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A DECISION-MAKING MODEL FOR SELECTING THE GSM MOBILE PHONE ANTENNA IN THE DESIGN PHASE TO INCREASE OVER ALL PERFORMANCE

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Abstract—The wireless link between a mobile phone and its surrounding crucially depends on the quality and properties of the mobile phone antenna. The process of antenna selection is a multi-criteria decision-making problem with conflicting and diverse objectives. In this work, a model was built to select the best GSM mobile phone antenna in the design phase to increase the overall performance in the band. The model includes building an analytic hierarchy structure with a tree of hierarchical criteria and alternatives to ease the decision-making. The antenna options considered were limited to retractable whip antenna, loop chip antenna, monopole antenna, planar inverted F-antenna (PIFA), microstrip patch antenna, and printed slot antenna. An Analytical Hierarchy Process (AHP) was used to assist in building the model and help draw decisions. As a result of the decision making process, the monopole antenna was found to be the best choice for the GSM mobile phone antenna. Expert Choice™ software was used to conduct the experimental assessments. The judgments were found to be consistent, precise and justifiable with narrow marginal inconsistency values. The paper also presents a thorough sensitivity analysis to demonstrate the confidence in the drawn conclusions.

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1. INTRODUCTION

Most countries around the world use the GSM-900 and GSM-1800 frequency bands for mobile phone communications. GSM-900 uses 890–915 MHz to send information from the mobile station to the base station (uplink), and 935–960 MHz for the other direction (downlink). On the other hand, GSM-1800 uses 1710–1785 MHz for uplink and 1805–1880 MHz for downlink [1, 2].

The wireless link between a mobile phone and its surrounding crucially depends on the quality and properties of the mobile phone antenna. In mobile phones, there are several commonly used types of antennas (alternatives) that all share several distinguishing features such as; small weight, small size and ability to be fit inside the mobile phone housing, high gain of up to 8 dBi, and very good impedance matching over the operating band. The antennas that possess the above features, and are therefore commonly used inside mobile phones operating in the GSM band, include the monopole antenna [4], the planar inverted F-antenna (PIFA) [5], the microstrip patch antenna [6], the loop chip antenna [7], and the printed slot antenna [8–10].

The selection between the different types of antennas (alternatives), either before the start of the design and manufacturing stages, or by the buyer, is definitely not an easy task because of the many different, and often contradicting, selection criteria. These criteria include: The bands in which the antenna can operate, design and manufacturing cost, physical properties such as weight and ability to be fit inside the housing, number of operating frequency bands, the safety standards of the antenna in terms of radiation and health effect on the humans [11, 12], and the technical properties of the antenna such as matching, polarization, gain and radiation pattern [3].

The existence of wide alternatives of antenna types makes the selection of the best GSM mobile phone antenna a complex function of many variables and considerations [13, 14], and thus represents a multi-criteria decision-making problem. However, the complex interactions of the antenna properties [15, 16] make decision-making more difficult. Mobile antenna decision-making using multi-criteria decision analysis (MCDA) provides a method to eliminate the difficulty and has attracted the attention of decision makers for a long time.

This work introduces a decision support model utilizing the Analytical Hierarchy Process (AHP). The intention is to help decision makers implement a suitable type of GSM mobile phone antenna in the design phase to increase the overall performance in the band, limited in this study to retractable whip antenna, loop chip antenna, monopole antenna, planar inverted F-antenna (PIFA), microstrip patch antenna, and printed slot antenna.

2. SELECTION METHOD

2.1. The Analytical Hierarchy Process (AHP)

AHP is a widely used multi-criteria decision making (MCDM) tool designed to solve MCDM problems. The AHP method is gaining popularity because of its understandability and application simplicity. The AHP has found wide utility in several domains like biomedical, energy systems, and industrial applications [17–19] as well as social, economic, agricultural, ecological and biological fields [19, 20].

Unlike conventional methods, AHP uses pair-wise comparisons which allow verbal judgments that enhance the precision of findings, and further allow accurate ratio and scale priorities. AHP helps capture both subjective and objective evaluation measures, providing a useful mechanism for checking the consistency of the evaluation and alternatives, thereby, reducing bias in decision making [18, 19, 21]. When making complex decisions involving multiple criteria, the first step is to decompose the main goal into its constituent sub-goals, also called objectives, progressing from the general to the specific. In its simplest form, this structure comprises a goal, criteria or objectives, and alternative level. Each set of criteria would then be further divided, realizing, however, that the more criteria is included, the less important each individual criterion may become. Figure 1 illustrates the typical basic structure.

In the typical hierarchical structure, the main goal is laid on the top while the decision alternatives are at the bottom. Between the goal

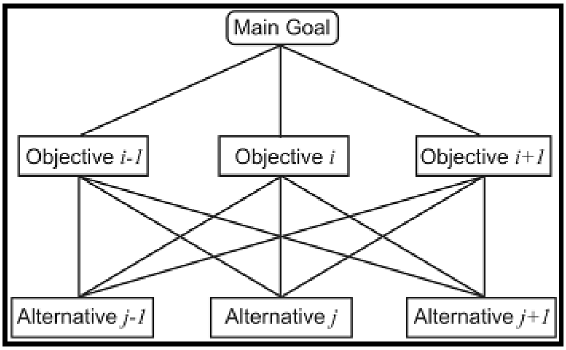

Figure 1. AHP hierarchy of goals, objectives and alternatives.

and alternatives reside the attributes of the decision problem such as the selection criteria and objectives. Next, relative weights to each item in the corresponding level are assigned. Each criterion has a local (immediate), and global priority. The latter shows the relative importance of alternatives. The sum of all the criteria beneath a given parent criterion in each layer must be unity. After the criteria factors are identified, each level is given a score with respect to its parent using a relative relational basis by comparing one choice to another. Relative scores for each choice are computed within each leaf of the hierarchy. Scores are then synthesized through the model, yielding a composite score for each choice at every layer, as well as an overall score. This relative scoring within each level will result in a matrix of scores, say $a(i, j)$. The matrix holds the expert judgment of the pair-wise comparisons.

As the judgment should be consistent, inconsistency test is required to validate the expert knowledge. In general, the inconsistency ratio should be less than 0.1 or so to be considered reasonably consistent [17–19]. Particularly, a matrix $a(i, j)$ is said to be consistent if all its elements follow the transitivity and reciprocity rules below:

$$a_{i,j} = a_{i,k} \cdot a_{k,j} \tag{1}$$

$$a_{i,j} = 1/a_{j,i} \tag{2}$$

where i, j, and k are any alternatives of the matrix [18, 19, 21]. The relational scale used in ranking is presented in Table 1.

Table 1. The AHP importance scale.

For any pair of objectives i, j:	
Score	**Relative importance**
1	Objectives i and j are of equal importance.
3	Objective i is weakly more important than j.
5	Objective i is strongly more important than j.
7	Objective i is very strongly more important than j.
9	Objective i is absolutely more important than j.
Note: 2, 4, 6, 8 are intermediate values.	

The pair-wise comparison matrices can also be represented as

$$A = \begin{bmatrix} a_{11} & \dots & a_{1n} \\ \vdots & \vdots & \vdots \\ a_{n1} & \dots & a_{nn} \end{bmatrix} = \begin{bmatrix} w_1/w_1 & \dots & w_1/w_n \\ \vdots & \vdots & \vdots \\ w_n/w_1 & \dots & w_n/w_n \end{bmatrix} \tag{3}$$

For a consistent matrix, we can demonstrate that

$$A = \begin{bmatrix} w_1/w_1 & \dots & w_1/w_n \\ \vdots & \vdots & \vdots \\ w_n/w_1 & \dots & w_n/w_n \end{bmatrix} \times \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} \tag{4}$$

Or in a matrix form:

$$\mathbf{A} \cdot \mathbf{w} = n\mathbf{w} \tag{5}$$

where $\mathbf{A}$ is the comparison matrix, $\mathbf{w}$ is the eigen vector and n is the dimension of the matrix. The equation above can be treated as an eigenvalue problem. For a slightly inconsistent matrix, the eigenvalue and the eigenvector are only slightly modified [19]. Saaty [21] demonstrated that for consistent reciprocal matrix, the largest eigenvalue is equal to the number of comparisons, or $\lambda_{\max} = n$. Then he gave a measure of consistency, called consistency index as a deviation or a degree of consistency using the following formula:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{6}$$

Knowing the consistency index, the next question is how do we use this index? Again, the research in [13, 14] proposed to use the index by comparing it with the appropriate random consistency index through picking randomly generated reciprocal matrix using the scale: 1/9, 1/8, ..., 1, ..., 8, 9 and then get the random consistency index. The average random consistency index of sample size 500 matrices is shown in the Table 2 below:

Table 2. Random index (RI) for the factors used in the decision making process.

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.58

Proposed by Saaty [21], a consistency ratio is a comparison between consistency index and random consistency index, or in formula:

$$CR = \frac{CI}{RI} \tag{7}$$

If the value of consistency ratio is smaller or equal to 10%, the inconsistency is acceptable. Alternately, if the consistency ratio is greater than 10%, the subjective judgment should be revised.

The specific steps of the analytical hierarchy process are shown in Table 3 below. A detailed presentation of the AHP method, its specific steps, and procedure are found in [21].

Table 3. The steps of the analytical hierarchy process (AHP).

1- Define the problem
2- Develop a hierarchical framework
3- Construct a pair-wise comparison matrix
4- Perform judgement of pair-wise comparison
5- Synthesizing the pair-wise comparison
6- Perform the consistency
7- Steps (3-6) are performed for all levels in the hierarchy
8- Develop overall priority ranking
9- Select the best alternative

2.2. The AHP Model for This Study

In this work, several factors and sub-factors affecting the decision making process model to select the best alternative of the GSM mobile phone antenna have been carefully proposed. The list of these criteria is presented in Table 4 that includes the dominant four main aspects indicated. These factors (criteria) and their sub-criteria were introduced in the AHP model for this study after wide literature review [1–5] and [9–11]. Then, data collection aimed at evaluating the comparability of the selected criteria was achieved by means of a questionnaire that was sent out to some twenty carefully selected experts in antenna worldwide, most of whom are from academic institutions and a few professionals. In fact, twelve respondents returned their filled questionnaires, which were deemed suitable samples for our study [22].

A brief description is given below for the criteria that were used for the selection of the phone antenna in this study:

- Operating frequency bands: are the operating frequency bands of the antenna, e.g., GSM has 4 bands some of which are used in North America (900 MHz, 1800 MHz) or in Europe (850 MHz, 1800 MHz), in addition to Bluetooth band (2.4 GHz) and Wimax (mobile internet) (3.5 GHz licensed).
- Antenna gain: It signifies the ability of the antenna to direct radiation in certain directions. Larger gain means the antenna has a narrower radiation beam. This gain also includes the effect of the antenna conductor and dielectric losses.

- Radiation pattern: signifies the shape of the radiation resulting from the antenna, e.g., an omni-directional pattern receives radiation equally from all directions and also sends radiation equally in all directions.
- Polarization: Is the trace of the Electric field vector as time progresses. It can be linearly polarized, elliptically polarized, etc..
- Number of operating frequency bands: The number of operating frequency bands with possibilities of single band, dual band, tri-

Table 4. Factors and sub-factors affecting the decision making process model to the problem addressed in this work.

Main factor	Sub-factor
Antenna Specifications	• Operating Frequency Bands • Antenna Gain • Radiation pattern • Polarization
Antenna Operation	• Number of Operating Frequency Bands • Modes (or standards) of operation • Safety For Human • Size (the ability to be fit into the housing)
Antenna Cost	• Cost of Design • Cost of Manufacturing • Market maturity
Antenna Technical Maturity	• Technical know-how • The Ease of Design • The Ease of Fabrication • Usability

band, quad-band or penta-band.

- Modes (or standards) of operation: refers to the type of transmission technology used in the mobile phone. A multimode phone operates across different standards such as GSM, CDMA, TDMA, AMPS, IS-95, iDEN.
- Safety: Means how much the radiation from the mobile phone will affect the person using the phone. Some mobile phones may cause more health hazards to humans than other phones. This is measured in term of "Specific Absorption rate (SAR)" defined as the power absorbed by the user per unit mass of human tissue. SAR is usually averaged either over the whole body, or over a small sample volume, typically 1 g or 10 g of tissue. The larger the SAR caused by an antenna inside the human head, the more it is likely to cause health hazards. There are international guidelines (in terms of SAR) for how much radiation a human being can withstand.
- Size (the ability to be fit into the housing).
- Cost of antenna: Includes cost of design and cost of manufacturing in addition to the market maturity.
- Market maturity: The availability of markets for the particular mobile phone antenna, e.g., some countries do not offer support and services for penta band antennas. This antenna will have an immature market
- Technical maturity of antenna: The ease of design and fabrication. Some antennas need more sophisticated design and fabrication techniques than others.
- Usability: means how commonly used the antenna is in the region of the world where the selection process is carried out.

A set of matrices representing pair-wise comparisons were developed for all the levels of the hierarchy. An element in the higher level is assumed to be the governing element for those in the lower level of the hierarchy. The elements in the lower level are compared with respect to one another according to their effect on the governing element above. This yields a square matrix of judgments as in matrix (3).

The pair-wise comparison is performed on the basis of how an element dominates the other and the judgments are entered using Saaty's 1 to 9 scale as in Table 1 [21]. An element compared with itself is always assigned the value of 1, so the main diagonal entries of the pair-wise comparison matrix are all unity. The expert begins by comparing pairs of main criteria (factors) with respect to the main goal by assigning importance. The number of resulting comparisons is given by $n(n-1)/2$, where n is the dimension of the pair-wise comparison matrix.

In this work, the Expert Choice$^{\mathrm{TM}}$ software package [23] was used to carry out the comparison. The alternatives (choices) of antenna types considered in this study included the retractable whip antenna, loop chip antenna, monopole antenna, planar inverted F-antenna (PIFA), microstrip patch antenna, and printed slot antenna. The expert begins by comparing (assigning importance of) pairs of the main criteria (factors) with respect to the main goal. The process is repeated to compare sub-criteria to the main criteria and comparing the alternatives to the sub-criteria.

3. RESULTS AND DISCUSSION

3.1. Factors and Sub-factors Pair-wise Comparison

A set of pair-wise comparison matrices are developed for all of the levels of the hierarchy. An element in the higher level is assumed to be the governing element for those in the lower level of the hierarchy. The elements in the lower level are compared with respect to each other according to their effect on the governing element above. This yields a square matrix of judgments. The pair-wise comparison is performed on the basis of how an element dominates the other, and the judgments are entered using Saaty's 1–9 scale. An element compared with itself is always assigned the value of "1", so the main diagonal entries of the pair-wise comparison matrix are all "1".

The expert (designer) begins by comparing pairs of main criteria (factors) with respect to the main goal by assigning importance. There will be $n(n-1)/2$ comparisons. Expert Choice$^{\mathrm{TM}}$ software package was used to carry out such comparisons. Verbal assessment is used to help the expert understand and summarize his knowledge efficiently. For instance, considering the antenna cost factor in Table 4 under which $n = 3$, three questions need to be answered by the expert. Typical question forms of this level may be put across as follows:

- How more important is the cost of design relative to cost of manufacturing from the antenna cost standpoint.
- How more important is the cost of design relative to market maturity from the antenna cost stand point.
- How more important is the cost of manufacturing relative to market maturity from the antenna cost standpoint.

A scale of verbal assessments is used to answer the above survey, namely: Extreme, Very strong, Strong, Moderate and

Equal importance, along with their corresponding reciprocal scale of importance. Table 5 presents the surveyed numbers for the above factor and its siblings.

Table 5. Pair-wise comparison matrix for different criteria (Antenna Cost factor).

Criterion	Cost of Design	Cost of Manufacturing	Market Maturity
Cost of Design	1	1/1.7	1/1.3
Cost of Manufacturing	1.7	1	1.5
Market Maturity	1.3	1/1.5	1

Note that the three questions above are essentially sufficient to fill the above matrix as a result of the transitivity and reciprocity rules stated in Equations (1) and (2). Now if the columns of the above table are normalized and the resulting rows are averaged, we get the following row averages: $(0.25\ 0.44\ 0.31)^T$. Note that the same weights were found using Expert Choice as shown in Figure 2. On the other hand, the consistency-ratio (CI) can be calculated using Equations (6), Table 2, and Equation (7) to be 0.0 which was calculated using the software as "Inconsistency" as mentioned in Figure 2. Clearly, as stated before, a CI ratio that is less than 10% is acceptable and the judgments are said to be consistent.

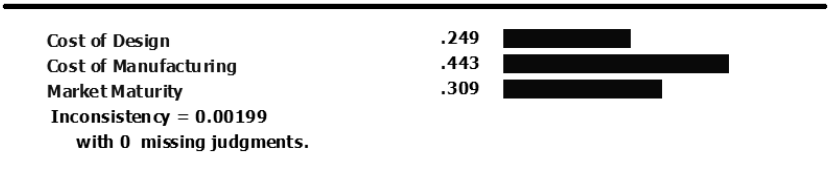

Figure 2. The contribution of sub-criteria to the main criterion (antenna cost).

Likewise, the main goal level is presented in Table 6. Here, CI value is ≈ 0.01. The ratio is still acceptable and the judgments are undoubtedly consistent.

Figure 3 presents the ratio of each criterion, where antenna specifications is evidently the most important factor in the presented case study with a total aggregate weight of 0.358. Conversely, the antenna cost factor is shown to be the least important carrying a weight of 0.167.

Table 6. Pair-wise comparison between main criteria.

	Antenna Specifications	Antenna Operation	Antenna Cost	Antenna Technical Maturity
Antenna Specifications	1	1.6	1.8	1.7
Antenna Operation	1/1.6	1	1.7	1.3
Antenna Cost	1/1.8	1/1.7	1	1/1.4
Antenna Technical Maturity	1/1.7	1/1.3	1.4	1

Figure 3. Resulting contribution of main criteria to main goal.

3.2. Alternatives Pair Wise Comparison

On the other hand, and more over to the pair-wise comparison of the main criteria, experts begin comparing all alternatives with respect to each sub-criteria by assigning importance. There will be $n(n-1)/2$ comparisons. Similarly, Expert Choice$^{\text{TM}}$ software package was used to carry out such comparison. Verbal assessment is used to help the expert understand and summarize his knowledge efficiently. For instance, considering the antenna gain sub-factor in Table 4 above under which $n = 6$, fifteen questions need to be answered by the expert. Typical question forms of this level may be put across as follows:

1. How more important is the retractable antenna relative to the loop chip antenna from the antenna cost standpoint.
2. How more important is the retractable antenna relative to the monopole antenna from the antenna cost standpoint.
3. How more important is the retractable antenna relative to the

PIFA antenna from the antenna cost standpoint.

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15. How more important is the microstrip patch antenna relative to the printed slot antenna from the antenna cost standpoint.

The same scale of verbal assessments, which was used in comparing the factors with respect to the goal, is used to answer the above survey, namely: Extreme, Very strong, Strong, Moderate and Equal importance, along with their corresponding reciprocal scale of importance. Figure 4 shows the upper part of the surveyed numbers for the antenna gain sub-factor and its siblings. Where numbers in between brackets indicate the reciprocal value of the number, i.e., (1.2) equals to (1/1.2).

It has to be mentioned here that a large number of questions ($15 \times 15 = 225$ questions) is needed to fill the comparisons between

	Retractable	Loop Chip	Monopole A	Planar Inve	Microstrip I	Printed Slo
Retractable Whip Antenna		1.4	1.3	1.1	1.3	1.2
Loop Chip Antenna			(1.2)	(1.4)	(1.4)	(1.2)
Monopole Antenna				(1.3)	(1.4)	1.0
Planar Inverted F- Antenna					1.0	1.3
Microstrip Patch Antenna						1.5
Printed Slot Antenna	Incon: 0.00					

Figure 4. The upper part of the surveyed numbers (pair-wise comparisons)for the antenna gain sub-factor.

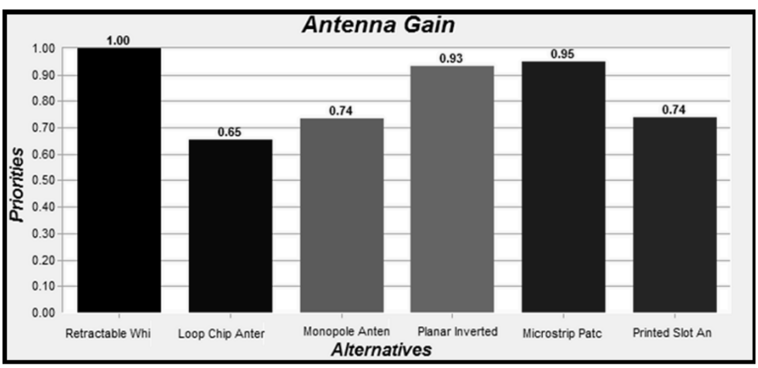

Figure 5. Relative pair wise comparison (priorities) of the alternatives with respect to the antenna gain criterion.

the alternatives with all sub-factors in the model. To reduce this huge amount of work needed from experts, a matrix containing all sub-factors and all alternatives in the model was sent to the experts just to assign a weight for each alternative (from 1–10) with respect to each sub-factor. Then authors took the responsibility to convert these values into suitable weights to answer the needed questions instead of the experts themselves.

The results of this pair-wise comparison were calculated using the ExpertChoice software. As an example, the normalized relative pair wise comparison (priorities) of the alternatives with respect to the criterion (antenna gain) is shown in Figure 5, where the most priority was found for the retractable antenna and the least priority was for the loop chip Antenna. Similarly, the normalized relative pair wise comparisons for all alternatives with respect to each criterion in the model can be calculated. This leads to decision for the best alternative of the antenna type. The summarized results of these priorities are shown in Tables 7 to 10.

Table 7. Summary of the normalized relative pair wise comparisons (priorities) of the alternatives with respect to the antenna specifications criteria.

Alternative/criteria	Gain	OFB	R.P	Polar.
Retractable Whi. Ant.	1	1	0.9	0.84
Loop Chip Antenna	0.65	0.7	0.77	0.62
Monopole Antenna	0.74	0.89	1	0.74
Planar Inverted Ant.	0.93	0.63	0.8	0.98
Microstrip Patc. Ant.	0.95	0.9	0.72	1
Printed Slot Antenna	0.74	0.85	0.5	0.71

Table 8. Summary of the normalized relative pair wise comparisons (priorities) of the alternatives with respect to the antenna operation criteria.

Alternative/criteria	NOFB	MO	SH	Size
Retractable Whi. Ant.	0.82	0.6	0.49	0.75
Loop Chip Antenna	0.65	0.55	0.63	1
Monopole Antenna	1	0.88	0.6	0.62
Planar Inverted Ant.	0.9	1	1	0.94
Microstrip Patc. Ant.	0.98	0.95	0.81	0.88
Printed Slot Antenna	0.9	0.81	0.56	0.72

3.3. Model Sensitivity Analysis

Finally, a sensitivity analysis is performed to show the effect of altering different parameters of the model on the choice of the most suitable antenna. First, the current values of the model are presented according to the pair-wise comparisons that have been carried out by the experts in the antenna fields. Figure 6 demonstrates the current weights of each factor. Obviously, the results are in favor of the monopole antenna. Now the best antenna type has been identified, and how would the model respond to any changes in the weights of the listed factors?

First, consider the antenna operation. By increasing the share of this factor to an extreme of 90% of the main goal, leaving 10% for the others while keeping the proportionality between each, it has been noticed that the proper choice became the planer inverted antenna (PIFA) with a score of 19.9%, where as the weight of monopole antenna is 16.2% with a difference less than 4% as illustrated in Figure 7. This indicates that although the weight of the antenna operation factor was exaggerated to unexpected weight which represents an unreasonable

Table 9. Summary of the normalized relative pair wise comparisons (priorities) of the alternatives with respect to the antenna cost criteria.

Alternative/criteria	CD	CM	MM
Retractable Whi. Ant.	0.84	0.88	0.92
Loop Chip Antenna	0.75	0.8	0.79
Monopole Antenna	1	1	1
Planar Inverted Ant.	0.54	0.6	0.7
Microstrip Patc. Ant.	0.71	0.73	0.61
Printed Slot Antenna	0.63	0.7	0.5

Table 10. Summary of the normalized relative pair wise comparisons (priorities) of the alternatives with respect to the antenna technical maturity criteria.

Alternative/criteria	TKnh	ED	EF	Usability
Retractable Whi. Ant.	0.85	0.92	0.88	0.44
Loop Chip Antenna	0.76	0.72	0.77	0.86
Monopole Antenna	1	1	1	0.56
Planar Inverted Ant.	0.72	0.59	0.49	1
Microstrip Patc. Ant.	0.86	0.71	0.72	0.8
Printed Slot Antenna	0.6	0.5	0.6	0.65

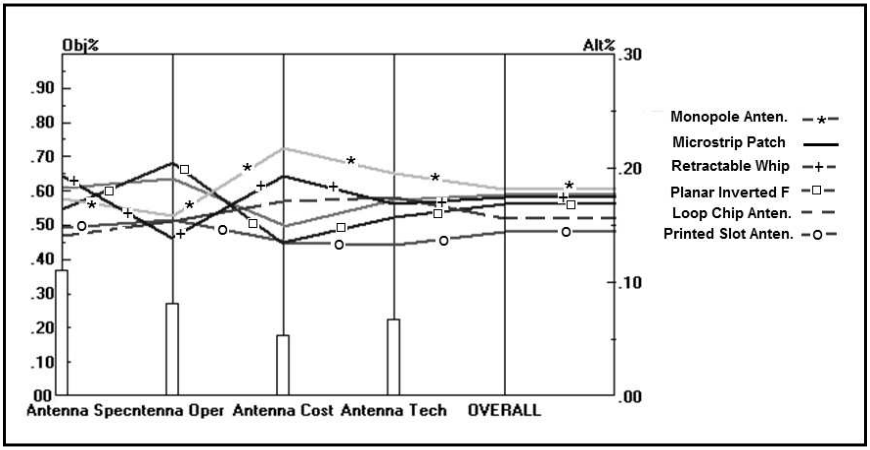

Figure 6. The sensitivity graph of the main factors with respect to the goal.

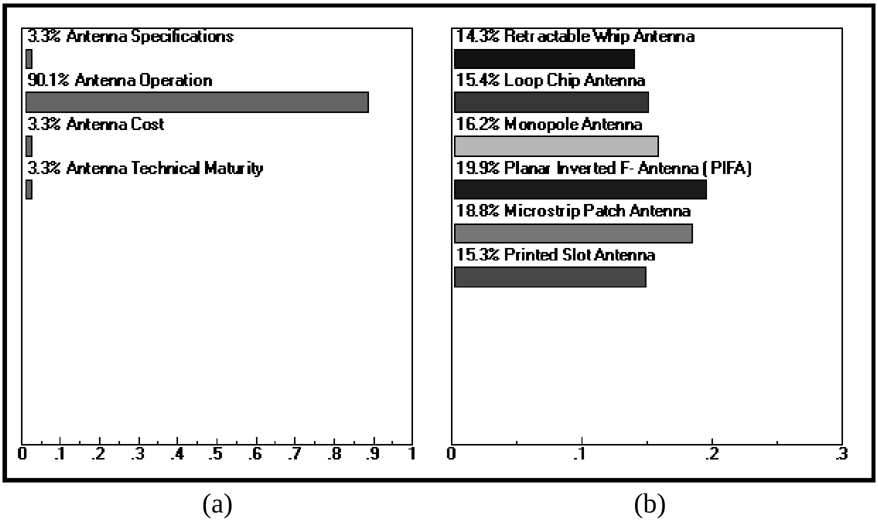

Figure 7. Sensitivity analysis of the antenna operation factor, (a) the new assigned weights and (b) the resulting scores of the alternatives.

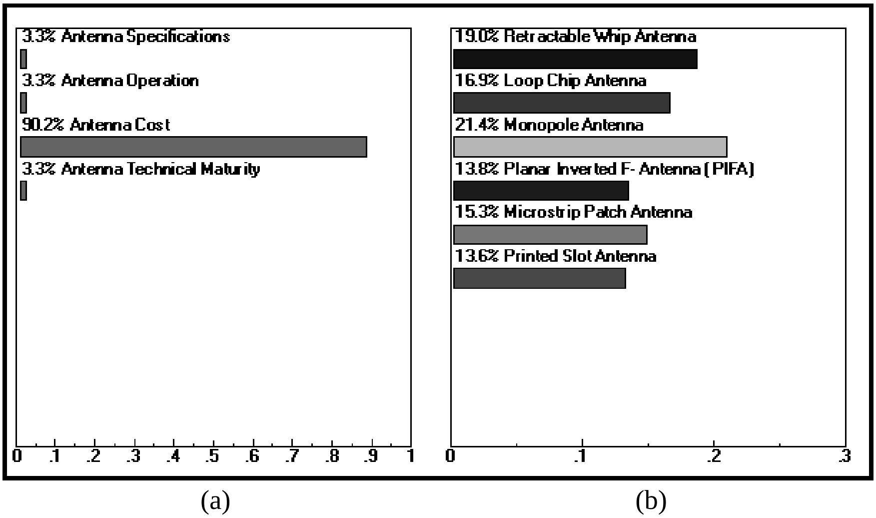

Figure 8. Sensitivity analysis of the antenna cost factor, (a) the new assigned weights and (b) the resulting scores of the alternatives.

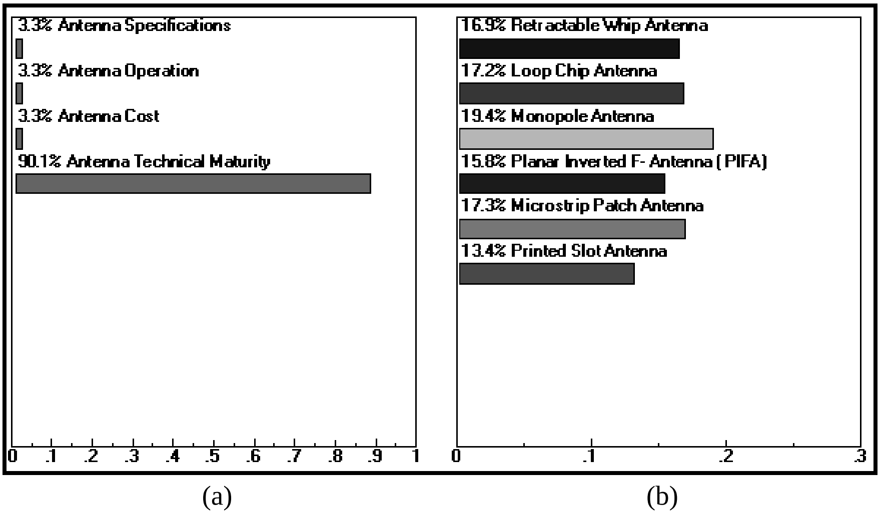

Figure 9. Sensitivity analysis of the antenna technical maturity factor, (a) the new assigned weights and (b) the resulting scores of the alternatives.

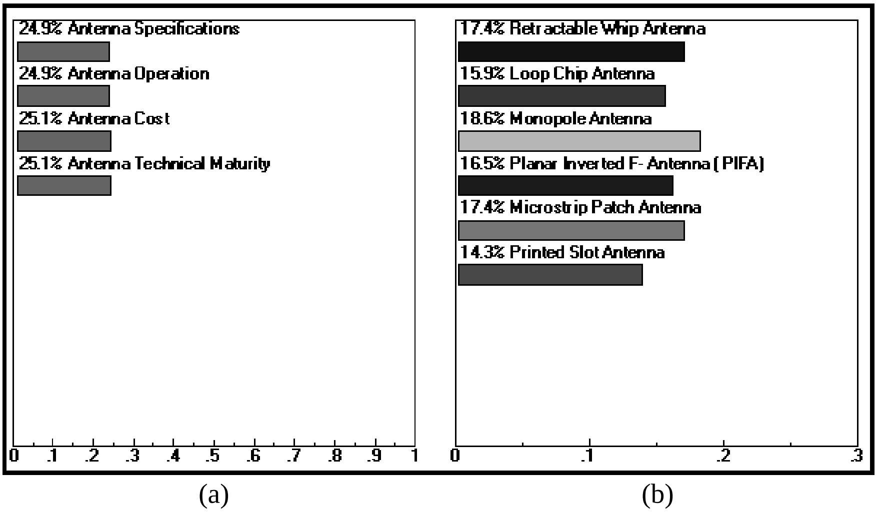

Figure 10. Sensitivity analysis with equal weight for all factors, (a) the new assigned weights and (b) the resulting scores of the alternatives.

Figure 11. Final ranking of alternatives.

change under normal conditions, none of the alternatives became dominant in the model. This means that the study was not sensitive to a small change in the weight of antenna operation factor. Moreover, the same conclusion can be drawn for the antenna cost factor, where the monopole antenna stays as the best choice with a score of 21.41%, as in Figure 8.

Similar analysis was held for the antenna technical maturity factor. The results showed that the monopole Antenna is also the best choice with a score of 19.4% as shown in Figure 9. Even at almost equal weights, as illustrated in Figure 10, still, the monopole antenna will score higher than other alternatives with a score of 18.6%.

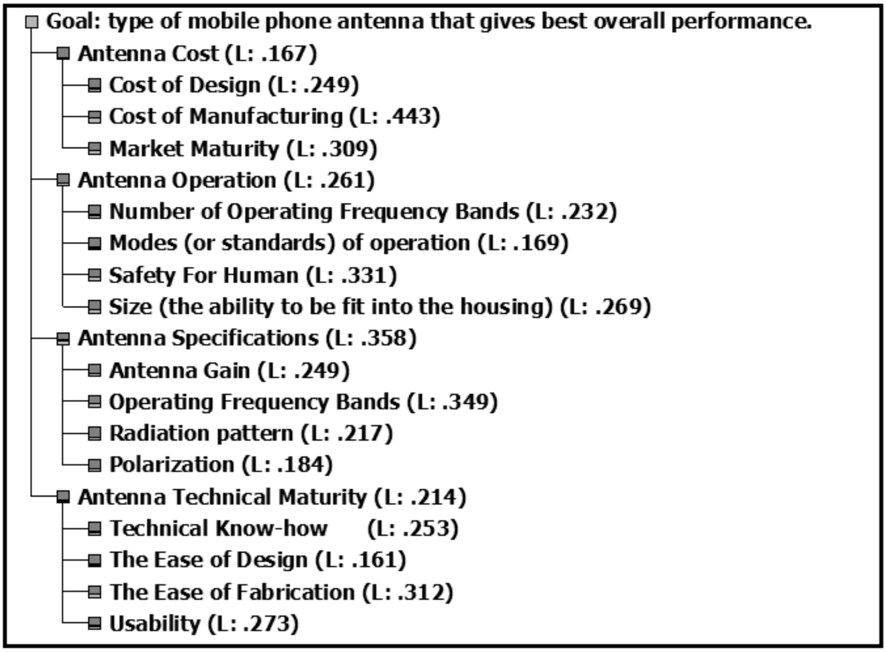

Figure 12. Importance of each criterion with respect to goal and parents.

The sensitivity analysis presented here demonstrates how consistent the decision is. The choice of the monopole antenna as the best alternative remain the same even with significant changes on the criteria weights, which can be justified by the consistent judgments made between the siblings of the parent goal and the pair-wise comparisons. Frankly, AHP analysis demonstrates an efficient knowledge based approach to help quantify experts' knowledge to qualitative analysis that help in multi-criteria decision making.

The best antenna choice in this case study was the monopole antenna. Figure 11 presents the scores of each antenna with a corresponding inconsistency of 0.0. It can be noticed that the weights of all alternatives (types of antenna) are close to each other, and there is no dominant alternative for the model, which means it is very difficult for a designer to judge the best antenna type without using a decision making approach.

Finally, a complete hierarchy of goals and objectives with the corresponding aggregate weights is shown in Figure 12. The antenna specifications factor contributes for the most weight in the hierarchy with a weight of 35.8% followed by the antenna operation factor with a weight of 26.1% where as the least weight was 16.7% for the antenna cost factor.

4. CONCLUSION

The selection of the GSM mobile phone antenna in the design phase to increase overall performance in the band is a function of various variables and thus is a multi-criteria decision making problem. The utilization of the Analytical Hierarchy Process provides a powerful tool for analyzing such problems and results in decision-support models that are quite reliable. The study showed that expert judgments for this study were quite consistent and further indicated that under prevailing conditions, relevant factors and aspects, and different types of antenna options considered in this study. The monopole antenna ranks highest as the best choice of antenna types to be used in the mobile phone to increase the overall performance. The study demonstrated that these results are highly reliable under reasonable changes in all factors and sub-factors included. It was observed that the developed analytic hierarchy process (AHP) expert model works adequately and yields acceptable results as well as dragging accurate decisions in antenna selection for mobile phone. It was made clear from the output of Expert Choice™ for each of the antenna types, that most of the area of the AHP priority stack is occupied by antenna specifications and antenna operations, thus, showing the desired dominance of these two criteria in the selection process. The developed model certainly eases the decision maker's mission of choosing the quantitative weights and making further calculations and, thereby, leaves the decision makers less susceptible to human errors. Moreover, this approach does not require the decision makers to have any in-depth technological knowledge regarding the available specification of antenna types and their capabilities. The pair-wise assessment through the verbal scaling made it easy for the expert to disseminate his/her comprehension and eventually reveal more representing knowledge and decisions. The above application of AHP theory is a step toward the elimination of bias or prejudice in the judgment of an expert, since the steps leading to the judgment are made explicit via relational assessment. This also helps uncover any gap in the expert's thinking in regard to qualitative factors in antenna selection which may not have been considered.

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