ENHANCING THE SELECTION OF COMMUNICATION TECHNOLOGY FOR RURAL TELECOMMUNICATIONS: AN ANALYTIC HIERARCHY PROCESS MODEL

T. N. Andrew[a], P. Rahoo[b], and T. Nepal[b]

[a]Faculty of Engineering & the Built Environment,
University of Johannesburg, e-mail: Theoandr@twr.ac.za
[b]Telkom-Ericsson-THRIP CoE in Rural Telecommunications, Computer Studies Department
Durban Institute of Technology, RSA, E-mail: Nepal@dit.ac.za

ABSTRACT

Rural Telecommunications planning in a developing country is a complex process that has to consider the various interrelationships in a rural sociotechnical system. A primary function of telecommunications planning is the selection or design of the most appropriate technologies for the particular rural application. However, the issues involved in the selection and deployment of rural communication technologies are not only technological, but are often complex and 'messy', cutting across various aspects of the rural society. Uncertainty and multiple conflicting objectives usually characterise the decision-making process in such an environment. This paper is concerned with the use of the Analytical Hierarchy Process as a suitable method of dealing with the qualitative and quantitative data in relation to conflicting objectives, in arriving at a consensus decision in a typical rural telecommunications planning situation, for the selection of the most appropriate access technology.

Keywords: Technology selection, Analytical Hierarchy Process, rural telecommunication.

1. INTRODUCTION

The Planning of rural telecommunications services is characterised by a multitude of complex issues (Andrew and Petkov, 2003). One has to deal with uncertainty and multiple conflicting objectives in the decision-making process when it comes to the selection of technologies for such an environment. The issues that influence the selection of communications technologies, in general, range from the 'pure' technical to some of the softer ones such as the security of the physical technology infrastructure. Issues such as the topography and the extreme environmental conditions of the particular rural area, the user-friendliness of the equipment, the erratic demand for services (from plain old telephone services (POTS) to broadband services) and security of equipment are some of the external issues that the telecommunications operator faces. These issues are compounded by cost issues such as capital expenditure, operating expenditure, return on investment, depreciation and upgrade costs. Technical criteria such as system features, compliance with technology standards, reliability, ease of maintenance, compatibility with future technologies and network management capabilities, further complicate the selection of communication technology.

Currently there is no systematic methodology available to the only fixed line telecommunications operator in South Africa, for an objective choice of rural telecommunication technologies. It is common for the Network Operator's systems engineer or other persons to place on a shared computer network, a proposed telecommunication system for criticism, correction or comment. This stays on the system until the comments/criticisms from the colleagues are exhausted, and then it becomes a routine system for installation. Absolute objectivity in any decision-making is arguably unachievable since a decision reflects the values of the stakeholders concerned. There is therefore then a need to create an environment in which the subjectivity in the selection process could be managed. The Analytic Hierarchy Process (AHP), a multicriteria decision analysis technique suggested originally by Saaty (1990) provides for such an environment.

It must also be noted that traditionally, Telco planners have had a choice of only a few technologies to provide network access solutions, so the selection process was relatively trivial. These days, this "comfort zone" is rapidly eroding as a result of the ever-increasing availability of technologies, together with the push for newer technologies such as next generation networks, and the increase in the complexity of interactions between the various factors affecting the planning process. The interdependence between technology, socio-economic issues, and socio-cultural issues has been discussed in (Andrew and Petkov, 2003).

In dealing with multiple conflicting criteria and various types of data in the decision making process regarding rural telecommunication technology, one needs a way of viewing the problem in an organised but complex framework. This framework must allow for interaction and interdependence among all factors that influence the selection of technologies, and still enable one to think about them in a simple way. There are two fundamental ways of dealing with complex problem situations: The systems approach and the deductive approach. These are not mutually exclusive in that the deductive approach is often used within the systems approach. AHP and other multicriteria decision analysis techniques have certain similarities with both approaches. It provides a logical framework that enables an individual or a group of stakeholders to make effective decisions in complex situations by providing a structure in the decision making process.

This paper illustrates the applicability of using the AHP for providing more appropriate solutions in the selection of communication technologies for rural areas. Section two provides an overview of the theoretical concepts of the decision making process. The salient methods that are used in dealing with complex messy environments will be highlighted. Section three provides an overview of the AHP methodology as applicable to this paper. In section four the suggested approach is applied to a typical technology selection problem where a model for selection of communication technologies is developed. The results of the execution of the model using the Expert Choice software will then be discussed. The paper will conclude with some final remarks on the suitability of using the AHP for the selection of communication technologies for rural areas.

2. ON SIMON'S MODEL OF THE DECISION MAKING PROCESS AND ITS APPLICABILITY TO SELECTION OF RURAL TELECOMMUNICATION TECHNOLOGIES

Decision-making in a nutshell is the process of evaluating and choosing among a set of alternative elements, or courses of action, for the purpose of attaining a certain goal/s (Simon *et.al.*, 1987). In the context of this paper the goal is the selection of the most appropriate telecommunications technology available for a particular rural area. The process of selection is similar to the general process of decision-making. Decision-making is integral to all human activity either consciously or sub-consciously. The literature on decision-making has been steadily increasing over the years with the rise in the complexity of problems and the demand for development of new techniques and tools to deal with these problems. It is beyond the scope of this paper to provide an in-depth treatment of decision-making. Rather, only those salient aspects of decision-making necessary for the understanding of this paper will be covered.

According to Simon (1977) the decision making process consists of three phases: -

Intelligence phase: In which the decision maker/s examines the economic, technical, political and social environment to identify the new conditions that call for new actions.

Design phase: in which the decision maker/s design and develop possible courses of action. This includes the formulation of a model, setting the criteria for choice and searching for alternatives.

Choice phase: in which in traditional terms the decision is made i.e. the decision maker/s select the best alternative.

Later on Simon added a fourth stage to the above process - *Implementation*. Simon's model of decision-making is considered as the most general one. Its simplicity is a source of its power. Similarly, for the selection process of rural telecommunication technologies, the intelligence, design and choice phases could be clearly identified. The intelligence and the design phase are usually more complicated than the selection phase. The former require a mix of expertise and a set of approaches known in recent years as problem structuring techniques (see Rosenhead, 1989).

If technology selection was based on a few quantifiable specifications then the process would be relatively simple. However in the case of rural telecommunications in developing countries, socio-economic and political issues not only add to the complexity of the intelligence phase, but have consequences for the choice phase as well. The criteria for technology selection are now both numerous and wide-ranging. They are better analysed and synthesised by a group of experts rather than an individual. The challenge for the selection phase of decision making for rural telecommunications is to match the parameters of the engineering problem to the available possible solutions. A bouquet of technology solutions is usually provided by external (to the telecommunications operator) vendors and the challenge for the Telco engineers is in the selection of the most appropriate solution.

Multicriteria Decision-Making (MCDM) includes three general groups of approaches: utility theory, AHP and the outranking methods (Saaty, 1990). Here we chose to use the AHP for its simplicity, ease of use and available software supporting it. The Analytic Hierarchy Process is well suited for the Choice phase of Simon's model (Dyer and Forman, 1992). It has been shown that AHP can be used in fact for all the phases of Simon's decision-making process (see Petkov and Mihova-Petkova, 1998). However, in this paper its use will be limited to the choice phase. Further details on this approach are provided in the next section.

3. AN OVERVIEW OF THE ANALYTIC HIERARCHY PROCESS

The AHP is a method of breaking down a complex, unstructured situation into its component elements; arranging these elements into a hierarchic order; assigning numerical values to subjective judgements on the relative importance of each element; and synthesising the judgements to determine the priority of elements. A brief overview of AHP is provided here, and for more information, one may draw on the formal definitions and the richness of examples in Saaty (1990).

According to Weistroffer and Hodgson, Schoemaker and Waid found that, in a 1982 study comparing five conceptually different approaches for multi-criteria weighting, AHP was perceived as the easiest method to use, and the one whose results were considered most trustworthy. According to a study (Zapatero *et.al.*, 1997), in which twenty-four business professors compared decision support packages to a spreadsheet package by solving six decision problems, it was found that *Expert Choice*, an AHP-based software package, was one of the highest rated. The AHP technique and the *Expert Choice* software was therefore used in this study for these reasons as well.

A problem in AHP is structured in the form of a hierarchy of goals, sub goals or factors and alternatives. At the core of the Analytic Hierarchy Process lies a method for converting subjective assessments of relative importance with respect to the root of a cluster of factors to a set of overall scores or weights of those factors. The method was originally devised by Saaty (1980). It has proved to be one of the more widely applied MCDM methods, see for example Zahedi (1986); Golden *et. al.,* (1989); Shim (1989) for summaries of applications. The input to AHP models is the decision maker's answers to a series of questions of the general form, 'How important is criterion *A* relative to criterion *B*?' These are termed pairwise comparisons. Questions of this type may be used to establish, within AHP, both weights for criteria and performance scores for options on the different criteria.

It is assumed that a set of criteria has already been established. For each pair of criteria, the decision-maker is then required to respond to a pairwise comparison question asking the relative importance of the two. Responses are gathered in verbal form and subsequently codified on a nine-point intensity scale (see, Zahedi, 1986) as follows:

How important is *A* relative to *B*?	Preference index assigned
Equally important	1
Moderately more important	3
Strongly more important	5
Very strongly more important	7
Overwhelmingly more important	9

Two, 4, 6 and 8 are intermediate values that can be used to represent shades of judgement between the five basic assessments. If the judgement is that *B* is more important than *A*, then the reciprocal of the relevant index value is assigned e.g. if *B* is felt to be very strongly more important as a criterion for the decision than *A*, then the value $^1/_7$ would be assigned to *A* relative to *B*.

Because the decision maker is assumed to be consistent in making judgements about any one pair of criteria and since all criteria will always rank equally when compared to themselves, it is only ever necessary to make $^1/_2 n(n-1)$ comparisons to establish the full set of pairwise judgements for *n* criteria. In the case of multiple decision-makers responses are pooled using geometric means (Chan and Lynn, 1991). The result from all pairwise comparisons is stored in an input matrix $\mathbf{A} = [\boldsymbol{a}_{ij}]$ that is an *n x n* matrix. The element $\boldsymbol{a}_{ij}$ is the intensity of importance of criterion n_i compared to criterion n_j. Thus a typical matrix for establishing the relative importance of three criteria might look like:

$$\begin{bmatrix} 1 & 5 & 9 \\ ^1/_5 & 1 & 3 \\ ^1/_9 & ^1/_3 & 1 \end{bmatrix}$$

Note that while there is complete consistency in the (reciprocal) judgements made about any one pair, consistency of judgements between pairs is not guaranteed. Perfect consistency in all judgements is unrealistic in the real world, and the theory of AHP does not demand this. Inconsistencies occur due to clerical error, lack of information, lack of focus or concentration while making judgements and an inadequate model structure. The vector of weights is the normalised eigenvector corresponding to the largest eigenvalue of the matrix A (Saaty, 1990). The mathematical procedure is implemented in a software package, *Team Expert Choice^{TM}*.

In addition to calculating weights for the criteria in this way, AHP also uses pairwise comparisons to establish relative performance scores for each of the options (such as the different communication technologies) on each criterion. In this case, the series of pairwise questions to be answered solicits the relative importance of the performances of pairs of alternatives in terms of their contribution towards fulfilling each criterion. Responses use the same set of nine index assessments as before. If there are *m* options and *n* criteria, then *n* separate *m* x *m* matrices must be created and processed.

With weights and scores all computed using the pairwise comparison approach just described, options are then evaluated. The overall preference score for each option is simply the weighted average of its scores on all the criteria. Letting the preference score for option *i* on criterion *j* be represented by s_{ij} and the weight for each criterion by w_j, then for *n* criteria the overall score for each option, S_i, is given by:

$$S_i = w_1 s_{i1} + w_2 s_{i2} + \ldots + w_n s_{in} = \sum_{j=1}^{n} w_j s_{ij}$$

All options will record a weighted score, S_i, somewhere in the range, zero to one. The largest is the preferred option, subject as always to sensitivity testing and other context-specific analysis of the ranking produced by the model.

Team Expert Choice takes care of possible inconsistent judgements by calculating a measure of inconsistency, the so called consistency ratio and giving a warning message when the results suffer from this problem, so that the decision maker can make the judgements once again.

4. A CASE STUDY ON THE SELECTION OF RURAL TELECOMMUNICATION TECHNOLOGIES FOR THE BABANANGO AREA.

4.1 Development and Execution of the Model

The following case study revolves around the provision of rural telecommunications for the Kwabonanbi area in Northern KwaZulu Natal (KZN), South Africa. This is a typical rural setting in KZN with varying population granularity and a central hub of economic activity, and varying land topography. A focus group session with four 'experts' from the telecommunications network provider was held at the Telkom–Ericsson–THRIP Decision-Making Laboratory in KZN, for the purposes of the technology selection. The authors facilitated the group session, and *Team Expert Choice* was used as the software aid.

After a general discussion on the various issues that may impact on the provision of telecommunication services in the Kwabonanbi area the focus group individually but simultaneously started to produce a list of the possible criteria that will need consideration, when selecting communication technologies for that area. The Nominal Group Technique on *Team Expert Choice* was used for this purpose. The focus group produced an initial list of 66 criteria affecting the selection of rural telecommunication technologies for the Kwabonanbi area. This list was further refined and reduced to 51 different criteria, which was then compared to a pre-developed theoretical model based on the traditional criteria for technology selection for telecommunications in general. It was found that the predefined model lacked many of the 51 criteria agreed to by the focus group. With the overall goal being the 'selection of technology for rural telecommunications' the 51 criteria were categorised into five first level categories: 'Cost', 'Service Standard', 'Environmental issues', 'Social and demographic issues', 'Regulatory and technical standards'.

The final hierarchy model used in the AHP experiment is shown in Figure A1 in the Appendix with all the relevant criteria. Of particular note are the criteria such as 'social responsibility', 'parallel infrastructure', terrain factors', 'security', and granularity of population that are more applicable to rural areas and, which adds to the complexity of deciding the most appropriate technology for the particular rural area. After further discussion on the Babanango area and the set of criteria established, the focus group decided that the possible technology choices were the DECT A9800, Copper, OFTC (combination of fiber and copper), and GSM.

The four 'experts' individually executed the analytic hierarchic process on the model with the assistance of the *Team Expert Choice software*. Individual relative weights were allocated to each criterion after a pairwise comparison. For example, in comparing 'cost' with 'service standard' with respect to the goal a relative weight was allocated to the two–criteria; in comparing 'capital expenses' to 'operating expenses' with respect to 'cost' a relative weight was allocated to the two criteria. If the inconsistency ratio for all the pairwise comparisons was greater than 0.2 the individual 'expert' went through another iteration of the process. Finally the four technologies were compared pairwise to each of the 36 terminal nodes (leaves).

4.2. Results and Analysis

A synthesis of the four individual 'experts' relative weights was performed using *Team Expert Choice* and the resulting weights for the individual technologies and the overall inconsistency index is shown in Figure 1.

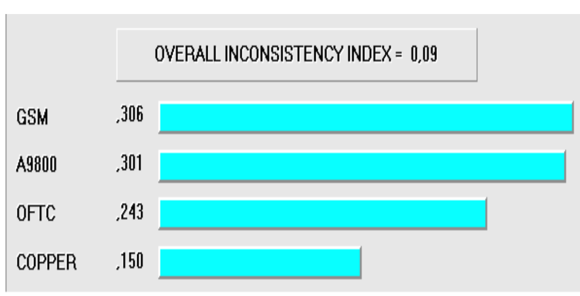

Figure 1: The overall relative weights and inconsistency index allocated by the AHP to the four technologies considered for the Babanango area.

The overall inconsistency index of 0.09 is well within the acceptable limit of less than 0.2. This means that there was an acceptable degree of consistency among the 'experts' in assessing the individual criteria, indicating credible pairwise comparisons. Whereas at the commencement of the exercise the group was uncertain as to the most appropriate technology for the area, upon reflection and discussion of the results the group agreed with the respective order of choice of technologies. One of the advantages of the AHP process is that one could test the sensitivity of the final choice to retrospective changes in the assessment of a criterion or parts of the model.

5. CONCLUSION

It must be stressed that any decision-making technology serves as an enhancement to human judgement by, amongst other things, managing the tyranny of the quantity of conflicting criteria, and the subjectivity of the individual decision makers towards an acceptable consensus decision. This entire AHP modelling session for this case study was conducted with the focus group in approximately 3.5 hours. The traditional processes would have taken far longer to reach a consensus choice such as the one accomplished in this case study. In summary the AHP can be used as an elegant and efficient technology selection approach for rural telecommunications that could formalise the judgements of 'experts', concerning multiple conflicting criteria, in a structured way towards a consensus and confident choice.

This process would be refined with experience, increasing the accuracy of and the time taken to make the most appropriate choice of rural telecommunications technology. It is envisaged that an AHP decision-making template would be developed for the selection of rural telecommunication technologies that would be regularly updated and improved.

6. REFERENCES

Andrew, T. N. and Petkov, D (2003), The Need for a Systems Thinking Approach to Planning of Rural Telecommunications Infrastructure, *Telecommunications Policy,* 27 (1-2), 75 - 93.

Chan, Y. L. and Lynn, B. E. (1991) "Performance evaluation and the Analytic Hierarchy Process". *J. Mgmt Account. Res*. 57 – 87.

Dyer, R. F. and Forman, E. H. (1991) *An Analytic Approach to Marketing Decisions*, Prentice Hall, Englewood Cliffs.

Golden, B., Wasil, E. and Harker, P. (Eds.) (1989) *The Analytic Hierarchy Process: Applications and Studies,* Springer Verlag, New York.

Petkov D. and Mihova-Petkova O. (1998). The Analytic Hierarchy Process and Systems Thinking, in Stewart T.J. and van der Honert R.C. (Eds), *Trends in Multicriteria Decision Making*, Lecture Notes in Mathematics and Mathematical Systems, Springer, Berlin, Vol 465, 243-252.

Rosenhead, J. (Ed) (1989) *Rational Analysis for a Problematic World,* Wiley, Chichester.

Saaty, T. (1980) *The Analytic Hierarchy Process,* John Wiley, New York.

Saaty, T. (1990) *The Analytic Hierarchy Process*, RWS Publications, Pittsburgh**.**
Shim, J. P. (1989), "Bibliographical research on the analytic hierarchy process (AHP)" S*ocio-economic Planning Sciences,* 23, 161-7.
Simon, H., (1977) *The New Science of Management Decision,* rev. ed., Prentice Hall, New Jersey.
Simon, H., Dantzig, G., Hogarth, R., Plott, C., Raiffa, H., Schelling, T., Shepsle, K., Thaler, R., Tversky, A. and Winter, S. (1987), "Decision Making and Problem Solving", *Interfaces*, 17(5), 11-31.
Weistroffer, H. R. and Hodgson, L. (1998) "Using AHP for Text Book Selection" in Stewart, T. and van den Honert, R. C. (eds.), *Trends in Multicriteria Decision Making,* Springer-Verlag, Berlin, Germany.
Zahedi, F. (1986), "The Analytic Hierarchy Process: a survey of the method and its applications", *Interfaces,* 16, 96-108.
Zapatero, E. G., Smith, C. H. and Weistroffer, H. R. (1997), "Evaluating multiple attribute decision support systems" *Journal of Multi-criteria Decision Analysis,* 6, 201 – 214.

Appendix 1: Model for selection of technology for rural telecommunications

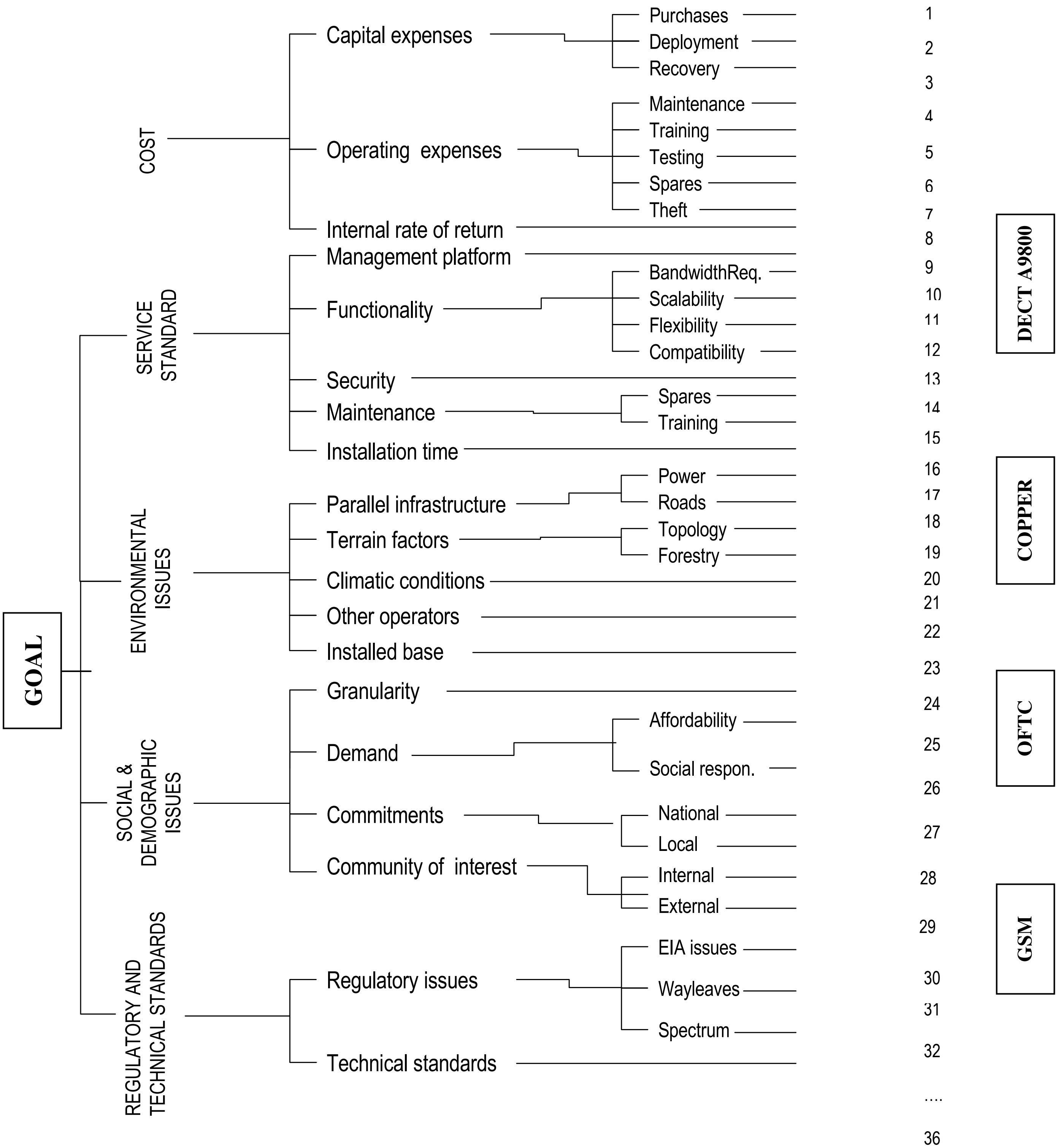

Figure A1: AHP Model for the Selection of Telecommunications Technology for the Babanango Area.
NOTE: The four technologies will be compared pairwise to each of the 36 terminal nodes (leaves)

Appendix 2. Steps in the Analytic Hierarchy Process (adapted from Saaty, 1990)

1. Define the main goal, subgoals, factors and alternatives
2. Compare in a pairwise fashion the elements in a cluster with respect to their contribution to the root of the cluster in the hierarchy.
3. Calculate local priorities.
4. Synthesize global priorities.
5. Conduct sensitivity analysis and what-if analysis.

N.B. If the alternatives at the lowest level of the hierarchy are more than 7, then apply absolute rating of the alternatives instead of pairwise comparisons. For more information see Saaty(1990).

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About the authors:

Theo Andrew is a Professor and Executive Dean of the Faculty of Engineering and the Built Environment at the University of Johannesburg, South Africa. He holds a PhD in IT from the University of Natal. Previously he managed the Center for Excellence in Rural Telecommunications at the Durban Institute of Technology. His research and publications are in the areas of rural telecommunications, systems thinking, developmental engineering, and engineering education.

P.Rahoo was a postgraduate student at the Center for rural telecommunications

T. Nepal is the Senior Director in the Department of Information Technology at the Durban Institute of Technology (DIT), South Africa. He holds a DTech degree in IT from DIT. His research and publications are in the fields of Information Technology, Group Decision Support Systems and Timetabling