Rats and Rice: Belief Network Models of Rodent Control in the Rice Fields of Cambodia

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EXTENDED ABSTRACT

Rodents have long been the most significant pests of rice in Southeast Asia. Under traditional, smallholder rice farming systems, rodents generally cause chronic production losses in the order of 5-10% per annum. However, chronic yield losses of 15-30% are not unusual due to increases in annual cropping frequency (ACIAR 2001).

Many farmers have adopted chemical methods of rodent control (rodenticides), such as acute poisons and anticoagulants, to reduce crop damage. However, these carry significant environmental and human health risks. In Cambodia, rodents are a food source for many rural communities and human poisoning can occur if rodents that have ingested poisons are consumed.

In response to this, an Australian Centre for International Agricultural Research (ACIAR) project titled “Farmer-based Adaptive Rodent Management, Extension and Research System in Cambodia” (referred to as the FARMERS project in this paper) has been trialing a physical method of rodent control called the Community Trap Barrier System or TBS (ACIAR 2001). TBS consists of a lure crop and trapping mechanism that attracts and traps rats from surrounding areas before the main rice crop is planted. This helps to reduce the rat population and provides a halo of protection that can potentially protect a large area of crop if groups of smallholder rice farmers cooperate in its implementation.

Over the past four years, Cambodian rice farmers, researchers and extensionists partaking in the FARMERS project have developed a good understanding of the ecological, technical and socio-economic constraints of Community TBS. However, this knowledge is scattered among several people. System modelling can provide a means for capturing and integrating this knowledge and using it for decision support. However, effective participation of all stakeholders in the model development process is essential to ensure that the models are relevant and culturally appropriate by incorporating local and experiential knowledge, and to ensure that model development provides a learning mechanism for local communities.

This paper describes a participatory modelling process used to develop a model describing factors influencing the effectiveness of TBS, and a benefit-cost model of various rodent control options available to rice farmers in Cambodia. Rice farmers from the Samrong Commune, and researchers and extensionists from the Cambodian Agricultural Research and Development Institute (CARDI) and the Office of Agricultural Extension (OAE) Kampong Cham, were involved. Participatory research techniques were used to capture their understanding of factors believed to influence TBS effectiveness and of factors considered when selecting a particular rodent control method. Bayesian Belief Networks (BBNs) were then used to model TBS effectiveness and the benefit-cost of alternative rodent control options.

The outcomes suggest that BBNs provide a useful framework for the participatory development of decision support tools. The particular advantages of BBNs are that they facilitate the integration of knowledge and data from diverse sources, can easily combine biophysical, economic and social variables (either quantitative or qualitative) and deal explicitly with uncertainty. They also provide a good tool for communicating management system understanding and behaviour among stakeholders.

1. INTRODUCTION

System modelling can provide a means for capturing and integrating knowledge surrounding natural resource management systems that can then be used for decision support. However, effective participation of all stakeholders in the model development process is essential to ensure that the models are relevant and culturally appropriate by incorporating local and experiential knowledge, and to ensure that model development provides a learning mechanism for local communities.

Participatory model development is not an easy task, however. Any framework used in the modelling process must be flexible, adaptable to local conditions, able to integrate different system components, understood by and facilitate communication between stakeholders, and deal with variability and uncertainty (Cain *et al.* 2003). Bayesian Belief Networks (BBNs) have the potential to provide a good participatory modelling framework because they (a) providing a flexible modelling environment, (b) allow uncertainty in knowledge to be expressed using probabilistic relationships, (c) allow biophysical, economic and social variables to be related, (d) have a graphical (flow chart) interface that facilitates communication between stakeholders, and (e) are easily updated as new knowledge emerges.

Because of these attributes, BBNs have had success in the development of decision support models for a wide range of natural resource management applications (see Cain *et al.* 1999; Cain 2001; Cain *et al.* 2003; Wooldridge and Done 2003). This paper reports on the application of BBNs in the participatory development of a Community TBS Effectiveness model and a benefit-cost model for evaluating alternative rodent control options in Cambodia.

2. METHODS

The overall method used in the FARMERS project was based on action research, where participants were facilitated through four phases, namely, (a) planning, (b) action, (c) observations and (d) reflections with respect to Community TBS. The participatory development of rodent control models aimed to capture people's observations and provide a tool for reflecting on these by:

- unlocking (eliciting) existing knowledge and beliefs from stakeholders;
- combining and modelling existing knowledge and beliefs; and,
- making sense of existing knowledge and beliefs by communicating systems understanding among stakeholders (convergence thinking).

This is similar to the SECI model for knowledge creation (Nonaka and Konno 1998). This model describes how tacit knowledge through a process of socialisation, is externalised (becomes explicit), combined via communication across a group of people, and finally internalised by group members as learning.

2.1. Eliciting Knowledge and Beliefs

Community TBS Effectiveness

In the development of the Community TBS Effectiveness model, the aim of knowledge elicitation was to capture the factors believed to influence Community TBS Effectiveness and the dependencies between them. Knowledge elicitation was conducted in a workshop setting. A workshop was first held with five smallholder rice farmers involved in trialing TBS in the Samrong Commune near Kampong Cham, Cambodia. In this workshop, farmers were asked to list the main factors that they believed influenced the effectiveness of Community TBS. These factors were written onto pieces of butchers' paper. Then for each main factor, farmers were asked to list the sub-factors believed to influence it.

This list of main factors and sub-factors was used as input into a second workshop held at Kampong Cham with eight staff from CARDI and OAE. In this workshop, participants worked in small groups and each group was assigned a main factor to discuss. Groups conducted a mind-mapping exercise that drew upon the sub-factor list provided by the farmers, and their own knowledge, to develop an influence (cause and effect) diagram of the sub-factors influencing each main factor. Each group then described their influence diagram to the other groups to obtain feedback. Influence diagrams for each main factor were then combined to produce an overall influence diagram for Community TBS Effectiveness.

Benefit-Cost of Rodent Control Alternatives

Again, knowledge elicitation was conducted in a workshop setting. However this time, the aim was to rate and weight criteria considered when choosing among rodent control methods. The FARMERS project team had previously obtained these criteria from farmers and these were used as input to a workshop conducted with eight CARDI staff. First, the farmers' criteria were separated into two groups, benefit criteria and cost criteria.

Workshop participants then reviewed the criteria in each group. Four cost and two benefit criteria were finalised (see Table 1).

Table 1. Rodent control selection criteria.

Cost Criteria	Benefit Criteria
Material Costs Labour Costs Environmental Damage (impact on wildlife) Financial Costs (these are monetary costs)	Reduced Yield Damage Disease Reduction

To capture the relative importance of each criterion in rodent control method selection, two pie charts were used; one for benefit criteria and the other for cost criteria (see Figure 1).

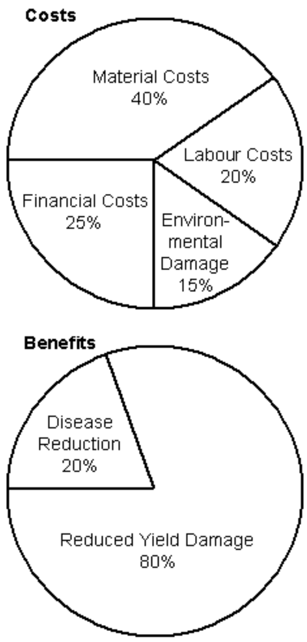

Figure 1. Example of pie charts used to capture relative criteria importance of individual people.

Each workshop participant was asked to complete the two pie charts, dividing the cost pie into four pieces (one piece for each of the four cost criteria) and the benefit pie into two pieces (one piece for each of the two benefit criteria) to represent the percentage importance of each criterion in rodent control method selection.

Individual workshop participants then rated nine rodent control methods against each of the benefit and cost criteria using a simple rating matrix (see Table 2). A relative rating scale of High, Moderate and Low was used. Workshop participants were asked to rate Community TBS first and then all remaining alternatives relative to it.

Table 2: Example of rating matrix used to capture criteria ratings of individual people.

Alternatives	Criterion 1	Criterion 2
Bamboo Trap	Moderate	Moderate
Chemical	Low	Low
Community TBS	High	High
Dogs and Digging	Low	Moderate
Electricity	High	High
Hunting	Moderate	High
Individual TBS	High	High
Netting	High	Moderate
Plastic Barrier	High	Moderate

2.2. Modelling Knowledge and Beliefs

Community TBS Effectiveness

Netica™ (Norsys Software Corporation 1998) was used to create a BBN model from the influence diagram produced during the knowledge elicitation workshops for Community TBS Effectiveness. Nodes and links were used to represent the influence of sub-factors on main factors, and of main factors on Community TBS Effectiveness (see Figure 2).

States for each node in the model were specified in consultation with CARDI staff. Conditional probability tables (CPTs) in the model were completed using subjective probability estimates. A CPT calculator developed by Cain (2001) was used during the probability elicitation process in order to maintain logical consistency in the probability estimates for CPTs. The CPT calculator also reduced the number probabilities that had to be elicited.

Due to time constraints it was not possible for the rice farmers to participate in the elicitation of CPTs of all nodes in the Community TBS Effectiveness Model. Therefore probabilities for all nodes but the Community TBS Effectiveness node were elicited from researchers, extension staff and the local field officers. Probabilities for the Community TBS Effectiveness node were elicited from farmers during a second workshop (see Table 3).

For parentless nodes in the model (nodes that have nothing linked to them), uniform probability distributions were specified.

Benefit-Cost of Rodent Control Alternatives

Netica was used to create a BBN model in which two nodes were created for each rodent control selection criterion (see Figure 3). These were a node to represent the criterion rating and another to represent the criterion weighting (relative importance). Each criterion rating node was given three states – High, Moderate and Low – which were assigned arbitrary values of 3, 2 and 1 respectively. Criterion weighting nodes were given five states – 0 to 0.2, 0.2 to 0.4, 0.4 to 0.6, 0.6 to 0.8 and 0.8 to 1 – representing percentage importance ranges.

A separate node containing the nine rodent control methods was linked to each criterion rating node to show that the criteria ratings depend upon the rodent control method. All of the cost/benefit criteria rating and weighting nodes were linked to a Cost/Benefit Score node, in which an equation (1) was used in perform the sum of the criteria ratings multiplied by their respective weightings.

$$\text{Score} = \sum_{ij}(\text{Criterion Rating} \times \text{Criterion Weighting}) \quad (1)$$

Finally, the Cost and Benefit Score nodes were linked to a Benefit Cost Ratio node containing an equation (2) to divide the benefit score by the cost score, producing a benefit cost ratio.

$$\text{Benefit Cost Ratio} = \text{Benefit Score}/\text{Cost Score} \quad (2)$$

Probabilities for the criteria weighting and rating nodes were obtained from the criteria importance pie charts and criteria rating matrices completed by the eight CARDI staff attending the workshop. CPTs for the Cost Score, Benefit Score and Benefit Cost Ratio nodes were populated by converting their equations to probability tables using Netica's Equation to Table function.

2.3. Making Sense of Knowledge and Beliefs

In order to make sense of the knowledge and beliefs surrounding Community TBS Effectiveness and Rodent Control Benefit Cost, the behaviour of the BBN models was tested by conducting scenario and sensitivity analysis with the people who participated in their development.

Scenario analysis was conducted by selecting particular states of nodes in the BBNs and observing the impact that this made on the probability distribution of outcomes. Figure 4, for example, shows the Community TBS Effectiveness Model with the best-case scenario inserted. The model shows that even in the best-case scenario, Community TBS was expected to have only a 64% chance of being highly effective.

For sensitivity analysis, the impact of changing the state of particular nodes in the BBNs was observed.

3. RESULTS

Community TBS Effectiveness

Table 3 shows that farmers believed poor TBS site location, poor TBS maintenance and poor TBS lure crops to be factors that greatly reduced Community TBS Effectiveness. This was also highlighted by sensitivity analysis using the model (see Table 4), which showed that Community TBS Effectiveness was most sensitive to TBS Site Locations, TBS Maintenance and TBS Lure Crops, and least sensitive to Farmer Participation in TBS. This result was surprising to the researchers because farmer participation was thought to have a relatively large influence on the success of Community TBS (i.e., a larger area of crop would be protected from rodent damage with more farmers participating). To clarify this outcome, the farmers were asked to simply list the factors directly affecting Community TBS Effectiveness in order from most to least important. This order was: (1) TBS Site Locations, (2) TBS Maintenance, (3) Farmer Knowledge and Skills of TBS, (4) TBS Lure Crops and (5) Farmer Participation in TBS, which closely matched the outcomes of the sensitivity analysis. Therefore, although a surprise to the researchers, the behaviour of the Community TBS Effectiveness Model seemed to make sense to the farmers.

A difference in the interpretation of Community TBS and effectiveness may be one explanation for the difference in beliefs between farmers and researchers. Farmers may have focused more on the effectiveness of TBS over individual crop areas, while researchers had larger community crop areas in mind. Also, farmer participation in TBS in Samrong Commune has been low and farmers may have found that TBS effectively protects their crops despite this low participation rate. Further research will be needed to clarify the situation.

Benefit-Cost of Rodent Control Alternatives

Figure 3 shows that the researchers and extensionists participating in developing the Rodent Control Benefit Cost Model considered Financial Costs to be the most important (approx. 43% of participants gave it a weight of between 0.4 and 0.6), and Environmental Damage the least important (approx. 57% of participants gave it a weight of between 0 and 0.2) cost criterion. Reduced Yield Damage was by far the most important benefit criterion (approx. 57% of participants gave it a weight of between 0.8 and 1).

Table 3. Probabilities elicited from rice farmers for Community TBS Effectiveness.

Factors Affecting Community TBS Effectiveness					**TBS Effectiveness (%)**	
Farmer Participation	TBS Site Locations	Farmer Knowledge/Skills	TBS Maintenance	TBS Lure Crops	High	Low
High	Good	Good	Good	Good	90	10
Medium	Good	Good	Good	Good	90	10
Low	Good	Good	Good	Good	85	15
High	Poor	Good	Good	Good	7	93
High	Good	Poor	Good	Good	75	25
High	Good	Good	Poor	Good	10	90
High	Good	Good	Good	Poor	30	70
Low	Poor	Poor	Poor	Poor	5	95

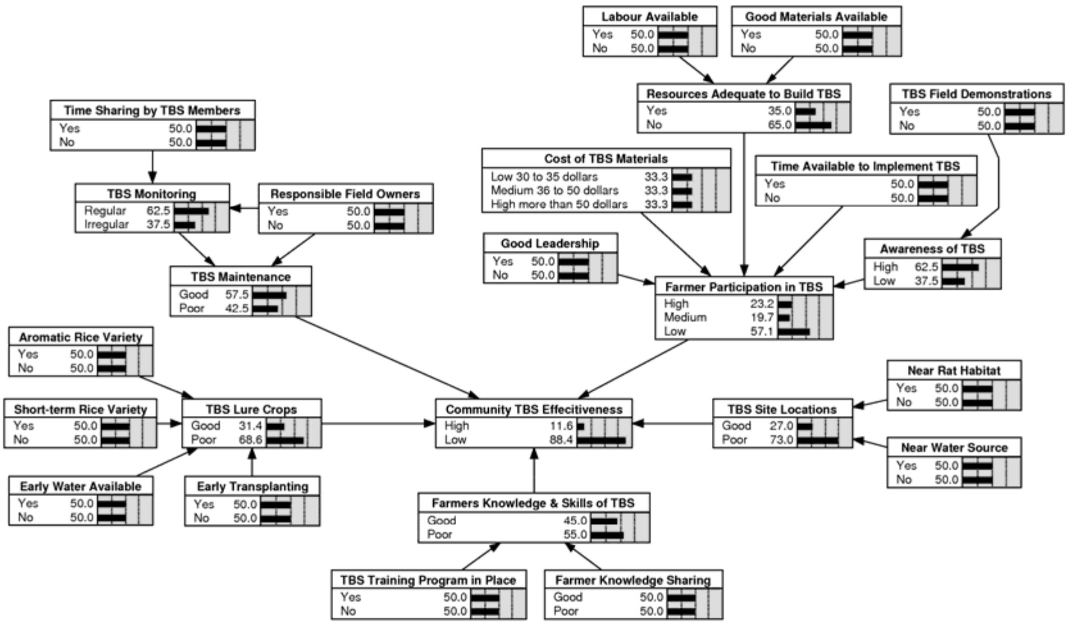

Figure 2. BBN for Community TBS Effectiveness.

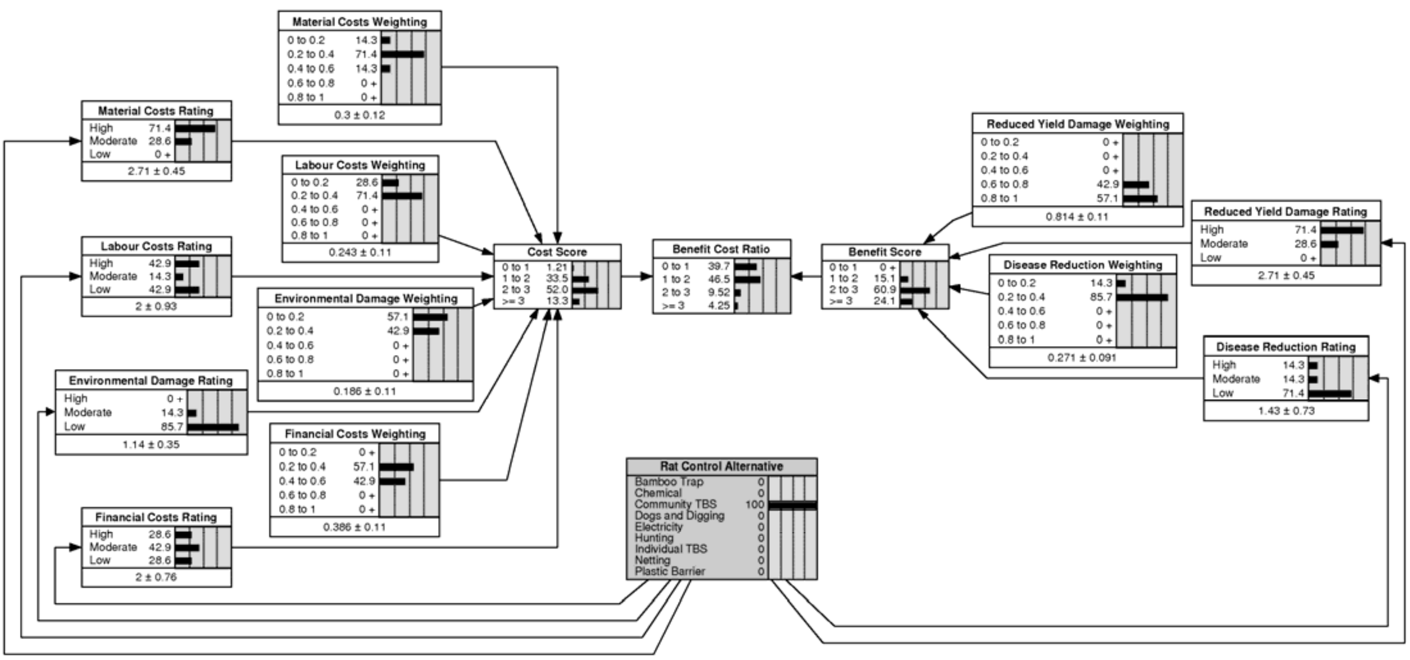

Figure 3. BBN for Benefit-Cost of Rodent Control Alternatives (Community TBS has been selected).

On the cost side of the model, most participants rated Community TBS high for Material Costs (71%) and low for Environmental Damage (86%). On the benefit side, Community TBS mostly received a high rating for Reduced Yield Damage (71%) and low rating for Disease Reduction (71%). Overall, Figure 3 shows that for approx. 40% of participants, the costs of Community TBS exceeded the benefits (benefit cost ratio 0 to 1). For the remaining 60%, the benefits exceeded the costs (benefit cost ratio greater than 1).

The model in Figure 3 was also used to identify those rodent control alternatives that were most likely to give a high benefit cost. This was done by selecting a benefit cost ratio of 2 to 3 in the Benefit Cost Ratio node and observing probabilities for rodent control methods is the Rat Control Alternative node. Community TBS had a relatively high preference under a high benefit cost scenario. Chemical Control also had a relatively high preference. This is because Chemical Control rated low to moderate for all cost criteria except Environmental Damage, for which all participants gave it a high rating. However, Environmental Damage was given a low importance by most, reducing the influence of its high rating on the benefit cost outcome. This may explain why chemical control has been a popular rodent control method among Cambodian rice farmers despite its obvious environmental and human health risks.

Table 4. Sensitivity analysis for Community TBS Effectiveness (nodes are ranked from most (1) to least (5) influential on Community TBS Effectiveness).

Rank	Node	Community TBS Effectiveness = High (% Probability)	Difference (% Probability)
1	TBS Site Locations = Good TBS Site Locations = Poor	27.9 5.5	22.4
2	TBS Maintenance = Good TBS Maintenance = Poor	16.0 5.6	10.4
3	TBS Lure Crops = Good TBS Lure Crops = Poor	17.9 8.7	9.2
4	Farmer Knowledge & Skills of TBS = Good Farmer Knowledge & Skills of TBS = Poor	12.4 10.9	1.5
5	Farmer Participation in TBS = High Farmer Participation in TBS = Low	11.8 11.4	0.4

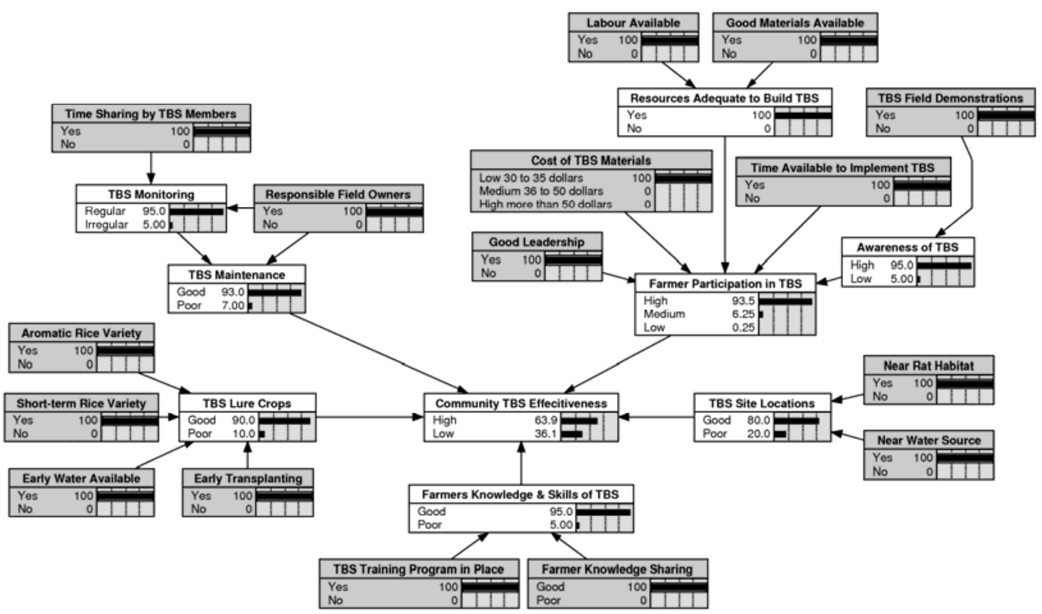

Figure 4. Community TBS Effectiveness Model with best-case scenario inserted.

4. DISCUSSION AND CONCULSIONS

The models described in this paper were developed in a very short time using a small number of participants and serve only to provide examples participatory modelling using BBNs. Since developing these models, CARDI staff have adopted the participatory modelling approach to developing their own models. The continued use of the modelling approach by CARDI highlights the potential of participatory modelling to build local capacity for the ongoing development and use of decision support tools.

Although simple, the models described in this paper demonstrate some of the particular benefits of using BBNs in participatory modelling. The first is the ability to incorporate the different beliefs and viewpoints of people into models. The Rodent Control Benefit Cost Model highlighted this by integrating criteria ratings and weightings obtained from many people.

The second is the ability to easily integrate biophysical, social and economic variables, either quantitative or qualitative, into models. The Community TBS Effectiveness Model highlighted this by allowing variables such as Cost of TBS Materials, Good Leadership and Rice Variety to be incorporated.

The third is flexibility. Both a cause and effect model (Community TBS Effectiveness Model) and an MCA model (Rodent Control Benefit Cost Model) were built using BBNs in this study.

The fourth is the ability to communicate management system behaviour among stakeholders. This was highlighted by the results of sensitivity analysis using the Community TBS Effectiveness Model. Although the behaviour of the model was surprising to the researchers, it seemed to make sense to the farmers. Because the model was graphical and allowed for interactive scenario and sensitivity analysis, it provided a communication mechanism for discussing system behaviour.

Last but not least, BBNs allow models to be readily updated as new knowledge and data comes to hand. For instance, the conditional probabilities in models can be updated over time using on-going monitoring or survey results, and variables can be added and removed without the need for specialist programming expertise. CARDI plan to survey a larger population of rice farmers to update probability distributions for criteria ratings and weightings in the Rodent Control Benefit Cost Model. They also intend to assess TBS effectiveness, as well as those factors believed to influence it, for several rice farming communities so that probabilities in the Community TBS Effectiveness Model can be updated based on case observations.

5. ACKNOWLEDGMENTS

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6. REFERENCES

ACIAR (2001), Non-chemical control of rodents in lowland irrigated rice crops. *ACIAR Research Note RN 26 9/01*, ACIAR, Canberra.

Cain, J., Batchelor, C. and Waughray, D. (1999), Belief Networks: A framework for the participatory development of natural resource management strategies, *Environment, Development and Sustainability*, 1, 123-133.

Cain, J. (2001), *Planning improvements in natural resources management: Guidelines for using Bayesian networks to support the planning and management of development programs in the water sector and beyond*, Centre for Ecology and Hydrology, Wallingford, UK.

Cain, J., Jinapala, K., Makin, I.W., Somaratna, P.G., Ariyaratna, B.R., and Perera, L.R. (2003), Participatory decision support for agricultural management: A case study from Sri Lanka, *Agricultural Systems*, 76, 457-482.

Norsys Software Corporation (1998), *Netica Application User's Guide*, Norsys Software Corp., Vancouver, BC, Canada, Available from www.norsys.com.

Nonaka, I. and Konno, N (1998), The Concept of 'Ba': Building a foundation for knowledge creation, *California Management Review*, 40 (3), 40-54.

Wooldridge, S. and Done, T. (2003), The use of Bayesian belief networks to aid in the understanding and management of large-scale coral bleaching, *MODSIM 2003 Conference Proceedings: Integrative Modelling of Biophysical, Social and Economic Systems for Resource Management Solutions*, Townsville, Australia, 14-17 July 2003.