A STOCHASTIC MODEL FOR ECONOMIC APPRAISAL OF DAIRY CALF MORTALITY

By

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Summary

An attempt has been made to look into economic cost of dairy calf mortality. In the light of Martin's model, a stochastic model has been developed incorporating a calf insurance scheme into it to minimise the economic loss associated with calf mortality. An illustration with hypothetical but realistic data infers that 36.42 percent of loss per calf at five weeks of age can be averted through the introduction of calf insurance.

Introduction

Of many problems during operation of dairy farm, calf mortality (CM) is one which generally makes a set-back to a dairyman or an individual and the country as a whole from economic point of view. Economics of CM provide various lines of action to follow up economically optimum schedule of calf rearing. It appears to be a first attempt by Martin *et. al.* [1] to develop a model to estimate the economic cost of dairy CM, but the model is incomplete in the sense that some factors viz. value of by-products after death of the calf, and introduction of calf insurance are not taken into account. Moreover, the rearing cost of a calf during a particular week in which a calf dies is not appropriately incorporated in the model.

A new stochastic model considering all possible factors is developed to investigate the economics of CM in this paper. In fact, an emphasis is placed on calf insurance so that a farmer or dairyman can avert his losses associated with risk and uncertainty of life of the calf.

ASSUMPTIONS AND NOTATIONS

Various assumptions and factors are considered to develop the aforesaid model. First and very important factor is the probablity that a calf will die during a given age interval. Secondly, the calf will follow one of the three states viz. death (D), survival-sale ($\bar{D}S$) or survival-no sale ($\bar{D}\bar{S}$), with the probability of a calf being in any one of these states during a given time interval being dependent on having followed one of these states in the previous time interval. Thirdly, the sale price of by-products viz. skin, meat, bone etc. if calf dies during a given age interval. The fourth factor which has been emphasised in the paper is the calf insurance. Information regarding type and terms of animal insurance contract was obtained from Fire Oriental and General Insurance Company, Bareilly, India. As per information, sum insured will not exceed 100% of market value. The market value varies from area to area, from breed to breed and time to time. The valuation of animal is generally done by veterinary doctors after complete examination. Premium rates for the animals owned by individual, institutions, co-operatives etc. will depend upon the number of animals and whether they receive regular efficient veterinary attention or not. Since the calf mortality is generally expected to be high till 12 weeks of life, the premium rates would be considerably more for calf as compared to adult one. The insurance usually cover the risk viz, death due to accident or diseases. If risk takes place, the owner of the animal would get sum insured or market value at the time of risk-taking, whichever is less. Insurance of the calves below four months of age is not being practiced so far in our country. However, in the present study we make an assumption that calves are insured from first week of their life. Thus, on the basis of the information obtained from the insurance company, the premium rate for present hypothetical data which is used to show the application of the model can intuitively be assumed as Rs. 1.5% per week per calf of its market value (*i.e.* sum insured) at the time of insurance.

Athough the operation of dairy takes place in continuous time, for the development of the model we shall assume that risk-taken occurs at discrete interval with none of the relevant criteria of the model undergoing any changes in numerical values in the interval of time between risk-taking trials. This discrete approximation to continuity is usually reasonably good provided the time interval under study is short as compared to average life span of an economically productive animal. Following are some necessary notations.

which will be used for the development of the model.

q_i : Probability of dying during i-th week the age.

$p_i=1-q_i$: Probability of surviving through the i-th week to the beginning of $(i+1)$th week of age.

s_i : Probability of being sold during i-th week of age given that calf survives through $(i-1)$th week.

$s_i=1-s_i$: Probability of not being sold during i-th week of age given that calf survives through $(i-1)$th week.

p_{ij} : Probability associated with j-th event (death, survival-sale & survival-no sale) during i-th week of age.

d_i : Number of days that calf survives during i-th week of age given that calf survives through $(i-1)$th week.

T : The complete life time in weeks after birth.

t : Variable time index taking integer values from 1 to T.

V_t : Sale price of calf during week t.

P_t : Sale price of by-paoducts of calf dies during week t.

I_i : Premium of calf insurance for i-th week.

$\alpha_i I_i$: Maximum indimnity payable at death during i-th week of age, α_i is the cooption value for i-th week depending upon breed, climatic zones, environmental factors etc.

B_i : Cost of building attributable to the care of a given calf during i-th week of age.

L_i : Cost of labour attributable to the care of a given calf during i-th week of age.

F_i : Cost of feed attributable to the care of a given calf during i-th week of age.

M_i : Cost of medical care attributable to the care of a given calf during i-th week of age.

C_i : Total cost attributable to the care of the given calf during i-th week of age, mathematically.

$$C_i=B_i+L_i+F_i+M_i$$

r_{ij} : The monetary return associated with j-th event during i-th week of age.

R_D : The expected monetary return if calf dies.

$R_{\bar{D}S}$: Expected monetary return if calf survives and ultimately the calf is sold out.

$R_{\bar{D}\bar{S}}$: Expected monetary return if calf survives and ultimately the calf is not sold out. It is usually zero.

R : Total expected monetary return.

Development of Stochastic Model

To build up a stochastic model, it is started by considering the fate of the calf from birth until time, T, the probability that the calf will experience a specified fate, and expected monetary return to the dairyman or individual associated with a specified fate.

To start with, let us consider first week the week begins on the day of the birth of the calf. The three possible events which can take place during this week are :.

(*i*) the calf enters into state D (Death) or

(*ii*) the calf enters into state $\bar{D}S$ (the calf survives throughout the week and is sold at the end of the week) or

(*iii*) the calf enters into state $\bar{D}\bar{S}$ (the calf survives through out the week and is not sold but allowed to be in either of the states excluding birth, begins all over again in the next week). These events are mutually exclusive and exhaustive. The probabilities associated with these events in first week are

$$p_{11}=q_1 \qquad \ldots(3.1)$$

$$p_{12}=p_1 s_1 \qquad \ldots(3.2)$$

$$p_{13}=p_1 \bar{s}_1 \qquad \ldots(3.3)$$

respectively. The monetary return associated with these events are given below :-

$$r_{11}=P_2+ \alpha_1 I_1-(V_2+d_1C_1/7+I_1) \qquad \ldots(3.4)$$

$$r_{12}=V_2-C_1-I_1 \qquad \ldots(3.5)$$

$$r_{13}=0 \qquad \ldots(3.6)$$

respectively.

The coefficient $d_1/7$ of C_1 in (3.4) will enable us to determine a reasonable cost of the care of a given calf if the calf dies after d_1 days in the first week.

Now, if calf survives throughout the first week and is not sold, then second week starts and the same three events are repeated all over again. The probabilities of these events in this week are now

$$p_{21}=p_1\,\bar{s}_1\,q_2 \qquad \ldots(3.7)$$

$$p_{22}=p_1\,\bar{s}_1\,p_2\,s_2 \qquad \ldots(3.8)$$

$$p_{23}=p_1\,\bar{s}_1 p_2\,\bar{s}_2 \qquad \ldots(3.9)$$

respectively. The monetary return associated with these events in the second week are given below :—

$$r_{21}=P_2+\alpha_2 I_2-(V_2+C_1+d_2C_2/7+I_1+I_2) \qquad \ldots(3.10)$$

$$r_{22}=V_3-(C_1+C_2+I_1+I_2) \qquad \ldots(3.11)$$

$$r_{23}=0 \qquad \ldots(3.12)$$

respectively.

Continuing in this way and supposing that the calf survives throughout $(t-1)$ weeks and is not sold, the same three events occurring during t-th week are considered. The probabilities of these events in t-th week would be, respectively, as follows :—

$$p_{t1}=\left[\prod_{i=1}^{t-1} p_i\bar{s}_i\right] q_t \qquad \ldots(3.13)$$

$$p_{t2}=\left[\prod_{i=1}^{t-1} p_i\bar{s}_i\right] p_t\,s_t \qquad \ldots(3.14)$$

$$p_{t3}=\prod_{i=1}^{t} p_i\bar{s}_i \qquad \ldots(3.15)$$

The monetary return associated with these events in t-th week are given, respectively, as follows :

$$r_{t1}=P_t+\alpha_t\,I_t-(V_t+\sum_{i=1}^{t-1} C_i+d_tC_t/7+\sum_{i=1}^{t} I_i) \qquad \ldots(3.16)$$

$$r_{t2}=V_{t+1}-\sum_{i=1}^{t}(C_i+I_i) \qquad \ldots(3.17)$$

$$r_{t3}=0 \qquad \ldots(3.18)$$

The expected monetary return over a period of T weeks associated with first event, *i.e.*, the death of the calf at some time up to T, is therefore given by

$$R_D = \sum_{t=1}^{T} p_{t1}\, r_{t1} \qquad \ldots(3.19)$$

The expected monetary return over a period of T weeks associated with second event, *i.e.*, the survival and subsequent sale of the calf at some time up to T, is therefore given by

$$R_{\bar{D}S} = \sum_{t=1}^{T} p_{t2}\, r_{t2} \qquad \ldots(3.20)$$

Similarly, the expected monetary return over a period of T weeks associated with third event, *i.e.*, the survival and subsequent sale of the calf at some time up to T, is therefore given by

$$R_{\bar{D}\,\bar{S}} = \sum_{t=1}^{T} p_{t3}\, r_{t3} \qquad \ldots(3.21)$$

Thus, the total expected monetary return to an individual or dairyman over a period of T weeks associated with these three events is given by

$$R = R_D + R_{\bar{D}S} + R_{\bar{D}\,\bar{S}}$$

$$= \sum_{t=1}^{T} (p_{t1}\, r_{t1} + p_{t2}\, r_{t2} + p_{t3}\, r_{t3}) \qquad \ldots(3.22)$$

Since $r_{t3}=0$ for all t, then expression (3.22) reduces to

$$R = \sum_{t=1}^{T} (p_{t1}\, r_{t1} + p_{t2} r_{t2}) \qquad \ldots(3.23)$$

The expression (3.23) is our stochastic model to determine the economic cost of dairy calf mortaiity.

APPLICATION OF THE MODEL

To illustrate the application of model, we have considered a hypothetical but realistic example of a herd consisting of 200 cows.

Assuming that 100 live heifer calves were born, of which 20 died in the first five weeks of life according to the table given below :-

Week :	1	2	3	4	5
Died :	8	7	3	1	1

Using life-Table method, the respective probabilities of survival and deaths of the calves during each one week interval are obtained and shown in Table 1.

Table-1

Life table of survivalship of dairy calves

i	0_i	c_i	q_i	p_i
1	100	8	0 080	0.920
2	92	7	0.076	0.924
3	85	3	0.035	0.964
4	82	1	0.012	0.988
5	81	1	0.012	0.988
6	80	0	—	—

i=time in week after birth, 0_i=number of calves alive at least i week after birth, c_i=number of calves dying between i-th and $(i+1)$th week, q_i and p_i are already definnd in section 2.

Table 2 represents the cumulative cost to raise dairy calves to five weeks of age, and sale price of the calves during each week. The costs shown in the table are based on a report from National Dairy Research Institute, Karnal, India. The average

Table-2

Cumalative cost to raise dairy calves to five weeks of age, and average sale price of the calves

Weeks	*Cost (in Rs.)*	*Average sale price (in Rs.)*
1	75.00	150.00
2	99.00	190.00
3	123.00	230.00
4	137.00	270.00
5	150.00	310.00
6	—	350.00

sale price of heifer calf at birth is assumed to be Rs. 150.00, with an increase in value of Rs. 40.00 per week during first five weeks of life.

Information on sale price of by-products of calf if dies are obtained from Contract section of Indian Veterinary Research Institute, Izatnagar, India. The sale price of by-products do not change substantially ever weeks, particularly in the present case when we have considered the calves up to five weeks of age. But, it is not constant over years as it depends upon market, place, contract per year etc. However, from information available in hand we have arrived on an average sale price of by-products as Rs. 5.00 per calf.

Before we apply the aforesaid data into model, certain assumptions need to be made in the absence of reliable and complete Life-Table on calf mortality. We first assume that calf deaths during a week occur uniformly throughout the week. Under this assumption, a calf dying in week t is as likely to die before mid week as after. Thus, on an average, the cost of the care of a calf during week t is half of C_t, the total cost of the care of the calf provided the calf would have survived the entire week t. The term $d_t C_t/7$ in the expression (3.16) would, therefore, be replaced by $C_t/2$. We further assume that the calves are not sold until they reach the end of 5th week of life. Therefore, $s_i=0$ for $i=1, 2, 3$ & 4, and $s_i=1$ for $i=5$ as calf is sold at age of 5 weeks old.

All the necessary data would now be applied into model to complete the economic loss associated with calf mortality. It is obvious from the model (3.23) that there are two components R_D and $R_{\bar{D}S}$ contributing towards the total expected monetary return R. Since we have already assumed to sell the calves at age 5 weeks old, the expression in the model will be summed up from 1 to 5. Table 3 below gives the expected monetary returns to a dairyman during each week associated with the events over a period of 5 weeks under proposed and Martin's model. In column 3 & 6 the monetary returns are nil up to 4 weeks as it was decided to sell the calf at the age of 5 weeks old. Thus, the total expected monetary return per calf to a dairyman over a period of 5 weeks would be Rs. 129.83. Had been the mortality rate zero the dairyman could have on an average received Rs. 188.75 (*i.e.*, Rs. 350.00 Rs. 150.00-Rs. 11.25 as premium for calf insurance in five weeks=Rs. 188.75) per calf at 5 weeks of age. Therefore, a dairyman is in loss of Rs. 58. 92 per calf because of 20% calf mortality rate.

Table-3

Expected monetary return during each week

t	*Under proposed model*			*Under Martin's model*		
	$pt_1\ rt_1$	$pt_2\ rt_2$	*Total*	$pt_1\ rt_1$	$pt_2\ rt_2$	*Total*
1	—2.78	—	—2.78	—15.00	—	—15.00
2	—8.86	—	—8.86	—19.37	—	—19.37
3	—5.78	—	—5.78	—10.17	—	—10.17
4	—2.54	—	—2.54	— 3.92	—	— 3.92
5	—3.10	152.89	149.79	— 4.40	160.16	155.76
Total :	R_D=—23.06 $R_{\bar{D}}S$=152.89 R=129.83			$R_{\bar{D}}$=—52.86 $R_{\bar{D}}S$=160.16 R=107.30		

The model (3.23) reduces to martin's Model when $P_t=0$ for all t, I_t and $\alpha_t I_t$ are zero for all t, that is no calf insurance and $d_t C_t/7$ is replaced by $C_t/2$. We shall now find out the extent of loss which can be averted through calf insurancc by applying all necessary aforesaid data into Martin's model. Having done all calculations on similar lines as we did for the model (3.23), the total expected monetary return per calf to a dairyman over a period of 5 weeks is obtained to be Rs. 107.30 (Table 3). But, if the calf mortality rates were zero, the total expected monetary return to a dairyman could have been Rs. 200.00 per calf at 5 weeks of age. Thus, a dairyman suffers a loss of Rs. 92.70 per calf as result of 20% calf mortality rate. Now comparing the two losses as a result of 20% calf mortality, it is found that 36.42% of loss per calf at 5 weeks of age can be averted through the introduction of calf insurance.

Concluding Remarks

Results in the preceeding sections revealed that when calves were assumed to be insured there was reduction in loss by 15.13% because of calf iusurance. Reduction in loss through calf insurance will however, depend upon the premium rates, sum insured, and return from insurance if risk take place. Nevertheless that much of reduction of loss would be worthwhile in the economy of dairy enterprises and even to a dairy farmer.

The model can be used to predict the economic loss associated with calf mortality at a future time under given market and

management condition. In fact, the whole application of the model rest on practical and reliable data on completet life-table of calves, their market and management condition etc. which we lack at pressnt.

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