

Environmental and behavioural factors affecting the prevalence of foot lameness in New Zealand dairy herds – a case-control study

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ABSTRACT

A case-control study of environmental and behavioural factors influencing foot lameness was undertaken on 62 dairy herds comprising an average of 185 milking cows in Taranaki, New Zealand. Thirty two case herds were identified as having had at least 10 per cent of the cows lame during the milking season in which the herd was studied, and thirty control herds were selected on the basis that no more than 3 per cent of cows in these herds had been lame per year for at least two years immediately prior to investigation. Each herd was visited at both a morning and an afternoon milking, and 58 risk factors were measured between the time the farmer began to assemble the cows for milking and the completion of milking.

Comparison of single variables between case and control herds identified 24 which showed differences ($p < 0.10$). These variables were then subjected to stepwise multivariate logistic regression, and statistically significant variables in this analysis were used to create a tentative "path diagram" of possible "causal web" relationships between the various risk factors and the outcome variable, the lameness prevalence level. Information from a review of the published literature was used to include further variables to the 24 into the initial (or null hypothesis) path model.

Logistic path analysis was then used to eliminate non-significant paths from the diagram, leaving 19 arrows joining 13 variables in the final path diagram, compared with 33 joining 20 variables in the initial version. The most influential variables in explaining variation between case and control herds were the average level of maintenance of the track and the degree of patience shown by the farmer in bringing the cows in for milking. Overall, factors associated with the movement of animals to the milking shed explained 40 per cent of the variation (deviance) with regard to the lameness prevalence level. Risk factors associated with characteristics of the milking process explain 24 per cent, and risk factors associated with characteristics of the cows in the herd explain 9.5 per cent. Recommendations are made on management changes which deserve further investigation as ways of reducing lameness problems in dairy herds.

INTRODUCTION

A case-control study was conducted on 62 herds located in Taranaki, a major dairying area in the North Island of New Zealand in order to examine the contribution of various environmental and behavioural factors to variation in the prevalence of foot lameness in dairy cattle.

Lameness in cattle is considered to be among the most important health problems in dairy production, and the one which has probably the greatest adverse effect on the welfare of the modern dairy cow.⁽²⁶⁾ Foot lameness has a negative impact on feed intake, milk production and body condition. Expression of oestrus may be reduced, there is increased risk of early culling, and direct expense is incurred for treatment.⁽¹⁹⁾ Lameness appears to be a greater problem in housed than in pastured animals. Approximately 85 per cent of cases of lameness in dairy cattle are due to lesions of the feet; 15 per cent are due to lesions elsewhere on the limb.⁽²³⁾

Greenough *et al.*⁽¹²⁾ state that lameness may result from direct trauma or more often from a combination of predisposing influences. They describe the risk factors as a causal web consisting of groups of factors. The main groups are nutrition, conformation, management and environment. The importance and relationship of these predisposing causes of lameness are still a matter of speculation. It is likely that the principal risk factors differ among countries with different cattle management systems, and it is unclear which are the main factors influencing the prevalence of lameness under New Zealand conditions.

An overall prevalence of lameness of 14.2 per cent has been reported by Arkins from Ireland.⁽³⁾ Webster⁽²⁶⁾ estimates that

the annual prevalence in housed cattle probably rises to 25 per cent if cases treated by farmers are included. In a recent Australian study Harris *et al.*⁽¹⁴⁾ observed a lameness prevalence of 7.5 per cent in 9097 pasture-fed cows, and the disease occurred in 88 per cent of the 73 herds studied. Dewes⁽⁷⁾ quotes a prevalence of 14 per cent under New Zealand conditions.

Dewes⁽⁷⁾ also reports that lameness seems to cause significant economic losses to New Zealand dairy production. Bridges⁽⁵⁾ did a case study on dairy farms to obtain an indication of economic losses due to lameness. He calculated an average loss in income per farm of 1.04 per cent due to reduced milk production in lame cows.

MATERIALS AND METHODS

Collection of data

The factor under study was the herd prevalence of foot lameness due to traumatic injuries in dairy cattle. The diagnoses of lameness which led to a herd being classified as a case or control were made by veterinarians and based on clinical examination.

Farms were selected for inclusion into the study on the basis of the following criteria. Local veterinary practices were asked to propose a number of farms with known lameness prevalence history. These farms were then contacted and further information on lameness prevalence was collected. Based on this information a decision was made on their inclusion in the study.

Thirty two case farms (high lameness prevalence) had a history that at least 10 per cent of the cows had shown lameness during the year in which the farm evaluation was carried out. Thirty control farms (low lameness prevalence) were selected as having had no more than 3 per cent of cows lame per year over a period of at least 2 years immediately

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prior to the farm evaluation. Information on 58 potential risk factors, concentrating on access track design and maintenance, milking shed layout and operation, cow characteristics and behaviour, and farmer characteristics and behaviour, was collected between October 1985 and December 1987 in spring and summer. In order to minimise observer bias data was collected by a single investigator (R.N.C.). Fifteen variables, which were not measurable by objective methods, were estimated subjectively on a scale from 1 (ideal) to 5 (poor). Each scale was quantified and described by the investigator to ensure that scoring was consistent between farms. Each herd was visited during both a morning and an afternoon milking, each visit beginning when the farmer began assembling the cows to bring them to the milking shed, and ending after all cows had been milked.

Statistical analysis

The objective of this study was to identify which of the 58 risk factors examined appeared to vary significantly between high and low lameness prevalence herds, and to develop a testable hypothesis about the ways in which each of the risk factors might influence the occurrence of foot lameness. A major difficulty in analysing data of this type is that various factors are physically or biologically linked in one or more ways, and cannot be regarded as statistically independent in their effects. For example, farms with poorly maintained tracks may also tend to have more congestion points on the track, and the use of a biting dog may influence lameness both directly and also by changing the speed of movement of the cattle along the race. Thus a simple analysis which considers only differences between high and low lameness prevalence herds with regard to a single variable at a time may show apparent differences which are really due to the effect of a positively linked (correlated) variable rather than the variable actually being measured. Alternatively, a negatively linked variable may reduce the apparent effect of a variable which has genuine importance.

Statistical methods termed multivariate techniques are now available which can examine the associations between a group of potential risk factors and the outcome measure – in this case the lameness prevalence level in the herd. Such techniques are by their nature mathematically complex, and a precise statement of the methods used is given in Appendix 1. This description will give only an outline.

Preliminary analysis

As a first step the association between single variables and lameness prevalence level was tested.

Multivariate analysis

Variables which showed sufficient evidence of an association in the preliminary analysis were included in a multivariate analysis where all of these potentially important variables could be considered together. Where the outcome is dichotomous, meaning it can only take two possible alternative values (high or low prevalence level) rather than a wide range of values over a continuous range, special methods are required to deal with the statistical difficulties which arise. A suitable technique in such a case is logistic regression, which was used in the second phase of the analysis to identify significant risk factors, and interactions between pairs of factors which might be linked (see Appendix 1).

Path analysis

This was then extended into a logistic path analysis.⁽⁶⁾ In this procedure a diagram (*Fig. 1*) is drawn up to represent the

most plausible set of possible causal links in a chain leading to lameness prevalence level as the outcome variable. The decision to include a link at this stage is based on the published literature and field experience with lameness. All potentially significant links are represented by arrows from each variable to those lower down the chain which it may affect, and *Fig. 1* shows the direct and indirect links which were included in this starting "path diagram", known as a null hypothesis path model. Logistic path analysis was then used to evaluate statistically whether each of the arrows in the original diagram justified inclusion in the final diagram on the basis that its inclusion increased the ability to predict correctly whether herds fitted into the high or low prevalence groups. The final path diagram (*Fig. 2*) contains only arrows which meet this requirement. Statistical significance is shown by the number of stars attached to a path (* represents a probability of less than 5 per cent that an association is due to chance, ** represents a probability of less than 1 per cent), while the sign on a path shows whether the association is positive (high values of the risk factors associated more with high lameness prevalence level) or negative. For risk factors which can only take two values (use of footbath and whether or not the dog bites cows) calculations were made of the numerical "adjusted odds ratio", which estimates the relative risk attached to the particular factor being positive.

In this final path diagram, arrows joining two variables represent a direct potentially causal link between them, while arrows which join two variables through one or more intermediate variables represent a link which cannot be explained totally by the statistical strength of the direct association. For example, use of a biting dog influences lameness prevalence level directly, but also influences the patience of the farmer in bringing the cows in for milking, which in turn influences lameness directly, thus adding a second and separable pathway through which the dog influences lameness. In this way a statistically valid representation of a putative "causal web" for lameness prevalence level can be refined from a starting point drawn up through existing knowledge. Arrows which remain in the final diagram may represent true causal pathways, paths due to a mediating mechanism operating through unknown factors not measured in the study and hence not represented in the first path diagram, or spurious relationships. A case-control study design does not allow more definitive conclusions to be drawn, and other (usually more costly) research methods are needed to follow up the ideas generated by a case-control study.

RESULTS

Preliminary analysis

24 potential risk factors were statistically significantly associated with lameness prevalence level ($p < 0.10$). Tables I and II show the means and odds ratios of these variables. The odds ratio in Table II measures the relative likelihood that a high lameness prevalence herd will be positive for this factor, compared with a standard likelihood of 1.0 for a low lameness prevalence herd. Thus a high prevalence herd is 9.67 times more likely to have a biting dog help bring in the cows for milking, but much less likely (0.28 times) to feed meal in the milking shed. The remaining 34 variables which were not significantly associated with lameness prevalence level are listed in Tables III and IV.

Multivariate analysis

The 24 variables which were found in stage 1 to demonstrate a statistically significant association with

TABLE I: MEANS AND STANDARD DEVIATIONS (SD) OF CONTINUOUS AND ORDINAL RISK FACTORS STATISTICALLY SIGNIFICANTLY DIFFERENT BETWEEN HIGH AND LOW LAMENESS PREVALENCE HERDS IN A PRELIMINARY ANALYSIS (P<0.10)

Risk Factor	High Prevalence		Low Prevalence	
	Mean	SD	Mean	SD
Average Width of Main Track (m)	4.02	1.02	4.76	2.14
Average Maintenance State of Main Track	3.56	1.02	2.68	1.04
Number of Congestion Points along Main track	6.13	3.00	2.68	1.04
State of Worst Maintained Section of Track	4.38	0.79	3.78	1.10
Patience of Farmer behind Cows	3.13	1.02	2.0	0.88
Patience of Farmer in Shed	2.45	0.91	2.03	0.77
Space in Yard per Cow (m ² /cow)	1.27	0.51	1.08	0.22
Cow Flow on Track	2.58	0.85	1.82	0.77
Cow Movement into Bails	2.59	0.79	2.12	0.82
Contentment of Cows in Bails	2.14	0.74	1.68	0.82
Ground Surface Bails Cracked	1.06	0.25	1.30	0.65
Percent Friesian Type Cattle	66.3	32.6	46.4	36.2
Percent Jersey Type Cattle	27.3	32.9	46.3	33.8
Percent of Feet all pigmented	52.5	29.4	70.2	22.7
Percent of Feet Broken Pigmented	20.6	11.1	13.9	11.3
Percent of Feet White Colour	26.6	20.1	14.2	12.5

Factors are measured on a subjective score from 1 (good) to 5 (poor), if not stated otherwise

TABLE II: UNADJUSTED ODDS RATIOS OF DICHOTOMOUS RISK FACTORS (YES/NO) SIGNIFICANTLY ASSOCIATED WITH LAMENESS PREVALENCE LEVEL IN A PRELIMINARY ANALYSIS (P<0.10)

Risk factor	Odds ratio	95% Confidence Interval		
Use of Foot Bath	2.13	0.50	–	9.09
Backing Gate Moved Manually or with Motor (manually = yes)	2.78	0.56	–	13.9
Use of Dog	2.29	0.54	–	9.81
Use of Biting Dog	9.67	1.24	–	75.3
Attraction to Milking Shed by Feeding Meal	0.28	0.01	–	1.52
Feeding Zinc Supplement	0.49	0.12	–	2.03
Use of Backing Gate Bell	4.2*10 ⁻⁴	1.9*10 ⁻¹⁵	–	9.5*10 ⁷
Turnstyle Milking Shed Type	0.29	0.08	–	1.04

TABLE III: MEANS AND STANDARD DEVIATIONS (SD) OF CONTINUOUS AND ORDINAL VARIABLES NOT SIGNIFICANTLY ASSOCIATED WITH LAMENESS PREVALENCE LEVEL IN A PRELIMINARY ANALYSIS (P<0.10)

Risk Factor	High Prevalence		Low Prevalence	
	Mean	SD	Mean	SD
Herd Size	177.8	69.6	192.1	76.2
Longest Track Length (m)	1098	329.2	1103	533.8
Number of Tracks	1.81	0.78	2.07	0.87
Total Track Length (m)	1702	938.5	1736	1024.0
Average Slope of Main Track	2.47	0.84	2.33	1.09
Slope of Steepest Sections of Track	3.44	1.29	3.5	1.01
Number of Congestion Points along Total Track Length	5.85	3.10	4.80	2.13
Percent Concrete of Total Track	13.6	18.7	16.5	23.4
Percent Gravel etc. of Total Track	86.4	18.7	83.5	23.4
Yard Surface Slippery	1.88	1.04	1.77	0.94
Yard Surface Cracked	2.16	1.14	1.97	0.96
Ground Surface Bails Slippery	1.72	1.14	1.37	0.76
Milking Time in Spring per Cow (min)	0.70	0.20	0.64	0.22
Milking Time on Day of Visit per Cow (min)	0.62	0.19	0.55	0.19
Total Milking Time in Spring (min)	115.5	30.4	110.8	26.4
Total Milking Time on Day of Visit (min)	100.5	26.1	94.5	22.6
Number of Times Backing Gate Used	7.19	4.15	6.83	4.04
Speed of First Cow on Track (m/min)	53.2	10.9	53.2	10.11
Speed of Last Cow on Track (m/min)	42.0	8.16	43.3	8.88
Average Speed of First and Last Cow (m/min)	47.6	8.98	48.5	8.27
Contentment of Cows in Yard	2.09	0.94	1.8	0.89
Number of Bails in Shed	15.7	7.75	19.5	11.6
Percent Cows Breed Other than Friesian or Jersey	6.09	14.4	7.3	14.3
Percent Feet with Poor Conformation	22.0	8.33	19.6	7.5

Factors are measured on a subjective score from 1 (good) to 5 (poor), if not stated otherwise

lameness prevalence level were then examined by logistic regression, and 10 provided a statistically significant contribution to explaining variation in lameness prevalence level. The final logistic regression model includes the following 10 risk factors, which are listed in order of entry to

the regression equation: "Patience of Farmer behind Cows", "Average Maintenance State of Main Track", "Space in Yard per Cow", "Use of Foot Bath", "Attraction to Milking Shed by Feeding Meal", "Use of Dog", "Feeding Zinc Supplement", "Contentment of Cows in Bails", "Percent Friesian

TABLE IV: DICHOTOMOUS VARIABLES NOT SIGNIFICANTLY ASSOCIATED WITH LAMENESS PREVALENCE LEVEL IN A PRELIMINARY ANALYSIS (P>0.10)

Frequency of Foot Bathing
Type of Foot Bath Solution
Use of Motor Bike
Use of Barking Dog
Use of Backing Gate with Dog
Use of Electric Backing Gate
Pressure exerted on Cows using Backing Gate
Drenching for Bloat carried out in Bails
Magnesium Supplementation Given
Trace Element Supplementation Given

Type Cattle” and “Use of Biting Dogs” (Table V). This model explains 77.1 per cent of the deviance (variation) in “Lameness Prevalence Level”. The first model, based solely on the risk factor “Patience of Farmer Behind Cows”, already represented a good fit to the data (Hosmer’s Chi squared test of goodness of fit $p>0.75$). When biologically plausible first order interactions between variables were allowed to enter into the model, it was possible to account for 99.9 per cent of the deviance in “Lameness Prevalence Level”. In this model “Patience of Farmer Behind Cows”, “Average Maintenance State of Main Track”, “Space in Yard per Cow”, “Use of Foot Bath”, “Attraction to Milking Shed by Feeding Meal”, “Dog Used”, “Feeding Zinc Supplement”, “Contentment of Cows in Bails” contributed significantly to explaining the deviance: The first order interactions between the variable “Space in Yard per Cow” and the factors “Patience of Farmer Behind

Cows” and “Dog Used” also contributed to explaining the deviance.

Path analysis

Fig. 1 shows the null hypothesis or starting model, and Fig. 2 describes the final path model. The final model was divided into three main clusters by grouping together variables which shared common features considered to be epidemiologically relevant – those which related to animal characteristics, the situation of the track or the situation in the shed. All statistically significant variables fitted into one of these three categories. Tables VI and VII give information on logistic regression coefficients and goodness of fit of each of the three component models.

The first cluster consists of factors representing risk factors on the track. If the score given the “Worst Maintained Section of Track” is unfavourable, the more likely it is that the farmer uses a foot bath for the cows. “Average Maintenance State of Main Track” is positively associated with “Worst Maintained Section of Track”. Poor average maintenance has a direct negative effect on “Cow Flow on Track” and an indirect negative influence on cow flow because it is also associated with a higher “Number of Congestion Points on Main Track”. Farmers tend to be less patient in herds where “Cow Flow on Track” is poor or where their dogs bite the cows while they are being brought for milking. The risk of high “Lameness Prevalence Level” increases with poor “Cow Flow on Track”, “Average Maintenance State of Main Track” and with “Use of Foot Bath”. This component model explains 40 per cent of the deviance or variation associated with “Lameness Preva-

TABLE V: BETA- COEFFICIENTS* AND STANDARD ERRORS OF THE FINAL LOGISTIC REGRESSION MODEL, NOT INCLUDING INTERACTION TERMS

Risk Factor	Beta- coefficient	Standard error
Patience of Farmer behind Cows	3.01	1.81
Average Maintenance State of Main Track	2.89	1.27
Space in Yard per Cow	7.78	3.45
Use of Foot Bath	2.43	1.20
Attraction to Milking Shed by Feeding Meal	-2.82	1.67
Use of Dog	1.58	0.88
Feeding Zinc Supplement	-2.02	1.35
Contentment of Cows in Bails	2.30	1.23
Percent Friesian Type Cattle	0.04	0.02
Use of Biting Dog	3.61	4.13

*Per unit increase in the variable

TABLE VI: BETA COEFFICIENTS OF THE COMPONENT MODELS PREDICTING LIKELIHOOD OF HIGH OR LOW LAMENESS PREVALENCE LEVEL

Model	Independent Variable	Beta- coefficient	Beta coefficients S.E.	p- value
Risk factors on track	Patience of Farmer behind Cows	1.73	0.45	0.001
	Average Maintenance State of Main Track	1.25	0.43	0.005
	Use of Foot Bath	1.44	0.76	0.064
Risk factors in shed	Use of Biting Dog	2.62	1.25	0.040
	Contentment of Cows in Bails	1.29	0.44	0.005
	Space in Yard per Cow	2.84	1.23	0.025
Risk factors in cows	Percent Feet Colour White	0.046	0.018	0.012

TABLE VII: GOODNESS OF FIT OF THE COMPONENT MODELS PREDICTING HIGH AND LOW LAMENESS PREVALENCE LEVEL

Model	Deviance	d.f.	p- value	Rank Correlation
Risk factors on track	51.5	58	0.713	0.68
Risk factors in shed	65.7	58	0.227	0.53
Risk factors in cows	77.7	60	0.062	0.37

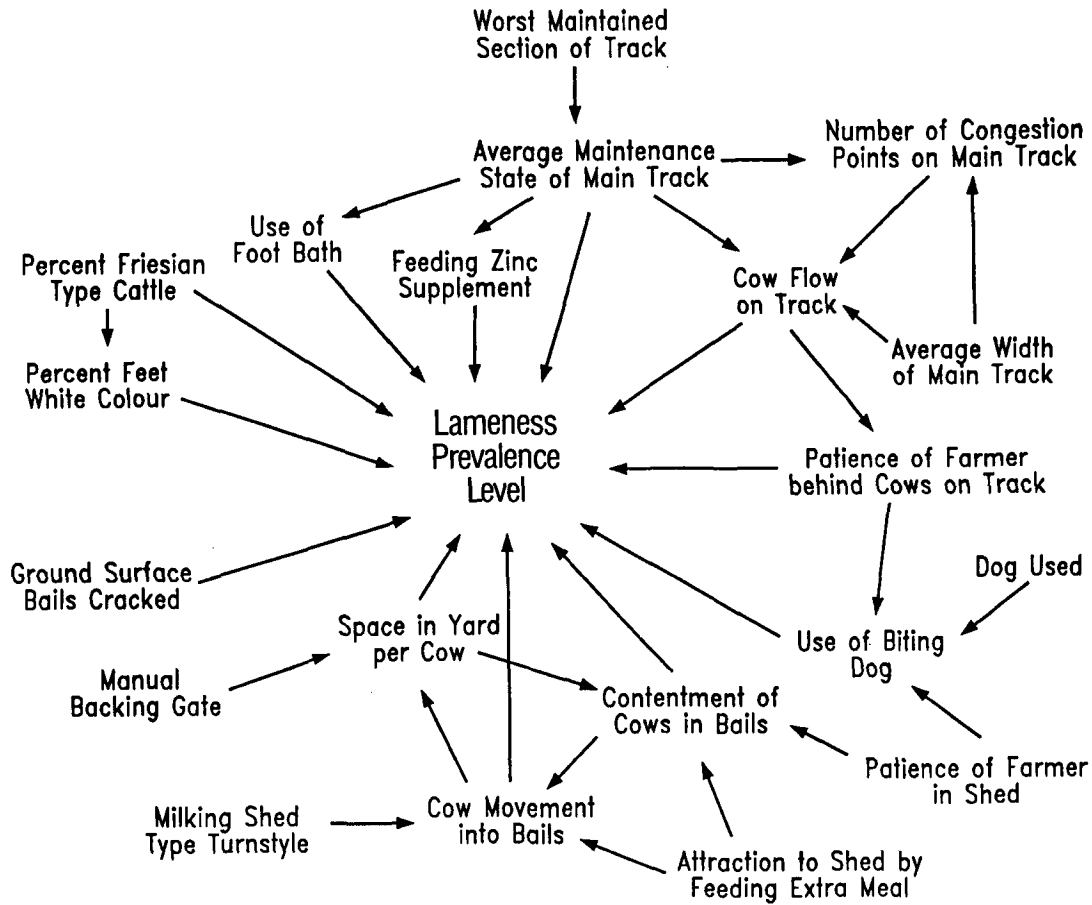


Fig. 1: Null hypothesis path model.

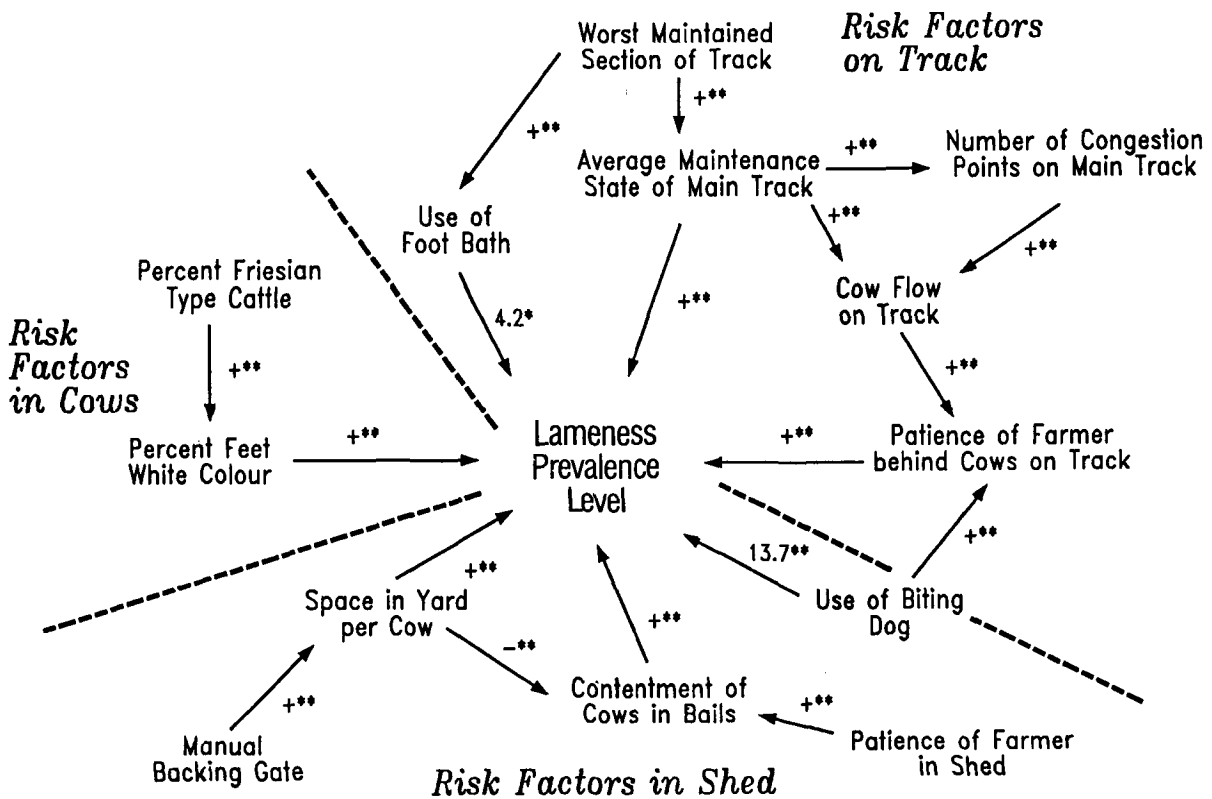


Fig. 2: Final path model.

lence Level". "Patience of Farmer behind Cows" alone accounts for 21.7 per cent of the variability and "Average Maintenance State of Main Track" adds another 13.7 per cent. "Cow Flow on Track" was not statistically significantly influenced by "Dog Bites" and Average Width of Main Track". "Feeding Zinc Supplement" appeared at first to be associated with lower lameness prevalence level, but it was found to be confounded with "Average Maintenance State of Main Track". When adjusted for the effects of other risk factors in the model, zinc feeding did not contribute significantly in predicting the likelihood of high or low lameness prevalence.

The variables of the second cluster describe risk factors in the shed. If the farmer is less patient on the track, it is more likely that he is also less patient in the shed. "Contentment of Cows in Bails" is worse if the farmer is less patient or if the cows have less space in the yard. "Space in Yard per Cow" is large on farms where the backing gate is moved manually. A high "Lameness Prevalence Level" is more common on farms with more space for each cow in the yard, or if cows are less content in the bails or if the dog bites. This component model explains 23.5 per cent of the deviance of "Lameness Prevalence Level". "Use of Biting Dog" contributes 7.7 per cent and "Contentment of Cows in Bails" another 6.95 per cent. Adjusted for the other variables in the component model, herds with high lameness prevalence level are 13.7 times more likely to have a biting dog. This particular variable presented intriguing problems in the analysis. The use of a biting dog can influence cow behaviour both on the track and in the milking yard. If the variable was placed in the cluster of "track factors", the deviance was absorbed by the variable "Patience of Farmer Behind Cows" and hence "Use of Biting Dog" was itself not significant. In other words, the two measures represent what is basically the same risk factor – forcing cows to walk at an abnormal pace, without adequate scope for selecting their path. However if "Use of Biting Dog" was included in the shed cluster it was the single most important explanatory variable in the group, having a direct effect on "Lameness Prevalence Level". It is not possible to determine from the data whether this difference represents a true effect of the dog both on the track and in the milking yard, or whether it is a statistical artefact. Adjusted for the effects of other risk factors already in the model "Contentment of Cows in Bails", "Patience of Farmer in Shed", "Attraction to Milking Shed by Feeding Meal" and "Manual Backing Gate" did not significantly contribute to explaining deviance in "Lameness Prevalence Level".

The third cluster consists of variables describing animal characteristics. There is a high collinearity (i.e. interchangeability) between the variables describing the percentage of breed type and the ones describing colour of feet (Rank correlation >0.83). Therefore the variable with the highest correlation to "Lameness Prevalence Level" from each group was included in the path analysis. "Percentage Feet White Colour" was positively associated with "Percentage Friesian Type Cattle". In herds with high "Lameness Prevalence Level" "Percentage Feet White Colour" was higher. This risk factor explains 9.5 per cent of the deviance in the outcome variable "Lameness Prevalence Level".

DISCUSSION

As the simpler disease problems are solved, those with more complex causes involving multiple interacting factors become of increasing relative importance. Research techniques well suited to studying single cause-effect relationships are not

well suited to clarifying which out of a range of possible interlocking pathways are genuinely important in a multifactorial disease problem. Foot lameness in dairy cattle is such a problem where numerous factors are thought to contribute to determining the severity of the problem, on any particular farm, but it is difficult to distinguish their separate contributions and the links between related variables.

The methods used in this study allow the linkages between single factors in the proposed causal chain to be investigated, and a proposed set of causal pathways to be examined and reduced to a smaller number of statistically significant paths. In this way 33 arrows were included in the original diagram, between 20 variables drawn by statistical analysis from the original 58. After the path analysis had been completed there were 19 arrows joining 13 variables in a statistically and biologically plausible explanatory diagram which provides ideas on how lameness occurrence could be investigated and perhaps influenced. It must be accepted that the number of farms studied is at the bottom end of the acceptable range for the use of a technique such as logistic path analysis, but the time demands for the field work made it impossible to conduct a larger study from within a veterinary practice. The aim of the study was to generate ideas for investigation by other methods.

The two factors which are most strongly linked to high prevalence of lameness in dairy cattle herds are the average maintenance state of the main track and the patience of the farmer handling the cows on the track. Farms where average track maintenance was poor or where the farmer demonstrated less patience with the herd on the track, were significantly more likely to have a high level of lameness prevalence. These two factors provided by far the largest contribution to explaining the difference in lameness prevalence value.

The finding that poor average maintenance state of the main track increases the risk of lameness supports the suggestion made by Bridges.⁽⁵⁾ Patience behind the cow was shown to be positively associated with average track maintenance both directly and also indirectly through an intermediate variable (Cow Flow on Track). Other researchers have reported that lameness prevalence is increased if the farmer hurries with the cows along the track, and even more if he tends to harass them.⁽⁵⁾⁽²⁷⁾ Amstutz⁽²⁾ emphasizes that one of the more frequently observed management errors that result in lameness is rough handling, such as crowding animals through narrow doorways or hurrying them across slippery floors. He recommends that dairy cows should always be handled quietly and slowly to prevent injuries.

The positive association between the presence of a foot bath and lameness has to be seen more as an effect of higher lameness prevalence than as a cause. That means farmers who have a lameness problem in their herd are more likely to use a foot bath. But it indicates also that regular use of a foot bath should be encouraged in herds with a high prevalence of interdigital disease, heel erosion and solar ulceration. Otherwise it would be unlikely to be of benefit. This leads to the suggestion that other important causal factors seem to be involved in the case herds in this study which may not be controllable by a foot bath. Radostits and Blood⁽²³⁾ question the effectiveness of foot baths for the general control of diseases of the feet of cattle, because the recommendations are empirical and no supporting evidence has been published. The presence of a foot bath was found to be highly significantly associated with the score of the worst maintained part of the track. A possible explanation for this causal chain could be that farmers with a badly maintained track encountered

more problems with lameness and tried to solve them by introducing a foot bath, which did not solve the underlying causes of the lameness problem.

Greenough⁽¹³⁾ reports that some workers claim that zinc supplementation may reduce the prevalence of lameness. The results of this study cannot prove this, but low prevalence farms seem significantly more likely to use zinc supplementation. The 95 per cent confidence interval of the odds ratio includes 1, which does not allow conclusions to be drawn from this result. Zinc supplementation is given in New Zealand as a preventive measure against the unrelated mycotoxic disease facial eczema, and farmers who manage their cows to minimise lameness may also be more inclined to take preventive measures against facial eczema.

Among the risk factors in the shed the presence of a biting dog is the most important one. As described earlier, this factor can also be included in the cluster describing the situation on the track, where it has only an indirect effect through patience of the farmer. It appears likely that the use of a biting dog is significant both on the track and in the yard, but for statistical reasons it can be distinguished more clearly when it is analysed in a separate cluster from "Patience of Farmer behind Cows on the Track", since the two factors are so closely related that they cannot be distinguished when they are analysed together. The space available for each cow in the yard has conflicting direct and indirect effects on lameness prevalence. The lower the density of cows in the yard the higher is the risk of lameness. Under these conditions, with cows having more space for individual movements, there seems to be a higher probability of foot injuries. Nevertheless they are more content under low density conditions. And the herds with more content cows are at a lower risk of high lameness prevalence. The contentment of the cows in the shed is negatively influenced by less patient behaviour of the farmer in the shed.

The results of this study show that several risk factors modify the social behaviour of the cows. Factors such as the patience of the farmer in handling the cows and use of a biting or non-biting dog interfere with the social forces of leadership and dominance controlling spacing and order within a moving cow herd.⁽⁷⁾ If the cows are under pressure from the farmer or his dogs, crowding is likely to develop and thus the choice of foot placement may be restricted. The available space per animal in the yard and the type of backing gate interfere with the spacing requirements of cows. Metz and Wierenga⁽¹⁸⁾ call close proximity one of the main causes of aggression in cattle. Potter and Broom⁽²²⁾ write that mechanical damage to the feet will frequently result from competitive social interactions in which animals are engaged in pushing contests or when one animal moves rapidly to avoid an aggressor. Yet it is not possible to give a minimum distance as the mean inter-individual distance varies with the confidence of the animal in the social situation. Arnold⁽⁴⁾ writes that cows low in social dominance rank move about more than those that rank high, to avoid infringing on the personal space of dominant animals. Albright⁽¹⁾ compared aggressive activity between cows kept in a corral under crowded and uncrowded (4 times as much space) conditions. He came to the conclusion that cows under restricted spacing conditions were in fact less active and had less encounters with herdmates. He writes that the situation might be different once the group size is too big for animals to recognise herdmates and their status in the social order. This could explain the result of this study which suggests that lameness prevalence was lower if less space in

the yard was available per cow. Estimates of maximum herd sizes for recognition of individual herd members range from 50 to about 100 animals.⁽¹⁾⁽¹⁰⁾⁽¹⁵⁾ The average herd size in this study was 185 (s.d. 72.5) animals.

In high lameness prevalence herds it was more likely that on average the feet of the cows were less pigmented (which is more common in Friesian type cattle) and that the percentage of Jersey type cattle was low. Peterse⁽²¹⁾ reports that when cattle breeds are compared for lameness, black-and-white breeds appear to be more susceptible and Jerseys seem to have considerably less claw problems. Radostits and Blood⁽²³⁾ quote that lameness may be more common in certain heavy breeds such as the Holstein-Friesian than in lighter breeds like the Ayrshire, Guernsey, and Jersey. This may be due to different growth and wear rates of hoof horn. Webster⁽²⁶⁾ states that black hooves are harder than white ones.

The risk factors were grouped into three clusters. One describes the situation on the track, the second the situation in the shed and the third the characteristics of the cows. The risk of high lameness prevalence was mainly determined by the factors on the track. Characteristics of the animals were of lowest importance. The importance of the cluster of risk factors on the track may be due to the fact that in New Zealand cattle are kept on pasture throughout the year and cows have to walk the distance between their pasture and the milking shed four times a day. In the study area the average length of the longest race was 1.1 km (s.d. 0.437).

From the information gathered in this study it can be concluded that the main areas of advice for farmers having a problem of high lameness prevalence in their dairy herds should be on the maintenance of the track and animal handling. Farmers may well not be aware of the importance of regular and efficient maintenance of the track.⁽⁵⁾

A case-control study is a cheap and efficient way to identify associations between the occurrence of a disease and risk factors which may (either positively or negatively) influence it. However it cannot prove that the associations are cause-effect relationships – other epidemiological methods such as cohort study or intervention study are required to test the hypotheses which arise out of the initial case-control study.

It is accepted that the limitations of case-control studies combined with the relatively small number of herds (62) included in the study should make the reader cautious in over-interpreting the significance of specific findings in this study. There are various sources of bias which could potentially affect interpretation of the results, especially the fact that many of the variables had to be assessed subjectively. Therefore although the logistic regression model explains an unusually high proportion of the variability in the data, this should not be taken to show that the factors measured account for almost all the variation between herds in lameness prevalence. Nevertheless, as a practical study of controllable factors associated with the occurrence of lameness in dairy herds, it is believed that the findings are biologically plausible, helpful to veterinarians in understanding the contribution of various groups of risk factors, and provide useful guidance for the development of future research in this field.

The findings of this study suggest that emphasis in further investigations should be given to the surface of farm tracks along which cows are brought for milking, and to the patient handling of animals before and during milking as high priority areas in which changes could possibly reduce lameness in severely affected herds.

APPENDIX 1

Method of Statistical Analysis Used

Results were analysed in 3 steps. In a preliminary analysis the association of potential risk factors with lameness prevalence level was tested for static significance. The classic Chi squared test of independence was used for the analysis of categorical data.⁽⁹⁾ Other variables (i.e. continuous and ordinal) were analysed without any transformation using Student's t-test⁽²⁵⁾ Variables showing statistically significant association ($p < 0.10$) with lameness prevalence level were included in a multivariate analysis. Logistic regression was used to identify the most important risk factors.⁽¹⁶⁾ The model was built in a forward stepwise manner by progressively including variables which significantly improved the goodness of fit at a p-value of less than 0.10. Variables already included into the model were removed if the p-value exceeded 0.15 after later variables had been introduced. Only biologically plausible first order interaction terms were allowed to enter the model. The final model was selected based on the likelihood ratio test. For the final model beta regression coefficients were estimated, which represented a particular factor's effect adjusted for the effects of the other factors in the model.⁽²⁴⁾

Logistic path analysis was then used to examine the network of potential causal pathways which make up the "causal web".⁽⁶⁾ As a first step a path diagram showing the hypothetical relationship between "causes" and "effects" was set up around the variables which had on statistical grounds been included in the final logistic model. Other significant variables from the preliminary analysis considered to be of biological relevance for the structural relationship between the factors were included in this null hypothesis model.⁽²⁰⁾ All variables were regressed on the variables with paths leading to them. If the variable taken as "effect" was dichotomous, coefficients were estimated by logistic regression analysis. Least squares multiple regression was done stepwise including "causes" that significantly improved goodness of fit of the component model to the data ($p < 0.10$). Paths not statistically significant were dropped from the diagram. No path coefficients were calculated, because for the analysis of categorical data it is not possible to assign numerical values to path relationships in the manner used for continuous variables.⁽⁸⁾ Logistic regression coefficients of dichotomous risk factors can be converted into odds ratios and thus presented as numerical values.⁽¹⁷⁾ Otherwise the logistic regression coefficient should only be interpreted for indication of sign (negative or positive) attached to the path.⁽⁸⁾ The relative importance of the parameters added stepwise to a component model was assessed by evaluating their percentage contribution to a decrease in deviance.⁽¹¹⁾ Rank correlations were used to quantify the association between observed and fitted values for each component model, which gives an indication of the success of the model.⁽²⁵⁾

The computer programs used in the statistical analysis were PANACEA (PAN Livestock Services, Reading, England) and STATISTIX (NH-Analytical Software, St. Paul, Minnesota, U.S.A.).

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