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# On a Model for Estimating Losses due to Foot and Mouth Disease in India

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SUMMARY

A model has been developed by incorporating a cost-benefit analysis system to study the merits and demerits of various strategies used to prevent, control or eradicate a disease in its operative area. This model will help in estimating the economic losses caused by morbidity and mortality and gain derived due to introduction of vaccination programme as a main strategy to control the disease. The model developed in the present study is

$$R = \sum_{t=1}^{T} \left(p_{t1}\ r_{t1} + p_{t2}\ r_{t2}\right) - v$$

Application of the model has been demonstrated by using data collected from FMD outbreak at IVRI, Izatnagar (U.P) cattle farm. The overall expected economic losses due to morbidity and mortality were Rs. 15.44 and Rs. 4.58 respectively which were 3.16% and 0.94% respectively of the average price value of animals. The overall total expected economic loss due to morbidity and mortality combined was Rs. 20.02 amounting to 4.10% of the average price value of the animals in the farm. Though presently the total cost of vaccination per animal per dose is Rs. 4.00 including Rs. 3.50, the price of one dose of vaccine, even then vaccination strategy for controlling the FMD in the country is a profitable preposition in endemic areas. Even in the absence of mortality which is not a common phenomena in Zebu breeds, vaccination of the animals against FMD is still a profitable strategy in Indian context in the endemic areas.

*Key words:* Model, Economic losses, Foot and mouth disease.

## *1. Introduction*

To evaluate the improvement in production and welfare, it is necessary to develop a model containing costs of resources required for implementing the programme and at least capable of estimating direct economic losses caused by FMD outbreak in a population. It is better, if one can accommodate indirect economic losses, like deliterious effect on food conversion efficiency, secondary mastitis infection, reduction in agricultural output attributable to lameness of draught animals, restriction on the world trade and deviation from the optimal production system due to risk and uncertainty caused by FMD also in the model but it is really difficult to quantify them. However, it is important to mention here that this model is so developed that indirect losses could also be easily incorporated in the model without any further mathematical derivation subject to their quantification.

It is difficult to exactly quantify the losses that will be caused by FMD at any given rate of incidence as they are dependent upon many variable factors including age, breed condition, production state, immune status of host, pathogenicity of the virus strain and environmental factors such as the presence of organism causing secondary infections.

James and Ellis [2] discussed in detail benefit cost analysis of FMD control programme. They identified certain losses which were difficult to be quantified. They also established that the benefit excessed the cost of a factor between 5:1 and 8:1 though no methodology has been mentioned to arrive this conclusion.

Review of literature revealed that no attempt has been made to develop a model to assess the economic losses caused by FMD. Keeping above situations in view, a model has been developed incorporating all possible factors responsible for economic losses due to FMD. This model will enable the investigator to simulate all possible situations going to arise in a FMD outbreak so that merits of various strategies could be ascertained.

## 2. *The Model*

Assumptions and Notations

Various assumptions and factors are considered to develop the aforesaid model. These are:

(i) The animal will follow one of the three states, viz., the animal will get infected by FMD and will die (ID), the animal will get infected by FMD and will survive ($I\bar{D}$), he will not be infected by FMD ($\bar{I}$).

(ii) Individual infected by a virus type in a particular time interval will acquire immunity after recovery against that for a definite period.

(iii) The animal will die or survive provided he has been infected in the same time interval or in any time interval.

(iv) The incubation period is constant.

Each epidemic should be divided into intervals of the length of incubation period of the disease in such a way that, in so far as possible, there is a clustering of cases in the middle of each interval.

Although the disease operates in continuous time, for the development of the model we shall assume that risk of attack of disease occurs at discrete interval. This discrete approximation to continuity is usually reasonably good because 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 this model :

$p_i$ = probability of getting infected during i-th interval of epidemic.

$q_i$ = $(1 - p_i)$ = probability of not getting infected during i-th interval of epidemic.

$a_i$ = probability of dying during i-th interval given that animal got infected before or during i-th interval of epidemic.

$\bar{a}_i$ = $1 - a_i$ = probability of not dying during i-th interval given that animal got infected before or during i-th interval of epidemic.

$p_{ij}$ = probability associated with j-th event (got infected and survived, got infected and died, not-infected) during i-th interval of epidemic.

T = The complete epidemic period in intervals after outbreak of epidemic.

t = Variable time index taking integer value from 1 to T.

$A_t$ = Sale price of animal died during interval t.

$B_t$ = Sale price of by-products of animal die during interval t.

$B_{1t}$ = Cost of infrastructure attributable to the care of a given animal died during t-th interval.

$L_{1t}$ = Cost of labour attributable to the care of a given animal died during t-th interval.

$M_{1t}$ = Cost of medical care attributable to the care of a given animal died during t-th interval.

$C_{1t}$ = Total cost attributable to the care of a given animal died during t-th interval, mathematically,

$$C_{1t} = B_{1t} + L_{1t} + M_{1t}$$

where $A_t$, $B_t$, $B_{1t}$, $L_{1t}$ and $M_{1t}$ will be calculated on per animal basis for different group of animals such as calves, young calves, heifers, animals in milk, dry and working animals, and appropriate weightage will be given to each group of animals depending on its proportion in the population.

$B_{2t}$ = Cost of infrastructure attributable to the care of a given animal got infected during t-th interval.

$L_{2t}$ = Cost of labour attributable to the care of a given animal got infected during t-th interval.

$M_{2t}$ = Cost of medical care attributable to the care of a given animal got infected during interval t.

$M_{2t}$, $B_{2t}$ and $L_{2t}$ will be calculated on per animal basis for different groups of animals such as calves, young calves, heifers, animals in milk, dry animals, and working animals and appropriate weightage will be given to each group of animals depending on its proportion in the population.

$E_t$ = Loss attributable to a given animal got infected during t-th interval.

$E_t$ will be calculated considering losses due to infertility, abortion, lameness, loss in weight and milk. Appropriate weightage will be given to different groups of animals such as calves, young calves, heifers, animals in milk, dry animals, working animals depending on their proportion in the population. For each group, loss will be calculated on per animal basis separately then $E_t$ will be calculated using these losses and their respective weights.

It is difficult to quantify losses like deliterious effect on food conversion efficiency, secondary mastitis infection, reduction in agricultural output attributable to lameness of draught animals, restriction on world trade, and deviation from the optimal production system due to risk and uncertainty caused by FMD. If it will be possible to estimate or quantify these losses, it should also be included in the calculation of $E_t$.

V = Cost of vaccination attributable to a given animal.

$C_{2t}$ = Total cost attributable to a given animal got infected in t-th interval, mathematically,

$$C_{2t} = B_{2t} + L_{2t} + M_{2t}$$

$r_{ij}$ = Monetary loss associated with j-th event during i-th interval of epidemic.

$R_{I\bar{D}}$ = Expected monetary loss if animal got infected and survived.

$R_{ID}$ = Expected monetary loss if animal got infected and died.

$R_{\bar{I}}$ = Expected monetary loss if animal did not get infected (zero in this case).

Associated Probabilities and Development of the Model

Let us consider that the first interval begins before the day when first case of FMD takes place. The three possible events which can take place in this interval are :

(i) The animal enters into state $I\bar{D}$ (gets infected and survives).

or

(ii) The animal enters into state ID (the animal gets infected and dies).

or

(iii) The animal enters into state $\bar{I}$ (the animal does not get infected).

These events are mutually exclusive and exhaustive.

The probabilities associated with these events in t-th interval would be, respectively, as follows:

$$p_{t1} = p_1 \prod_{i=1}^{t} \bar{a}_i + q_1 p_2 \prod_{i=2}^{t} \bar{a}_i + \ldots + p_t \bar{a}_t \prod_{i=1}^{t-1} q_i \qquad \text{(I)}$$

$$p_{t2} = p_1 a_t \prod_{i=1}^{t-1} \bar{a}_i + q_1 p_2 a_t \prod_{i=2}^{t-1} \bar{a}_i + \ldots + p_t a_t \prod_{i=1}^{t-1} q_i \qquad \text{(II)}$$

$$p_{t3} = \prod_{i=1}^{t} q_i \qquad \text{(III)}$$

The probability of getting infected and probability of death due to FMD will be estimated by Natarajan and Singh [1]. The monetary losses associated with events in t-th interval are given, respectively as follows:

$$r_{t1} = E_t + C_{2t} \qquad \text{(IV)}$$

$$r_{t2} = A_t + C_{1t} - B_t \qquad \text{(V)}$$

$$r_{t3} = 0, \quad \text{for all } t \qquad \text{(VI)}$$

The expected monetary loss over a period of T intervals associated with first, second and third events, are given by

$$R_{I\bar{D}} = \sum_{t=1}^{T} p_{t1} r_{t1}$$

$$\dot{R}_{ID} = \sum_{t=1}^{T} p_{t2}\, r_{t2}$$

$$R_{\bar{I}} = \sum_{t=1}^{T} p_{t3}\, r_{t3} = 0 \tag{VII}$$

Thus, the total expected monetary loss due to FMD over a period of T intervals associated with these three events is given by:

$$R = R_{I\bar{D}} + R_{ID} + R_{\bar{I}}$$

$$= \sum_{t=1}^{T} (p_{t1}\, r_{t1} + p_{t2}\, r_{t2} + p_{t3}\, r_{t3}) - V \tag{VIII}$$

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

$$R = \sum_{t=1}^{T} (p_{t1}\, r_{t1} + p_{t2}\, r_{t2}) - V \tag{IX}$$

The expression (IX) is our desired model to determine the economic loss due to FMD.

Application of the Model

To demonstrate the application of the model, only the following direct economic losses were considered for the application of model as they could be estimated precisely.

(a) Value of milk loss due to reduction in milk yield.

(b) Value of meat loss due to reduction in weight or growth rate.

(c) Cost of medicines.

(d) Cost of increased human labour hours for additional care.

and (e) Any other associated costs viz., arrangement of extra infrastructure, etc.

FMD outbreak started in the farm with one Brown-Swiss animal identified as a case and vanished on 24th day from the day of outbreak. In total 121 out of 670 animals of different breeds, grades, age-groups and sexes were got infected by the disease. Attack curve was obtained by plotting the periods along the x-axis and respective attack rates along the y-axis on suitable scales, where periods were obtained by grouping the whole FMD period into classes by taking incubation periods of 3, 4, 5 and 6 days as class-intervals. It is only 4 days incubation period attack rate curve which shows two peaks and the first peak is higher than the second peak. Since this curve strictly coincides with the theoretical FMD epidemic-curve, so 4 days incubation period was considered a suitable class-interval for grouping the total FMD period into classes or periods.

In the present study, the total FMD period of 24 days was grouped into six periods considering 4 days as class interval. The cases were distributed into these six periods and $p_i$ and $a_i$ were calculated using Natarajan and Singh [1]:

$$p_i \text{ or } a_i = D_i / [(N_i - D_i) + a_i D_i] \qquad (X)$$

where

$D_i$ = Number of animals became cases or died in i-th period (interval) of epidemic.

$N_i$ = Number of susceptibles or number of animals just before the i-th period.

$a_i$ = Fraction of time for which each dead animal or a susceptible before becoming the case in i-th period lived in this period.

Using the formula given in (X), $p_i$, $q_i$, $a_i$ and $\bar{a}_i$ were estimated utilizing the actual data and values were presented in Table 1.

**Table 1** : Estimates of $p_i$, $q_i$, $a_i$ and $\bar{a}_i$

| Period of infection | $\hat{p}_i$ | $\hat{q}_i$ | $\hat{a}_i$ | $\hat{\bar{a}}_i$ |
|---|---|---|---|---|
| 1 | 0.0060 | 0.9940 | 0.0 | 1.0 |
| 2 | 0.0359 | 0.9641 | 0.0 | 1.0 |
| 3 | 0.0389 | 0.9611 | 0.08 | 0.92 |
| 4 | 0.0494 | 0.9506 | 0.0 | 1.0 |
| 5 | 0.0330 | 0.9670 | 0.0279 | 0.9721 |
| 6 | 0.0135 | 0.9865 | 0.0 | 1.0 |

Disease followed an increasing morbidity trend and reached its maximum during the fourth period of epidemic from the date of outbreak. After that it started decreasing and vanished during the sixth period of epidemic. Since mortality is a rare occurrence in FMD so no definite trend was observed as far as mortality is concerned.

Direct economic losses due to morbidity and mortality caused by FMD outbreak were estimated on per animal basis using the methods given in the text. Probabilities $p_{t1}$ and $p_{t2}$ were also estimated using (I) and (II). All these estimated values alongwith total expected economic losses due to morbidity and mortality were presented in Table 2.

**Table 2 : Expected direct economic losses due to morbidity and mortality caused by FMD outbreak at IVRI, Izatnagar (U.P.) Cattle Farm**

| Period of infection | Average economic losses due to morbidity | $p_{t1}$ | Expected economic losses due to morbidity | Average economic losses due to mortality | $p_{t2}$ | Expected economic losses due to mortality | Total expected losses due to morbidity and mortality |
|---|---|---|---|---|---|---|---|
| I | 105.06 | 0.0060 | 0.63 | 0 | 0 | 0 | 0.63 |
| II | 83.06 | 0.0417 | 3.46 | 0 | 0 | 0 | 3.46 |
| III | 58.63 | 0.0739 | 4.33 | 453.36 | 0.0063 | 2.85 | 7.18 |
| IV | 33.70 | 0.1181 | 3.98 | 0 | 0 | 0 | 3.98 |
| V | 13.86 | 0.1429 | 2.40 | 423.05 | 0.0041 | 1.73 | 4.13 |
| VI | 4.13 | 0.1544 | 0.64 | 0 | 0 | 0 | 0.64 |
| Overall expected economic losses | | | 15.44 (3.16) | | | 4.58 (0.94) | 20.02 (4.10) |

*Note:* Values in parentheses indicate the percent economic losses to the average value of animals.

The average economic losses due to morbidity varied from Rs. 4.13 to 105.06 establishing declining trend showing maximum and minimum losses during the first and last periods of the epidemic. But the same trend was not repeated by expected economic losses due to morbidity because $p_{t1}$ followed just the reverse trend to the trend of average economic losses. The expected economic losses registered an increasing trend from first to third period of epidemic and then decreasing trend was depicted up to the end of the epidemic. The highest average economic loss observed in the beginning of the outbreak is a natural psychological human phenomena as the maximum efforts are put in the beginning of any epidemic to control it as early as possible.

The expected economic loss due to mortality and total expected economic loss due to morbidity and mortality did not follow any trend because mortality is a rare event in this disease.

The overall expected losses due to morbidity and mortality were Rs. 15.44 and Rs. 4.58 respectively which were 3.16% and 0.94% of the average price value of animals. The overall total expected economic loss due to morbidity and mortality was Rs. 20.02 amounting to 4.10% of the average value of animals in the farm.

An animal is vaccinated three doses during first year and two doses during every subsequent years against the foot and mouth disease. The price of one dose of IVRI vaccine is Rs. 3.50. Assuming the cost of storage, inoculation etc. of the vaccine bit higher side, let it to be Rs. 0.50. Then the total cost of vaccination per dose per animal will be Rs. 4.00. Even at this cost of vaccination, the vaccination strategy for controlling the FMD in the country is a profitable proposition in endemic areas. Even if there is no mortality in the herd, which is a common phenomena in indigenous breeds, the vaccination strategy is still a profitable proportion in Indian context in endemic areas.

## REFERENCES

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