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A Model For Termite Hazard In Australia

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Summary: A probability model to predict the time for termite attack on timber construction is developed. It makes use of the result from two previous studies, one from a collection of expert opinions, which provides a basis for establishment of statistics of four sequential event times, and the other from a termite tally for houses around Australia The tally gives data needed for identifying important parameters and constructing a hazard map as well as calibrating the proposed probability model. It represents the world's first predictive model of such an attack. Computer software has been written based on the model. It can be used for collecting additional expert opinions and for making risk predictions on termite attack. Application of the model indicates that the range of possible risks is so great that it is unrealistic to treat all houses as the same when assessing the impact of termites.

Keywords: termite, risk, hazard, probability, timber.

1 INTRODUCTION

Durability is one of the most important considerations in the use of timber in construction. Consumers and asset owners are concerned about effective service life and overall maintenance costs. To address the concerns of the wider community, inclusion of durability requirements in the future Building Code of Australia is currently being seriously considered by building code officials.

This paper considers probabilistic modelling of termite attack, one of the most important durability issues for timber construction. The model developed is based on two previous studies. The first is a survey of some 5000 houses around Australia and provides statistical data on house location, age, termite incidence inside the house and in the garden, and construction type (Cookson 1999). This survey will be referred to as the "Termite Tally". The second study is a collection of expert opinions on termite behaviour, referred to as the "Expert Opinion" model; it provides a quantitative estimate by experts of the mean and variability of observed times of termite attack (Leicester and Wang 2001). The two studies are brought together in the form of a probabilistic model of termite attack on housing.

2 PROBABILITY MODEL

In the following, a probability model is used to estimate a "true" risk and an "apparent" risk. The apparent risk is the risk estimate based on the historical memory of the house occupant. In the Termite Tally the average time of occupancy of the householders interviewed was found to be about 11 years. In this study the historical memory of the average occupant, denoted by t_{mem}, has been taken to be 20 years.

The probability density function of the time for a house to be attacked by termites is assumed to be of the type shown in Fig. 1. The equation for the density function is assumed to be

$$p = a + bt \quad (1)$$

where a and b are the distribution parameters, and t is the time since time zero, the time at which the house was constructed. The value of a may be either positive or negative, as shown in Fig. 1. The notation t_{max} is used to denote the upper limit of the density function, evaluated from the assumption that the area under the density graph must be unity.

For the case of $a \geq 0$, the true probability that the house has been attacked by time t, denoted by $P(house,attack,true,t)$, is given by

$$P(house, attack, true, t) = \begin{cases} at + \frac{1}{2}bt, & \text{for } t \leq t_{max}; \\ 1, & \text{for } t > t_{max}. \end{cases} \quad (2)$$

and the average time to the attack, denoted by mean(t), is given by

$$\text{mean}(t) = \frac{a}{2}t_{\max}^2 + \frac{b}{3}t_{\max}^3 \qquad (3)$$

For the case of $a < 0$, the true probability that the house has been attacked by time t is

$$P(house, attack, true, t) = \begin{cases} 0, & \text{for } t \le t_a; \\ a(t - t_a) + \frac{1}{3}(t^2 - t_a^2), & \text{for } t_a < t < t_{\max}; \\ 1, & \text{for } t \ge t_{\max}. \end{cases} \qquad (4)$$

and the average time of attack is

$$\text{mean}(t) = t_{\max} - \tfrac{1}{3}(t_{\max} - t_a) \quad (5)$$

The apparent risk of attack, denoted by $P(house,attack,obsv,t)$, is the same as the true risk for the case $t < t_a + t_{mem}$, where t_a denotes the start of the probability density functions shown in Fig. 1. For larger values of t the apparent risk is given by

$$P(house, attack, obsv, t) = A + Bt \qquad (6)$$

in which

$$A = at_{mem} - \tfrac{1}{2}bt_{mem}^2 \qquad (7)$$
$$B = bt_{mem}$$

Graphs for the apparent and true risks of attack are illustrated schematically in Fig. 2. In the following sections the proposed model will be verified and calibrated by the Expert Opinion and Termite Tally.

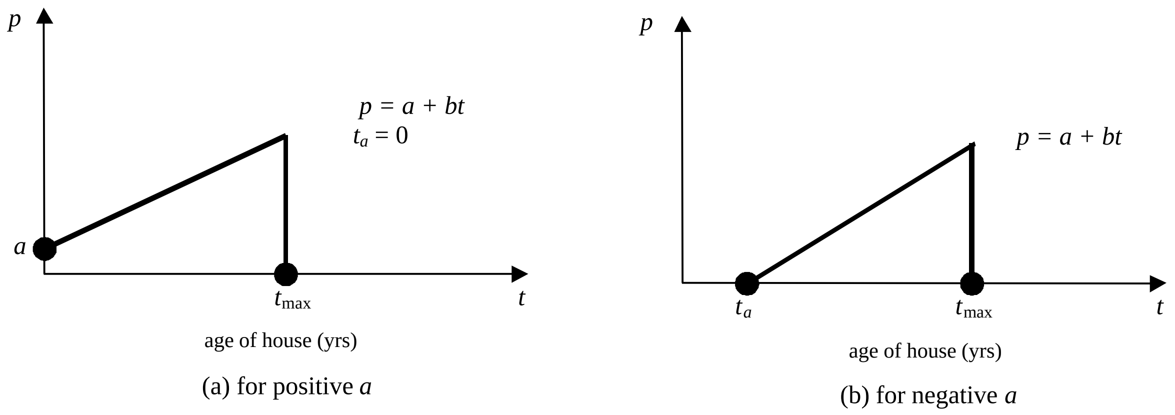
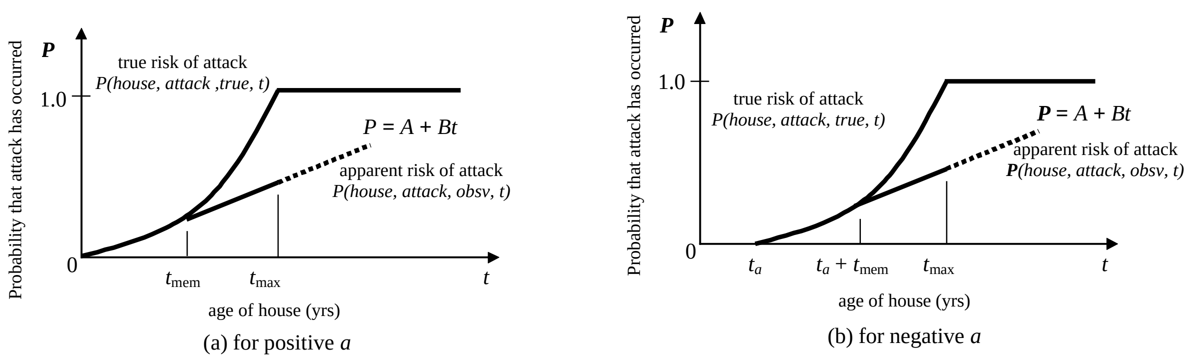


Figure 1. Probability density functions of the time of a termite attack.



b

Figure 2. Schematic illustration of the cumulative distribution functions of the attack time.

3 THE EXPERT OPINION MODEL

3.1 The base model

The time estimate model based on expert opinions applies to the configuration illustrated in Fig. 3. It relates to a taget house surrounded by 50 m of termite-free land. The distance of 50 m was chosen because this is about the limit of the foraging distance of most termite species. The model used then endeavours to estimate four sequential event times (see Fig. 4) defined as follows:

1. time t1: the time taken for the establishment of a mature colony within a distance of 50 m from the target house;
2. time t2: the time taken for the termite foraging galleries to progress to a house 20 m away from the nest site;
3. time t3: the time taken for termites to penetrate or bypass a chemical or mechanical barrier, if any;
4. time t4: the time taken (after penetrating the barrier) to reach and cause failure of a timber member.

Relevant data on these four event times were obtained via a limited survey of expert opinion. Details of this survey, together with the analysis procedure used to process the data has been described elsewhere (Leicester and Wang 2001, Leicester *et al.* 2001).

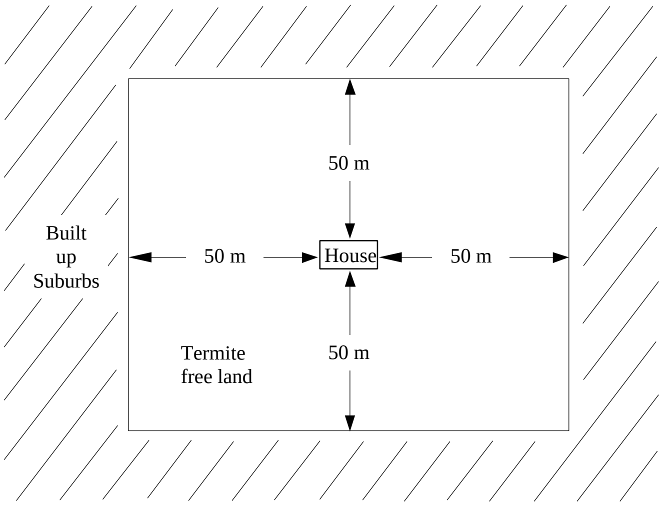


Figure 3. Hypothetical scenario for house and land at time zero.

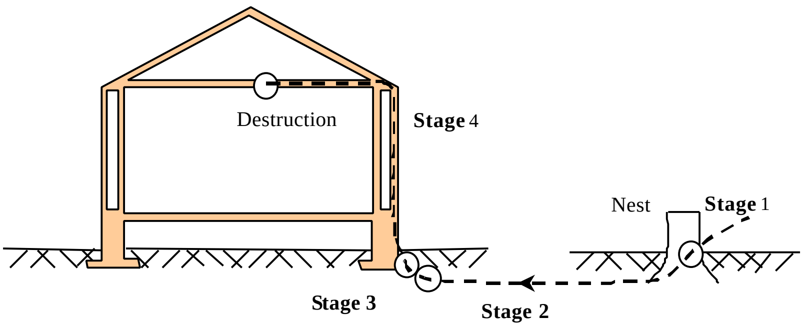


Figure 4. Illustration of termite progress.

In the survey, a set of parameters affecting each event time was obtained from experts. The set chosen is listed as P_1, P_2, …, P_{14}, as tabulated in Table 1. For each parameter, the experts were asked to list the importance of the parameter with regard to its influence on the relevant event time; this importance was rated on a scale of 1–10, with 10 being the most important; examples of the importance parameters chosen are also given in Table 1.

Table 1. List of event times and associated parameters

Event time	*Influencing parameter*	*Importance factor*
t_1 Time for establishment of a colony	P_1: geographical location	8
	P_2: age of surrounding suburbs	5
	P_3: number of potential nest sites	9
t_2 Time for termites to travel to the building	P_4: geographical location	8
	P_5: soil condition	6
	P_6: food source	7
t_3 Time for penetration or bypass of a termite barrier*	P_7: geographical location	4
	P_8: period between inspections	10
	P_9: maintenance parameter	7
t_4 Time to reach and destroy timber	P_{10}: geographical location	8
	P_{11}: ground-contact building element	5
	P_{12}: period between inspections	9
	P_{13}: type of material attacked	7
	P_{14}: timber environment	7

* Barriers considered were toxicant and repellant chemical barriers, Granitgard and Termimesh

For each parameter P_j, there is an associated parameter factor k_j. This factor k_j is given the value of +1, 0 or −1 depending on whether the parameter has been chosen to correspond to low, medium or high termite activity respectively. For example, Tables 2 and 3 show how the parameter factor k_3, associated with parameter P_3, is chosen. This parameter relates to the time for establishment of a termite's nest by assessing the number of potential nesting sites within a 50 m distance of the target house.

Table 2. Examples of potential nesting sites

The following refers to potential nest sites for colonies of termites

- Tree *(diameter larger than* 300 mm*)*
- Tree stump or untreated pole *(diameter larger than* 200 mm*)*
- Untreated landscape timber *(e.g. sleepers, retaining walls of length* >1.0 m, *height* >0.5 m*)*
- Woodheap*(height* >0.5 m, *ground contact area* >0.5 × 0.5 m, *length of periods that bottom layer of woodheap is untouched* >1 *year)*
- Compost heap
- Wood 'stepping stones'
- Subfloor storage *(height* >0.5 m, *ground contact area* >0.5 × 0.5 m, *length of period which it is untouched* >1 *year).*
- Solid infill under a verandah
- Any part of a building with water continuously leaking into it.

Table 3. Parameter P_3 indicating the effect of the number of potential nesting sites on time to establish a mature colony of termites

Number of potential nesting sites	*Effect on speed of establishment of a termite colony*	*Parameter factor*
<2	Low	k_3 = +1
2–5	Medium	k_3 = 0
<5	High	k_3 = −1

From the analysis procedure, the statisitics of an event time t_i can be evaluated from

$$t_i = M_i A_i \qquad (8)$$

where M_i is a constant and A_i is a random variable.

In particular the four mean values, denoted by mean(t_i), are given by

$$\text{mean}(t_i) = M_i \text{ mean}(A_i) \quad (9)$$

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The mean values and coefficients of variation of the random variables A_i are given in Table 4. The parameters M_i are given by

$$M_1 = (1 + 0.236\, k_1)\,(1 + 0.148\, k_2)\,(1 + 0.266\, k_3)$$
$$M_2 = (1 + 0.0771\, k_4)\,(1 + 0.0578\, k_5)\,(1 + 0.0675\, k_6)$$
$$M_{3A} = (1 + 0.454 k_7)\,(1 + 0.649\, k_8)$$
$$M_{3B} = (1 + 0.497 k_7)\,(1 + 0.710\, k_8) \quad (10)$$
$$M_{3C} = (1 + 0.222\, k_7)\,(1 + 0.556\, k_8)\,(1 + 0.389\, k_9)$$
$$M_{3D} = (1 + 0.205\, k_7)\,(1 + 0.513\, k_8)\,(1 + 0.359\, k_9)$$
$$M4 = (1 + 0.455\, k_{10})\,(1 + 0.284\, k_{11})\,(1 + 0.512\, k_{12})\,(1 + 0.398\, k_{13})\,(1 + 0.398\, k_{14})$$

Note that there are five values of M_3 and A_3 depending on the type of termite barrier used. The subscripts used refer to the type of barrier as follows:

A: granite-guard,

B: termimesh,

C: toxicant chemical,

D: repellant chemical

E: no barrier.

Table 4. Distribution parameters of A_i

Time	*Mean(A_i) (years)*	*COV(A_i)*
t_1	16.7	0.646
t_2	4.9	0.813
t_{3A}	20.9	0.775
t_{3B}	27.4	0.768
t_{3C}	37.9	0.675
t_{3D}	24.2	0.750
t_{3E}	0	0
t_4	14.5	0.625

3.2 The practical model

For practical application, the base model must be modified so that the target house is closer to the suburbs than 50 m. In addition, the model must allow for the possibility that there may be mature nests at time zero, the year in which the house is constructed. These modifications are illustrated in Fig. 5. A timeline of events is illustrated in Fig. 6. A rough approximation to the estimate of the attack time by an expert, denoted by t_{expert}, is

$$t_{\text{expert}} = P_{garden} t_2 + \left(1 - P_{garden}\right)\left[P_{suburb}\,\frac{d+10}{20}\,t_2 + \left(1 - P_{suburb}\right)\left(t_1 + t_2\right)\right] + t_3 + t_4 \qquad (11)$$

where $P_{garden} = P(garden, nest, true, 0)$, the true probability that a mature nest exists in the garden at time zero, and $P_{suburb} = P(suburb, nest, true, 0)$, the true probability that a mature nest exists in the suburb at time zero.

A suitable equation for estimating P_{garden} and P_{suburb} is

$$P_{garden} = P_{suburb} = \begin{cases} t_{\text{suburb}}/100, & t_{\text{suburb}} \le 100 \text{ years;} \\ 1 & t_{\text{suburb}} > 100 \text{ years.} \end{cases} \qquad (12)$$

where t_{suburb} denotes the age of the suburb at time zero, the year in which the target house was built.

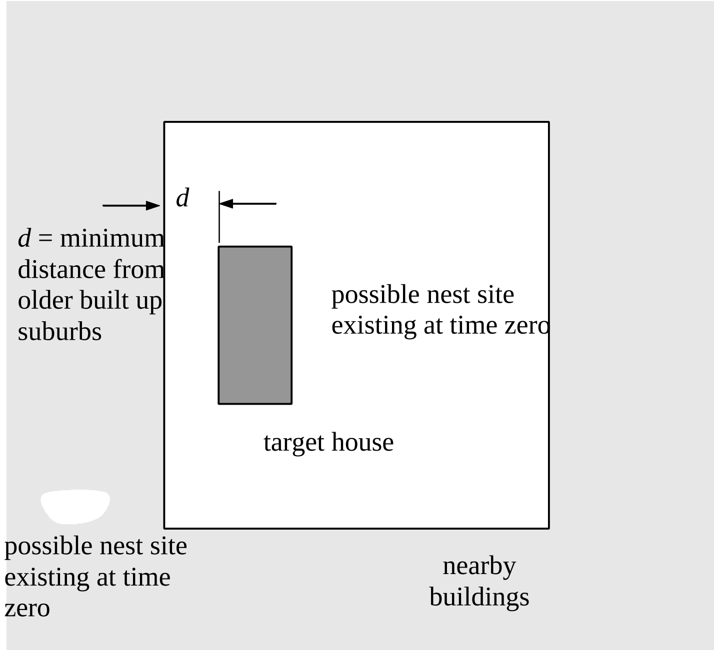


Figure 5. House and land surrounded by existing buildings and nest sites at time zero.

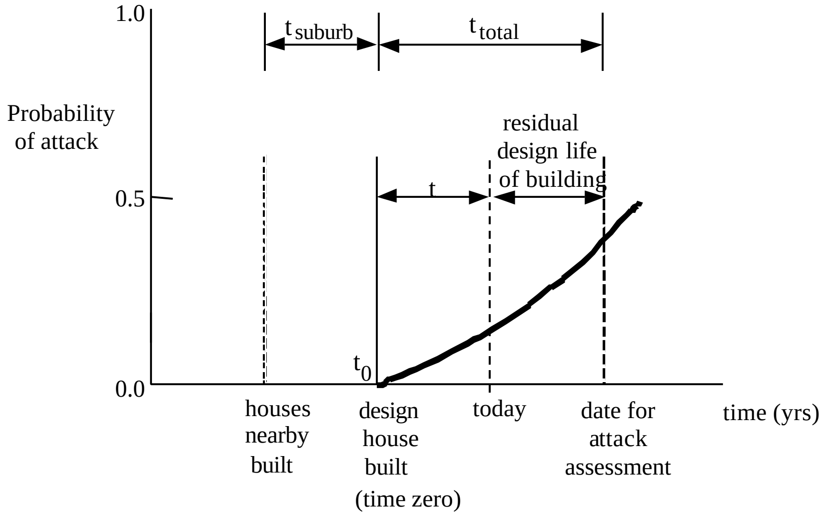


Figure 6. Schematic illustration of event times.

4 ZONATION FOR TERMITE HAZARD

The raw data from the Termite Tally was used to derive zones related to the termite hazard. To do this houses were grouped in terms of specified sets of parameters; then for each group, the termite hazard was taken to be proportional to the observed occurrence of termites in the garden. The data was first grouped to examine the effects of mean annual temperature and rainfall. For this purpose the data of the Termite Tally was grouped according to temperature-rainfall clusters, the cluster boundaries being chosen so that the sample size within each cluster is greater than 90.

The results are shown in Fig. 7. It is apparent that there is a reasonable effect of temperature on the termite hazard. However, the data does not show any clear effect of rainfall.

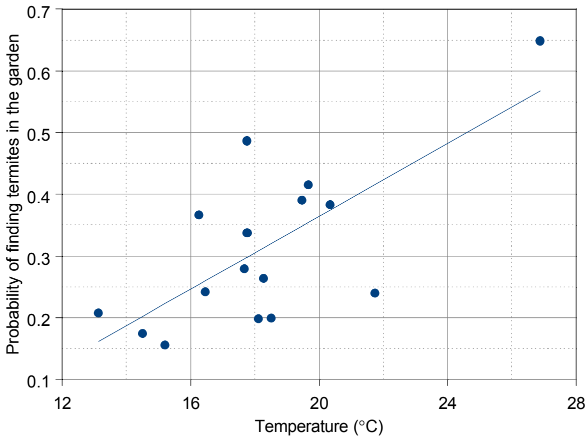
Therefore, a termite hazard map is proposed based on consideration of the mean annual temperature, denoted by T_m, as shown in Fig. 8(a), and consists of the three zones:

Zone 1: $T_m < 18$°C;

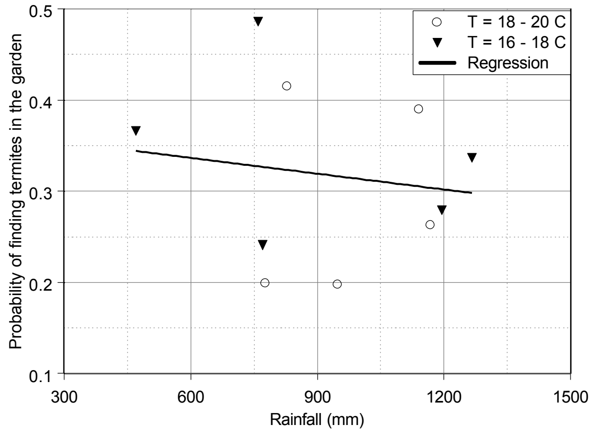
Zone 2: $18 \le T_m \le 25$°C;

Zone 3: $T_m > 25$°C.

As an alternative, Cookson(1999) has proposed that the termite hazard be divided according to agro-ecological zones as shown in Fig. 8(b).

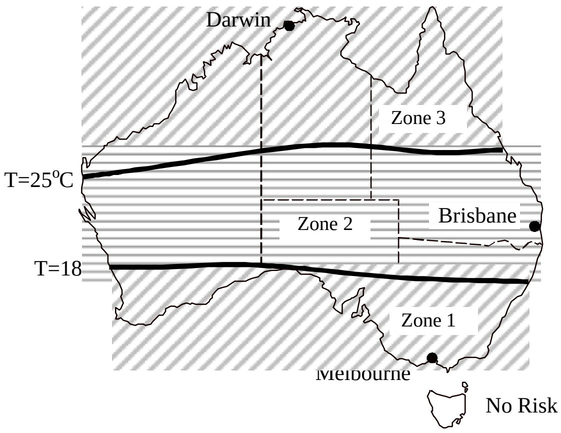


(a) Effect of temperature

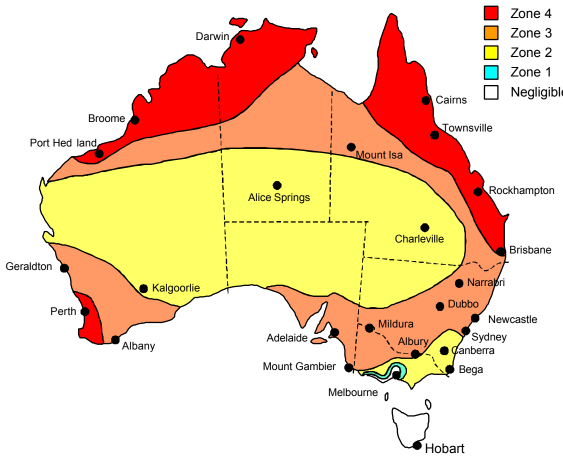


(b) Effect of rainfall

Figure 7. Effect of temperature and rainfall on the apparent incidence of termites in the garden.



(a) temperature



(b) agro-ecological

Figure 8. Termite hazard zonation.

5 CALIBRATION WITH TERMITE TALLY DATA

The data from the Termite Tally was used to calibrate the probabilistic model of attack. For brevity, only the data expressed in terms of temperature zonation will be discussed in the following. The data used for calibration are shown in Figs. 9 and 10. The apparent probability of finding termites in the garden, denoted by $P(garden,termite,obsv,t)$, and the apparent probability that a house has been attacked at some time in the past, denoted by $P(house,attack,obsv,t)$. The data is plotted in terms of t, the age of the houses at the time of the survey for the Tally. Each plotted data point is based on data taken from the Termite Tally; the average sample size for each point is 165 with a minimum value of 51. There is obviously a very strong effect of age of house on the incidence of termite attack. In fact, it was found that in the data of the Termite Tally, the probability of termite attack on a house is more strongly correlated with the age of the house than with any other parameter.

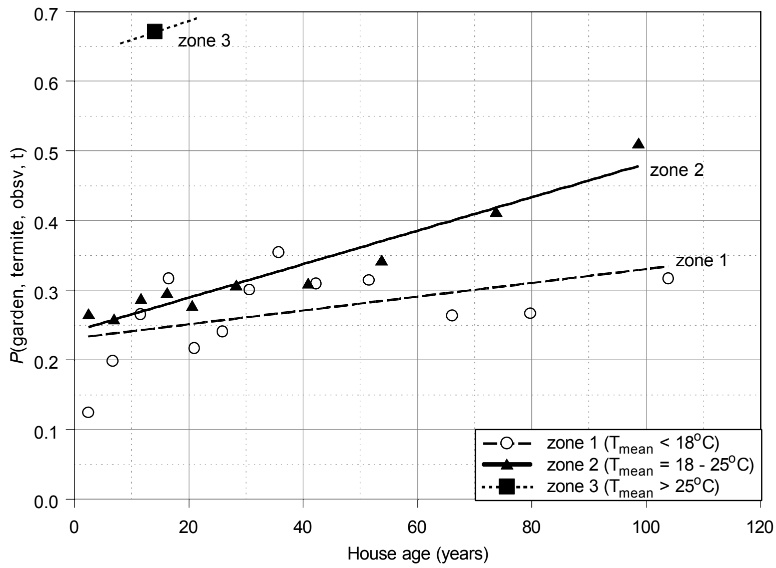


Figure 9. Relationship between age of house and the apparent incidence of termites in the garden.

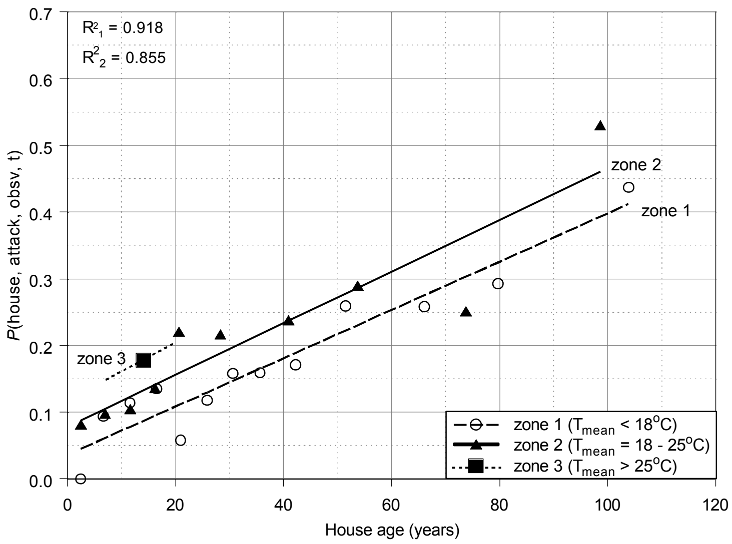


Figure 10. Relationship between age of house and the apparent incidence of termites in the house.

In applying the model, it was decided that in the absence of further information the effect of age of house would be taken to be the same in all zones. To do this a choice of the parameter B = 0.004 was used in Eq. (6). Thus to use the model to predict termite attack, only one input parameter is required and this was taken to be the mean value, denoted by mean(t). Fig. 11 shows a fit of the model to data from the Termite Tally for average conditions.

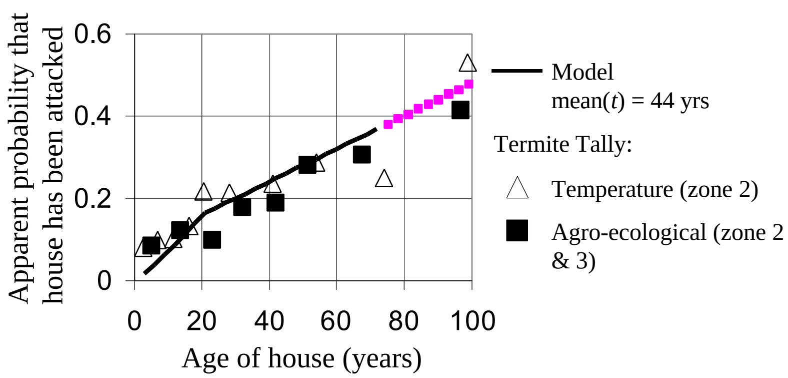


Figure 11. Comparison of apparent risks derived from the model and the Termite Tally.

From the data of the Termite Tally as shown in Fig. 9, it is assumed for calibration purposes that a typical value of the apparent incidence of termites in a garden at time zero may be taken to be

$$P(garden, termite, obsv, 0) = 0.25 \quad (13)$$

If it is assumed that the reported frequency of termite occurrences represent only half the true value, and that the occurrence of termites in the garden is an indication that there is a nest there, then the true probability that a termite nest exists in a garden at time zero is

$$P_{garden} = P(garden, nest, true, 0) = 2 \times P(garden, termite, obsv, 0) = 0.5 \quad (14)$$

Furthermore it will be assumed that the probability of a termite nest occurring in the surrounding suburbs at time zero is the same as that of a nest occurring in the garden, then $P_{suburb} = P_{garden}$, and consequently

$$P_{suburb} = 0.5 \quad (15)$$

Substitution of these values and $d = 2$ into Eq. (11) leads to the mean attack time based on expert opinion, denoted by mean(t_{expert}), to be given by

$$\text{mean}(t_{expert}) = 0.25\ \text{mean}(t_1) + 0.9\ \text{mean}(t_2) + \text{mean}(t_3) + \text{mean}(t_4) \quad (16)$$

To make use of this information, it is a reasonable approximation to assume that there exists a relationship

$$\text{mean}(t) = \beta\ \text{mean}(t_{expert}) \quad (17)$$

where β is a constant.

Table 5 shows a comparison between mean value estimates for average conditions. Two of the estimates are those by experts for average conditions, ie with $k_j = 0$ in Eq. (10). Two further estimates of mean values have been made by fitting the model to the Termite Tally data for average conditions. Assuming that the best expert opinion estimate for typical conditions in the past 20 years is mean(t_{expert}) = 30 years and the best model fit to the Termite Tally data is given by mean(t) = 45 years. Then an assumption that $\beta = 1.5$ is a reasonable estimate of the constant β in equation. This value will be used in the application of the probabilistic model.

For completeness, estimates of related coefficients of variation are included with the data in Table 5; it is seen that for all practical purposes, the variability is the same for all the estimates.

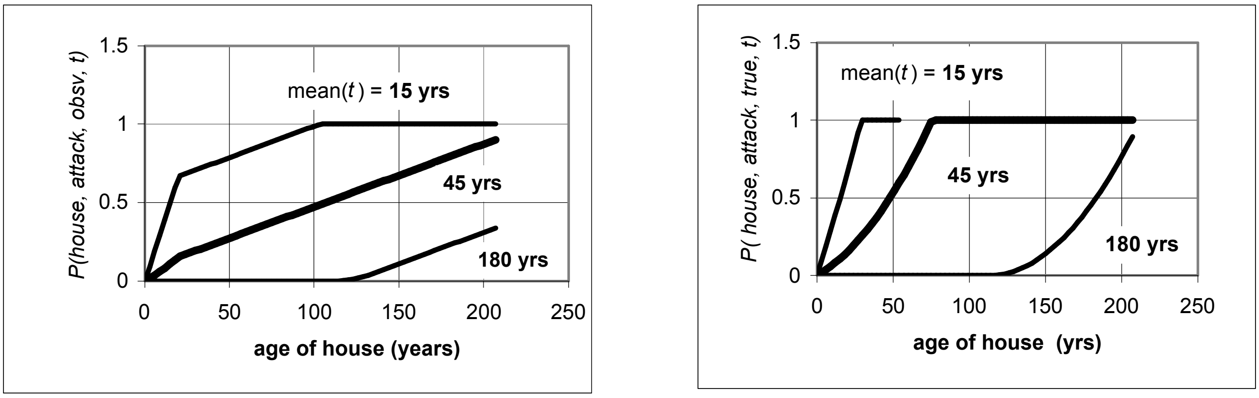
Table 5. Attack time of average models

Data source	*Mean time of attack (years)*	*Coefficient of variation*
Expert opinion model (no termite barrier present)	23.8	0.42
Expert opinion model (with termite barrier present)	53.8	0.43
Termite Tally (temperature zone 2)	44.1	0.46
Termite Tally (agro-ecological zones 2 & 3)	50.2	0.43

6 APPLICATION OF THE PROPOSED MODEL

For any given set of input parameters, the value of mean(t_{expert}) can be obtained from Eq. (16) of the Expert opinion model, Eq. (17) used to estimate the mean(t), and then the probabilistic model used to give an estimate of the risk of termite attack for houses of various ages. Thus the model may be used to examine the cost effectiveness and relative risks involved with various termite resistance strategies.

It is of interest to see the predicted range of risks that are involved. By substituting k_j = -1, 0, +1 into Eq. (10), the values of mean(t_{expert}) are found to be 10, 30 and 120 years; from Eq. (17) this leads to values of 15, 45 and 180 years respectively for mean(t). The resulting apparent and true risks for these three cases are shown in Fig. 12. The wide range of possible risks indicates that it is not realistic to group all houses in the same category. For example, Fig. 12(b) shows that the risk of attack on houses within the first 100 years may range all the way from 0 to 100%, depending on the input parameter conditions.



(a) apparent risk (b) true risk

Figure 12. Possible range of apparent and true risks of termite attack.

7 CONCLUSIONS AND RECOMMENDATIONS

In this paper, the analysis of a Termite Tally and the collection of Expert Opinion are brought together in the form of a risk model of termite attack on timber housing. It represents the world's first predictive model of such an attack. The model takes into account the effects of numerous parameters, as listed in Table 1. In addition, the format for collecting Expert Opinion allows for the introduction of new parameters and concepts regarding termite attack as these become apparent.

A novel aspect of the model is that it introduces a parameter that represents the historical memory of an interviewee when providing data such as that reported in the Termite Tally. Application of the model show that the effects of the differences between the true and apparent risks of attack may not be significant for low risk scenarios such as in the design of house frames; however, there may be significant errors (on the unsafe side) in high risk scenarios, such as in the design of fencing and noise abatement structures, if the differences between true and apparent risks are not taken into account

The model may also be used to provide a probabilistic format for defining the performance specification of termite barriers and inspection procedures, and should prove to be an extremely useful tool in the development and assessment of asset management strategies and building regulations. Computer software based on the developed model has been written. It can be used for collecting further Expert Opinion and for making quantified risk predictions of termite attack.

Perhaps one surprising result observed in running the model is that it predicts that for the possible variety of scenarios in Australia, there is an extremely wide range of risks involved. Hence ignoring the application of this model and treating all scenarios as similar, can lead to very inefficient and/or very risky design procedures and building regulations.

8 ACKNOWLEDGEMENTS

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