Introduction of anthrax via green hides: risk analysis revisited

MAF Quality Management staff conduct training programmes and workshops on quality management and elements of risk analysis. The published risk analysis associated with the importation of hides was reviewed and a very different result was obtained.

At the core of most risk analysis problems is a chance event which occurs a number of times. For example, the risk of introducing a certain disease via the importation of livestock from a population where the disease prevalence is not zero. The risk is related to both the chance that each animal is infected and the number of animals imported.

In many circumstances we are dealing with a large number of independent events, each with the same low probability and the binomial distribution is appropriate. Commonly policy makers are interested in the probability of at least one event occurring; in this case the calculations can be simplified somewhat as follows:

> *Let p equal the probability that the event will occur.*
>
> *Thus (1-p) is the probability that the event will **not** occur.*
>
> *Let n equal the number of independent occurrences of the event.*
>
> *Thus $(1-p)^n$ is the probability that the event will **never** occur.*
>
> *Thus the probability, P, of one or more events occurring (ie at least one) is $1-(1-p)^n$.*
>
> *Further, if p is small and n large and $(n \times p) << 1$, then P can be approximated to np.*

Even in some apparently simple cases, careful formulation of the problem is required if the correct answer is to be obtained. When the probabilities being calculated are not specified with sufficient precision, the outcome can be large over or under estimates of the resultant risk.

Recently we reviewed a problem involving the risk associated with the introduction of anthrax into New Zealand. The original analysis[1] was reprinted in the OIE *Revue Scientifique et Technique*[2]. It was subsequently reproduced in a well known epidemiology textbook[3] and a modified analysis has also been published in a textbook on zoonoses[4]. We have re-analysed the problem using the information and data given in the original publication.

Probability of anthrax introduction

As described in the original report, the analysis concerns the risk of an anthrax outbreak in livestock associated with the importation of hides and skins from Australia. The scenario was as follows:

- Green (ie unprocessed) hides and skins which may be contaminated with anthrax spores are imported into New Zealand for processing in tanneries.
- In some tanneries, wastewater is discharged without treatment. Thus, waterways downstream of the tanneries could be contaminated with anthrax spores.
- During floods spores that escape could be carried onto pasture and infect livestock.

Data and assumptions

The following data were given in the original paper. To assist the reader we have assigned a symbol to some variables (which we use in equations later), and commented on how the data were originally estimated.

- The probability that green hides or skins are infected with anthrax, $\mathbf{p_i}$ was estimated to be $9.94*10^{-7}$. *(This was calculated from reports of the annual incidence of anthrax in Australia and of the number of cattle and sheep slaughtered each year.)*
- The probability that anthrax spores survive to processing in New Zealand, $\mathbf{p_s}$, was estimated to be 0.9. *(Anthrax spores are known to be very resistant to adverse conditions; a high survival rate was therefore assumed.)*
- The number of Australian hides processed annually in New Zealand was estimated as 0.92 million. *(We presume that this figure was extracted from official records.)*

  The number of officially approved tanneries was 23. *(Data from Ministry of Agriculture and Fisheries records.)*
- The number of "risk" tanneries (ie those discharging wastewater into rivers), **t**, was assumed to be 5. *(There were no data on this; it was estimated to be approximately 20% of tanneries; ie 23 x 0.2 = 5 rounded to a whole number.)*
- The number of processing days in a year at each tannery, **d**, was calculated to be 235. *(We assume this was calculated by subtracting weekends and holidays from 365 days.)*
- The probability that there is a flood on any day at any of the "risk" tanneries is $\mathbf{p_f}$, and was estimated to be 25/365 = 0.0685. *(The background to the estimate of 25 flood days was not given.)*

Some other assumptions are implied in the approach used in the original paper. Important ones are:

- A contaminated hide will not cross-contaminate other hides during handling, transporting and storage, except (possibly) other hides processed on the same day at the same tannery.
- The probability that New Zealand stock will be infected with anthrax if spores escape from a "risk" tannery on a flood day is 1.
- Infected hides are completely randomly distributed among all hides imported from Australia.
- Spores on a hide can only escape into rivers on the day it is processed in the "risk" tannery.

Additional assumptions with our approach

Two other assumptions are made:

- All 23 tanneries in New Zealand process the same number of Australian hides each year.
- Each tannery processes a constant number of Australian hides each working day.

Derivation of risk per year of anthrax infecting livestock

In any year there would be pasture contamination with anthrax spores if on at least one occasion there was a flood at a "risk" tannery on a day that a contaminated hide was being processed. Hence we want to calculate the probability of this event. Stated more formally the event is defined as follows: *"There is a flood at a risk tannery on a day that a contaminated hide is processed on at least one occasion in a year".*

The "chance" events are:

- the probability of a flood, $\mathbf{p_f}$
- the probability that an Australian hide in a New Zealand tannery is contaminated,

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$p_a = p_i * p_s$ *(The product of the probabilities that the hide was contaminated originally and the pre-processing survival of spores).*

The "fixed" events are:

- the number of "risk" tanneries, **t = 5**
- the number of days hides are processed, **d = 235**
- the number of Australian hides processed each day by each tannery, **h = (0.92*10⁶/23)/235 = 170**

On any given day at any given tannery, what is the probability, p_x, that there is both a flood and at least one infected hide processed?

- **p_x = Pr{flood} * Pr{at least one infected hide processed}** *(events independent)*
- $p_x = p_f * \{1 - (1 - p_a)^h\}$ *(again the events, hide infections, are assumed independent)*

How many such events are there?

Number of events = number of risk tanneries * number of working days = t*d

Are all the probabilities p_x for these events independent? While the hide infections are assumed to occur randomly, floods will not be randomly distributed and so the probabilities on different days will not be independent. However, over a whole year it is reasonable to assume that the number of floods in a year follows a Poisson distribution and hence the number of floods on days when at least one infected hide is processed also follows a Poisson distribution. Hence we assume that the number of flood days when at least one infected hide is processed in a year across all risk tanneries follows a Poisson distribution with a mean of **p_x*t*d**. Hence the probability that there is at least one such occurrence, p_E, is **$[1 - \exp(-p_x*t*d)]$**.

Had we assumed independence of the probabilities, we would have concluded that p_E was equal to **$[1 - (1 - p_x)^{td}]$**. *(Note: In this example the two answers are virtually identical and it is well known that the Poisson distribution is a good approximation of the binomial distribution when the probability is small and the number large.)*

With the values and assumptions given above, we find that **p_E = 0.012 ; i.e 1.2 x 10^{-2} or about 1 in 82**. Hence we would expect one (or more) outbreaks of anthrax about once every 82 years.

This estimate of risk is very much higher than that, 7.72 x10^{-7}, calculated in the original paper. Using their method Hugh-Jones et al[4] calculated the risk to be 1.13 x 10^{-5}, less by a factor of approximately 1000 times than our result.

Adequacy of assumptions

Several of the assumptions made are questionable. Some are useful working approximations but others will have a critical bearing on the final result. We have examined this problem purely from an interest in getting the calculations correct using assumptions as near as possible to those made in the original paper.

To get a more realistic analysis of the risk, we would need to know more about the pattern of the disease in Australia, the handling of the hides through shipment from Australia to the tanneries, the processing of the hides, the management of wastewater, etc. Very clearly the assumption that escape of spores from a risk tannery during a flood always leads to infection of livestock needs further examination.

Comments on the original (Harkness) and more recent (Hugh-Jones et al) solutions

That the solutions obtained in both these cases cannot be correct can be deduced as follows. First, we can do a rough but very simple analysis. Because the number of hides imported is about 1 million and the risk of any hide being infected is about 1 in a million, we expect, on average, 1 infected hide to be imported per year. This hide will result in infection in livestock only if it is processed at a "risk" tannery on a flood day; the probability of this is [(5/23)*(25/365)] which equals 0.015.

Second, neither solution is properly dependent on the number of hides imported. The Harkness solution is dependent on this number only relative to the total number of hides processed; the Hugh-Jones et al solution is entirely independent of the number of hides imported. As noted in the introduction, in such cases the risk of importing the disease is crucially dependent on the volume of imports.

If the volume of imports increased 10 fold and the number of New Zealand hides processed also increased 10 fold, the Harkness solution would be unchanged. The Hugh-Jones et al solution would also be unchanged, no matter how the number of NZ hides processed changed. But logically the risk should increase about 10 fold.

An important point is that neither of these solutions precisely defines the event for which the probability is calculated. The Harkness report calculates the probability that a randomly chosen hide from a New Zealand tannery is infected. The Hugh-Jones et al exposition calculates the probability that a randomly chosen Australian hide brought into New Zealand is contaminated. In both cases this probability is multiplied by the number of days there are floods at "risk" tanneries when the tanneries are working. In both cases the event for which the probability is calculated is quite different from the event for which the number was calculated and the result has no useful meaning. Further both authors incorrectly calculate the number of floods on working days as 25*25/235 where it should be 25*235/365.

The probability required in both cases is the probability that there are one or more infected hides processed in any tannery on any working day; this probability can be multiplied by the number of "risk" tanneries and the number of floods on working days at any tannery to get an approximate annual risk of an outbreak. It is possible to roughly correct these two other methods for this. If we multiply the original estimate by 170/0.068 = 2500 (i.e. the number of hides processed per day at a tannery) and correct the error in the calculation of the number of flood working days we get an answer of 0.0117. Likewise if we multiply the Hugh-Jones probability by 170 (the number of Australian hides processed per day at any tannery) and again the correct the number of flood working days error we get an answer of 0.0116. These are quite close to the solution, 0.0122, that we obtained.

There are some other minor differences. We assumed 5 "risk" tanneries where the other authors assumed 23*0.2 = 4.6; as the tanneries must be "risk" or not, we considered it more appropriate to use a whole number. The other authors' solutions have also made some approximations, for instance in using p*n in place of $1-(1-p)^n$, and have regarded the number of flood days as fixed where we assumed a Poisson distribution.

Concluding remarks

This problem is a good example of the necessity to define very precisely the core chance event of any risk model that is being developed. In our training programmes we use many practical examples; during these sessions we request participants to write out the "event" in full. In our experience when this is understood, most problems can be resolved.

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