CIMAT: a Knowledge-based System for Developing Criteria & Indicators for Sustainable Forest Management

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Abstract

The Center for International Forestry Research (CIFOR) has carried out research to develop Criteria and Indicators for sustainable forest management (C&I) in eight countries since 1994. In the CIFOR framework C&I are organised hierarchically as principles, criteria, indicators, and verifiers. Based on an analysis and synthesis of the C&I research a set of C&I has been identified that can form the starting point for developing localised sets of criteria and indicators. This set is called the 'Generic Template'.

A knowledge based system called CIMAT (Criteria and Indicators Modification and Adaptation Tool) has now been developed to support the process of developing locally adapted C&I using the Generic Template as a starting point. In CIMAT all the principles, criteria, indicators, and verifiers of the Generic Template are represented as items that can be modified by the user. The modification can only take place when users explain their reason for the change. All the reasons in the system can be made dependent upon one another, they can be revised during modification, and they can be counter-argued by other users. The need to represent and maintain these reasons and their interdependencies is resolved through the use of a reason maintenance system (RMS). Another meta-level component of CIMAT is its ability to compare and analyze multiple knowledge bases.

Keywords: sustainable forest management, criteria and indicators, knowledge-based system, automated reasoning, reason maintenance system, argumentation.

1. Introduction

Criteria and indicators for sustainable forest management (C&I) are tools which can be used to collect and organise information in a manner that is useful in conceptualising, evaluating, communicating and implementing sustainable forest management. The Center for International Forestry Research (CIFOR) has been carrying out research on C&I for the Forest Management Unit (FMU) level from 1994. This research has taken place in Indonesia, India, Côte d'Ivoire, Cameroon, Brazil, Austria, Germany and USA (Prabhu *et al*. 1996, 1998a). C&I are already widely used in certification of forest management, and the development of standards, and are being increasingly adopted by forest managers to structure monitoring programs and to inform management decisions.

In CIFOR's approach, C&I are organised into a four level hierarchy of principles, criteria, indicators, and verifiers (PCI&V). The top two levels define the goals or values that the concept of sustainable forest management can be broken down into, the bottom two levels deal with variables used to actually measure or monitor progress towards achievement of these goals in any forest area. These four hierarchical levels have been linked conceptually in (Prabhu *et al*. 1999) to the four basic entities (wisdom, knowledge, information, and data) in information theory of (Liang 1994). An example of an ecological principle, criterion, indicator and verifier is given in Annex 3.

Based on an analysis and synthesis of its research on C&I, CIFOR has proposed a Generic Template that can be used as an effective starting point for developing locally adapted sets of C&I (CIFOR C&I Team 1999b, Prabhu *et al*. 1998a). The Generic Template recognises that a single C&I set is not likely to be universally applicable. Instead it foresees a process of adaptation and customisation to local conditions, expectations and management objectives. The purpose of the Generic Template, is to inject the results of international comparative research into this development process, cut down development time and ensure that structural and conceptual compatibility and rigour is maintained with other sets of C&I.

The top level of the Generic Template hierarchy consists of six principles of sustainable forest management, shown in Annex 3. Each principle is elaborated in terms of criteria, indicators and verifiers. A total of 238 statements are included within the hierarchy.

If the process of adaptation of this hierarchy to local conditions is not to be a daunting challenge it will need to be simple, understandable and designed to meet user needs, i.e. it must be user-friendly. In order to fulfil these conditions a software tool has been built, designed to help users to carry out modifications to the generic template simply yet rigorously. This software is called Criteria and Indicators Modification and Adaptation Tool (CIMAT).

This paper presents an overview of CIMAT. Section 2 describes the process of determining the needs of potential users of such a tool, resulting in an understanding of our user requirements. Section 3 describes the software tool itself, its main components and functionality. Section 4 takes a closer look at the most novel aspect of the tool, which is its mechanism for encouraging users to clearly state their reasons for changes, and allowing subsequent debate and counter-argument of these reasons. The result of using CIMAT is a new set of C&I, and so CIMAT also supports comparison between different C&I sets, making use of the history of argumentation. This feature is also briefly outlined in section 4. Section 5 outlines our evaluation plan and section 6 concludes and points out future directions for research.

2. User Requirements

Who are the users?

CIMAT is a tool for people who are developing C&I, using CIFOR's generic template as a starting point. Three groups of C&I users were identified.

- Experts within CIFOR's network of C&I researchers who have been involved in the evolution of the current C&I sets.
- International C&I stakeholders, including developers of national forest stewardship standards and forest managers.
- Forest assessors/certifiers.

Before we built CIMAT we needed to know what kind of a tool our users need, so that we could design a system to be genuinely useful, making their job quicker, easier, more manageable, cheaper or better quality. Some of the ways a computer could help may be clerical (producing useful reports, checklists etc). Some may be organisational (keeping track of version changes). Some may be human (helping a team of experts to co-ordinate their work more effectively). In order for us to match the tool to the task, we needed first to gain a better understanding of the needs and constraints of our users. To achieve this understanding a three-month-long process of user requirements capture has been carried out using an international standard methodology (Mazza *et al*. 1996) for the work. The resulting CIMAT User Requirements Document forms a full record of the users' requirements. A brief summary is in Annex 1.

Requirements Capture Method

The needs of these users were investigated as follows.

1. In-house experts and other C&I stakeholders resident in Indonesia were interviewed and their views elicited through informal questioning during the interviews. Notes of the interviews were taken and a summary written.
2. An email discussion group was set up, to involve international stakeholders and others, and their views on an initial discussion document about CIMAT were elicited. In addition they were asked to respond to a set of informal questions, similar to those used in the interviews.
3. Two fictional 'scenarios' of use of CIMAT were written, and feedback sought on these by in-house experts and on the email discussion group.
4. As part of the C&I assessment process, Smartwood and SGS-Forestry, two forest certification companies, carried out a simulated forest certification exercise in Central Kalimantan (Indonesia) using the generic template. The first part of this exercise was to modify the generic template to the conditions of the exercise. Protocols were observed of early modifications at a preparatory meeting in Oxford, UK, and further localisation during fieldwork planning meetings at CIFOR immediately prior to the exercise. These protocols provided valuable input about how C&I are used in a certification process and what modification processes are involved. They also provided an opportunity for acquisition of knowledge about how to 'localise' C&I.

5. A synthesis of the requirements from the previous steps was generated, in the form of a 'hitlist' of 50 requirements statements.
6. Confirmation and prioritisation of these requirements was carried out by a user survey (involving the email discussion group and the certification team). The survey used a formal questionnaire in which the users were asked to categorise the statements as 'Essential', 'Useful' or 'Not helpful'. A simple scoring method was used to analyse the results, to produce a ranking of requirements as high, medium or low priority. The high priority requirements are listed in Annex 1.

3. CIMAT overview : the object level

CIMAT's C&I knowledge base

At the heart of CIMAT is a knowledge base of C&I for sustainable forest management. It is thus a *knowledge system* (Stefik 1995). The core knowledge base includes CIFOR's generic template, plus knowledge about how to modify it and general knowledge about C&I. The knowledge base is essentially incomplete, and contains lots of 'hooks' upon which users can hang knowledge which is relevant to sustainability of forest management in the particular context they are interested in. CIMAT invites the user to bring their knowledge to the system, in order to enhance and build upon the knowledge within it. CIMAT is a knowledge-based system, but it is not a conventional expert system because it does not propose a solution to the C&I modification problem, nor will it act as an expert guiding a user through an assessment of sustainability. Instead it records the user's reason for particular modifications and structures this information in such a way that all these reasons can be used as knowledge for subsequent modifications. Its role is to manage knowledge, rather than to advise, and the 'locus of responsibility' (Whitby 1988) remains firmly with the user. In designing CIMAT we were informed by the work on argumentation in (Haggith 1996).

Each principle, criterion, indicator and verifier in the hierarchy is an 'object', which can be changed, deleted, added or moved. In the current prototype knowledge base the C&I are structured as a hierarchy of objects represented using the logic programming language, prolog (Clocksin & Mellish 1981). This enables modular knowledge base development and reasoning with the C&I knowledge in different ways in different parts of the hierarchy. The user may add additional remarks, comments and sources of relevant knowledge to all objects. Each object remembers the sequence of modifications that it undergoes, so it ends up with its history of how it has been modified. This provides an 'institutional memory aid' for users. The result is a network of indicator objects that change and evolve over time in response to the users' modifications and adaptations. As the user gives reasons for modifications, these are also included in knowledge base, as justification objects and assumption objects. The body of knowledge about modifications thus also grows and evolves over time.

In addition to the generic C&I knowledge base, and knowledge about modifications, there are a host of useful general documents providing guidelines for developing and using C&I (eg. Prabhu *et al*. 1996, Stork *et al*. 1997, Colfer *et al*. 1998), carrying out sustainability assessments using C&I and providing examples or illustrations of C&I in particular contexts. CIMAT includes a repository of such general information. To facilitate this, the existing information resources and their relevance and usefulness were investigated, resulting in a C&I information map (Davenport 1997, Prabhu *et al* 1998b) which forms the basis of the general knowledge base in CIMAT.

Functionality

CIMAT has two main functions - navigation and modification.

1. The first function is to support the user in navigating the C&I information resources, and the hierarchy of C&I. CIMAT provides navigation support using nested lists and menus. Navigation breaks down into navigation of the C&I hierarchy; and exploration of the general knowledge and information resources contained in CIMAT.
2. CIMAT's second function is to support the user in modifying their own set of C&I to meet their local conditions. In addition to the necessary editing facilities the modification guide includes simple dialogues to prompt users for their reasoning.

Other user interface features include a comprehensive help facility and access to utilities such as printing sets of C&I in various formats, saving files etc. The user interface is implemented in the Tcl/Tk scripting language which is platform independent and therefore offers a good complement to the knowledge core which is implemented in SICStus prolog (SICS 1995).

The user can modify any object in the C&I hierarchy, except for the six principles. The six modification options: Add, Change wording, Substantive change, Move, Delete, Restore.

For example, to reflect the local conditions in a commercial forest area in Kalimantan, and to reduce the effort involved in using the C&I set as the basis of monitoring, the user would probably choose to *delete* many of the C&I which are most appropriate for management of sensitive areas of high conservation status, such as the ecological C&I concerning genetic variability. They would also be likely to make *substantive changes* to some of the production-oriented C&I to reflect the kind of information they have available as a result of legal requirements for particular documentation, such as maps and management plans. They would make many of the indicators and verifiers specific by naming particular coupes, water courses, company personnel etc. In the social C&I, references to 'other stakeholders' would be changed by identifying particular local Dayak communities and other commercial interests in the area. A user may choose to group together under a social criterion several indicators concerning conflict by *moving* them from their original positions (for example, under the policy principle).

Every time a user modifies an item, they are asked to submit a reason explaining why such a modification is needed. Such reasons may be new or may already exist in CIMAT as a previously submitted reason. Reasons may take the form of facts or assumptions that can be retracted or reasserted depending on the context of a modification. For example, if there is no logging (fact), this can be used as a reason for removing an indicator about a particular logging technique. However this reason would obviously be no longer valid if an annual logging plan had been approved, i.e. it was now possible to log (new fact). Therefore if 'there is no logging' is the reason for removing some items from the hierarchy, CIMAT must be able to restore all these item if another user counters this argument by pointing out that the 'annual logging plan has been approved'. This gives rise to the problem that there is need for a rigorous way to represent and maintain all reasons and dependencies between them. CIMAT solves this problem by incorporating a Reason Maintenance System (RMS), for more details of which see the next section.

4. Argumentation and comparison: the meta-level

Some of the most interesting aspects of CIMAT result from it being not only an 'object-level' system, in which C&I knowledge can be represented and manipulated, but also containing 'meta-level' elements for reasoning about this knowledge. One aspect of this is the need to keep track of users' reasoning about modifications, which is achieved using a reason (truth) maintenance mechanism. The other aspect is CIMAT's ability to analyse the commonalities and differences in content and reasoning in two knowledge bases developed using the system.

Reason maintenance

A reason maintenance system (RMS) is usually one of two parts of a knowledge-based system. The other part is the problem solver, which is usually an inference engine, or theorem prover, which draws conclusions from and makes changes to an underlying knowledge base. In CIMAT this process of making changes to the knowledge base is carried out by the user. The RMS module maintains appropriate data structures to keep track of the reasoning carried out by the problem solver (i.e. the user) and keeps these data structures consistent. For more on RMS see (Doyle 1979, Doyle 1992, Forbus & de Kleer 1993).

RMSs are often used for solving problems related to *context determination, consequence determination, and belief revision* as explained in Kraetzschmar *et al*. (1997). Context determination involves determining all logical consequences of the clauses and the propositions (called context). Determining whether a particular proposition should be believed in a certain environment is the consequence determination problem. Any change to the reasons database may result in changes to the truth-value of a proposition. The problem of updating contexts because of changes to the clause database is called belief revision.

For a formal specification of the CIMAT reason maintenance system and its solution of the context and consequence determination and belief revision problems in C&I modification see (Purnomo *et al*. 1999). A brief explanation of its use to keep track of the reasoning about modifications is as follows.

A modification is accomplished by submitting a valid reason. The submitted reason can be a new reason or a valid reason that already exists in the system. It can be a reason for a C&I object's existence in the hierarchy or it can be a reason which counters any other reason in the system.

- To *add* an item, the user must submit a valid reason for its existence in the hierarchy - this can either be a new reason or one already in the system.
- To *delete* an item, CIMAT establishes the valid reasons in the system justifying its presence, and the user must counter these reasons by submitting counter-argument reasons. Again these may already exist or be new. A consistency check determines all other items whose truth-value may change as a result of the counter-argument. For example, if a number of C&I have been included for the reason R1:'Requirement to ensure high quality construction of logging tracks', and the user is deleting one of them for the reason R2:'No additional logging tracks will be constructed', then the other items which were justified by R1, which has now been countered, can also be deleted. If the user accepts deletion of these items, then the net of reasons is updated accordingly.
- To *restore* an item, the process is similar to that of deletion, except that the user can either restore an

object by assigning it a valid justification for being in the hierarchy, or they can counter-argue the reasons given for its deletion. In the latter case, their counter-argument may affect the validity of other objects in the hierarchy. For example, if a user has deleted a number of social C&I on the basis of R3:'There are no local community stakeholders', a second user may wish to counter-argue this with R4:'The local Dayak people have traditional rights to the forest land'. Once this counter-argument (R4) is added, all the items deleted for reason R3 can be restored.

- *Moving* is the combination of deleting an item and adding a new one in any other place in the C&I hierarchy.
- *Substantive changing* is also treated as the combination of deleting the old item and adding a new one. The only difference is that during changing there is no shift in locus of the modified item.
- *Minor wording changes* do not require reasons.

Knowledge base comparison

Once a user has modified their C&I they may wish to compare the result with the original. Two developers or teams may wish to compare their results. One of the high priority user requirements was to be able to compare a C&I set with a new Generic Template as CIFOR's research leads to new developments. To facilitate this, a comparison submodule of CIMAT has been developed. The comparison involves:

1. Broad comparison of the two sets of C&I summarised in a numerical manner. This gives a picture of where gross differences in detail and elaboration occur between the sets.
2. Comparison of indicator objects in the two sets carried out by matching of the texts of the objects. This provides a complete description of all the indicator objects that the two sets have in common, plus all the differences. This is carried out principle by principle, and involves exhaustive matching of object texts. It lines up all those indicator objects that occur in both sets and all those that are different in the two sets.
3. Analysis of the argumentation involved in generating the two sets. This exploits CIMAT's recording of the user's reasoning when making changes, and the histories of the objects, to provide a comparison of how different users reason in different ways from each other in modifying the generic template. It provides a picture of which indicators have been controversial in one instance but not in another.

5. Evaluation

An important role of the user requirements is to provide a framework for evaluating the first working prototype of CIMAT. The primary evaluation question is thus 'Does CIMAT do what the users require?' Our evaluation work is aimed at providing useful feedback for future developments of the system, as opposed to attempting to measure improvements in users' performance of known tasks (see Doukidis *et al*. 94). The user requirements have been used to produce structured evaluation tools and question sets. Trials of the prototype began early in 1999. Early tests have been useful in revealing bugs and interface problems.

Preliminary results suggest that CIMAT is being well received by users. The argumentation aspect has been a success though it is too early to determine how it will perform, and how usable it will be, once complex bodies of arguments have developed. However, it is already provoking interesting feedback on methods for handling alternative, conflicting, opinions amongst teams of users. Many users wish that the system were available for use over the Internet. Another useful piece of feedback is that users who may already use sets of C&I from other sources (such as the Forest Stewardship Council, whose C&I are widely used for forest certification) are interested in being able to incorporate these sets into CIMAT. If this can be achieved the potential audience for CIMAT becomes even broader than we anticipated.

6. Conclusions and Future Work

The construction of CIMAT has successfully shown the applicability of knowledge based systems techniques to assist in delivering knowledge about Criteria and Indicators of sustainable forest management. A useful tool is now available for use by forest managers to inform their decisions and help them to address the question of sustainable management in a structured way. Crucially CIMAT has been built in the expectation that forest managers, with considerable local knowledge, can modify and adapt the C&I to suit their local circumstances, thus integrating local and remote sources of knowledge. The argumentation component of CIMAT helps to structure the user's reasoning about these changes.

Our future research will involve two main thrusts. The first new direction is the development of computer support for applications of C&I to assess sustainability, to inform monitoring decisions, and to structure large bodies of detailed monitoring information. This research will be focussed on exploring how to support C&I use in adaptive forest management involving communities and other forest stakeholders. The second new direction is the promotion of debate and argumentation around C&I using telematics –

the WWW and email – to develop further tools for structuring the work of multi-disciplinary teams of C&I developers with different viewpoints, and to explore ways of building consensus.

Annex 1

High priority user requirements for CIMAT

CIMAT should:

- Provide users with CIFOR's generic set (template) of PCI&V.
- Support easy navigation around its information and around the C&I set.
- Support customisation (localisation) of the generic C&I template to a local area.
- Use links between C&I to help users to reduce the number of indicators they will use and to think about how single indicators can address multiple issues.
- Enable users to undo changes they have made to the generic template and start again.
- Provide help screens.
- Guide the user through modification of C&I using a series of screens which prompt them at each step.
- Allow the user to save their changes to the C&I set.
- Allow the user to output a modified C&I set to a word processor.
- Allow the core generic C&I template to be updated as CIFOR does more research.
- Display the C&I as a multi-level list.
- Retain a history of local modifications thereby acting as an 'institutional memory aid'.
- Allow the user to print their modified C&I set as a table.
- Support customisation (localisation) of the generic

Annex 2

List of Principles

P.1 POLICY, PLANNING AND INSTITUTIONAL FRAMEWORK ARE CONDUCIVE TO SUSTAINABLE FOREST MANAGEMENT

P.2 MAINTENANCE OF ECOSYSTEM INTEGRITY

P.3 FOREST MANAGEMENT MAINTAINS OR ENHANCES FAIR INTERGENERATIONAL ACCESS TO RESOURCES AND ECONOMIC BENEFITS

P.4 CONCERNED STAKEHOLDERS HAVE ACKNOWLEDGED RIGHTS AND MEANS TO MANAGE FORESTS COOPERATIVELY AND EQUITABLY

P.5 THE HEALTH OF THE FOREST ACTORS, CULTURES AND THE FOREST IS ACCEPTABLE TO ALL STAKEHOLDERS

P.6 YIELD AND QUALITY OF FOREST GOODS AND SERVICES ARE SUSTAINABLE

Annex 3

Examples of Criteria, Indicators, and Verifiers under P.2

P.2 MAINTENANCE OF ECOSYSTEM INTEGRITY

C.2.1 The processes that maintain biodiversity in managed forests (FMUs) are conserved

I.2.1.1 Landscape pattern is maintained

V.2.1.1.1 FMU compiles information on areal extent of each vegetation type in the intervention area compared to area of the vegetation type in the total FMU

V.2.1.1.2 Number of patches of each vegetation type at the FMU is maintained within natural variation

V.2.1.1.3 Largest patch size of each vegetation type is maintained within critical limits

V.2.1.1.4 Area weighted patch size is maintained within critical limits

V.2.1.1.5 Contagion index of the degree to which vegetation types are aggregated, is maintained within critical limits

V.2.1.1.6 Dominance of patch structure does not show significant change as compared to unlogged site

V.2.1.1.7 Fractal dimension of patch shape is maintained within critical limits

V.2.1.1.8 Average, minimum, and maximum distance between two patches of the same cover type are maintained within natural variation

V.2.1.1.9 Percolation index, specifying landscape connectedness, is maintained within critical limits

V.2.1.1.10 Linear measures of the total amount of edge of each vegetation type exist

V.2.1.1.11 Amount of edge around the largest patch does not show significant change as compared to undisturbed forest

I.2.1.2 Change in diversity of habitat as a result of human interventions are maintained within critical limits

V.2.1.2.1 Vertical structure of the forest is maintained within natural variation

V.2.1.2.2 Size class distribution does not show significant change over natural variation

V.2.1.2.3 Frequency distributions of leaf size and shape are maintained within natural variation

V.2.1.2.4 Frequency distribution of phases of the forest regeneration cycle is maintained within critical limits

V.2.1.2.5 Canopy openness in the forest understorey is minimized

V.2.1.2.6 Other structural elements do not show significant change

V.2.1.2.7 The distribution of above ground biomass does not show significant change as compared to undisturbed forest

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