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App2Adapt: Using Tablet Technology to Elicit Conditional Probabilities for Bayesian Belief Network Modelling

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Abstract: The aim of this study is to use touch-screen computer tablet technology (e.g. iPAD) and its interactive flight console capabilities (e.g. touch screen 'sliders') as an improved method to stakeholder-driven climate change adaptation research. Climate change vulnerability and adaptation have strong human dimensions meaning that the experiences of stakeholders often plays an important role when assessing adaptation options and/or the determinants of adaptive capacity. Methods such as Bayesian belief networks (BBNs) can draw upon the extensive knowledge and beliefs of stakeholders in a straightforward manner yet are underpinned by a robust mathematical framework (i.e. Bayes theory). This is critically important for advancing climate change adaptation research and policy adoption. This project is borne out by the observed difficulty that stakeholders have, at times, displayed when assigning conditional probabilities to BBNs. This methodological step is recognised as the most difficult challenge when developing these knowledge-based models. In response to this, we have developed a computer tablet application (through the App2Adapt project), tailored specifically to improve elicitation of stakeholder-generated conditional probabilities. This app has been developed based on the experiences of the research team and through field-testing at different stages of the design process, including application to a real-world example. The development of this app and usage of this rapidly emerging technology in stakeholder engagement process will lead to significant improvement of using BBNs as a methodological approach to climate change adaptation research.

Keywords: climate change adaptation; iPad application; Bayesian belief networks; stakeholder engagement

1. INTRODUCTION

Climate change adaptation and vulnerability have strong human dimensions (Moser 2005; IPCC 2007) meaning that the experiences of stakeholders often play an important role when assessing adaptation pathways and/or the determinants of adaptive capacity (Moser 2005). Therefore modelling methodologies such as Bayesian belief networks (BBNs) that can draw upon the extensive knowledge and beliefs of stakeholders in a straightforward manner yet are underpinned by scientific robustness are critically important for advancing climate change adaptation research and policy adoption (Catenacci and Giupponi 2012). The utility of using BBNs in engaging with stakeholders has recently been demonstrated in climate adaptation (Richards et al. 2012) and sustainable resource research (Tiller et al. 2013).

However, the efficacy of using BBNs for eliciting 'expert opinion' is compromised by one of the core steps in constructing BBNs, that of assigning conditional probabilities. This methodological step is recognised as the most difficult challenge when developing these knowledge-based models (Catenacci and Giupponi 2012; Richards et al. 2013). Our (i.e. the co-authors) usual approach has been to print off conditional probability tables (CPTs) created in Excel (or similar spreadsheet software) so that the individual stakeholders could provide their probabilities using a 'pen and paper' approach. From this, we have observed first-hand the difficulty that stakeholders at times have displayed in populating these CPTs, particularly when three or more parent nodes are associated with a child node. Consequently, stakeholders have been confronted with populating relatively large CPTs (i.e. requiring eight or more probabilities to be assigned). We then observed that some stakeholders would noticeably struggle with assigning probabilities that reflected their beliefs about the different scenarios in a single CPT. Furthermore, this struggle would be repeated across the multiple CPTs that required parameterising a full BBN (typically four CPTs), reducing the robustness of the model and its outcomes.

Borne out by this observed difficulty by some of the stakeholders, we have developed a computer tablet application (app) aimed at specifically improving on our current approach of eliciting stakeholder-generated conditional probabilities.

In this paper, we first present the rationale for developing and using our app as a means of obtaining expert-based conditional probabilities. We then describe the software environment for the app along with its general architecture. More specifics about the app development process are then detailed including highlighting the key features of the app and the testing procedure. We then present some results of preliminary testing undertaken to compare the 'pen and paper' and app approaches to parameterising a BBN and its use in a full stakeholder workshop setting. Finally, we conclude with some overall comments about the future application of this app including potential areas of refinement and upgrade.

2. RATIONALE FOR THE APP

The rationale for using an app approach is that (i) there is a high and rapidly increasing level of familiarity with touch-screen technology (aided by similar technology of smart phones); (ii) this interactive technology can provide a graphical user interface that better facilitates visual methods of eliciting probabilities (e.g. sliders and buttons); (iii) additional background data (e.g. contextual information on climate change) can be included within the app and dynamically accessed by the researchers and/or the stakeholders to provide further context for the BBN CPTs; (iv) conditional probability data can be immediately uploaded to cloud storage (data management and security); and (v) ease of use and learnability would enable users to better perform their tasks and minimise previous experiences of stakeholder fatigue.

3. DESCRIPTION OF THE APP

3.1 Development Software Environment

The app was developed in Apple's integrated development environment of Xcode 5.0.1 supporting Objective-C source code.

3.2 App Architecture

The app framework employs a coupled Master-Client system (Figure 1). The Master app (Master) provides the interface for the researchers or manager of the BBN development to define the BBN structure (nodes and states) and control the transfer of data between the Master, Clients and cloud storage (e.g. a file-hosting service such as Dropbox). The Client app (Client) provides user-interface for stakeholders to assign conditional probabilities for the BBN. Communication between the Master and Client apps occurs via Bluetooth utilising the Bluetooth core data framework. Bluetooth was chosen as the method of transferring data because of its independency from wireless networks.

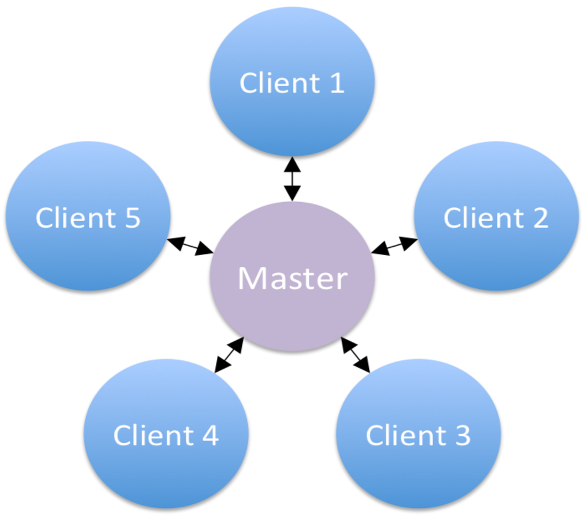

Figure 1. Example of a Master-Client system used by the app (in this case five clients (iPADs) are connected to the Master app, however the number of clients that can be used is unlimited).

3.2.1 Master App architecture

The Master app is used by the researcher only (i.e. the Stakeholders do not use this app) to set up the structure of a BBN, including discretisation of the nodes, distributing this data to multiple iPADs (Clients) and then collecting and collating the populated CPTs. Therefore, the architecture of the Master provides two core functions; (i) create a BBN structure and transfer this data to the Client(s) and (ii) upload the conditional probability data from the Client(s) and transfers this to storage (Figure 2).

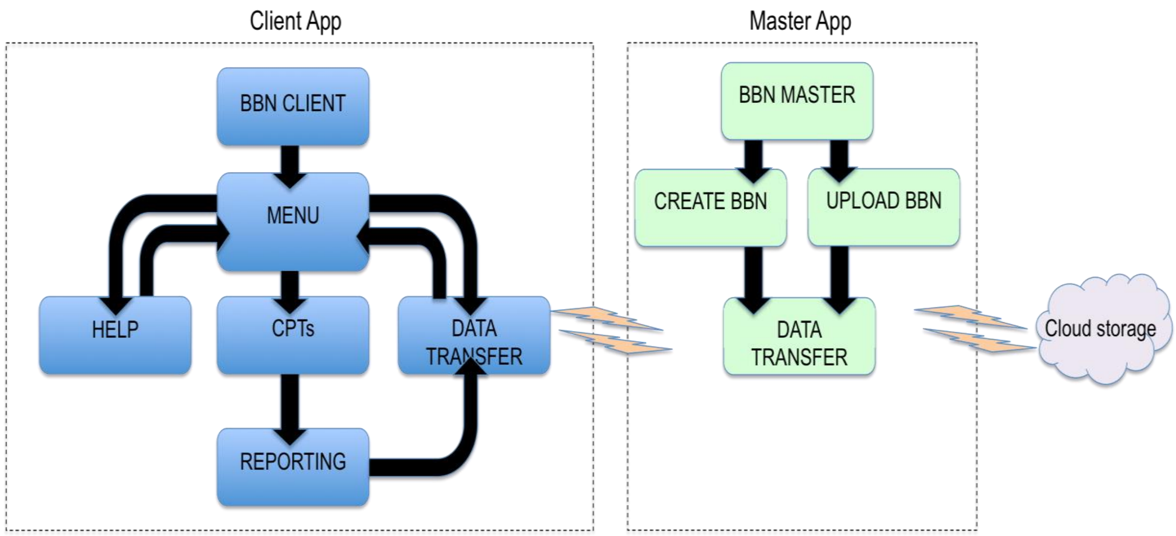

Figure 2. Main sub-components of the Master and Client system of apps.

The BBN structure is created using the Master component of the app (Figure 3) and a 'bottom-up' approach (i.e. 'parents' are added to 'child' nodes). The starting point is a child node that has no descendants (a leaf node), often used in research as an objective of our study e.g. the ability to implement some management option such as moving (retreating) infrastructure in response to sea-level rise. This child node is automatically 'activated', which enables the user to add parent nodes (maximum of four) using the side menu (see Figure 3). To add further hierarchical levels, the user can activate an existing parent node and add parent nodes to this (maximum of four). The node name and two states can also be entered for the currently activated node. Once the structure of the BBN has been defined (currently limited to three hierarchical levels), this data is transmitted to Client apps via Bluetooth (Figure 3c).

Figure 3. (a) Screen shot of a BBN structure in Master app. The arrows located on the right-hand side allow the user to add or remove nodes from different hierarchical levels above the child node (maximum of three levels). Node details (Name and two states) can be entered for the current activated node (indicated by the semi-transparent node); (b) Completed details of the BBN and its CPTs ready to be sent via Bluetooth to the Client apps.

3.2.2 Client app architecture

The main function of the Client app is to obtain the conditional probabilities from the stakeholders for each of the CPTs associated with the BBN structure. We elicit this information from the stakeholders through the use of interactive sliders (Figure 4), which the stakeholder adjusts by touching and dragging the slider ‘thumbnail’ to reflect their belief. The stakeholders are presented with a CPT consisting of all possible combinations of the parent node states (scenarios). Each scenario has an associated slider and thus for the case of two parent nodes, each discretised with two states there are four scenarios and hence four sliders.

The role of the slider (and specifically the position of the thumbnail) is to reflect the assignment of conditional probabilities for the child’s two states for that particular scenario. Moving the thumbnail to either extremes of the slider (i.e. furthest left or furthest right) equals assigning 100% probability to one state and 0% to the other. The slider has a linear scale and therefore placing the thumbnail in the centre equates to assigning 50% to each state. The default position for each slider is set at the mid-point. There are ‘check boxes’ (see Figure 4) next to each slider that the Stakeholder can use to indicate that they have chosen not to assign a probability (through positioning the slider) for that particular slider. This particular feature was added after soliciting feedback on the app during the testing / development process.

We have built in other features of the Client app to try and improve its efficacy as a platform for eliciting the conditional probabilities including visual changes such as adjusting the size of the sliders and background colour.

We also have added basic functionality to the CPTs to try and assist the stakeholders in assigning their probabilities. We do this by providing a function button that enables the stakeholder to re-order the scenarios/sliders in descending order based on the respective thumbnail locations of the sliders. The purpose of this is to help the stakeholders correlate their beliefs about the scenarios and the conditional probabilities that they assign.

We have also included an option of whether probabilities need to be assigned for the root nodes (nodes without parents and therefore the probabilities are unconditional).

Notionally, stakeholders are limited to the sub-components of the Client app that deals with populating the CPTs with guidance for using the app provided by the researchers (e.g. through a demonstration). However, Help screens can also be called by the stakeholder to guide them through the CPT process (accessed through the '?' icon shown in Figure 4 – right panel).

Figure 4. Main menu page (left) and CPT page (right) using a slider for each 'scenario'. Check boxes are also displayed on the CPT page immediately to the right of each slider – this option allows users to explicitly 'opt-out' of assigning a probability.

4. TESTING THE APPS

4.1 Testing app usability

The combined Master-Client app underwent testing in a series of one-on-one demonstrations at the end of 2013. At this stage of the development, we were testing for the usability of the app (e.g. how easy it was to use and navigate the efficacy of the built-in functions [e.g. re-ordering], functioning of the sliders etc) rather than collecting data (conditional probabilities).

4.2 Comparative testing

The efficacy of the Master-Client app was tested in early 2014 using a stakeholder that had previously used the 'pen and paper' approach to assign conditional probabilities. The purpose of this consultation was to obtain preliminary feedback about whether this app improved the ability to assign conditional probabilities. This stakeholder was involved in the development of a suite of BBNs in September 2010 as part of regional assessment of adaptive capacity in Australia (see Richards et al., 2013). The BBN that this person was involved in developing (Figure 5) was focused on the management of existing (current) infrastructure in a coastal area of south east Queensland (the child node). It consisted of two hierarchical levels of parent nodes (primary-level and secondary-level nodes), with each node discretised to two states and a maximum of three parent nodes specified for each child node.

The stakeholder was helped to familiarise with the BBN that the stakeholder was involved on (but not the conditional probabilities) because over three years had elapsed since they were involved in its development. This familiarisation process included presenting the research aims of the regional assessment, the context of the specific BBN that was developed and an overview of the methodological steps that undertaken during the development of the BBN (structure and assigning of conditional properties). The stakeholder was then asked to repeat the process of assigning conditional probabilities for their BBN but using the app (as opposed to the 'pen and paper' approach originally applied). Feedback was sought on the efficacy of using the app to assign conditional probabilities.

4.3 Testing the app in a stakeholder workshop

The final step of the current development and testing process of the app was to use it in a stakeholder workshop environment utilising stakeholders that had previously used the pen and paper method of populating BBNs. The app was used in a fisheries-based workshop carried out in Frøya, Norway in April 2014. The objective of this workshop was to explore the sustainability of commercial fishing from the perspective of commercial fishers. This was explored within the context of a ten-fold increase in aquaculture production within the same area, and it was an iteration of a previous workshops held two years prior on the same issue. The stakeholders were involved in developing a BBN around the priority issue of the continued existence of the commercial fishery on the island (Frøya) using the methodological approach outlined elsewhere (Richards et al., 2013; Tiller et al., 2013). However, the methodological step of populating the conditional probability tables for their BBN (which occurred during the workshop) was carried out using the app as opposed to the first time they took part in the workshop and used the pen and paper method. Instruction on using the app was provided by the facilitator (one of the co-authors) during the workshop.

5. RESULTS AND DISCUSSION

5.1 Preliminary Feedback on app usability

The one-on-one demonstrations provided insight into the usability of the app. Feedback elicited during these demonstrations included the following:

- Slider usability was straightforward;
- The need for 'opt-out' functions so that the user could explicitly indicate where conditional probabilities had not been specified;
- The name of the app needed changing;
- That the font type and size were inappropriate.

Many of these suggestions have been implemented, notably the inclusion of the 'opt-out' function. This suggestion was particularly salient as it highlighted an area that the app could not (until that stage) address i.e. the ability to allow the stakeholder an option of not specifying a conditional probability if they chose not to.

5.2 Comparing approaches to assigning conditional probabilities

The aim of this process was to test the app on a person who was familiar with the 'pen and paper' approach to populating CPTs. However, it was recognized that three and half years had elapsed between the initial BBN development (2010) and assigning the conditional probabilities using the app (2014). The process of comparing methodologies for assigning conditional probabilities was therefore discussed with the stakeholder in the context of this elapsed time. The stakeholder stated that their recollection of the 'pen and paper' approach was not exact, however, this person recalled that the process of 'filling in the tables' was quite challenging.

The stakeholder considered the slider approach was easier and recalled the difficulty using the 'pen and paper' approach. In particular, the stakeholder found that there were benefits from being able to re-order the 'scenarios' in ascending/descending order (based on the probabilities that they had assigned), which allowed them to re-assess the relative influence of the different 'scenarios' that comprise a CPT.

The stakeholder also found that the use of graphical sliders made it easier to reflect their beliefs in the degree of influence that different parent nodes were having on the child node. For example, the stakeholder was explicit in their belief that one of their variables was a critical determinant of its respective child node in the BBN and found it a straightforward process to reflect this in the associated CPT.

One problem that the stakeholder highlighted, was that they (the stakeholder) tended to assign 0% and 100% probabilities (extremes of the slider) for the worst- and best-case scenarios in the CPTs. Conversely, when using the 'pen and paper' approach, the stakeholders involved in the original project (Richards et al., 2013) rarely assigned these probabilities for the best- and worst-cases. Furthermore, these 'boundary' condition probabilities often provided insights into the elicitation process (e.g. 'even with perfect conditions it is not assured that this will happen' etc) that did not emerge during this current testing of the app.

5.3 Use in a workshop environment

The final stage of the current testing process involved trialling the app during a proper workshop environment. The general feedback from the six stakeholders involved was positive, though the elder fishers 'joked' that it would be too modern for them, or that the buttons were too small. These types of banter were not uncommon when using the pen-and-paper methods either. We compensated with giving extra time with the stakeholders in question. The stakeholders generally grasped the concept of using the sliders to assign probabilities with relative ease, though.

A review of the conditional probabilities that were assigned also appeared to support the narrative that emerged from the workshop (i.e. the discussion that took place during the workshop while the model was developed). For instance, the importance of landing sites was brought up often during the workshop. Without functional landing sites for their fish and crustaceans, the fishers did not see any future for their trade. This was reflected in the BBN with landing sites and access to raw materials having the most influence.

Figure 5 shows the parameterised BBN that was produced during the workshop based on the beliefs of five of the stakeholders. The CPTs for the sixth stakeholder were not included here in this preliminary assessment because this stakeholder had chosen to use the opt-out option in assigning some of their probabilities. The main implication of this for displaying the group-level BBN is that separate auxiliary 'stakeholder' nodes are needed for each child node (as opposed to our example presented in Figure 5 where a single auxiliary stakeholder node is used for all child nodes). For the purpose of exemplifying the development of a BBN using the app we choose here to show a network using CPTs where the stakeholders did not select the opt-option. However, our full assessment of the BBN includes the probabilities from all six stakeholders. Furthermore, this does provide an example about the utility of including an 'opt-out' option in the app.

Using a sensitivity analysis (using 'Commercial Fishery' as the focus node), allows us to explore the important nodes and pathways as determined by the probabilities assigned by the stakeholders. This highlighted the relative importance of 'Landing Site' and 'Income' as important determinants for the continued existence of the Commercial Fishery. However, there was also notable divergence in the beliefs of the stakeholders, resulting in the Stakeholders node playing a prominent role in the sensitivity analysis.

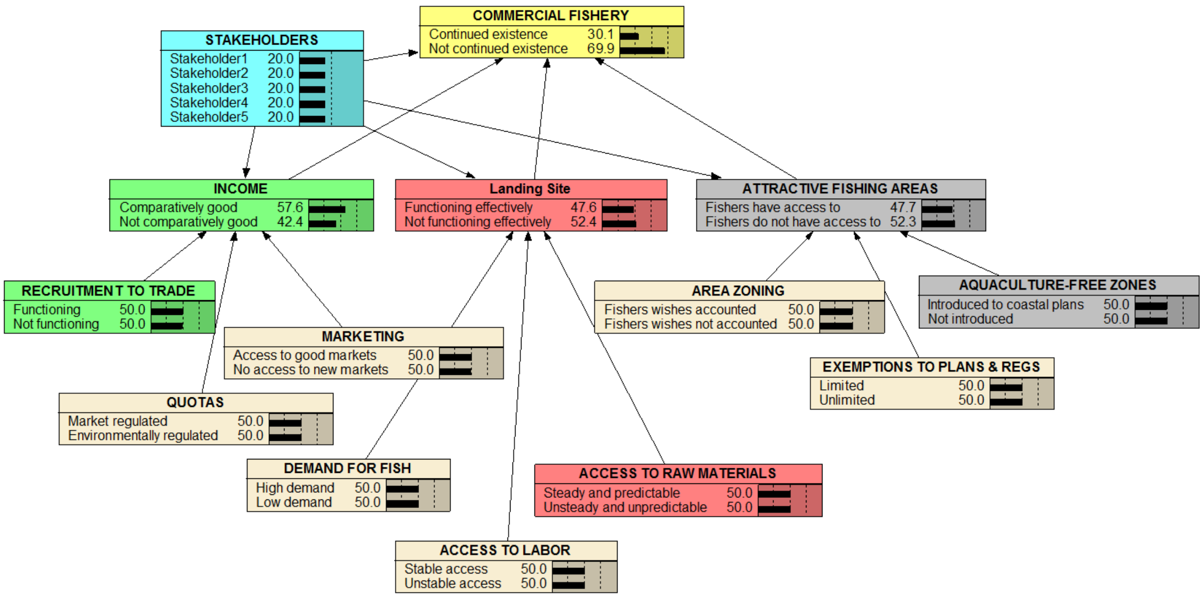

Figure 5. BBNs showing the most influential node pathways after sensitivity analysis. RED nodes are most influential, followed by GREEN nodes and then GREY nodes. The yellow node is the leaf node

around which the BBN is constructed. The BLUE node is the auxiliary stakeholder node that is used to weight the individual stakeholder probabilities (evenly weighted in this case).

6. LIMITATIONS AND FUTURE IMPROVEMENTS

Based on the preliminary findings of testing the current app and 'lessons learnt' from previous studies (e.g. Richards et al., 2013), the current version of the app generally meets the aim of improving the elicitation of conditional probabilities. However, there are several areas where the app could be improved – some of these areas emerged during the app testing process. We focus on two of them here. Firstly, a limitation that is imposed on the app is restriction of two states per variable. This ensures that linear sliders can be used to assign the conditional probabilities, however, it constrains the discretisation of variables to dichotomous states. Secondly, 'real' time sensitivity testing that highlights the relative influence of the parent nodes on the child node for a specific CPT would conceivably raise the utility of the app. This would provide an added visual cue for the stakeholders when they are endeavouring to reflect their expert opinion in the probabilities that they assign.

7. CONCLUSIONS AND WHERE TO FROM HERE?

The app has shown promise to meet the main aim i.e. improve on the current approach of eliciting conditional probabilities. The use of touch-screen technology appears to be particularly effective in engaging with stakeholders, probably because of the ubiquitous nature of this technology in society. That is, people can easily accept this new technology.

Feedback during the testing of the app has already greatly improved its utility (e.g. inclusion of 'opt-out' check boxes). Some suggestions for improving the app have not yet been implemented because of resource constraints (time and money), however, strong consideration is given to incorporating algorithms into the Master app to allow sensitivity and top-down/bottom up scenario testing to be performed on the parameterised BBNs (individually or aggregated using the individual stakeholders as a variable) and incorporation of algorithms in the Client app that provide visual indicators highlighting which are the important parent nodes for a given CPT.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

Catenacci, M. and Giupponi, C., 2012. Integrated assessment of sea-level rise adaptation strategies using a Bayesian decision network approach. Environ. Modell. Softw. 44, 1–14.

IPCC, 2007. Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7–22.

Kjærulff, U., Madsen, A., 2008. Bayesian networks and influence diagrams: A guide to construction and analysis, New York: Springer.

Moser, S.C., 2005. Impact assessments and policy responses to sea-level rise in three US states: An exploration of human-dimension uncertainties. Global Environmental Change 15, 353–369.

Richards R., Sano, M., Roiko, A., Carter, R.W., Bussey, M., Matthews, J., Smith, T.F. 2013. Bayesian belief modeling of climate change impacts for informing regional adaptation options. Environ. Modell. Softw. 44, 113–121.

Tiller, R., Gentry, R., Richards, R., 2013. Stakeholder Driven Future Scenarios as an Element of Interdisciplinary Management Tools; the case of future offshore aquaculture development and the potential effects on fishermen in Santa Barbara, California. Ocean & Coastal Management 73, 127–135.