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AN EXPERT SYSTEM FOR THE DIAGNOSIS OF TANK IRRIGATED SYSTEMS

A Feasibility Study

by

Odile Oswald

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INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE

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Preface

THIS WORKING PAPER forms part of a thesis titled "An Expert System for the Diagnosis of Tank Irrigated Systems: A Feasibility Study" submitted by Ms. Odile Oswald to Anna University, Madras. "The Diagnosis of Tank Irrigated Systems" is an analysis intended to bring an understanding of the system, to provide an evaluation of its performance with reference to some stated objectives and optionally to recommend how the expected objectives can be achieved by removing the bottlenecks in the system.

Expert systems are computer software that perform the reasoning process of an expert using his knowledge (rules and facts) and his reasoning strategies. To develop such a software system the knowledge used by the expert has to be acquired, explicated, and coded into facts and rules using an adequate knowledge representation.

The expert systems analysis was applied to tank irrigation systems in the State of Tamil Nadu, India, which account for one third of irrigation in that State.

The methodology followed for this feasibility study has been evolved from the standard methods proposed for the development of an expert system and was adapted to the particular case of tank irrigated systems' diagnosis. The knowledge required for this study was acquired through the background study of published literature, interview of knowledgeable experts on tank irrigation and the study of sample tanks.

This study leads to the conclusion that expert systems can be profitably developed on problems which are clearly defined and for which the knowledge exists in such a matured shape that it will enable a complete transcription to an expert system. For other problems, it points out the areas needing research where the knowledge and reasoning process are still intuitive or fuzzy.

Ms. Odile Oswald has done an excellent job in bringing out this paper. This work is a testimony to her capacity to synthesize highly theoretical work to the age-old problem of improving tank irrigated agriculture.

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Introduction

IRRIGATION IN THE WORLD

THERE ARE OVER 250 million hectares of irrigated land in the world representing more than 17 percent of the total cultivated area. Irrigation is quite vital for the agriculture of all countries located in the tropical region. For the past forty years, some of these countries have heavily invested in the development of new irrigated areas. Despite these efforts, there is a tremendous gap between the potential and the actual irrigated area. There are many reasons for the poor efficiency and low productivity of irrigated agriculture; among these, lack of adequate management and/or proper maintenance is often cited. The need and the interest in irrigation are still increasing. The scope for new irrigation schemes is decreasing and the only way to improve the productivity of irrigated agriculture lies in the better management of existing irrigation systems. Many systems are in such a state of disrepair that they have to be rehabilitated before the initial investments can be recovered; the first step is to carry out a diagnosis of the schemes in which rehabilitation is planned.

DIAGNOSIS OF IRRIGATED SYSTEMS

Through pertinent analyses, diagnostic teams are trying to find the reasons for the malfunctioning of these systems and to identify possible remedial measures. While the diagnosis of an irrigation system is generally multidisciplinary, qualitative and quantitative information is used in it. Agricultural activities and irrigation management depend on many sociotechnical aspects that are complex and interrelated. This research work was initiated with an initial implicit consideration that a pertinent or good quality diagnostic analysis is a prerequisite for successful rehabilitation. Thus came the idea of learning from diagnostic experts and trying to develop an expert system out of their knowledge.

EXPERT SYSTEM TECHNIQUES

Expert systems are a particular type of software that use an expert's knowledge, mind representation, reasoning procedure and heuristics. They are supposed to behave like an expert. These software belong to the field of artificial intelligence in which cognitive psychology and computer sciences are combined in an attempt to make the computer behave more like human beings. Expert systems use empirical knowledge acquired by the experts from experience as well as from their theoretical knowledge. The expert system technique has already been applied in the field of medical diagnosis, industrial process control and crop pest identification among other applications.

The interest for building an expert system is great since quite often experts are scarce and busy. It is a time-consuming process to become an expert, possessing intelligence, common sense, knowledge and experience; that is why maximum profit ought to be drawn out of such competence. Building an expert system that will perform defined expert appraisal requires catching hold of the right expert(s), to grasp his/her (their) knowledge and then transfer it to the computer software. The knowledge acquisition process consists in having the expert elicit the elements that he/she takes into account in the course of his/her reasoning, the elements in the background situation that lead him/her to validate the knowledge he/she is using, the scenario implicitly assumed and the basis of the assumptions made.

RESEARCH TOPIC AND METHODOLOGY

The basic purpose of this study is to test the feasibility of using expert systems in the diagnosis of irrigated systems; the Tamil Nadu tank-irrigated system has been selected to support this study. Tamil Nadu has some forty thousand tank-irrigated systems which are facing great changes in the rural setting; with these systems it is difficult to cater to the needs of a growing population. This has aroused a general awareness of the acute need to improve the management of these systems resulting in many ongoing diagnostic and pilot projects on these systems (that provided most of the pool of interviewed experts and sample diagnoses). Because all these systems are similar, a tool based on the diagnosis of a few tank systems could be profitably used on all the other systems. These are small farmer-managed irrigation systems and, therefore, the variability in agronomic conditions and the influence of outside administrative decisions should be less important than for bigger systems.

The methodology followed for this feasibility study has been evolved from the standard methods proposed for the development of an expert system. They were adapted to the particular case of tank-irrigated system diagnoses.

The first phase, **knowledge acquisition**, consists of a twofold action:

1. *Acquisition of background information.* In order to understand the problem and the experts' language, one has to get acquainted with the general problem of tank irrigation and with the specific local situation. Experts use much implicit information that can only be clarified if one is aware of the context. Similarly, the hierarchy set up by experts between various parameters on any particular diagnosis can only be identified and understood in comparison with other alternatives. The diagnosis must be able to divide the problems which are specific to the tank-irrigated system under study from those that come from the general context and that can only be solved at this level. The background information

for this research was obtained through a study of the irrigation sector in Tamil Nadu and of two particular tank systems in South Arcot District, Tamil Nadu State.

2. *Acquisition of experts' knowledge and strategies*. The objective of this step is to elicit from experts how they actually make the diagnosis of a tank system. The categories evolved from their experience, the hypotheses, rules of thumb, measurements and parameters that they take into account should all be ascertained. This was achieved first, through individual interviews of experts of all the fields involved in tank-irrigated system diagnosis (irrigation system, agriculture, economy and sociology) and second, through studies of real cases of diagnostic processes. A distribution of the experts and a sample diagnosis are given in Tables 1 and 2.

Table 1. Classification of interviewed experts.

Type	Number	Locals (in India)	International (in India)	International
Civil engineers	11	6	3	2
Economists	10	4	2	4
Sociologists	15	5	2	8
Agronomists	10	4	3	3
Total	46	19	10	17

Table 2. Classification of a sample diagnosis.

Type	India	Sri Lanka	Africa	Total
Tank systems	12	2	1	15
Big systems	1	0	1	2
Total	13	2	2	17

The studies of different kinds of systems are chosen to get at missing parts of the diagnostic process to help build an expert system which will allow assessment of the possible extensions of such an expert system either to a different type of irrigated system or to a different country situation. The general recommendations are to consider only one team of experts and try to analyze and implement their diagnostic process. However, in the case of tank diagnosis, the problem was aggravated by the fact that the teams seldom had the same members, or the same framework. In a given diagnostic setup, a team is constituted by members that go back to their other activities after the diagnosis. Each team performs a diagnosis on only one or two systems. This does not give us much chance to collect their full mind process on different types of systems. It seemed, therefore, compulsory under the present conditions to obtain knowledge through different teams. By adopting this procedure, flexibility was introduced in the methodology of knowledge acquisition and the selection of the interviewed experts. In this way, the sample diagnoses were extended in order to make use of the various opportunities created by multi-experts diagnosing tank systems with different objectives.

The second phase, **transcription into an initial limited prototype** consisted of:

1. Identifying the characteristics required for the development shell (knowledge representation, reasoning strategies and system functionalities) and selecting a possible shell.

2. Trying to develop with the knowledge obtained from a limited prototype on a representative problem subset. Then the concepts, rules and operations collected in Phase 1 have to be reformulated and transferred into a customized software package designed to reproduce the experts' method of diagnosis.

This directly leads on to the third phase, **feasibility, validation and generalization:**

1. The transcription to an expert system enables to assess the feasibility and the possible developments of such an expert system considering the nature of the knowledge acquired and the identification of missing transition paths.

2. Checking the behavior of the model on the control tanks gives an idea of the validity of such a tool.

3. Analyzing the possible generalization and applying to other types of systems and to other locations.

Diagnosis

CONCEPTS RELATED TO THE DIAGNOSIS

A DIAGNOSTIC TOOL is meant to assess the **performance** of an irrigation system, carry out a proper **diagnosis** and provide a relevant **diagnostic**. Here are the definitions adopted for these three words:

Performance: the manner or quality of functioning.

Diagnosis: a thorough analysis of facts and problems in order to gain an understanding of the system, the process leading to the diagnostic.

Diagnostic: the conclusion of the diagnosis; opinion is reached after the analysis.

Appraisal of an irrigated system is the preliminary step in attempting to seek any improvement of that system. This is generally achieved through a diagnosis of the system. It requires one to understand the difference between how a system should work and how it does work; and measure the distance between its actual and its ideal state, that is, design, policy or individual expectation versus reality (Lowdermilk 1983). The evaluation of an irrigation system assumes that some ideal standards exist for this irrigation system. Yet expectations regarding a system vary widely with vested interests of individuals and institutions. Therefore, the diagnosis of an irrigation system leads to a nonunique performance assessment heavily molded by the references enforced by the objectives.

Diagnosis is always based on technical data, mechanisms and facts that are objective characteristics of a situation and they remain true in any chosen reference state. Only the interpretation of these data is subjective and varies with references and individuals. If an analysis is to be objective, it would have to be exhaustive which is impossible. Not all parameters are to be investigated for any particular diagnosis nor need to be. The characteristic of a good experts' strategy is that it only asks for what is required – no excess information and yet all necessary information to produce a relevant and accurate diagnosis (Pollok 1985). The objectives and ideals are multiple and so are the methods of analysis and, consequently, the parameters and the performance criteria selected. This is why so many performance indicators have been devised.[1]

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[1]The diagnosis is relevant provided it leads to an adequate understanding of the situation regarding objectives and through enough to ensure a certain reliability of the diagnostic issues (it depends on the client requirements). See annex 1 in Oswald 1989.

BASIC TECHNICAL FIELDS OF THE KNOWLEDGE BASE

All technical fields concerned with the irrigated agriculture come under four domains; most of the fields are interlinked:

Civil engineering: meteorological data, hydrology, water resources, water storage, hydraulics and irrigation structures, aquifers, losses and discharge distribution in the channels;

Agronomics: cropping pattern, soil conditions, water scheduling, inputs, labor, agronomic considerations, irrigation practices and crop requirements;

Economics: home economics, market conditions, loans and project economics; and

Social structure: equity, local organizations, institutions, political tensions, leadership, tradition, kinship and groupism effects, laws and rules related to land and water, taxation conditions and irrigation management.

DIAGNOSIS REASONING CYCLE[2]

Any diagnosis comprises a **framework**, that is a client, one or several institutions, money, men and time constraints which define the background of the diagnosis, an **objective** that defines (or objectives that define) the general orientation and requirements of the diagnostic job, and a **site** that sets the general context and the present case.

Three successive phases can be identified in a diagnosis:

Phase 1. Understand the reference system of the diagnosis that includes the prevailing **framework**, the context situation of the **site** and the general orientations defined by the **objectives**. Uttered official objectives compete with unavowed ones and these latter are often of major importance. Diagnosis can be made at any level of specificity and precision, yet external financial and technical constraints are the controlling factors that must be set in the framework and many elements can be inferred from a good acquaintance with the local situation.

Phase 2. Achieve the diagnosis in situ; this is a recurring loop process leading to the conclusions. At each cycle some elements are changing; the understanding of the system reached, the working hypotheses which are evolving with progression of the diagnosis and the new reference system (time and money left, applied objectives defined after initial orientation and the new understanding of the system, etc.).

[2]See figures 2.1 and 2.2 in Oswald 1989.

The diagnostic process cycle includes testing and validating working hypotheses, collecting and analyzing relevant data, constructing a new evolution scenario taking into account the factors identified that modify the dynamics of the system, analyzing the results, identifying problems (symptoms) and their potential causes, and arriving at conclusions regarding this process. A comparison with the quality and precision required for final conclusions will decide whether a definition of new working hypotheses is required for a new (next) cycle.

Phase 3. Present the results, formulate the understanding of the situation that has been reached, define recommendations and complete the job financially and administratively.

GENERAL THINKING PROCESS OF DIAGNOSIS

For medical diagnosis, either the patient suffers from an obvious known problem (broken leg) or he presents a set of symptoms the causes of which are unknown. Then the basic diagnostic strategy consists in identifying the clinical signs characteristic of the patient's disorder. The clinician tries to restrain the problem to a class of problems: pattern matching with predefined categories (infection, obstetrics, etc.) and then to a limited number of possible cases. Systematic routine medical control, checking the easy, frequent or the informative clinical signs as temperature or blood pressure give him the first basic clue about the nature of the problem. He starts from the available information onwards (forward reasoning); this leads him to formulate a hypothesis that he will try to verify (backward reasoning) until the solution is found.

In phase 1 of tank-irrigated system diagnosis, an initial understanding must be obtained between the expert, the client and the funding agency to prevent later disagreement. This is generally a combined backward and forward process in which the elements of the terms of reference induce forward reasoning and the cases formally analyzed by the expert induce hypotheses (backward reasoning). Then a sweeping overview of the system will help to establish an adequate initial understanding of the system (forward reasoning); this enables to identify the main domains, their problems and the elements in the fields in which bottlenecks exist. This general multidisciplinary expertise is very difficult to obtain since it requires a synthesis expertise (good knowledge in each field and on the interfaces between the domains). It is typical of experts and is often based on an object representation. On starting a diagnosis, the expert only has a fuzzy idea based upon basic characteristic features (physical aspects, historical background, etc.), and while trying to fit this idea into one of his patterns (mind categories evolved from his former experience and knowledge), the expert will identify an initial prototype which the system fits (pattern matching between object and classes).

In phase 2, the loop process is a backward process with local forward digressions induced by particularly striking information. Working hypotheses are tested and causes are investigated for each symptom. This part calls for other processes like simulation, generation of ideas and political choices which are not mere backward or forward processes.

Expert Systems

CHARACTERISTICS OF EXPERT SYSTEMS

THEORETICALLY, EXPERT SYSTEMS are capable of reasoning through a procedure comparable to the one adopted by the specialist solving a problem pertaining to his discipline (physician, geologist, etc.). The difference between algorithmic and declarative programming is a key concept of expert systems. In order to carry out a traditional program, information scientists prepare a method of resolution (an algorithm) describing a step-by-step procedure of treating data, culminating in a certain result (imperative programming). However, in expert systems, a variety of knowledge is stored in the knowledge base. Any chunk of knowledge thus stored makes sense by itself. These chunks are formulated in such a way that a hypothesis is made not on how they are going to be used but on what they imply (declarative programming). Therefore, this knowledge can be accessed any time according to the inference engine intimations. One of the essential characteristics of these software programs is their ability to deal with qualitative information and symbolic data besides the classical quantitative characteristics. Chunks of knowledge are based on the semantics of knowledge rather than on the means used to access the value of knowledge. While in conventional programming the sequence of orders is based upon a rigid logical sequence of orders, expert systems draw some information (uncertain and partial conclusions) from fuzzy logical inferences. Nevertheless, formal logic is also used to prevent the coexistence of two contradictory elements.

The structure of an expert system includes three components: the knowledge base (facts and rules), the user interface and the inference engine (Figure 1 – page 10)

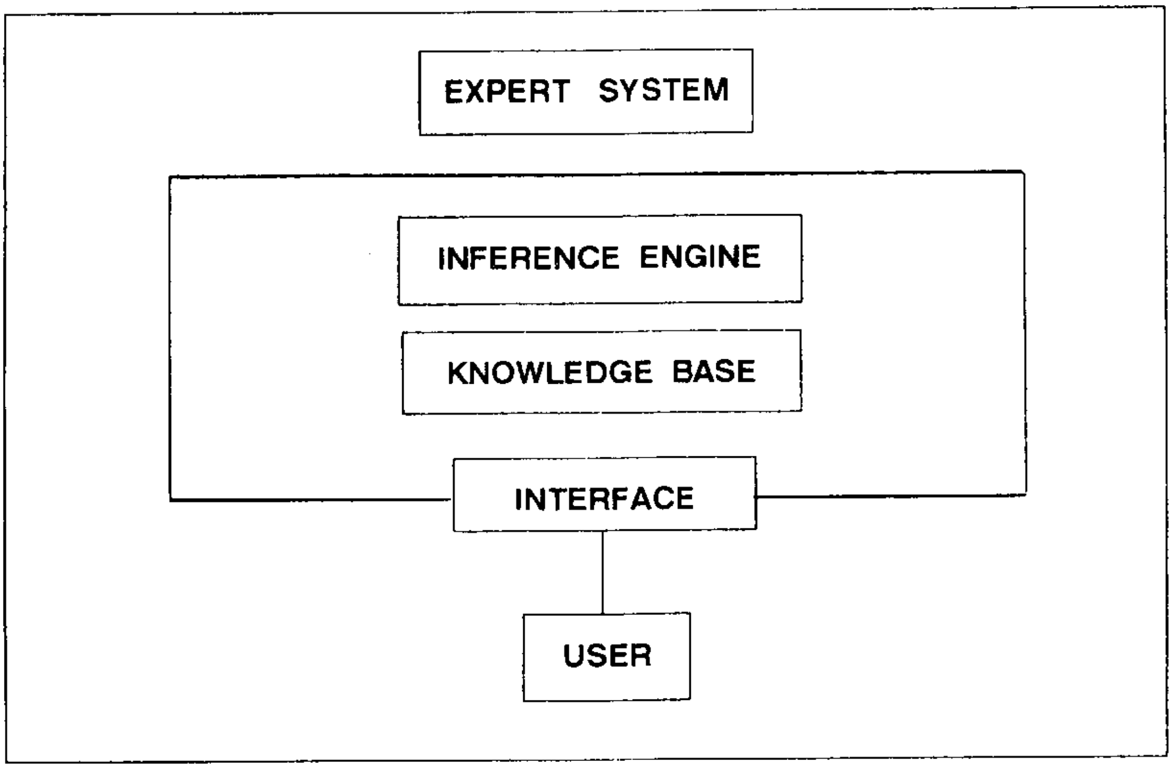
EXPERT SYSTEM STRUCTURE

The Knowledge Base

The knowledge base contains all the information specific to the field of experience which is stored according to the knowledge representation conventions (academic notions as well as rules and heuristics used for appraisal by the expert). The knowledge base consists of the rule base and the fact base.

At first, the fact base contains all the crude information initially given to the expert system by its modeler and the patterns that his knowledge and experience

Figure 1. Organization of an expert system.



have led him to build it up. These symbolic objects are condensed pictures of stereotyped situations formalized according to a knowledge representation. Knowledge representation is the logical representation used by the software to formalize the elementary chunks of knowledge in adequate forms (Charniak E. 1985). Many different types of representation have been used depending on the type of software used, on the language structure and on the type of problem. Some of them may be more convenient than others. It is rather a difference in tool than a difference in basic concepts. The main representations used for the fact base are:

1. **Triplets**	<object>	<relation>	<value>
Examples:	tank	name	Kodur
	weir	is a part of	tank
	rice	is a	crop

2. **Frames** which are structured objects dominated by a central concept (event, person, notion) that include a set of slots describing the attributes of that concept; they are based on the concept of object.

The rule base is the collection of all the links between the various elements of the fact base as well as the heuristics to be applied. They are generally formalized with production rules:

If <premisses> Then <consequences>

Example:

If <tank_storage is silted up> Then <reduction_of_water_availability>
& check <reduction_of_command_area>
& check <reduction_of_cropping_intensity>

They can be written in zero order logic (no variable admissible) or in first order logic (with variables) in which case they are powerful tools that can be applied to a class of objects.

The Inference Engine

The inference engine is a program which utilizes the knowledge and the heuristics contained in the knowledge base to solve the problem specified by the user. The inference engine carries on the reasoning process from the information received through the user interface in the course of the execution of, and the data available in, the fact base:

The process of solving a problem is generally diagramed as a search tree, with each node in its branching structure representing a new state (a new configuration of knowledge) which can be the solution or a step toward the solution. The major difficulty in searching a complicated search tree is that examining all alternatives involves an unreasonable amount of time on even the fastest computer. Therefore, heuristics and strategies have to be added to limit the search even though they act against a systematic analysis and may decrease the quality of the solutions obtained.

Different inference engines have been designed according to the type of **logical chaining** they use (Farenny 1975):

* Some are goal-driven and work with backward chaining: the final goal to be verified is reduced to a set of subgoals that the inference engine tries to verify. If these subgoals cannot be verified, the engine searches for another set of subgoals that could lead to the same conclusions. If this is still not possible, the initial hypothesis is rejected and a new goal is chosen.

* Some follow a forward chaining logic and start from the available information in the knowledge base to draw conclusions following the heuristics traditionally used by the expert. It goes on from the verified facts until the required goal is deduced.

* Some combine both the procedures.

The inference engine is the heart of an expert system. The reasoning process appropriate to the particular case is treated repeating the basic inference cycle and its four sequential steps are restriction, filtration conflict resolution and execution:

* "A priori" determination of the rules likely to be triggered in the present state of the problem is called the restriction step.

* Identification of the appropriate rules, all the premises of which are verified, is called the filtration step. At this step, the software tries to match the present new situation with the patterns of its knowledge base.

* Choice of the rule to be triggered among the fireable ones. This step is the conflict resolution step. It may be considered that the first rule is the one to be triggered but any other criterion characteristic of the engine mode of conflict resolution might have been chosen. There are many criteria that human beings use alternatively in an adaptable strategy whereas the inference motor strategy is less flexible.

* Start of the chosen rule: the execution.

Engines can have two main **strategies** of exploration of the graph:

* When the exploration is said "in depth first," the priority is given to the new rules fireable.

* In the other strategy said "in width first," all the potential rules are tested before any one is executed.

Engines differ from the **control** type; the control may be irrevocable (when the set of the fireable rules is empty either the engine returns to the prior step and tries to fire another rule, or it stops) or the engine may be said to be working by "successive attempts and backtracking" (prior conclusions are suppressed and the reasoning becomes non-monotonous)

The User Interface

The user interface enables people not aware of the knowledge representation used in the software to use the expert systems; it has to be as convenient as possible. The expert system is designed to answer a problem provided the problem is suggested to it and it is given some elements of answers to its questions. This is done through the user interface. The user interface conveys to the user the questions raised by the software as well as the information presently required, and gives back the answers (or the nonavailability of the information) to the software.

EXISTING SHELLS

Expert system shells cover a wide range of tools; some of them are quite simple, while others are quite elaborate. All of them have a knowledge representation scheme, an inference or search mechanism, a means of describing a problem and a way to determine the status of a problem while it is being solved. Some other system functions may also be available and will aid in selecting an adequate development tool (like explication modules or consistency checking). In Table 3 (page 14), a comparative table of some expert systems is given.

BUILDING AN EXPERT SYSTEM

Knowledge acquisition and building an operational expert system need a well-defined and structured problem as well as identified and available experts.

Methodology for Building Expert Systems

Traditionally, the expert system development is considered under four stages: problem selection, initial prototype expanded prototype and delivery system (Figure 2):

* Problem identification determination and specification correspond to the requirement stage in a conventional development software. The major objective of this stage is to ensure that the problem will satisfy a real need and be technically feasible.

* The initial prototype development includes the selection of an inference mechanism, an adequate knowledge representation and a development tool to demonstrate the technical and economic feasibility of the target expert system on an initial subset problem.

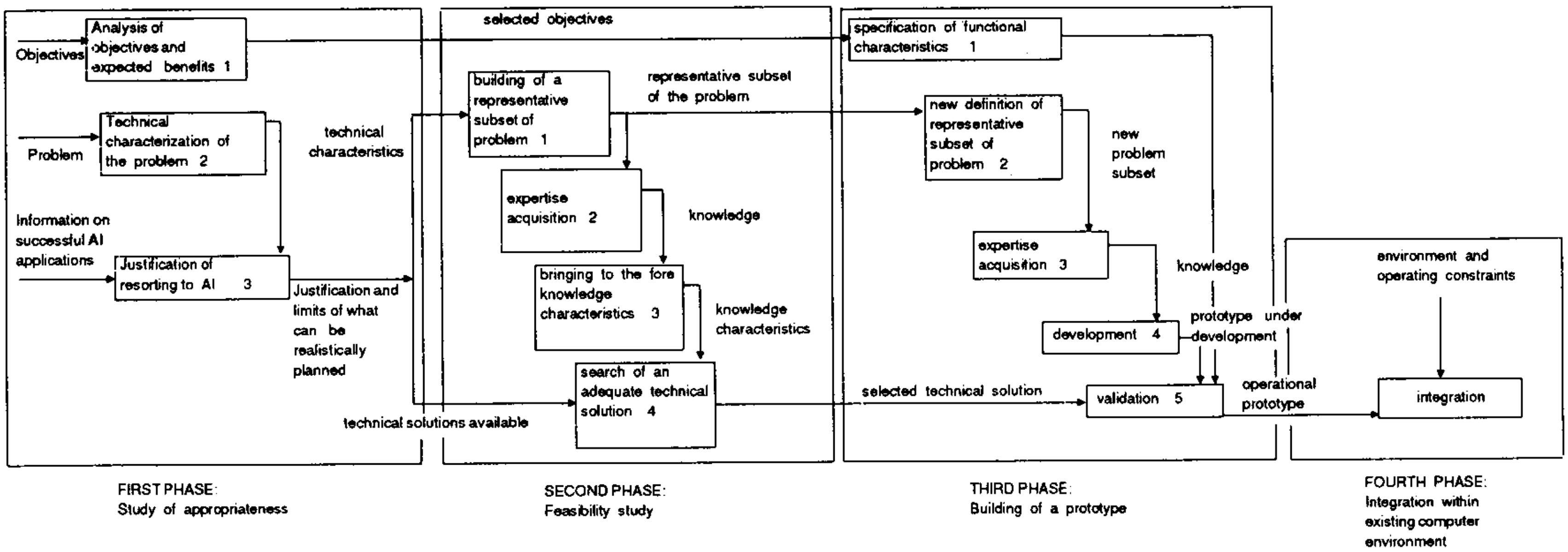
* The next phase of development, called an expanded prototype, will consist of devising a suitable expert system architecture, knowledge representation and strategy (according to project complexity). This phase should lead to the prompt completion of the project with a limited budget and still enough knowledge to ensure that all essential parameters are included. The initial problem subset is expanded to full complexity and interaction with the related systems (database, program, measuring equipments, video interaction and so forth). Validation of the expert tool will occur at this level.

* The fourth phase leads to the final delivery product, with the integration of appropriate hardware constraints and optimization.

Table 3. Some comparative expert system shells.

PRODUCT	EXSYS	Insight2	KES	P.C. easy	Mc EXPERT	Expert Kit	MP LRO	Guru	Golem	MI	SNARK	S1	SNOPS	NEXPERT
MANUFACTURER	EXSYS Inc.	Level 5 res.	Soft ar. Eng.	Tex. Inst.	Mind-Soft	ACT Inc.	CRIL	Ise-Gecos	Microcomp.	Framentec	Ilot	Framentec		Neuron data
Language	C	Turbo Pascal	Lisp, now C	Lisp	Pascal	Le-Lisp	Le-Lisp	C	Pascal	Prolog, soon C	Pascal and C	Lisp, soon C	Le-Lisp	C
KNOWLEDGE REPRESENTATION AND REASONING STRATEGIES														
IF/THEN rules	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Frames	no	no	yes	no	no	no	yes	no	no	no	no	yes	no	yes
Cases/examples	no	no	no	no	no	yes	no	yes	yes	?	yes	?	yes	yes
Metarules	no	no	no	no	yes	yes	yes	no	yes	yes	yes	proc. control	yes	yes
Decision tree	no	no	no	no	no	no	yes	no	no	no	no	no	no	yes
Forward chaining	yes	yes	no	yes	yes	yes	yes	yes	yes	no	yes	no	yes	yes
Backward chaining	yes	yes	yes	yes	yes	no	limited	yes	yes	yes	limited	yes	limited	yes
Multiple answers	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Unknown as an answer	no	yes	yes	yes	no	yes	yes				yes	yes	yes	yes
Certainty factors	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	no	yes
Combined certainties	yes	yes	yes	yes	no	yes	yes	yes	no	yes	yes	yes	no	yes
Maximum no. of rules	500	1900		dep. on config.	1000		dep. on config	dep. on config.	dep. on config	dep. on config.	dep. on config		dep. on config	
DEVELOPER AND USER INTERFACE														
Skill level	novice	intermediate	expert	intermediate	novice	novice	intermediate	novice	intermediate	intermediate	intermediate	expert	intermediate	expert
Trace	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Editor	yes	yes	no	yes	no	lisp ed.	yes	yes	no	yes	yes	yes	yes	
Explanation module	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
INTEGRATION, DELIVERY AND SUPPORT														
External data	ascii files	ascii & dBASE	dBASE prg. &	dBASE & DOS	ascii	ascii	ascii	ascii, dBASE	asci,pgr.	ascii,dBASE	ascii, Vax	ascii	ascii	ascii,dBASE
External programs	.com & .exe	any	any	.com & . exe	no	through Lisp	through Lisp	pgr.	yes	through C	through C	any	through Lisp	through C
Compiled systems	no	yes	yes	no	no		yes	no	no		yes	yes	yes	yes
Support machines	PC XT & AT	PC XT & AT	PC XT & AT	PC XT & AT	Mac, PC	Mac	mac, PC, vax	PC AT and XT	PC AT and XT	PC AT and XT	c, PC AT,SUN	vax symbolics	mac	MAC, PC,VAX

Figure 2. Methodology for building expert systems.



Knowledge Acquisition

Knowledge acquisition is a long, difficult and ill-formalized process. It requires collection of the experts' knowledge and the real tactics of their thinking process. However, it may be mentioned that the extraction of their knowledge is not an easy task. Here are some of the standard methods used to extract knowledge (Table 4).

Table 4. Knowledge acquisition methods (Hoffman 1987).

Method Category	**Description**
Method of "familiar" tasks	Analysis of the tasks that the expert usually performs
Structured and unstructured interviews	The expert is queried with regard to knowledge of facts and procedures
Limited information tasks	A familiar task is performed but the expert is not given certain information that is typically available
Constrained processing type	A familiar task is performed but the expert must do so under time or other constraints
Method of tough cases	Analysis of a familiar task that is conducted for a set of data that presents a tough case for the expert

All the foregoing methods cannot always be applied, and they do not have the same advantages. A method is not necessarily a key to success:

* There often are semantic problems that hamper communication: current words are used in such a way that their inaccuracies and ambiguities mask the real reasoning process.

* Experts often have a natural tendency to present their knowledge in a logical and didactic way which does not highlight their real reasoning mechanisms; they often are unable to formulate the knowledge which appears obvious to them.

* Uncertain inferences are still another problem which is not satisfactorily tackled.

* In handling difficult problems, people proceed by stages; to cover all difficulties their reasoning is often inexact and general and then, as contradictions appear, they gradually reorganize their thoughts until all contradictions disappear. It is quite difficult to allow temporary inconsistency in the base and to establish qualitative inconsistency thresholds above which the patterns have to be modified.

* Consensus among experts should be a must to validate knowledge in a multiexperts' base and preserve its consistency.

Results

KNOWLEDGE ACQUISITION

THE BACKGROUND STUDY, comprising the irrigation sector study and the control tank study leads to the identification of many different parameters that have some influence on a tank-irrigated system. The outcome is a general frame with various aspects of a tank-irrigated system. Any tank can fit in such a frame provided adequate values are given to each facet of the frame (see Annex). Any diagnosis will consist of identifying the right pattern in which the present tank-irrigated system fits in and analyzing within that frame, the particular aspects which are relevant to the present objectives of the diagnosis.

The **individual interview of experts** was quite informative not for the rules or knowledge it provided but for the understanding it gave on the nature of a diagnosis. The experts interviewed in their offices, on a real case, are quite unable to explain the actual thinking process they would follow in order to achieve the diagnosis of a tank-irrigated system. They tend to improvise a rational foundation to their thinking that, in fact, they do not use. Whenever they talk to you about their tasks they tend to give to their talk a didactic shape close to theory. They can give different aspects they happen to look at, in a jumble. But they can seldom give all the logical links between the values taken by the various parameters and the conclusions they draw. They need a real case with actual **site, objectives**, and a general diagnostic **framework** (money, time, men and institutions) to give shape to their reasoning process. These three elements put together provide the necessary information to make decisions, compromises and to limit the depth of the various tasks; without these external arbitration, the diagnosis is not feasible and does not make sense. The real case sets the problems to be solved and induces the whole diagnosis: contrary to the medical case, the diagnosis of a tank-irrigated system is not a general and unique notion and there is no general and unique way to make it.

Each field has got criteria and technical performances (if we may use this word for all the fields including sociology) that are not necessarily relevant to the present problems. There are loose linkages in an irrigation system and there is no fixed logical link between the general diagnostic of a system and the elementary performances. The fact that some parts of the command area do not have access to water under certain conditions or times may be considered as a problem or may not according to the reference system evolved from the objectives of the diagnosis. A diagnosis on a particular site aims at finding out which particular deficiencies on this system can be solved in the system itself or the problems on which the client has a possible action.

Therefore, the general diagnosis is not a mere gathering of elementary criteria. The knowledge of the various domain experts provides elementary chunks of reasoning. Each of them only leads to the evaluation of criteria but not to a general thinking process. Each discipline has got at least one "standard" method to which the expert will try to refer when he has not been placed in a real case that would compel him to make decisions and choices different from standard methods. These standard methods are an important support for the reasoning process as long as there is no interference with another field or a difficult choice to make. A conclusion that cannot be chained to the general process does not lead anywhere. The fact that we had to collect information from different experts doing the same kind of work rather than from one expert is a big hurdle for the quality of the information collected. It did not provide much chance to collect consistent and complete knowledge. What we have got is such a variable kind of experts that it seems difficult to merge the different approaches that they have in one expert system, and come up with a complete and consistent knowledge base (a prerequisite for an expert system). Each of them has different implicit assumptions and his/her set of rules is not necessarily consistent with those of the others.

The study of the **sample diagnosis** provided information on the process followed to make the necessary coordinations of the elementary partial conclusions.

Any of the four field experts identifies his/her specific problems, and has a specific way of achieving a diagnosis. The outcome of one expert working on a system is a technical diagnosis from a particular angle that may not give any particular answer to the initial questions: the diagnostic objectives. A diagnostic is not the sheer juxtaposition of the different conclusions. Therefore, **adapting the general process to the "real case"** must be judiciously done. In a real case diagnosis there generally is a funding agency, a client and the team making the diagnosis for the client. Usually, each of these three partners has different objectives. The outcome of the diagnosis will depend on the power relationship among them. Generally, in a diagnostic team there is a team leader who decides the overall process according to the general objectives. He makes the master diagnosis and retains or rejects elementary information according to his judgment. Although his decisions may happen to contradict some elementary logically based conclusions, they always prevail. The master process is not a logical process; it is rather a succession of subjective decisions and judgments. These judgments which solve the conflicts between the internal logic of elementary field and the general objectives are not logically evolved from a preexisting set of rules; they are political resolutions that have to be adapted to each case through a learning process.

The eight configurations presented in Table 5 (page 19) show how the different objectives bear on the general diagnostic process. These teams differ in their funding agency, the client and the expert team performing the diagnosis.

For each diagnostic team, time, number of experts, and budget allocated are different and this acts upon the team's decisions. Each of the partners has different objectives which are not necessarily compatible (Table 6 – page 20). The final objectives result from a combination of all partners' objectives weighted by their influence on this particular work as well as on other grounds. It is interesting to identify how the type of combination between the possible kinds of funding agency, client and team bears on the final selection of objectives and to what extent the diagnosis is molded by the partners (Table 7 page 21).

Table 5. Different types of diagnostic teams.

Diagnosis	–	2	3	4	5	6	7	8
Funding agency	GOI	EEC	EEC	EEC/FF	NGO	PLAN	PLAN	Sugar factory
Client	PWD	PWD	PWD	AU	NGO	Ag. Min.	IRDP	Sugar factory
Team	PWD	PWD+Ag. Min.	external	external	NGO+ external	Ag. Min.	IRDP+ external	External

Notes: GOI = Government of India, EEC = European Economic Community,
FF = Ford Foundation, NGO = Nongovernmental organization,
PWD = Public Works Department, AU = Anna University,
Ag. Min. = Ministry of Agriculture, IRDP = Integrated Rural Development Program.

Each diagnostic team is supposed to draw conclusions after a diagnosis; the path followed during the process is a particular progression within the possible decision tree. The general shape of this particular diagnosis is characterized by the various aspects of the tank systems. The diagnosis will analyze and select which aspects will be considered and which not. This selection is not made by emerging logical resolution but rather according to the decisions enforced on the diagnosis by the objectives, the site and the framework.

The first three diagnoses have the same client, but still there are discrepancies between their processes.

Diagnosis No. 1

The government has little money for tank maintenance and there are many tanks needing some kind of repair or important maintenance work. The PWD's specific task is concerned with maintenance works, and not with any other aspects of tank-irrigated systems (On-Farm Development [OFD] comes under agricultural engineering and agriculture production comes under agricultural services) Therefore, the PWD personnel are trained to spend the little funds that they have to cover the maximum urgent works on tanks. Their way of making a diagnosis is derived from the standard methods but they try to see which standards can be neglected and what seems imperative to keep the system working. Their diagnosis is influenced by what they can achieve in terms of physical work.

Table 6. The different partners' objectives.

Diag-nosis	Funding agency's objectives	Client's objectives	Team's objectives
1	-maintenance of tanks -maximum beneficiaries -efficiency of investments	-maintenance of tanks -maximum beneficiaries -efficiency of investments	-bring to civil standards -satisfaction of political and administrative chiefs -easy work
2	-international cooperation -modernizing small systems -productivity and equity -focus on control of money expenditures for project	-maintenance of tanks -maximum beneficiaries -opportunity to make best technical realization -increase PWD importance	-bring to civil standards -satisfaction of political and administrative chiefs -easy work -little focus on costs of structures -proved economic interest (Ag.)
3	-international cooperation -modernizing small systems -productivity and equity -focus on control of money expenditures for project	-maintenance of tanks -maximum beneficiaries -efficiency of investments -convince foreign consultants of interest of scheme	-do work as wished by EEC -make best of one's skills, time and PWD intermediaries. -set conclusions as EEC decides
4	-international cooperation -modernizing small systems -productivity and equity -focus on control of money expenditures for project -focus on participation -focus on management	-research of adequate methods for tank system rehabilitation -focus on participation costs and effects -focus on management and not on structures or on cost/benefit ratios	-research of adequate methods for rehabilitation of tank system -focus on participation costs and effects -focus on management and not on structures or on cost/benefit ratios
5	-focus on marginals -increase general welfare -political education of people	-focus on marginals -increase general welfare -political education of people	-focus on marginals -increase general welfare -political education of people -identify feasible projects
6	-build a local capacity to meet the nation's requirements -reduce dependence on imported goods (groundnut)	-increase production capacity -substitute groundnut for rice -focus on OFD -focus on agricultural system	-increase production capacity -substitute groundnut for rice -focus on OFD -focus on agricultural system -compete with PWD
7	-build a local capacity to meet the nation's requirements -plan India's future needs -reduce dependence on imported goods (groundnut) -tackle problems of migrations	-use tank systems to settle rural marginal farmers -increase laborer's wages and employment days per year -assure enough farm revenue to small farmers	-use tank systems to settle rural marginal farmers -increase laborer's wages and employment days per year -assure enough farm revenue to small farmers
8	-introduce sugarcane to cater to the needs of the factory -get returns on investments	-introduce sugarcane to cater to the needs of the factory -get returns on investments	-meet requirements of the sugar factory -introduce sugarcane to cater to the needs of the factory -get returns on investments

Notes: OFD = On-Farm Development. EEC = European Economic Community. PWD = Public Works Department.
Ag. = Agriculture

Table 7. Field priorities according to diagnosis.

Diagnosis	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Civil engineering:	1	1	1	3	4	na	5	4
system O&M	na	na	na	2	na	6	na	na
Agronomy:								
water efficiency	na	3	3	na	na	5	na	na
cropping pattern	na	na	na	na	3	2	4	3
agricultural production	na	2	1	na	na	1	na	1
Economy:								
farm economics	na	na	na	4	2	4	2	na
cost analysis	2	na	2	na	3	na	3	3
cost-benefit analysis	na	4	2	5	na	3	na	2
Sociology:	na	na	na	4	1	na	1	na
marginal focus								
water users' organizers	na	na	na	1	na	5	na	na

Notes: 1 to 8 = Priority order, na = not analyzed.

Diagnosis No. 2

On the EEC scheme, the money is not so much a constraint so that they can plan the best solutions on engineering grounds. The economic interest of civil works depends on the increase of agricultural productivity; and thus, it is up to the Department of Agriculture to make this analysis The analysis process (even more simple, since there is no comparative analysis and priorities to be set between different deficiencies) is the same except that the conclusions are different. As in the former case, their diagnosis is influenced by the fact that they would also carry out the work.

Diagnosis No. 3

Here the experts' team is independent of the PWD, paid by the funding agency and only qualified in civil, irrigation, agriculture and project economy disciplines. In the present case, we will have a closer cooperation among the various considered fields than between the PWD, and the Department of Agriculture (that are more likely to be united against the client); their final conclusions will be modified by the funding agency.

Diagnosis No. 4

The general framework is the same as the EEC tank modernization project. The poor results of the first phase have been ascribed to the lack of proper diagnoses and conclusions regarding social aspects and tank management. Therefore, on the request of Anna University (the present client), a different approach is taken aiming at identifying a new and better approach, especially one of social and management. Since it is a kind of trial, the costs/benefits aspects are not a high priority.

Diagnosis No. 5

The approach taken here is quite coherent but starts far from the other ones. The initial focus is on marginal farmers and landless people whereas for others (even in the social module) the focus is on people having water rights and, therefore, on land. The irrigation system and, even more so, the tank structures are not considered important; the tank irrigation may just be a means of helping or oppressing the marginal farmers.

Diagnosis No. 6

This diagnosis is done by and for the agriculture ministry and the boundaries of its systems start below the tank outlets; the irrigation system is more or less considered a fixed external setup one has to cope with. The flexibilities are at the cropping pattern level, the farming techniques, the varieties, the water application on the field, etc.

Diagnosis No. 7

In this perspective, top priority is given to increasing the labor utilization for tank systems. In order to prevent a massive migration of marginal farmers into towns, the IRDP has been concerned to assure them of stable incomes in the rural areas. Under these conditions, priority is given to all labor-intensive crops, a stable labor demand on the system around the year, as well as assuring small farmers of enough income. The productivity of the system is not number one priority: the migrants' costs to the government when they are in town appear to outweigh the productivity per unit of water and it may appear interesting to spend little money in the rural area and settle people there rather than spending more on them later in towns.

Diagnosis No. 8

The diagnosis is made by external consultants working on behalf of a private sugar company. The objectives of the sugar factory are clear; the cost-effectiveness of investments planned is essential; development considerations do not come into the picture; neither do the state agricultural requirements (groundnut).

These eight sample diagnoses give an indication of the different search paths within a general decision tree leading to a diagnosis, that may be selected by the different teams to reach their objectives. On in-depth analyzing of such cases, we could show the incredible combinatory explosion of the possible search paths.

If the political decisions were always carried out following the same preidentified patterns then, once the framework, the objectives, and the site were set, they could be translated into expert systems. It does not seem to be the case and, therefore, we have to leave the judgment out of the expert systems. It is doubtful that a thorough analysis of all the different possible national settings crossed with all the possible configurations of diagnostic partners (type of client, funding agency and team) could lead to a logical decision process. Only preexisting formalized rules and reasoning paths can be coded into a logical process. The development of an expert system is of interest insofar as the reasoning strategy can be reproduced on different cases.

In this multidisciplinary diagnosis, there usually are different experts following different logics. Quite often, one finds contradictions between the information they use or the rules they apply. Since the knowledge base of an expert system has to be consistent, different expert systems ought to be considered to overcome these contradictions. Yet, during each field diagnosis, experts use conclusions from the other fields. It seems impossible to provide enough interaction between the different expert systems and at the same time to preserve the internal consistency of each sub-expert system. The need for arbitration at a higher level explains how in a real diagnosis one can find people belonging to the same team using contradictory assumptions without bearing on the overall diagnostic conclusion; it is impossible to do this with a mere logically based process.

Whenever political arbitrations are inserted in reasoning, they shorten the chains of logically based rules and limit the scope for expert system application.

TRANSCRIPTION TO THE EXPERT SYSTEM

Choice of the Development Shell

The expert system development shell has to be adapted to the problem. The knowledge representation that appears to be most suitable for tank-irrigated systems is an object representation. Both forward and backward chaining should be provided. Partition of the knowledge base, meta-rules, priorities, connection with an external database, procedural attachment and a convivial user-interface are other important features required for this particular application. It is quite difficult to get a cheap and satisfactory expert system shell. Most of the efficient development tools have been developed on big systems and require a heavy investment that may not be justified at the feasibility study level. The knowledge representation and the inference engine require much working memory and a fast computer. The expert system shell used in this investigation was selected based on the specific constraints imposed on this research work. It is Nexpert from Neuron Data Inc., a shell that works on PC AT under a Microsoft Windows and DOS environment. Nexpert is written in C and complies with most of the features initially identified.

Transcription

The transcription of the knowledge acquired was conducted in parallel with the knowledge acquisition. The chunks of reasoning process that could be identified on each field are coded independently. For example, the different rules that lead to the assessment of water resource are developed in a separate knowledge base. They conclude on a set of parameters or facts describing the resource but do not show how this can be related to the general diagnostic process. Since a logic in the master diagnostic process could not be identified, these different chunks of knowledge cannot be chained up in a general diagnostic process. The external judgments, a basis of the general diagnostic process have to be left out of the expert system. Sub-expert systems were developed only in the civil engineering field and in the social science domain. They are not sophisticated programs. A similar development was not attempted for the agronomic and the economic fields; in both fields, apart from judgments and data collection, the core expert reasoning can be executed through a simulation tool (agronomy) and an economic program (economy) that could be developed much more efficiently with traditional programming. However, attempts were made to develop a kind of diagnostic pilot program in C that would enforce a chaining on the different sub-expert systems under particular objectives.

As it is organized,the program:

1. Prompts the user to select the leading field (irrigation system, agriculture system, economy or sociology).

2. Selects the sub-field priorities.

3. Identifies the diagnostic framework and constraints bearing on the diagnosis (time, money, etc.).

4. Identifies the type of system.

5. Prompts the user to give the selected reference system for the irrigated system (selection of a set of performance criteria or priorities).

6. Executes the expert system corresponding to the field selected (deep level) and whenever required asking for information from the other fields (low level).

7. Gives elements of conclusions in a report form.

This program is quite restricted with regard to flexibility and possible combinations of situations, criteria and strategies that were found in the real situations and it cannot perform any diagnostic in a satisfactory manner. The elementary parts of the diagnosis are quite often straightforward. The identification of the constraints is evolved from the values of criteria and conclusions are drawn on possible alternatives. These are based on logical rules. But the interesting part of the diagnosis does not lie in these intermediary conclusions but rather in the feasibility, cost and interest of the different alternatives. This latter part depends on the links between the different fields and the objectives. It is a subjective resolution evolved through a learning process that cannot be performed by the master program.

The expert system developed for the irrigation system is a good example of an expert system achieved. The different rules that lead to the assessment of the irrigated system are developed in a separate knowledge base, **irrsys.kb**. They are based on a set of parameters or facts describing the resource but they do not show how this can be related to the general diagnostic process. The organization of this knowledge base is based on three rules:

Rule 24

```
If there is evidence of resource_diag
And there is evidence of system_diag
And if <|modifications|>.value is possible
Then irr_sys_diag is confirmed
And execute rep_irr_sys(<|modifications|>)
do modif_eval modif_eval
```

Rule 50

```
If there is evidence of rainfall_diag
And there is evidence of run_off_diag
And there is evidence of storage_diag
And there is evidence of intakes_diag
And there is evidence of losses_diag
And there is evidence of losses_sluice_diag
And there is evidence of ground_wat_diag
Then resource diag is confirmed
```

Rule 65

```
If there is evidence of main_diag
And there is evidence of secondary_diag
And there is evidence of ofd_diag
And there is evidence of general_diag
Then system_diag is confirmed
```

The meaning of these three main rules is quite straightforward; rule 24 divides the diagnosis of the irrigation system into resource and layout. Rules 50 and 65 divide each of these subgoals into their principal components. Therefore, on launching the expert system the hypothesis to be suggested is irr_sys_diag (meaning make the diagnosis of the irrigation system) and the inference engine starts backward chaining to try to achieve the diagnosis. This backward chaining process lasts until all necessary hypotheses are tested; then the hypothesis irr_sys_diag is set to TRUE and the right hand actions of rule 24 are executed.

The actions on the right hand side are:

(i) first execute a report on the main findings, and

(ii) suggest modif_eval.

The irr_sys_diag is achieved through a set of 73 rules[1] that assess different aspects and identify which <|modifications|> could be "possible" (meaning: might be interesting).

<|modifications|> is a class of objects consisting of all the potential modifications. The class standard attributes of class are value (possible or not possible), cost, feasibility, interest, priorities, etc.

When rainfall_diag hypothesis is under test, rainfall data are retrieved from a data file written in WKS (microsoft lotus) format and external procedures are launched to compute some average graphs and histograms to help the user with the statistical analysis. But the interpretation of the graphs is left to the user.

The outcome could be a table of possible modifications with their contributions to various targets, but the final conclusions or even relative interests cannot be automatically drawn. Though quite modest, this achievement appears interesting: an intelligent analysis of the irrigation system by an expert system might enable to make rough pre-analysis of many irrigated systems (a time-consuming task) and increase the number of cases that an expert can assess.

FEASIBILITY, VALIDATION AND GENERALIZATION

The feasibility of the expert system seems difficult in the present context not because of the limits of the expert system technique but rather because of the nature of the reasoning process. The tank diagnosis is not a mere logical chaining based on quantitative or qualitative data but rather a set of subjective decisions which cannot be formalized in rules. An expert system could only be developed for the diagnosis of tank-irrigated systems if the judgments required for the general diagnosis are consistent for many similar applications. In such a case, the judgments evolved from

[1]Please see footnote 1 on page 5.

the experts' traditional learning process could be elicited from several sample diagnoses. These decision rules could then be formalized in an expert system that could be applied to the other cases. But in the case of tank diagnoses, we have as many different types of master resolutions as diagnoses.

The validation of elementary expert systems has been carried out on the two control tanks. The conclusions of the limited chunks are quite satisfactory, but the process of asking questions and reasoning is quite slow. Nexpert on PC AT is limited by windows environment which is restrained on PCs because of the DOS operating system. Since the programs must be written in C and must run under windows environment to be compatible with Nexpert, their programming has to be done according to the windows programming conventions. These conventions which are quite distinct from standard C conventions reduce the portability of the software on a different material.

The few diagnoses that were performed either on big systems or in a different context show that some specific knowledge base would have to be added to give a wider application field to an expert system.

In the case of big systems, the administration of the scheme is quite important compared to tank-irrigated systems and requires a specific assessment. Similarly, the assessment of the irrigation system has to take into account the functioning of the main system. This problem cannot be analyzed in the same way as the functioning of a rain-fed tank.

In applying the expert system developed in a particular country to a different country, the sector study would necessarily be different and so would be the implicit assumptions. If the system must perform the diagnosis in an African country, different sets of crops have to be added as well as a module to select the adequate crops for any location. The labor conditions in India, Sri Lanka, Guinea and Sudan are different: India and Sri Lanka make intensive use of animal power; in Guinea the level of mechanization is quite low (manual labor) and in Sudan most of the work is highly mechanized. In these cases the assessment of labor will require a different set of questions. These questions are necessary if the expert system scope has to be more general but they make the general reasoning process much longer. The more specialized an expert system, the faster it can achieve diagnosis since background knowledge is directly embedded in the rules and treated in an implicit form.

Summary and Follow-Up Proposals

MORE AND MORE attention is given to management problems in existing irrigation schemes and to develop possible means and tools to achieve a better management. Following this general trend, the present research used a new technique: expert systems to make the diagnosis of irrigated systems. The fields of application selected were the tank-irrigated systems in South India. Even though the diagnosis of an irrigated system is a common concept in irrigation management, the objectives and methods employed by such analyses have not been clearly defined. The diagnosis and its output, the diagnostic, highly depend on the diagnostic makers, the site under study, the framework of the diagnosis and the selected objectives for the current analysis. Information has been collected on the knowledge required to perform a diagnosis as well as on the methods followed by experts. A study of the target systems and their links with the context has been carried out through a sector study and a thorough system analysis of two tank-irrigated areas. Experts' reasoning paths and techniques have been analyzed during experts' interviews as well as on following diagnostic teams at work.

The attempts of transcription demonstrate the power and some of the limits of the expert systems' tool. At this stage, the initial multipurpose expert system tool for diagnosis of tank-irrigated systems cannot be developed. Yet, rather interesting solutions could be implemented on selecting the problems contemplated according to the capacities of the present tools. Many activities of irrigation experts cannot be yet transcribed into expert system rules: the multiexpertise, the pattern recognition of a tank-irrigated system based on numerous elements, the selection of relevant objectives, the application of political rules in a given setting and the combined process of learning and using preexisting knowledge are some examples of thinking methods that cannot be automated by expert systems.

The major problems faced in the development of this expert system for diagnosis were evolved by the nature and the characteristics of the knowledge gathered more than by any other computer limitations. Among the problems identified, those evolved by the methodology should be separated from those which are only due to the knowledge itself.

In an ideal methodology, the experts used to find the basic diagnostic rules and knowledge; methods should be selected initially, followed and studied while making a diagnosis of different systems. This was not the case in our methodology because expert teams seldom work on several cases. Therefore, in order to catch the diagnosis process under different objectives or on different systems, different teams were studied. This introduced a tremendous bias in the consistency of the knowledge gathered since no consistent method was used by the different teams. On the other hand, if the single team diagnostic process is only studied on one case the knowledge base developed is not likely to be complete. Our methodology left us half way between completeness and consistency which is not very convenient. In order to fill in the missing knowledge, expert systems could be used to simulate game diagnosis cases and thus identify a complete reasoning process of an expert team ready to collaborate with the tank diagnostic process.

Knowledge acquisition has two sources of problems. One source is the nature of these small systems in which the different parameters are connected to the output of the system through loose linkages. There is no strict causal link between one indicator and one cause; there are several possible causal reasons which cannot be eliminated with a mere checking on the system. Therefore, either different alternatives must be kept in mind and studied simultaneously (it then becomes fast but very complicated), or solutions are selected or rejected based on a conviction or on an arbitrary choice of the diagnostic maker. The second source (and not the least) of problem in the knowledge required for diagnosis is the nature of diagnosis. Diagnosis is a political decision making during which political objectives are selected. Then management concerns must be associated with the objectives; this is, quite often, a matter of political belief and assumptions have to be made on how the various concerns are transcribed in the present system. This leads to a set of priorities and choices which are still more arbitrary because of these loose linkages in the systems. An alternative way of tackling this problem would be to build the knowledge rules for one irrigated system under one selected, fixed objective, and then complete the knowledge gathered by complementary works on different systems, different objectives and combined objectives until a complete consistent knowledge can be gathered.

In other words, expert systems can be profitably devised wherever some expertise exists based on experience matured enough to be formulated in its final rules and whenever there is a definite will to use the expert system instead of formally acting experts.

The interest of the expert system technique on a non-adequate subject is great since it enforces the analysis of the reasoning process held during a diagnosis in a very rigorous way. All assumptions and rules used must be brought out and listed. Step by step, the logical and political decisions which point out the questionable links and dubious assumptions are torn to pieces. The elements and conclusions which cannot be clearly explained must induce further investigation on the thinking process that has led to them.

Once an expert system is achieved (even if it only performs a limited part of the former tasks of the experts), it frees the experts of systematic work which they are compelled to do and gives them more time to spend on other topics. On the other hand, an evident drawback is that it deprives experts of some of their former sources of experiences. Finding out all the logical rules, assumptions and steps taken to make a diagnosis is a very profitable exercise and could be used as a training process for experts.

One big hurdle of this diagnosis process that could not be overcome with expert systems is the way to analyze and transcribe the learning process which is the first phase of the diagnosis process. This then leads to further openings in the Artificial Intelligence world. Some other field of Artificial Intelligence focuses on these learning processes and appears more suitable for our first diagnosis phase (among which neuron networks seem quite adapted). Some ulterior development of this work would be to study how sample cases (the expert experience) can be stored in such a way as to enable to bring out conclusions or general use rules.

This is a pioneer work in the application of expert systems to tank-irrigation. As such, there are many attempts, problem selections and methods followed that may not have been optimal for the present research work and that would not be taken afterwards in the same manner. This work brings interesting conclusions regarding further development of expert systems that can be planned and the areas where further research should be taken to provide more accurate information on the knowledge and processes of irrigated system diagnoses.

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ANNEX

Figure A1. Notion of type for a tank irrigated system.

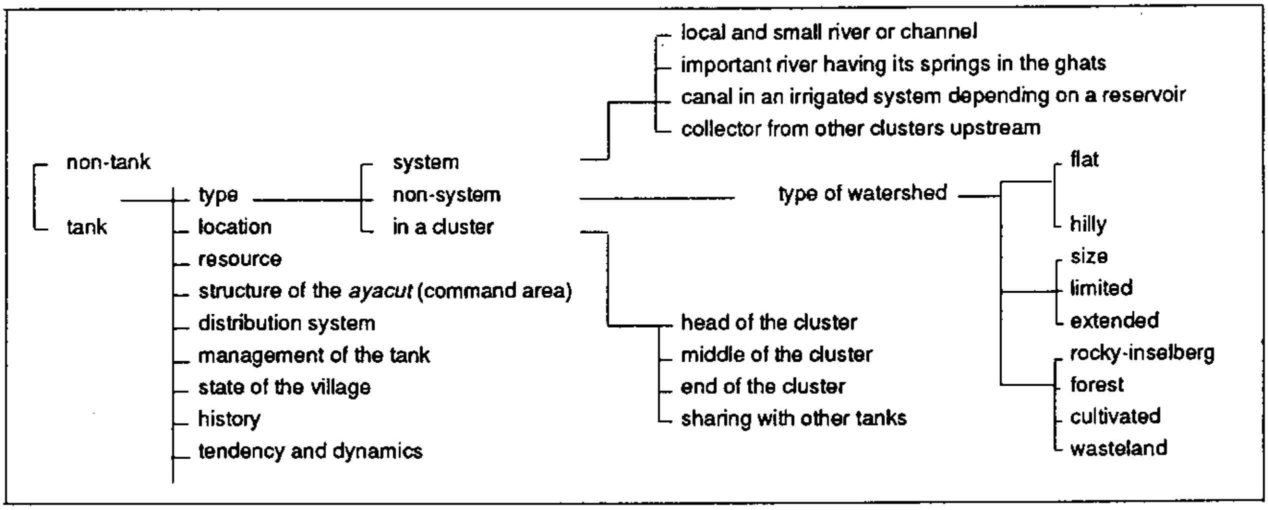

Figure A2. Agricultural context of a tank irrigated system.

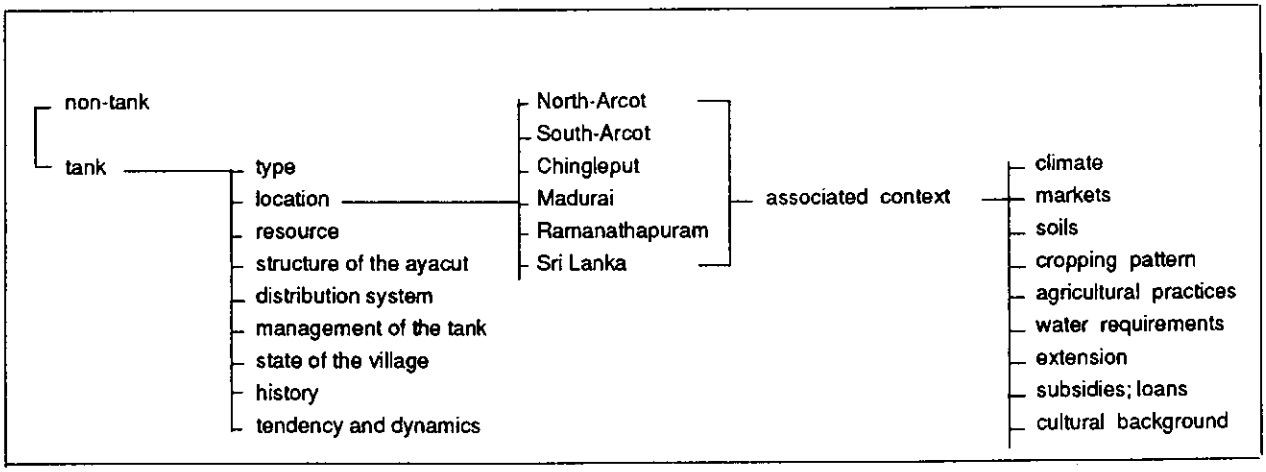

Figure A3. Elements of agricultural context that can be loaded from a database.

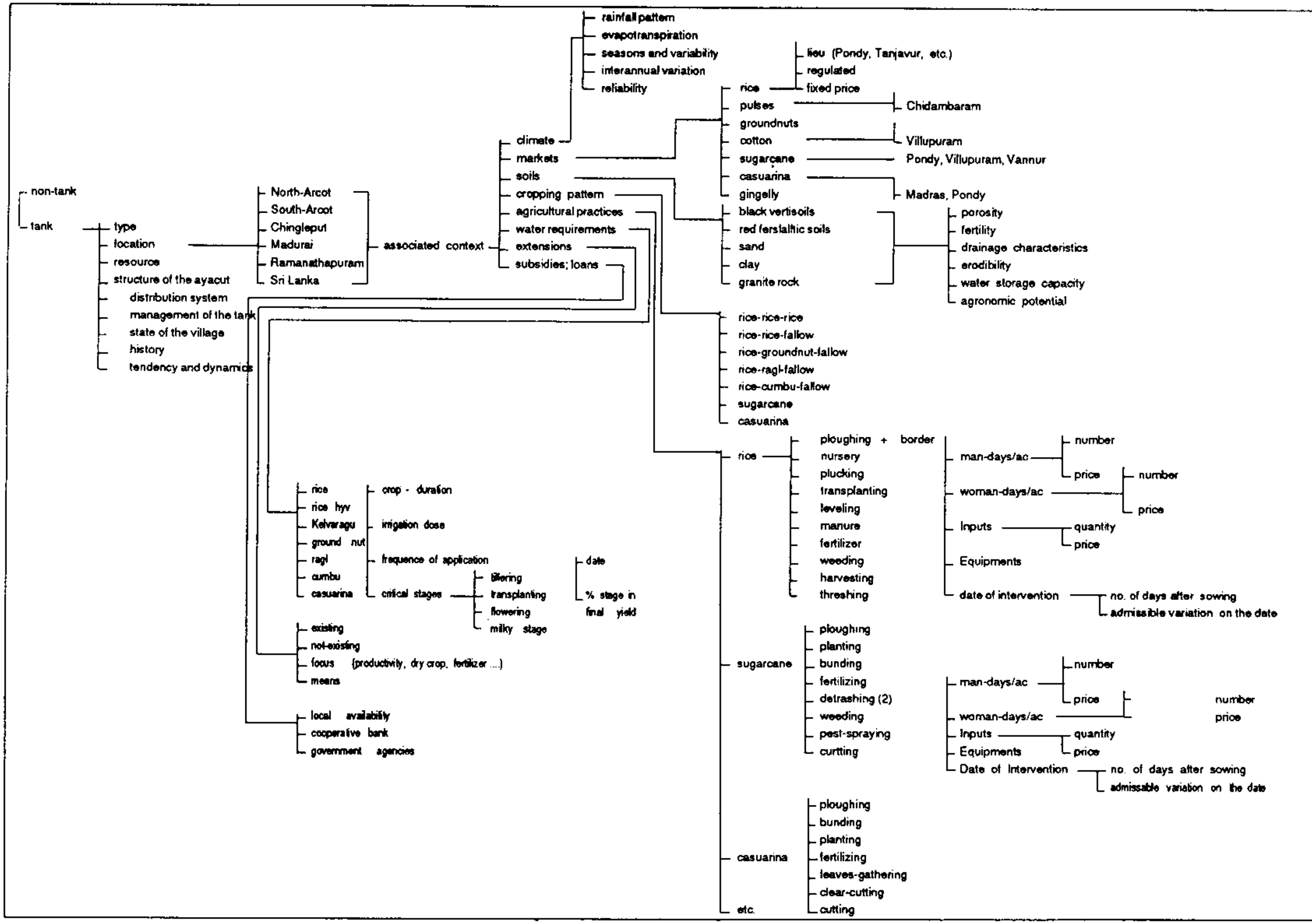

Figure A4. Resources of a tank irrigated system.

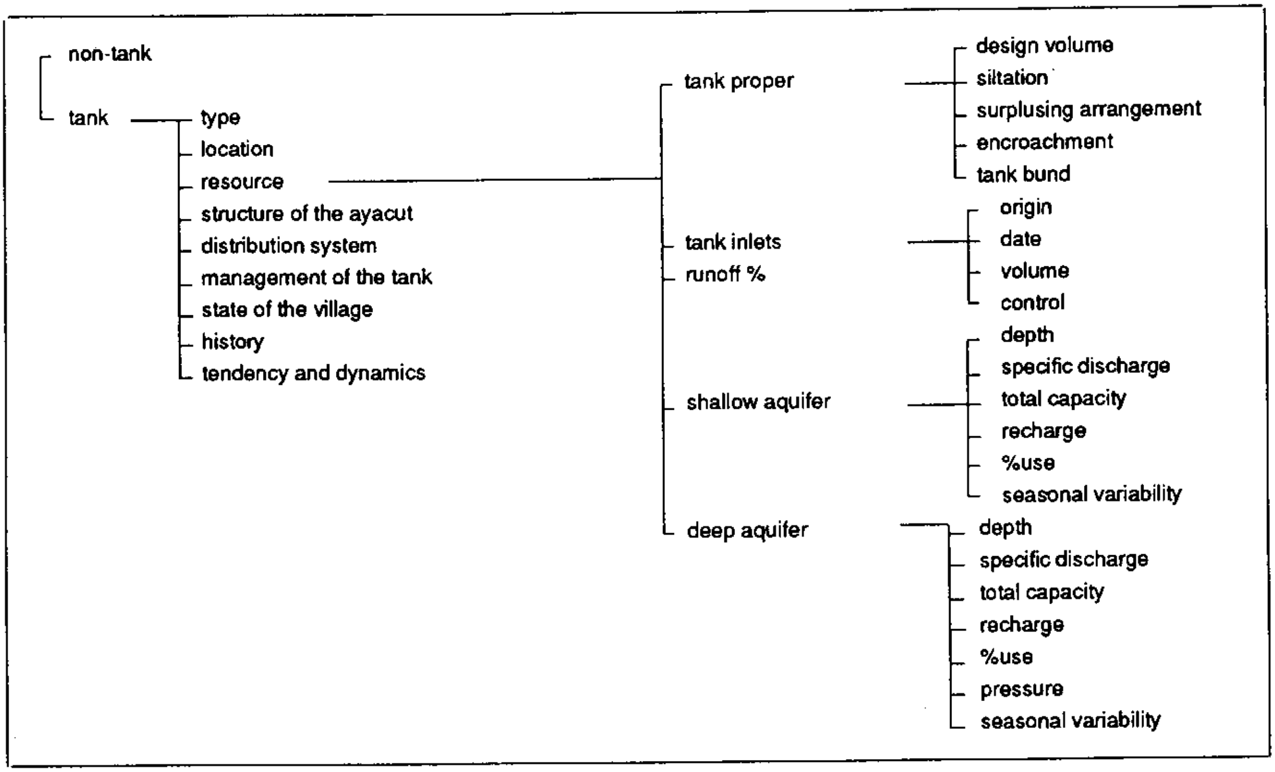

Figure A5. Characteristics of the command area and of the distribution system.

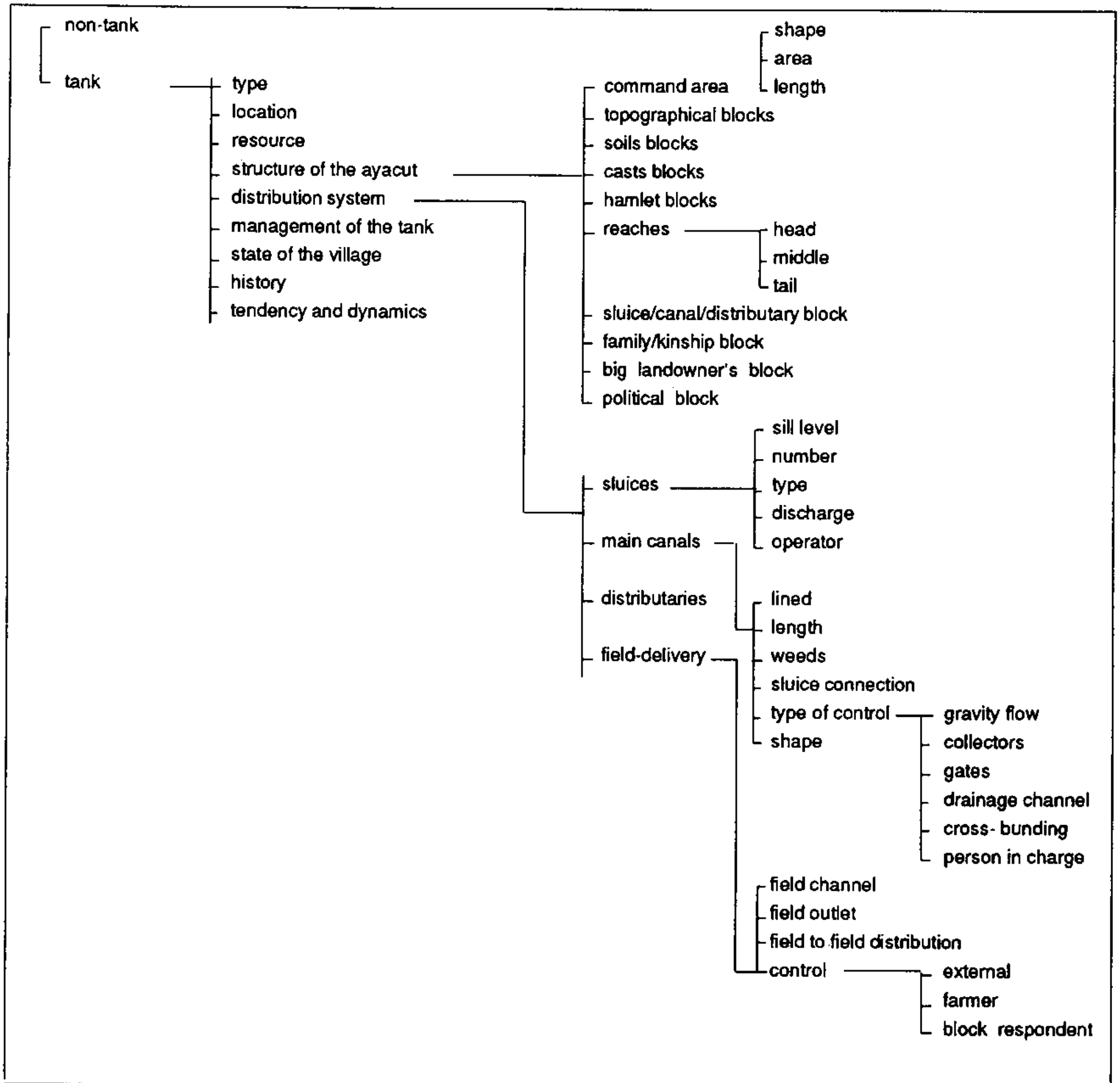

Figure A6. Management aspects of a tank irrigated system.

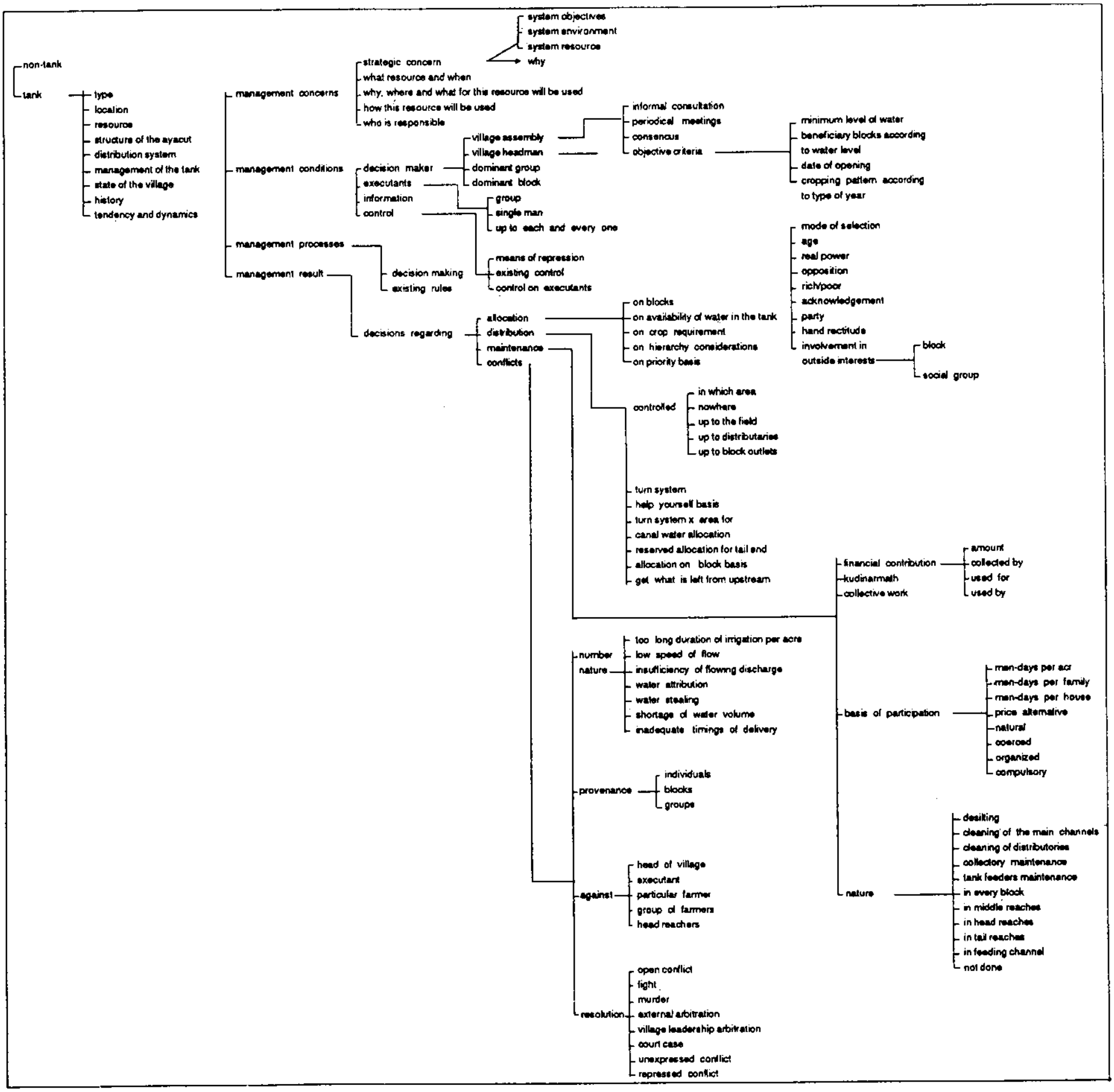

Figure A7. Elements accounting village status, history and dynamics.