Rural Telecommunications Infrastructure Selection Using the Analytic Network Process

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Abstract

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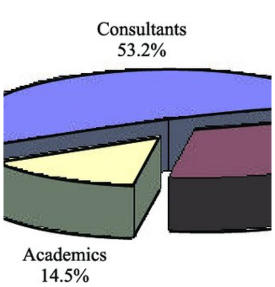

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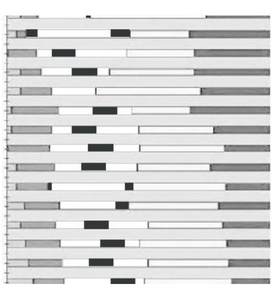

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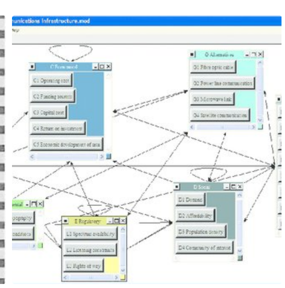

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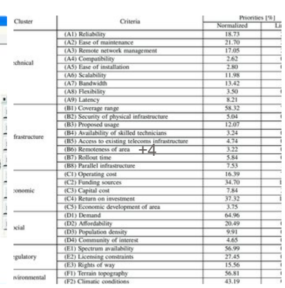

Ordering and clustering of criteria according to relevance and

Paper

Rural Telecommunications Infrastructure Selection Using the Analytic Network Process

Yousef Gasiea, Margaret Emsley, and Ludmil Mikhailov

Abstract—The decisions involved in rural settings are of complex nature, with some aspects compounded by the presence of intangible criteria. Hence, a suitable approach is needed that can produce effective solutions. This paper describes the applicability of a multicriteria decision-making method, specifically the analytic network process (ANP), to model the selection of an appropriate telecommunications infrastructure technology, capable of deploying e-services in rural areas of developing countries. It aims to raise awareness among telecommunication planners about the availability of ANP, and to demonstrate its suitability to enhance the selection process. The proposed model is constructed based on concerned experts' views of relevant selection criteria and potential technology alternatives. Its network structure caters for all possible dependencies and interactions among criteria and alternatives.

Keywords—analytic hierarchy process, analytic network process, multicriteria decision making, rural telecommunications, technology selection.

1. Introduction

Telecommunications technology is evolving rapidly and offers information links between urban and rural areas that can overcome distance barriers and provide e-services to these hardly accessible areas. Recent technological advances in transmission systems like fiber optics, wireless and satellite can now supply services to these locations at affordable prices. However, with different criteria for technology evaluation and various telecommunications infrastructure alternatives available nowadays, the selection process becomes complicated; there is uncertainty and multiple conflicting objectives with sociological, demographical, environmental, political, cultural, economic and technical aspects. This raises the need for some kind of structure or model, based on a suitable multicriteria decision making (MCDM) method.

Some relevant papers cited in literature tackling problems from rural telecommunications field using such methods, with particular focus on the application of analytic hierarchy process (AHP) to rural telecommunications include: Nazem *et al.* [1] use the AHP, to develop a two-phased decision support system to aid the design of rural area telecommunication networks and in [2] examines ways of building an effective rural telecommunications network to facilitate rural development in an information-intensive society. Lee and Kim [3] present a methodology using analytic network process and zero-one goal programming (ZOGP) for information systems projects selection problems that have multiple criteria and interdependence property. In another paper, Nazem *et al.* [4] develops a specific multicriteria decision support mathematical programming model for dealing with the definition of a "hub structure" that is the selection of a number of "nucleus cities" in the context of a rural network planning process. Chemane *et al*. [5] use DecidelT tool based on MCDM to improve the quality of decisions in selecting internet access technologies. Sasidhar and Min [6] use AHP to select the optimal access technology for a rural community under a multiple number of criteria such as cost quality and speed. Nepal [7] applies AHP to the evaluation of rural telecommunications infrastructure. Finally, Andrew *et al*. [8] present a model regarding the applicability of using the AHP for enhancing the selection of communication technologies for rural areas.

While significant decision models are being presented in these papers, but, very few studies have considered all criteria relevant to rural telecommunications, and most of them obviously apply no factor interactions. For example, if a model's emphasis is mainly technical, then the economic, social, regulatory and environmental criteria are probably not adequately addressed. Basically, the AHP is a suitable method when optimization is not pursued, resources are not restricted, and interdependencies between factors do not exist [9]. However, such models do not consider important issues such as interaction among and between decision making levels/clusters as well as dependency among qualitative factors. These are important issues in rural telecommunications decision problems which cannot not be structured hierarchically because they involve many interactions and dependencies requiring a MCDM method to holistically deal with qualitative and quantitative data, with different conflicting objectives, to arrive at a consensus decision in relation to the choice of a suitable rural telecommunication technology.

To the best knowledge of the authors, applications of the analytic network process (ANP) to the selection of rural telecommunications infrastructure technologies have not been cited in the published literature. This paper therefore attempts to fill this gap in the literature to particularly allow for the explicit consideration of dependencies and interactions in the decision making process and still maintains the acknowledged advantages of the AHP method. The ANP is chosen in this paper because of its several advantages

over the AHP and other MCDM methods, such as its holistic approach, in which all the factors and criteria involved are laid out in advance in a network system that allows for dependency. Its power lies in its use of special ratio scales to capture interactions for making accurate predictions and reach better decisions [10]. Moreover, its suitability in offering solutions in a complex multicriteria decision environment, together with the availability of software supporting its functions, further acknowledge its applicability to tackle such a problem. It has also proved to be successful in utilizing expert knowledge to tackle several selection problems, e.g., [3] and [11].

The remainder of this paper is organized as follows. Section 2 articulates the selection of rural telecommunications infrastructure problem. The underlying methodology of the proposed approach, the ANP, is briefly introduced in Section 3. The development of the proposed model is explained in Section 4. The pairwise comparisons are described in Section 5. The results are discussed in Section 6 and the paper ends with conclusions in Section 7.

2. The Choice of Technology for Rural Telecommunication Infrastructure

There is a need to provide access to the main telecommunications network and expand connectivity to such areas, thus enabling the rollout of the appropriate telecommunication services. However, the choice of appropriate telecommunications infrastructure technology that will provide the required e-services within various constraints is a challenge. Typically, technology selection is based on a mixture of different criteria, one of which is the remoteness of a village. If the village is within 35 km of the nearest local exchange, telecommunication services can be provided to that village using a one-hop last-mile link. However, if the village is further away, at least two transmission hops must be established [12]. Hence, two types of telecommunications infrastructure technologies are needed to provide rural telecommunication services, namely backbone network (core) and access network (last mile).

The backbone network provides the long-haul signal transmission from the country's main telecommunication centre to the remote access network, i.e., trunking services [12]. This network may be wireless or wireline, including analogue and digital transmission technology over fiber optic, wireless or satellite transmission media [5]. The access network provides the connectivity between the end-user and the backbone network and may be based on wireless or wireline technologies, e.g., copper wires or wireless, connected to network nodes at the edge of the backbone network. Technologies in both networks can be circuit-switched or packet-switched. Any decision made for each of these two segments must take into account the characteristics of rural settlements.

The primary focus of this paper is mainly on the backbone network by attempting to provide a structure of the decision problem and proposing a technology selection model of such an infrastructure. The telecommunications backbone is, in general, a key problem for rural information infrastructure, as low population density is linked to high cost of service for any communications technology, especially for wireline services. It poses the greatest challenge to bringing affordable telecommunication services to rural residents. However, once it is in place and running, it will be possible to connect other nearby rural villages with a wide range of telecommunication technologies and needed services. The infrastructure technology selection process, especially in the case of rural telecommunications in developing countries, is a multi-faceted, multi-criteria decision making problem, requiring consideration of some wide-ranging qualitative factors related to socio-economic and political issues. These are hard to quantify and will have great impact on the selection process, in respect of the social, environmental, regulatory and demographical concerns, etc.

Furthermore, in order to incorporate other tangible factors, in the absence of past statistical data to analyze, such as technical and economic related factors, etc., it is necessary to use a suitable multicriteria method for analysis and synthesis by a group of experts rather than an individual. A telecommunication operator usually receives several technology solutions from external vendors. The challenge of matching the parameters of an engineering problem to the available solutions becomes a challenge to the telecommunications engineer in this particular selection phase [8]. A typical conceptual rural telecommunications infrastructure selection model is illustrated in Fig. 1.

Fig. 1. A conceptual model for the selection of rural telecommunication infrastructure (revised and adapted from [13]).

The obvious significant implication of this conceptual model is that the technical factors are only one subset among others when selecting rural telecommunication technologies, albeit a necessary part. The other factors, such as the sociological, environmental, economic, regulatory and the infrastructure-related are regarded as essential factors that also need to be considered. This can be envisaged as a holistic approach in which the outcome of the selection process is not only dependent on the technical factors, but arises out of the interactions among the various factors. An ANP-based decision model is therefore proposed as a suitable methodology because "*decisions obtained from a network can be significantly different from those obtained from a more complex hierarchy*" [14]. It is constructed to include an in-depth and comprehensive examination of all pertinent factors and will be dependent on the perceptual weightings, provided by telecommunications experts.

3. The Analytic Network Process

The ANP is a multi-attribute decision making approach developed by Thomas L. Saaty and was originally called the supermatrix technique [15]. It is a generalization of the AHP decision methodology where hierarchies are replaced by networks, allowing the capturing of the outcome of dependence and feedback within and among the clusters of elements. Its network structure differs from a hierarchy as illustrated in Fig. 2 [10]. The hierarchy has a goal, levels of elements and connections between the elements.

Fig. 2. Examples of a hierarchy (a) and a network (b).

It has no inner dependence and no feedback from lower to higher levels. Unlike the hierarchy, the network structure has no levels but clusters of elements where every element can depend on any other element. The influence is transmitted from one cluster to another (outer dependence) and back, either directly from the second cluster, or, by transiting through intermediate clusters along a path which sometimes can return to the original cluster forming a cycle [10]. The existence of feedback indicates there is mutual outer dependence of criteria in two different clusters, which prevents the problem from being modeled hierarchically due to the difficulty in deciding which cluster is higher/lower than the other. Also, because of inner dependence, the relationships between same level criteria are not represented hierarchically.

The specific ANP model is based on the reasoning, knowledge and experience of experts in the field and relies on the process of eliciting managerial inputs, allowing for a structured communication among decision makers, so that it can act as a qualitative tool for strategic decision-making problems. "*It is a relatively new methodology that is still not well-known to the operations research community and practitioners*" [9]. With its capability to deal with dependence and feedback, it is the most general framework for a detailed analysis of societal, governmental and corporate decisions that is available today to the decision-maker [15]. Therefore, in recent years, there has been an increased use of the ANP in a variety of decision making problems and numerous applications have been published in literature [16].

The ANP is a coupling of two parts. The first part consists of a control network of criteria that controls the interactions in which the criteria should be identified, organized and prioritized in the framework of a control network. The second part is to derive a network of influences among the factors and clusters, i.e., the influence of elements in the feedback system with respect to each of these criteria. Paired comparison judgments of homogeneous elements are performed and synthesized to obtain the priorities of these criteria. The ANP then joins all possible outcomes together in its structures and both judgement and logic are used to estimate the relative influence from which the overall answer is to be derived [15]. The *SuperDecisions* software can be used to perform matrices computation and solve AHP/ANP problems [17].

4. The Development of the Decision Model

In this section, we introduce an ANP model and its development to show how the ANP can be used in the rural telecommunications environment. As each telecommunication infrastructure provider will have its own set of criteria. The attempt here is to present a generalized model based on factors and alternatives identified from the published literature, best practices and telecommunications experts that could then be adapted or extended to support a particular context or a situation of a developing country.

4.1. Setting Selection Criteria

To adapt the ANP methodology for such a technology selection process, it is the foremost activity of the researcher to examine the relevant issues involved. Hence, the first task is the definition of the criteria that will be used for the selection of the appropriate technology for rural connectivity. The activities used to consolidate the final list of the selection criteria, were:

- an intensive literature survey of past studies on similar problems, including: [5], [6], [8], [12] and [18]; the outcome of this activity was the consolidation of an initial list of criteria that comprises the most important factors for the problem at hand;
- interactions with telecommunication experts both from industry and academia from all over the world, who were contacted through e-mail to provide feedback on the initial list of criteria; from the aforementioned activities, a consolidated list of 31 selection criteria, deemed to affect the planners' decision in the choice of rural telecommunications backbone infrastructure, can be observed in Table 1.

Table 1
Ordering and clustering of criteria according to relevance and importance

Cluster	Criteria	Mean
(A) Technical	(A1) Reliability	4.00
	(A2) Ease of maintenance	3.94
	(A3) Remote network management	3.88
	(A4) Compatibility	3.81
	(A5) Ease of installation	3.72
	(A6) Scalability	3.54
	(A7) Bandwidth	3.53
	(A8) Flexibility	3.52
	(A9) Latency	3.30
(B) Infrastructure	(B1) Coverage range	3.80
	(B2) Security of physical infrastructure	3.73
	(B3) Proposed usage	3.40
	(B4) Availability of skilled technicians	3.34
	(B5) Access to existing telecoms infrastructure	3.32
	(B6) Remoteness of area	3.26
	(B7) Rollout time	3.11
	(B8) Parallel infrastructure	2.97
(C) Economic	(C1) Operating cost	4.13
	(C2) Funding sources	4.11
	(C3) Capital cost	3.98
	(C4) Return on investment	3.63
	(C5) Economic development of area	3.32
(D) Social	(D1) Demand	3.77
	(D2) Affordability	3.73
	(D3) Population density	3.48
	(D4) Community of interest	3.42
(E) Regulatory	(E1) Spectrum availability	3.74
	(E2) Licensing constraints	3.52
	(E3) Rights of way	3.30
(F) Environmental	(F1) Terrain topography	3.24
	(F2) Climatic conditions	3.00

4.2. *The Online Survey*

In order to rank the selection criteria according to their relative importance, an online questionnaire was designed. Telecommunication experts were asked to rate the importance of each factor using a five-point Likert-type scale, ranging from: *not important = 1*, *moderately important = 2*, *strongly important = 3*, *very strongly important = 4* and *extremely important = 5*. A pilot survey was conducted before posting the questionnaire online and subsequently the questionnaire was slightly modified.

Fig. 3. Categorization of respondents by their professional background.

Fig. 4. A graphical representation of the online survey results in percentages.

Table 2
Comparisons of some features of potential alternatives

Alternative	Advantages	Disadvantages
(G1) Fiber optic cable	High speed More reliability High flexibility	High cost Long rollout time Most difficult to deploy
(G2) Power line communication	Simplicity Low cost Use of power lines	Less reliability Data signal disruption Noise and interference
(G3) Microwave link	High speed Low cost equipment Fast deployment	Low reach and line of sight Licensing constraints Less bandwidth and flexibility
(G4) Satellite communication	Wide coverage Ease of deployment Overcomes topography	High latency High cost Limited bandwidth

The obtained responses effectively reached 62 responses, which is considered adequate because the purpose of the survey was mainly to obtain a range of diversified expert opinions with respect to each particular selection factor.

The respondents' profiles showed that all of them are generally involved in telecommunications field, where some of them are particularly dealing with rural telecommunications projects. They can be categorized by their professional backgrounds into three categories as shown in Fig. 3: of the 62 respondents 20 (32.3%) of them work as telecommunication engineers, 33 (53.2%) as consultants and 9 (14.5%) as academics. This mix up of the respondents' expertise confirms their familiarity with the selection factors and also indicates that they were very well placed to provide useful data for such a survey.

The results were then analyzed using SPSS (SPSS Inc., 2006), and univariate descriptive statistics were generated, including the relative importance index for each factor. Figure 4 summarizes the obtained results and shows that all proposed criteria are mostly within the *strongly important* and *very strongly important* categories, the only exception being the results of the "operating cost" criterion which is inclined more towards the *extremely important* grade.

4.3. Grouping of Criteria into Clusters

The mean rating values were used to group the criteria into six clusters coded A through F according to relevance, in this order: (A) Technical, (B) Infrastructure, (C) Economic, (D) Social, (E) Regulatory, and (F) Environmental. Each cluster only includes criteria that are comparable or do not differ by orders of magnitude [10]. Table 1 shows the coding and the ordering of criteria for all clusters.

4.4. Alternatives Identification

The activities abovementioned in Subsection 4.1 were repeated in order to identify potential technology alternatives. The published literature, e.g., [19], identified four technological solutions to provide rural backbone infrastructure to promote e-services in rural areas of developing countries that include two wireline technologies: fiber optic cable and power line communication, and two wireless technologies: fixed wireless and satellite, which were initially highlighted as candidate decision alternatives for this research. After consultation with telecommunication experts, the alternatives finally selected for this research are (G1) fiber optic cable, (G2) power line communication, (G3) microwave link and (G4) satellite communication. Table 2 briefly summarizes some characteristics of alternatives.

4.5. Assessing Dependencies

After structuring the decision problem, the next step is to examine the dominance of influence among criteria. In order to fulfil this task, a new survey questionnaire was distributed to experts who had an overview of the research, were interested and actually involved in the field of rural telecommunications, who were asked to identify the dependencies among criteria. Seven completed questionnaires were collected. The majority rule was then used to aggregate the responses into a single matrix, which was developed using a zero-one matrix of criteria against criteria using a binary value of 1 to signify dependence of one criterion on another, and zero otherwise [20]. A majority condition of 4 out of 7 (4/7) experts' consensus (i.e., 57%) was considered as a minimum requirement for any entry that indicates the existence of a direct relationship between any pair of criteria.

Table 3 shows all possible connections, where the entries can take the following values:

0 indicates no relationship exists based on 7 experts' consensus;

0 indicates the entries have obtained < 4 experts' consensus;

1 indicates the entries have obtained ≥ 4 experts' consensus.

Table 3

The aggregated dependency matrix showing connections among all elements

As a result, the entries represented by 1 indicate the existence of a direct relationship from criterion i to criterion j based on the consensus of at least 4 experts, i.e., if criterion i depends on criterion j, the entry a_{ij} will take 1. The criteria in the rows are evaluated with respect to the criteria in the columns, i.e., the 1 in the columns will determine which criteria in the rows are to be pairwise compared with respect to that column. Subsequently, a pairwise comparison matrix will be constructed only for the dependent criteria. Using the *Design module* of the *SuperDecisions* software [17], the network model was constructed according to Table 3, the connections between clusters are illustrated in Fig. 5. A cluster is connected to another cluster when at least one element in it is connected to at least two elements in another cluster. It should be noted that two-way arrows connecting the clusters represent interdependencies among elements, where an arrow direction signify dependence and starts from an element to another that may influence it [17].

Figure 5 contains the entire inner dependence – the parent element and the elements to be compared are in the same cluster so that the cluster is linked to itself and a loop link appears – among elements within each cluster except in the environmental and alternative clusters. It indicates that the connections between the elements are in the same cluster. For example, column A8 means A2, A4, A5, A6 are interrelated with respect to A8.

The proposed model also contains outer dependence which is the relationship between elements in one cluster with others in other clusters [15]. For example, in Table 3, when considering A8, the elements G1, G2 G3 and G4 in the (G) *Alternative cluster* are interconnected and pairwise compared with respect to A8 in the (A) *Technical cluster*. The exception is the regulatory and environmental

Fig. 5. The ANP network model with connections among elements/clusters.

clusters, i.e., none of the elements in both clusters depend on elements from other clusters with respect to a common attribute within a cluster. Also, the technical and social clusters have no outer dependence on the economic cluster.

Feedback links in which one compares the alternatives with respect to criteria, as in a hierarchy, and also compares the dominance of one criterion versus another for each alternative exist in this structure. Table 3 illustrates that there is mutual outer dependence of criteria in two different clusters as can be seen between the alternative cluster and all other clusters; technical and social clusters and infrastructure and economic clusters. For example, G1 is the parent element and all elements in other clusters except in cluster G are its children elements, which indicates that criteria may be compared with respect to an alternative. This is the strength of the ANP approach because dependence and feedback are incorporated in real life problems, in which a decision process not only compares alternatives with respect to criteria but also vice versa. For instance, in addition to separately comparing G1, G2, G3 and G4 with respect to A1 and A7, A1 and A7 must also be compared with respect to G1. A pairwise question to be asked is: what is a more dominant characteristic of fiber optic cable technology, its reliability or its bandwidth? However, since feedback involves cycles, and cycling can be an infinite process, the operations needed to derive the priorities become more demanding than with hierarchies [20].

Based on the above analysis, it is obvious that the developed inner and outer dependence and feedback among the network structure shown in Table 3 excludes the hierarchy form and calls for the network form to model the selection of rural telecommunications infrastructure technology.

5. Pairwise Comparisons

After constructing the ANP network, the next phase is the measurement and data collection stage which involves compiling a list of experts to provide judgements for pairwise comparisons. Both the AHP/ANP derive ratio scale priorities by making paired comparison of elements on common elements. The subjective judgements are to be entered and assigned a numerical value based on the nine-point scale suggested by Saaty [21] to obtain the corresponding pairwise judgment matrices. A score of 1 indicates the equality between the two elements whereas score 9 represents the dominance of the row element in the matrix over the column element. A reciprocal value is automatically assigned in the opposite position in the matrix, i.e., $a_{ij}= 1/a_{ij}$.

In this model, pairwise comparisons are identified according to the connections developed in Table 3 and then relevant pairwise comparison matrices are created accordingly. The columns in the table present the parent elements, while the rows present the children elements in the structure. For example, G1 is a parent element and A1 through F2 are its children elements. The elements that are to be pairwise compared are always all in the same cluster. They are compared with respect to their parent element, the element from which they are connected.

There are a number of comparison matrices for every parent element, and one comparison matrix for elements in the same cluster originating from the same parent element.

Fig. 6. An example of *SuperDecisions* pairwise comparison process.

For example, there are four comparison matrices for criterion B6, one for each of clusters A, B, C and G. Elements within D cluster cannot be compared with respect to B6 because there should be at least two entries of 1 available within any cluster to perform pairwise comparisons. Therefore, A1, A2, and A5 through A9 are pairwise compared with respect to B6; B1 through B5, B7 and B8 are pairwise compared with respect to B6; C1 and C5 are pairwise compared with respect to B6; and G1 through G4 are pairwise compared with respect to B6. This results in local priorities of the children elements with respect to the parent element. It is only necessary to make $n(n-1)/2$ comparisons to establish the full set of pairwise judgements, where n denotes the number of elements (nodes). For example, six pairwise comparison questions are required for A1 because $n = 4$ for the alternatives outer dependence on A1, while for A8, twelve pairwise comparison questions are needed because $n = 4$ for the inner dependence within the technical cluster, and also $n = 4$ for the alternatives outer dependence on A8.

In this developed structure; there are a total of 92 judgement matrices which include 674 pairwise comparison questions for both inner and outer dependences developed within the network. It is obvious that the task of asking such a large number of questions would be very enormous and would require intensive efforts and extended time. Hence, in order to establish a more rational approach to collect pairwise comparison judgements from qualified telecommunication experts, and also to economize efforts, it was decided to design and use several online questionnaires to gather data from experts. The questionnaires included all required pairwise questions to assess expert judgments in relation to the relative influence of affecting elements on the affected ones.

An example of such pairwise question is: "In selecting an appropriate backbone infrastructure technology in rural areas of developing countries, which influences fiber optic cable technology more, ease of installation or ease of maintenance? Conversely, given the ease of installation, which of these technologies are more dominant, fiber optic cable or satellite?"

Since the clusters in this network are not equally important, their weights in the cluster matrix are obtained by pairwise comparisons. Each cluster is taken in turn as a parent cluster, and the other clusters connected to it are pairwise compared for importance with respect to their influence on it [17]. It should be noted that the pairwise comparisons to assess the influence of some cluster on all other clusters is actually what distinguishes the ANP from the AHP.

For example, one of the cluster comparison questions addressed to the experts is: "Which influences the selection of rural telecommunications backbone infrastructure more, economic or technical issues?" The obtained cluster weights are used in a later stage to weight all the elements in the unweighted supermatrix. The individual expert pairwise comparisons are aggregated into a representative group judgment, by applying geometric means.

A score corresponding to the group judgment regarding this question is then clicked to highlight the technology providing more reliability relative to the technology providing less reliability. While, a score of 1 indicates the equality between the two technologies, the blue scores represent the dominance of the row element in the matrix (e.g., G1) over the column element (e.g., G2) and the red scores are vice versa. A reciprocal value is automatically assigned in the opposite position in the matrix.

An example of the comparison process used in *SuperDecisions* is shown in Fig. 6. It presents the pairwise comparisons between alternatives G1 and G2, regarding the reliability factor. The question being asked is "With respect to reliability, which technology is more reliable: fiber optic technology or power line communication?" The group judgment was that G1 is between *very strongly* and *extremely* more reliable than G2, therefore the comparison value of 8 is entered.

The comparison between all other alternatives regarding different criteria is done in the same way.

The next stage of the process includes the computations of the relative importance of the elements. For each comparison matrix a local priority vector (also referred as an eigenvector) is computed, by applying the eigenvector approach [14], provided that the inconsistency ratio (IR) of this matrix is less than 0.1.

Table 4
Comparison matrix of alternatives with respect to reliability, $IR = 0.0958$

	Alternative	G1	G2	G3	G4	Eigenvector
(G1)	Fiber optic cable	1.000	8.240	3.350	5.730	**0.580**
(G2)	Power line communication	0.121	1.000	0.178	0.217	**0**
(G3)	Microwave link	0.299	5.630	1.000	3.830	**0.262**
(G4)	Satellite communication	0.175	4.610	0.261	1.000	**0.114**

Table 5
Ordering and clustering of criteria according to relevance and importance

Cluster	Criteria	Priorities [%] Normalized	Priorities [%] Limiting
(A) Technical	(A1) Reliability	18.73	2.42
	(A2) Ease of maintenance	21.70	2.81
	(A3) Remote network management	17.05	2.21
	(A4) Compatibility	2.62	0.33
	(A5) Ease of installation	2.80	0.36
	(A6) Scalability	11.98	1.55
	(A7) Bandwidth	13.42	1.74
	(A8) Flexibility	3.50	0.45
	(A9) Latency	8.21	1.06
(B) Infrastructure	(B1) Coverage range	58.32	7.96
	(B2) Security of physical infrastructure	5.04	0.69
	(B3) Proposed usage	12.07	1.65
	(B4) Availability of skilled technicians	3.24	0.44
	(B5) Access to existing telecoms infrastructure	4.74	0.65
	(B6) Remoteness of area	3.22	0.44
	(B7) Rollout time	5.84	0.80
	(B8) Parallel infrastructure	7.53	1.03
(C) Economic	(C1) Operating cost	16.39	7.53
	(C2) Funding sources	34.70	15.94
	(C3) Capital cost	7.84	3.60
	(C4) Return on investment	37.32	17.15
	(C5) Economic development of area	3.75	1.72
(D) Social	(D1) Demand	64.96	1.74
	(D2) Affordability	20.49	0.55
	(D3) Population density	9.91	0.27
	(D4) Community of interest	4.65	0.12
(E) Regulatory	(E1) Spectrum availability	56.99	0.67
	(E2) Licensing constraints	27.45	0.32
	(E3) Rights of way	15.56	0.18
(F) Environmental	(F1) Terrain topography	56.81	0.71
	(F2) Climatic conditions	43.19	0.54

The *SuperDecisions* can also deal with the issue of improving consistency of the matrices, by identifying the most inconsistent judgments. The matrix consistency can then be improved by providing more consistent judgements by the decision makers so that $IR \leq 0.12$. For further explanation of inconsistency and how to calculate it, one can refer to [22].

An example of an aggregated comparison matrix within the alternative cluster (G) with respect to reliability (A1), and the corresponding values of the eigenvector, is shown in Table 4.

From this table we can see that in terms of reliability, the fiber optic cable technology has the highest priority (0.580) followed by microwave links and satellite with (0.262) and (0.1244), respectively. The less reliable technology is the power line communication (0.044). Since IR is less than 0.12, this matrix is considered of acceptable consistency.

The eigenvector derived in this way is then entered as a part of some column of a supermatrix. It represents the impact of a given set of elements in a component on another element in the system, where a component in a supermatrix is the block, defined by a cluster name at the left and a cluster name at the top. If an element has no influence on another element, its influence priority is assigned zero [20].
The formation of a supermatrix in the ANP allows for the resolution of the effects of the interdependence that exists between the elements of the system.
The *SuperDecisions* performs necessary matrix operations for structuring of the three supermatrices, associated with this model, as shown in the Appendix. Table A1 illustrates the unweighted supermatrix that contains the local priorities derived from pairwise comparisons throughout the network; they can be read directly from this matrix. The weighted supermatrix shown in Table A2; is obtained by multiplying all the elements in a component of the unweighted supermatrix by the corresponding cluster weight, i.e., each block of column eigenvectors belonging to a component is weighted by the priority of influence of that component. This makes the entire columns sum to unity exactly, i.e., the weighted supermatrix is said to be “column stochastic”. Finally, the limit supermatrix is obtained by raising the weighted supermatrix to the power k, where k is an arbitrarily large number, to allow for convergence of the interdependent relationships.
The final values of priorities of all the elements are obtained by normalising each block, so that the columns of the limit supermatrix become identical. The values of the priorities of all elements can be read from any column [15] as can be seen in Table A3.
The *SuperDecisions* has also been used to produce the priorities shown in Table 5. It contains the relative importance of all criteria considered in the model. For example, under the limiting priorities' column, one can observe that the most important factors among all are the *Return on investment* criterion with a priority of 17.15% followed by the *Funding sources* criterion with 15.94%. According to the *Normalized* priorities column, the most important criterion is the *Demand* with a priority of 64.96%, followed by the *Coverage range* with 58.32%. Among the technical criteria; the *Ease of maintenance*, *Reliability* and *Remote network management* criteria have the highest priorities of 21.71%, 18.73% and 17.05%, respectively. The *Spectrum availability* and *Terrain topography* factors are regarded as the most important within regulatory and environmental clusters, with priorities of 56.99% and 56.81%, respectively.
The relative importance of all other criteria considered in the model can be seen in Table 5.

6. Conclusions

This research paper reports on the applicability of using a MCDM method to enhance the selection process of an essential rural infrastructure technology. An ANP model incorporates both qualitative and quantitative approaches to a decision problem. The qualitative part includes:

- identification of the decision problem;
- ensuring the suitability of ANP to solve the problem;
- decomposing the unstructured problem to a set of manageable and measurable levels;
- compiling a list of experts to provide judgements for making the decision.

The quantitative part includes:

- designing a questionnaire to collect input data through pairwise comparison;
- estimating the relative importance between any two elements in each matrix and calculating the relevant eigenvectors;
- measuring the inconsistency of each matrix by employing the consistency ratio;
- eventually constructing the supermatrix using the eigenvectors of the individual matrices.

Based on the performed analysis, it is shown that the problem has inner and outer dependences and feedback among the elements, which excludes the hierarchy form (AHP) and requires a network form to model the selection process. The paper illustrates the use of the ANP method, but no real life conclusions should be drawn from it, as each telecommunication infrastructure provider will have its own set of criteria. The attempt here is to present a generic model based on factors and alternatives identified from the published literature, best practices and telecommunications experts that could then be adapted or extended to support a particular context or a situation of a developing country. Planners may therefore augment this model with their own company-specific factors that might change the priorities.

The obtained results reflect the preferences of experts who made the judgments, therefore, they cannot be considered as an objective assessment of the relative suitability of the four technologies as backbone infrastructure in rural areas. Final alternatives scores should, therefore, be thought of as an input to the decision-making process rather than its end. This process would be refined with experience, optimising the accuracy and time taken to reach proper decisions regarding the choice of telecommunication infrastructure in rural surroundings.

Appendix

Table A1
The unweighted supermatrix

Table A2
The weighted supermatrix

Table A3
The limit supermatrix

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Ludmil Mikhailov received the M.Sc. degree in automatic control from the Technical University in Sofia, Bulgaria, and the Ph.D. degree in technical cybernetics from the Bulgarian Higher Certifying Commission, in 1976 and 1982, respectively. He was an Associated Professor in the Institute of Control and System Research at the Bulgarian Academy of Sciences. Currently he is a Senior lecturer at the Manchester Business School, the University of Manchester. He is the author of about 90 technical papers in peer-reviewed journals and international conferences. His current research interests include multiple criteria decision analysis, fuzzy logic systems, decision-making under uncertainty, and intelligent decision support systems.
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... Also, since the main objective of the online survey was only to highlight the most significant performance indicators used in the logistics industry in order to build the decision model, both the number of the indicators and the number of respondents were deemed as sufficient. As a matter of fact, the number of respondents in this research is also higher than other studies with a similar aim, such as Gasiea, Emsley, & Mikhailov's (2010) research, where 62 responses were considered sufficient, while Chang (2013) included 34 responses for the survey. Apart from the significance degrees of the performance indicators, certain questions regarding both their job titles and working years (as can be seen in Fig. 2) were also asked to the respondents. ...

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