	121.00	283.00	$1,022.93
3	3362.00	175.00	128.00	303.00	$1,091.38
4	3633.00	179.00	137.00	316.00	$1,143.65
5	2872.00	161.00	116.00	277.00	$1,002.74
6	2990.00	155.00	114.00	269.00	$969.79
7	2927.00	151.00	113.00	264.00	$955.42
8	2742.00	145.00	112.00	257.00	$940.37
9	2814.00	140.00	105.00	245.00	$883.15
10	2262.00	128.67	100.31	228.97	$846.62
11	2073.00	117.92	83.69	201.62	$728.33
12	2000.00	110.00	78.00	188.00	$676.34

3. Income from calves.
Income from calves is calculated by the number of calves in each "category" averaged over the total number of calves in that parity giving an average calf value for that parity.

Lactation	Ave income per lactation	Bobbies	Slinks	Beef	Dairying	Total Value per lactation
1	$36.11	$50.00	$6.66	$50.00	$110.00	$216.66
2	$14.17	$50.00	$6.66	$0	$0	$56.66
3	$33.33	$50.00	$6.66	$0	$110.00	$166.66
4	$14.17	$50.00	$6.66	$0	$0	$56.66
5	$21.33	$50.00	$6.66	$50.00	$0	$106.66
6	$14.17	$50.00	$6.66	$0	$0	$56.66
7	$14.17	$50.00	$6.66	$0	$0	$56.66
8	$14.17	$50.00	$6.66	$0	$0	$56.66
9	$21.33	$50.00	$6.66	$50.00	$0	$106.66
10	$14.17	$50.00	$6.66	$0	$0	$56.66
11	$25.00	$50.00	$0	$0	$0	$50.00
12	$46.25	$75.00	$0	$0	$110.00	$185.00

4. Expected slaughter value of removed cows

Slaughter value of cows is calculated by carcass weight*market value
At present dummy values for slaughter value are included, as a calculation for this value is difficult based on present market values. Information on live weight is obtainable from Dairyman.

Parity	Live weight(kg)	Slaughter weight	Slaughter Value
1	420	210.0	$300.30
2	435	217.5	$311.03
3	450	225.0	$321.75
4	450	225.0	$321.75
5	450	225.0	$321.75
6	450	225.0	$321.75
7	450	225.0	$321.75
8	450	225.0	$321.75
9	450	225.0	$321.75
10	450	225.0	$321.75
11	450	225.0	$321.75
12	450	225.0	$321.75

5. Feed costs for stock on the farm.
This part of the calculations is only to be included if differential feeding occurs between the different lactation groups.
Feed is considered to be a fixed cost unless different groups are being fed separately. Grass costs are not included in this because the cost of feed is equal between the groups.

Parity	Feed Cost
1	$0
2	$0
3	$0
4	$0
5	$0
6	$0
7	$0
8	$0
9	$0
10	$0
11	$0
12	$0

6. Extra costs in case of removal

Extra costs per parity are weighted, by the removal probability per parity, to calculate the expected extra cost of removal, per parity.

Parity	Extra cost per removed cow	Probability of removal per parity (Hazard)	Expected extra cost per parity
1	20.59	0.08	1.54
2	20.59	0.08	1.60
3	20.59	0.08	1.74
4	20.59	0.13	2.63
5	20.59	0.17	3.45
6	20.59	0.20	4.10
7	20.59	0.21	4.25
8	20.59	0.31	6.45
9	20.59	0.30	6.13
10	20.59	0.68	14.01
11	20.59	0.22	4.57
12	20.59	0.36	7.48

7. Cost of an average replacement heifer at an age of 2 years

$1,000.00

8. Calculations for determining annuity factors.

Annuity factors are determined for each parity as follows below.
The length of lifespan from entry into the herd and ist time for disposal (period j) is calculated.
This period j is then multiplied by the survival time for each parity. The discount factor for this period is calculated. Next the annuity for each parity is calculated by survival*length of j /discount rate. These values are summed to give the total annuity value.

Parity	Cumulative Length period j in years	Survival X Length period j in years	Discount rate to power of decision interval (1.0d(tj-ti))	lj/(1.0d(tj-ti))	Annuity survival x lj/(1.0d(tj-ti))
1	1	1.00	1.05	0.95	0.95
2	2	0.93	1.10	0.91	0.84
3	3	0.85	1.16	0.86	0.74
4	4	0.78	1.22	0.82	0.64
5	5	0.68	1.28	0.78	0.53
6	6	0.57	1.34	0.75	0.42
7	7	0.45	1.41	0.71	0.32
8	8	0.36	1.48	0.68	0.24
9	9	0.25	1.55	0.64	0.16
10	10	0.17	1.63	0.61	0.11
11	11	0.06	1.71	0.58	0.03
12	12	0.04	1.80	0.56	0.02
					5.01

9. Expected income margin per parity.

The expected margin is calculated first. This comprises income-costs for each parity.
The margin is then calculated taking into account discounting and then including survival in the final column. The final column is summed to give the total value over all parities.

Parity	Probability of survival	Expected margin (no discount)	Expected margin (discount)	Expected margin (discount) including survival.
1	1.00	$201.64	$192.04	$192.04
2	0.93	$1,046.21	$948.95	$877.78
3	0.85	$1,133.69	$979.33	$835.31
4	0.78	$1,155.18	$950.37	$742.03
5	0.68	$1,020.62	$799.68	$544.33
6	0.57	$979.85	$731.18	$414.29
7	0.45	$965.33	$686.04	$311.13
8	0.36	$948.07	$641.69	$230.89
9	0.25	$898.35	$579.08	$143.00
10	0.17	$846.76	$519.84	$90.13
11	0.06	$748.75	$437.78	$24.22
12	0.04	$715.10	$398.20	$17.14
		$9,944.45	$7,465.97	$4,422.27
		(expected margin)	(discounted expected margin)	(total margin incl survival)

10. Annuity value.

The average income margin per cow per year (annuity) is calculated by division of the sum of the expected margin by the annuity sum, as calculated in the two preceding sections.

Expected average income margin per cow per year (annuity) $881.91

11. RPO Calculation.

The replacement margin is calculated by the subtraction of the expected margin of the replacement cow from the margin of the present cow.

The retention payoff is then calculated from the point of optimum replacement, which is the last parity where the replacement margin is positive. (highlighted in red)
The RPO is a calculation involving the probability of removal, margins and discounting as can be seen by the calculations in the RPO column.

Parity	Probability of survival	MNR	ANR	RPO
0				$12.04
1	1.00	$201.64	$881.91	$713.43
2	0.93	$1,046.21	$881.91	$612.07
3	0.85	$1,133.69	$881.91	$431.04
4	0.78	$1,155.18	$881.91	$236.54
5	0.68	$1,020.62	$881.91	$153.60
6	0.57	$979.85	$881.91	$100.59
7	0.45	$965.33	$881.91	$52.06
8	0.36	$948.07	$881.91	$10.60
9	0.25	$898.35	$881.91	$0
10	0.17	$846.76	$881.91	$0
11	0.06	$748.75	$881.91	$0
12	0.04	$715.10	$881.91	$0

Module 3: Individual Calculations.

To return to any of the previous pages click on the appropriate button above.
To view the whole section of each calculation scroll downwards.

This section comprises the calculations required to calculate the individual RPO value.

1. Production per parity.
Milk production her is fudged as the calculations required for the prediction of milk yield are confidential.

Cow ID	Parity	Litres of milk produced (L)	Fat (kg)	Protein (kg)	Milk solids (kgMS)	Gross return on milk produced
10	1	3425.00	172.00	121.00	293.00	$1,040.07
	2	3791.00	194.00	145.00	339.00	$1,225.24
	3	4034.00	210.00	154.00	364.00	$1,311.98
	4	4359.00	215.00	164.00	379.00	$1,370.65
	5	3446.00	193.00	139.00	332.00	$1,201.59
	6	3588.00	186.00	137.00	323.00	$1,164.90
	7	3512.00	181.00	136.00	317.00	$1,148.27
	8	3290.00	174.00	134.00	308.00	$1,126.15
	9	3374.00	168.00	126.00	294.00	$1,059.89
	10	2714.00	155.00	120.00	275.00	$1,015.50
	11	2474.00	150.00	120.00	270.00	$1,011.21
	12	2200.00	140.00	115.00	255.00	$965.49

2. Income from calves.

This calf information is obtained from DairyWin up until the current age, but from then the future income is estimated as described in the general calculation module.

Cow ID	Parity	Ave income per lactation
10	1	$25.00
	2	$110.00
	3	$50.00
	4	$3.33
	5	$110.00
	6	$25.00
	7	$50.00
	8	$110.00
	9	$50.00
	10	$110.00
	11	$25.00
	12	$25.00

3. Expected slaughter value of removed cows.
These figures are obtainable for the individual from DairyWin or will have to be input by the farmer.

Cow ID	Parity	Live weight(kg)	Slaughter weight	Slaughter value
10	1	440	220	$314.60
	2	450	225	$321.75
	3	480	240	$343.20
	4	480	240	$343.20
	5	480	240	$343.20
	6	480	240	$343.20
	7	480	240	$343.20
	8	480	240	$343.20
	9	480	240	$343.20
	10	480	240	$343.20
	11	480	240	$343.20
	12	480	240	$343.20

4. Extra costs in case of removal.

Extra costs per parity are weighted, by the removal probability per parity, to calculate the expected extra cost of removal, per parity.

Cow ID	Parity	Extra cost per removed cow	Expected removal per parity	Expected extra cost per parity
10	1	0	0.08	0
	2	0	0.08	0
	3	0	0.08	0
	4	60	0.13	7.692
	5	0	0.17	0
	6	0	0.20	0
	7	0	0.21	0
	8	0	0.31	0
	9	0	0.30	0
	10	0	0.68	0
	11	0	0.22	0
	12	0	0.36	0

5. Feed costs

CowID	Parity	Feedcosts
10	1	$0
	2	$0
	3	$0
	4	$0
	5	$0
	6	$0
	7	$0
	8	$0
	9	$0
	10	$0
	11	$0
	12	$0

6. Expected income margin per parity.

Cow ID	Parity	Probability of survival	Expected margin (no discount)
10	1	1.00	$379.67
	2	0.93	$1,342.39
	3	0.85	$1,383.43
	4	0.78	$1,366.29
	5	0.68	$1,311.59
	6	0.57	$1,189.90
	7	0.45	$1,198.27
	8	0.36	$1,236.15
	9	0.25	$1,109.89
	10	0.17	$1,125.50
	11	0.06	$1,036.21
	12	0.04	$990.49
			$12,679.29
			(expected margin)

7. RPO Calculation.

The MNR values generated by the individual data are compared with the ANR data generated in the general calculation module.
The RPO value corresponding to the cows current parity is reported in Output Module.

CowID	Parity	Survival	MNR	ANR	RPO
10	0				$1,206.14
	1	1.00	$379.67	$881.91	$1,821.03
	2	0.93	$1,342.39	$881.91	$1,525.55
	3	0.85	$1,383.43	$881.91	$1,022.79
	4	0.78	$1,366.29	$881.91	$907.08
	5	0.68	$1,311.59	$881.91	$685.26
	6	0.57	$1,189.90	$881.91	$569.00
	7	0.45	$1,198.27	$881.91	$433.78
	8	0.36	$1,236.15	$881.91	$282.70
	9	0.25	$1,109.89	$881.91	$193.34
	10	0.17	$1,125.50	$881.91	$137.24
	11	0.06	$1,036.21	$881.91	$60.46
	12	0.04	$990.49	$881.91	

Module 4: Output.

The output data presented below gives the following information about each individual animal in the herd.
1. The current parity of the animal.
2. The optimal lifespan of the animal.
3. The remaining number of parities for the animal.
4. The RPO (retention payoff) value for the animal.
5. The RPO for each year of the cows remaining lifespan.

The RPO value is the animals total extra profit that she is expected to generate if she is kept in the herd to her optimum lifespan rather than replacing her immediately.

RPO is an economic index that makes it possible to rank cows on future profitability. A value below zero means that replacement is the most profitable choice.

It can also be thought of as the amount of money that could be invested in keeping this animal within the herd. Obviously if you spend her total RPO "value" to keep her, then her economic value is zero and replacement is the most economic option.

A cow should be kept in the herd as long as her expected profit (MNR) in the next lactation is higher than the lifetime average return from a replacement heifer.

Cow ID	Current Parity	Optimal Lifespan (parities)	Remaining expected lifespan (yr)	RPO	RPO per year of remaining lifespan
10	4	11	7	$685.26	$97.89
25	2	9	7	$624.01	$89.14
177	8	7	-1	$0	$0

Cows may be ranked using the RPO value or the RPO per year of her remaining lifespan. The latter is a more useful figure to rank animals with because you can then compare the profitability of each animal directly.

Cows with and RPO of zero or less should be removed.

Those cows with the lowest RPO should be removed first.