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GIS software selection:
a multi criteria decision making approach

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Abstract: Building a new GIS project is a major investment. Choosing the right GIS software package is critical to the success and failure of such investment. The problem of selecting the most appropriate GIS software package for a particular GIS project is a multi criteria decision making (MCDM) problem. Solving this problem requires consideration of a comprehensive set of factors and balancing of multiple objectives in determining the suitability of particular software for building a defined GIS application. In this paper a MCDM technique, analytic hierarchy process (AHP), is used to assist system developers to select the most appropriate GIS software for a specific application. An AHP decision model is formulated and applied to a hypothetical case study to examine its feasibility in solving GIS software selection problem. The use of the proposed model indicates that it can be applied to improve the decision making process and to reduce the time taken to select a GIS software.

Keywords: GIS, Software Selection, MCDM, AHP

1. Introduction

Geographic Information Systems (GIS), a promising branch of Information Systems (IS), have achieved considerable success in recent years. This area of IS has concentrated on the construction of computer-based information systems that enable capture, modeling, storage, retrieval, sharing, manipulation, analysis, and presentation of geographically referenced data (Worboys & Duckham, 2004). GIS software packages/tools provide a unified approach to working with geographic information.

In the last few years, the GIS software market has undergone a remarkable change. The number of GIS software packages/tools has increased significantly and prices have declined dramatically. Many of these packages/tools were developed to fit different user needs and were designed to execute on a variety of hardware platforms (Longley et al., 2005).

Building a new GIS project is a major investment. Choosing the right GIS software package/tool is critical to the success and failure of such investment, i.e., the impact of a bad decision can be high not only in monetary terms but in terms of its impact on management's attitude. The problem of selecting the most appropriate GIS software package/tool for a particular GIS project is not a well-defined or structured decision problem. The presence of multiple criteria (both managerial and technical) and the involvement of multiple decision-makers will expand decisions from one to several dimensions, thus, increasing the complexity of the solution process (Lai et al., 1999). However, a literature search did not find any thorough discussion of GIS software selection or comparison of selection methodologies. Therefore, the IS literature was reviewed.

The most suitable time in the system development life cycle (SDLC) to consider software and hardware requirements is at the end of the system analysis phase when the user requirements have been positively identified as shown in Figure 1. This ensures the compatibility between the functionality of hardware/software and the requirements of the applications to be performed by the proposed information system (Lo & Yeung, 2002). Detailed description of the different phases of the SDLC is reported elsewhere (George et al. 2004).

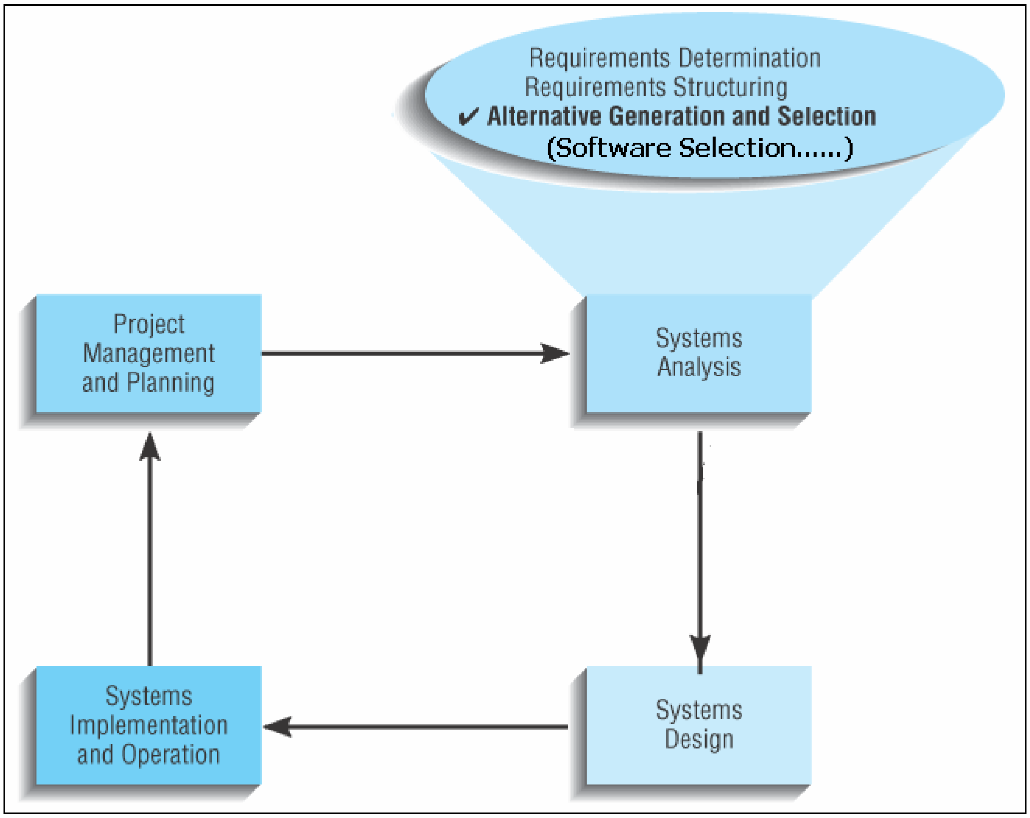


Figure 1 - Systems Development Life Cycle (adapted from George et al. 2004).

Ranking and scoring are the two traditional approaches used for software selection. In using the ranking approach, the available software solutions are ranked based on their relative contribution to a given criteria. The process is repeated for every criterion. The ranks are then aggregated and used in the decision. The scoring approach is very similar, except that available software solutions are scored (on a scale of, say, 1 to 10) rather than being ranked as in the ranking approach. The aggregated scores or ranks are used in making the selection decision.

While ranking and scoring approaches are capable of handling both tangible and intangible criteria, they still fail to provide the decision maker with a means to evaluate the relative importance of the criteria. Aggregation of the scores or ranks is an attempt to convert the multi-dimensional problem into a single dimensional problem. However, such aggregation completely ignores the varying levels of importance placed upon each criterion. Thus, existing methodologies for software selection fail to address all aspects of the problem (Muraidhar et al., 1990; Bandor 2006).

So, there is a need for developing a systematic GIS software selection process of identifying and prioritizing relevant criteria and evaluating the trade-offs between technical, economic and performance criteria. The approach should also reduce time and develop consensus decision making. This paper is primarily concerned with providing such a framework. In this paper a MCDM technique, the analytic hierarchy process (AHP), is used to assist system developers to select the most appropriate GIS software for a specific application. An AHP decision model is formulated and applied to a hypothetical case study to examine its feasibility in improving the decision making process.

2. GIS software

GIS software packages/tools provide a unified approach to working with geographic information. GIS software vendors, the companies that design, develop and sell GIS software, build on the top of basic computer operating capabilities. The latter include security, file management, peripheral drivers, printing and display management. GIS software is constructed on these foundations to provide a controlled environment for geographic information collection, management, analysis, and interpretation.

GIS software is a fundamental and critical part of any operational GIS. The GIS employed in a GIS project has a controlling impact on the type of studies that can be undertaken and the results that can be obtained. There are also far reaching implications for user productivity and project costs.

Today, there are many types of GIS software product to choose from and a number of ways to configure implementations. One of the exciting and at times unnerving characteristics of GIS software is its very rapid rate of development. This is a trend that seems set to continue as the software industry pushes ahead with significant research and development efforts

The GIS marketplace has four key vendors that deliver "generic" platforms: ESRI, Intergraph, Autodesk, and GE Energy. Leading the market in software revenues in 2003 were the Environmental Systems Research Institute, Inc. (ESRI), located in Redlands, CA and the Intergraph Corporation, based in Huntsville, AL. Together, these two companies accounted for nearly half (47.1%) of the industry's total software revenues in 2003. Other software leaders include IBM, Leica Geosystems, & MapInfo (Bernhardsen 1999; Bolstad 2005; Clarke 2003; Demers 2005; Heywood 2002; Longley et al. 2005).

Longley et al. (2005) classified GIS software into the five main types shown in Table 1.

Software Type	Explanation
Desktop GIS software	Desktop GIS software owes its origins to the personal computer and the Microsoft Windows operating system and is considered the mainstream workhorse of GIS today. It provides personal productivity tools for a wide variety of users across a broad cross section of industries. The desktop GIS software category includes a range of options from simple viewers (such as ESRI ArcReader, Intergraph GeoMedia Viewer and MapInfo ProViewer) to desktop mapping and GIS software systems (such as Autodesk Map 3D, ESRI ArcView, Intergraph GeoMedia, and MapInfo Professional), and at the high-end, full-featured professional editor/analysis systems (such as ESRI ArcGIS ArcInfo, Intergraph GeoMedia Professional, and GE Smallworld GIS). Desktop GIS software prices typically range from $1000- $20000 per user.
Server GIS	Server GIS runs on a computer server that can handle concurrent processing requests from a range of networked clients. Initially, it focused on display and query applications, but now offers mapping, routing, data publishing, and suitability mapping. Third generation server GIS offers complete GIS functionality in a multi user server environment. Examples of server GIS include AutoDesk MapGuide, ESRI ArcGIS Server, GE Spatial Application Server, Intergraph GeoMedia Webmap, and MapInfo MapXtreme. The cost of server GIS products varies from around $5000-25000, for small to medium-sized systems, to well beyond for large multifunction, multiuser systems.
Developer GIS	Developer GIS are toolkits of GIS functions (components) that a reasonably knowledgeable programmer can use to build a specific-purpose GIS application. They are of interest to developers because such components can be used to create highly customized and optimized applications that can either stand alone or can be embedded with other software systems. Examples of component GIS products include Blue Marble Geographics GeoObjects, ESRI ArcGIS Engine, and MapInfo MapX. Most of the developer GIS products from mainstream vendors are built on top of Microsoft's COM and .Net technology standards, but there are several cross platform choices (e.g., ESRI ArcGIS Engine) and several Java-based toolkits (e.g., ObjectFX Spatial FX). The typical cost for a developer GIS product is $1000 - $5000 for developer kit and $100-500 per deployed application.
Hand-held GIS	Hand-held GIS are lightweight systems designed for mobile and field use. A very recent development is the availability of hand-held software on high-end so-called 'smart phones' which can deal with comparatively large amounts of data and sophisticated applications. These systems usually operate in a mixed connected/disconnected environment and so can make active use of data and software applications held on the server and accessed over a wireless telephone network. Examples of Hand-held GIS include Autodesk OmSite, ESRI ArcPad, and Intergraph Intelliware. Costs are typically around $400-$600.
Other types of GIS software	There are many other types of commercial and non-commercial software that provide valuable GIS capabilities such as public-domain, open source and free software. For example, Geographic Resources Analysis Support System, commonly referred to as GRASS GIS, is a Geographic Information System (GIS) used for data management, image processing, graphics production, spatial modeling, and visualization of many types of data. It is Free (Libre) Software/Open Source released under a GNU General Public License (GPL).

Table 1 - Main GIS Software Types

3. The Analytic Hierarchy Process (AHP)

A multi criteria decision problem generally involves choosing one of several alternatives based on how well those alternatives rate against a chosen set of structured and weighted criteria (the decision model). The criteria themselves are weighted in terms of importance to the decision maker (s), and the overall score of an alternative is the weighted sum of its rating against each criterion. The ordering of the alternatives by their decision scores is a prioritized ranking of those alternatives by preference.

Over the last three decades, a number of multi criteria decision making (MCDM) methods have been developed. Among them, the Analytic Hierarchy Process (AHP) is perhaps the most prominent and successful method. AHP is a method that allows the consideration of both objective and subjective factors in selecting the best alternative. This approach is used to arrive at a ratio–scale cardinal ranking of alternatives for multi attribute decision problems (Forman & Selly 2001).

Since its introduction in the mid 1970s by Dr. Thomas L. Saaty, AHP has been applied in a wide variety of practical applications in various fields including some areas similar to GIS software selection such as car purchasing (Byun, 2001), vendor selection (Tam & Tummala, 2001), IS project selection (Muralidar et al., 1990; Schniedejans & Wilson, 1991), and software evaluation (Kim & Yoon, 1992; Ossadnik & Lange, 1999; Mamaghani, 2002; Nagi & Chan, 2005).

The analytic hierarchy process is based on three principles (Mollaghasemi, M. & Pet-Edwards 1997, Malczewski 1999, Forman & Selly 2001): decomposition, comparative judgments, and synthesis of priorities. The decomposition principle requires that the decision problem be decomposed into a hierarchy that captures the important elements of the problem.

In developing a hierarchy, the top level is the ultimate goal of the decision at hand (e.g., Select the suitable GIS software). The hierarchy then descends from the general to the more specific until a level of attributes is reached. This is the level against which the decision alternatives of the lowest level of the hierarchy are evaluated. Each level must be linked to the next higher level, and adjacent elements within one level must not be too disparate, so that they can be compared using a common relative-importance scale. Figure 2 illustrates the four- level hierarchical structure of a simplified GIS software selection decision making problem.

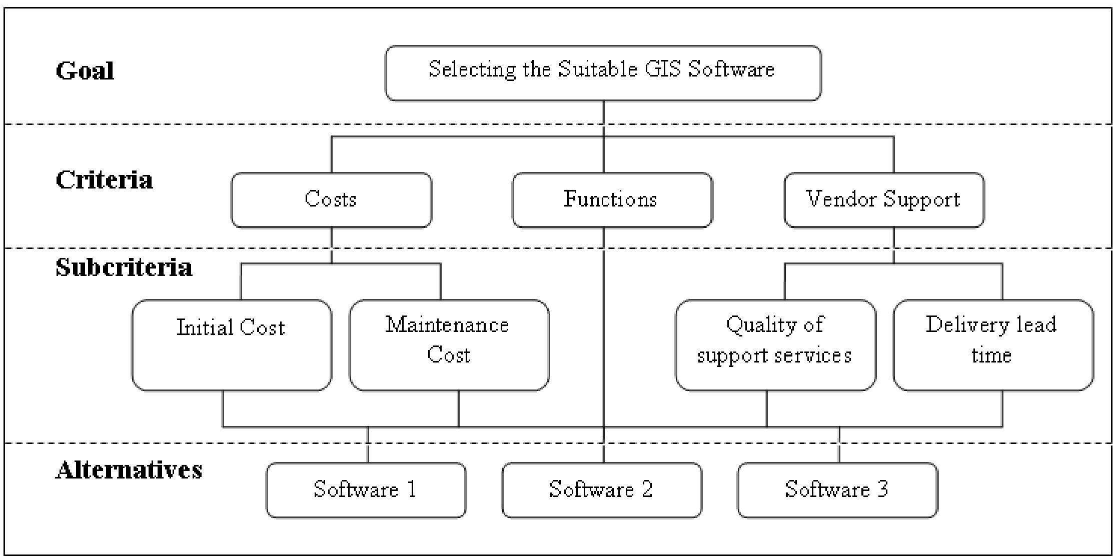


Figure 2 - Hierarchy of a GIS Software Selection Decision

The principle of comparative judgments requires assessments of pair-wise comparisons (on a scale of relative importance) of the elements within a given level, with respect to their parent in the next-higher level. In general, this comparison takes the form: “How important is element 1 when compared to element 2 with respect to the element above?” AHP employs an underling scale (Table 2) with values from 1 to 9 to rate the relative preferences for two elements in the hierarchy with respect to their parent. The derived pair-wise comparisons of relative importance, $a_{ij} = w_i / w_j$, for all decision elements and their reciprocals, $a_{ji} = 1/ a_{ij}$, are inserted into a reciprocal square matrix $A = \{a_{ij}\}$ as shown in equation (1).

$$A = \begin{bmatrix} 1 & w_1/w_2 & . & w_1/w_n \\ w_2/w_1 & 1 & . & w_2/w_n \\ . & . & . & . \\ w_n/w_1 & w_n/w_2 & . & 1 \end{bmatrix} \quad (1)$$

Definition and Explanation	**Intensity of importance**
• Equally important – the two activities contribute equally to the objective.	1
• Moderately Important- experience and judgment slightly favor one activity over another.	3
• Strongly Important- experience and judgment strongly favor one activity over another.	5
• Very Strongly Important- an activity is favored very strongly over another	7
• Extremely Important- the evidence favoring one activity over another is of the highest possible order of affirmation	9
• Intermediate Values- when compromise is needed • The scale 1.1, 1.2,….,1.9, or even a finer one, can be used to compare elements that are close together, or are near equal in importance; similarly from 2.0 to 2.9, etc.	2,4.6.8

Table 2 - The AHP pair-wise comparison scale (adapted from Mollaghasemi & Pet-Edwards 1997)

The analytical solution of equation (2) then provides the relative weights for each decision element. According to the eigenvalue method (Forman & Selly 2001), the normalized right eigenvector ($W = \{w_1, w_2, ..., w_n\}^T$) associated with the largest eigenvalue ($\lambda_{\max}$) of the square matrix A provides the weighting values for all decision elements.

$$AW = \lambda_{\max} W \qquad (2)$$

A Consistency Index (CI) is used to measure the degree of inconsistency in the square matrix A (where, $CI = (\lambda_{\max} - n)/(n-1)$). Comparing the estimated CI with the same index derived from a randomly generated square matrix, is called the Random Consistency Index (RCI) as shown in Table 3. The ratio of CI to RCI for the same order matrix is called the Consistency Ratio (CR). Generally, a CR of 0.10 or less is considered acceptable, otherwise the matrix A will be revised to improve the judgmental consistency (Mollaghasemi & Pet-Edwards 1997).

Size of matrix (n)	1	2	3	4	5	6	7	8	9
Random Index (RCI)	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Table 3 - The Random Consistency Index (RCI) (adapted from Mollaghasemi & Pet-Edwards 1997)

The final step (synthesis principle) is to aggregate the relative weights of decision elements in order to compute the priority for each alternative. The composite (weighted) priorities of the elements in a certain level are obtained by multiplying current local priorities by the priority of their corresponding criterion in the level above and adding them across for each element in the current level according to the criteria it affects. This composite priority vector is then used to weight the priorities of elements at the level below and this process continues to the bottom level where the overall priorities of the alternatives are produced as shown in equation (3).

$$R_i = \sum_k w_k r_{ik} \qquad (3)$$

Where R_i is the overall score of the i th alternative; w_k is the vector of priorities associated with the k th element of the criterion hierarchical structure, $\sum w_k = 1$; and r_{ik} is the vector of priorities derived from comparing alternatives on each criterion. The most preferred alternative is selected by identifying the maximum value of $R_i \, (i = 1,2,...,m)$.

There are many advantages of using the AHP in solving GIS software selection problem. First, a review of the literature indicates without a doubt, that software selection is a multi-criteria decision making problem. None of the existing methodologies (ranking, or scoring) were designed for this situation. The AHP was designed specifically for decision making in a multi-criteria environment.

Secondly, the GIS software selection problem is characterized by the existence of both tangible and intangible criteria. The AHP approach can easily handle both types of criteria. Thirdly, the scale used in eliciting pair-wise comparisons in the AHP is judgmental rather than purely quantitative (as in the scoring approach).

Fourthly, several authors have suggested the use of a steering committee for software selection. The AHP process can be adapted very easily where decision making is performed by a group rather than an individual. Fifthly, one of the attractive features of the approach is its ease of use. It can be designed as a part of a decision support system. The computations are very simple and can be performed using many software packages (Muraidhar et al., 1990). Detailed description of MCDM and AHP is reported elsewhere (Mollaghasemi & Pet-Edwards, 1997; Forman & Selly, 2001, InfoHarvest Inc, 2001).

4. Criteria for selecting GIS software

In order to formulate the AHP decision model, it is necessary to identify the factors that influence the choice of GIS software. After discussions with many GIS consultants, and operations manager, reviewing the literature for software evaluation and selection and studying the international standard ISO/IEC 9126 which provides a framework for the evaluation of software quality, we identified five essential evaluation criteria to use in selecting the best GIS software: cost, functionality, usability, reliability, and vendor (ISO/IEC 9126,1991; Collier et al,1999; Ossadnik & Lange,1999; Lai et al, 1999; Bernhardsen, 1999; Clarke, 2003; Nagi & Chan, 2005; Longley et al., 2005; Keil & Tiwana, 2006).

4.1 Cost

Cost is an important factor in selecting software packages (Keil & Tiwana, 2006). It is simply the expenditure associated with GIS software and includes product, license, training, maintenance, software subscription and support services costs. Technically, these costs can be grouped under two major criteria, namely, capital expenditures and operating expenditures.

Capital expenditures are the non-recurring costs involved in setting up the GIS. They include product costs (the basic cost of the GIS software), license costs (the cost of the GIS software in terms of number of users) and training costs (the cost of training provided to customers).

Operating expenditures are the recurring costs involved in operating the GIS, which include maintenance costs and software subscription costs (the annual, pre-paid cost of upgrading the product to a major software release when it is launched) , costs of support services, and data customization or conversion costs (Tam & Tummala, 2001; Nagi & Chan, 2005).

4.2 Functionality

Functionality refers to extent to which the software package contains all the features and functions specified in your request for proposal (RFP) which is generated based on the organization needs assessment (Keil & Tiwana, 2006). A GIS is often defined not for what it is but for what it can do. A thorough examination of GIS capabilities is the critical step in how to pick GIS software, because if the GIS software does not match the requirements for a problem, no GIS solution will be forthcoming. On the other hand, if the GIS software has a large number of functions, the system may be too sophisticated or elaborated for the problem at hand (Clarke, 2003). Thus, functionality is usually considered when selecting software.

Based on a review of the literature and on consultations with GIS experts, we identified eleven key functional elements of a GIS tool as shown in Table 3 (Clarke, 2003; Tomlinson, 2003; Longley et al., 2005; Point of beginning, 2005).

Function	Explanation
Operating System/Network Support	This is always the first important consideration. Verify your OS supports the product best suited to your particular needs. If you want to operate on a network, be sure the OS is robust enough and the GIS software supports network licensing, such as Network Client-Server Support, Server Operating System, Client Operating System, and Internet Server Enabled.
Geographic Data Management	Database administration tools for managing data access by users, locking of data during edit and maintenance of metadata.
Tabular Attribute Data Management	Software environment and capabilities for storing and managing database attributes linked to map features in the GIS database. May involve use of a vendor-proprietary system for attribute storage or a commercial relational database management package.
GIS Data Import/ Export Utilities	Utility programs bundled with the GIS package for translation of GIS or CAD data to or from another format, including common industry-standard formats like DXF, SIF, DLG or SDTS.
GIS Data Entry and Editing	A range of interactive and batch processing functions for entry of map data through such means as board digitizing, coordinate geometry entry (COGO), scanning and heads-up digitizing, along with capabilities for editing GIS data, performing error checking and resolution, map rectification and transformation of coordinate systems and map projections.
Map Design and Composition	Interactive capabilities for the design of map plots and displays, automatic creation of thematic maps and legends, and modifying map symbology and annotation for custom map displays.
Basic Geographic Query and Analysis Functions	Basic tools for performing attribute or map-based queries and displays, basic distance and area measurements, query and access to scanned documents, buffer generation, polygon overlay operations and other query and analysis functions.
Network Analysis	Spatial analysis operations based on linear networks (e.g., road or pipeline systems), including such operations as shortest path tracing and region allocation. Network analysis capabilities in GIS packages often allow users to design network models based on attributes of network segment.
Terrain and 3-D Data Processing and Analysis	Capabilities for storing three-dimensional data normally in a grid or triangular integrated network (TIN) format with functions for 3-D analysis such as contour mapping, 3-D display, draping of map features over a 3-D display, slope and aspect analysis, etc.
Raster Image Processing Capabilities	Capabilities for the manipulation and processing of raster images (e.g., digital aerial photos or orthophotography, satellite images), including functions for the import and rectification of raw imagery, digital image enhancement and automated classification of multi-spectral imagery.
Application Development Languages	Programming environment for customizing applications accessing software functions provided by the package, including proprietary languages included with the GIS software package or industry standard tools (e.g., C++, Visual Basic, Delphi) that may be used for application development.

Table 4 - Key GIS Functions

4.3 Reliability

Software Reliability is an important attribute of software quality. It is necessary that the reliability of software should be measured and evaluated, as it is in hardware. IEEE 610.12-1990 defines reliability as:

> *The ability of a system or component to perform its required functions under stated conditions for a specified period of time,*

and IEEE 982.2-1987 defines Software Reliability Management as:

> *The process of optimizing the reliability of software through a program that emphasizes software error prevention, fault detection and removal, and the use of measurements to maximize reliability in light of project constraints such as resources, schedule and performance.*
> (Rosenberg et al,1998; Keil & Tiwana, 2006).

ISO/IEC 9126-1991 defines three sub-criteria of reliability: Maturity, Fault tolerance, and Recoverability. These sub-criteria are defined in Table 5.

Sub-criteria	Definition
Maturity	Attributes of software that bear on the frequency of failure by faults in the software
Fault tolerance	Attributes of software that bear on its ability to maintain a specified level of performance in case of software faults or of infringement of its specified interface
Recoverability	Attributes of software that bear on the capability to re-establish its level of performance and recover the data directly affected in case of a failure and on the time and effort needed for it

Table 5 - Reliability sub-criteria (adapted from ISO/IEC 9126, 1991)

4.4 Usability

Usability is the effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in particular environments (Tiits, 2003). ISO/IEC 9126-1991 defines three sub-criteria of usability: Understandability, Learnability, and Operability. These factors are defined in Table 6.

Sub-criteria	Definition
Understandability	Attributes of software that bear on the users' effort for recognizing the logical concept and its applicability.
Learnability	Attributes of software that bear on the users' effort for learning its application.
Operability	Attributes of software that bear on the users' effort for operation and operation control.

Table 6 - Usability sub-criteria (adapted from ISO/IEC 9126, 1991)

The process of assuring usability of a product is called usability engineering. Usability engineering is a continuous process, which continues during the whole life cycle of the product. The main thing that usability engineering adds is very strong co-operation with the users during the whole project, since feasibility study to finished product. From the web-pages of major GIS software companies there is hardly anything said about usability. Only on ESRI's web-page it is clearly stated that the company practices usability engineering to ensure the productivity and satisfaction of the customers (Tiits, 2003).

4.5 Vendor

The quality of vendor support and its characteristics are of major importance in the selection of software. Technically, vendor specific criteria include quality of support services, costs of support services, delivery lead time, vendor's experience in related products; vendor's experience in the application area, vendor's training capabilities, problem solving capabilities, and vendor's reputation (Nagi & Chan, 2005; Tam & Tummala, 2001; Keil & Tiwana, 2006).

5. A hypothetical example

Here, a hypothetical example is presented to illustrate how the AHP process can be used. The local government of ABC City is planning to build a GIS-based emergency management application. This application will facilitate communication among all fire stations and will provide critical information in graphical form to the firefighters in emergency vehicles. After finishing the user requirement analysis, the GIS building team has developed a formal specification to be used in the process of soliciting and evaluating the GIS software alternatives. Then, a short-listing of the suitable GIS software was prepared via a market survey.

In summary, this example will consist of a selection problem where there are three competing GIS software alternatives (Software 1, Software 2, and Software 3) and their prioritization is based on four criteria deemed important for this particular organization. The criteria are (1) Minimum cost, (2) Suitable functionality, (3) Usability and (4) Vendor Support.

There are several MCDM software packages that employ AHP technique such as Expert Choice (www.expertchoice.com), RightChoiceDSS (www.tgkconsulting.com), Criterium DecisionPlus (www.infoharvest.com), etc. In this paper Criterium DecisionPlus (CDP) version 3.0 is used for solving this multi criteria decision making problem.

CDP combines analytical power, ease of use and an extensive graphics interface that together make CDP transparent to first-time audiences yet meet the demands of sophisticated analysts. A five-step decision-making process based on CDP when it uses AHP (InfoHarvest Inc, 2001) is presented as follows.

5.1 Brainstorm the problem

Decision Plus's brainstorming capability assists the decision maker(s) in defining the problem and identifying all the related issues. During the brainstorming session, the decision maker(s) starts with a clean canvas and concludes with the goal, the decision criteria supporting that goal, the potential sub-criteria supporting each criterion, and alternatives identified as shown in Figure 3.

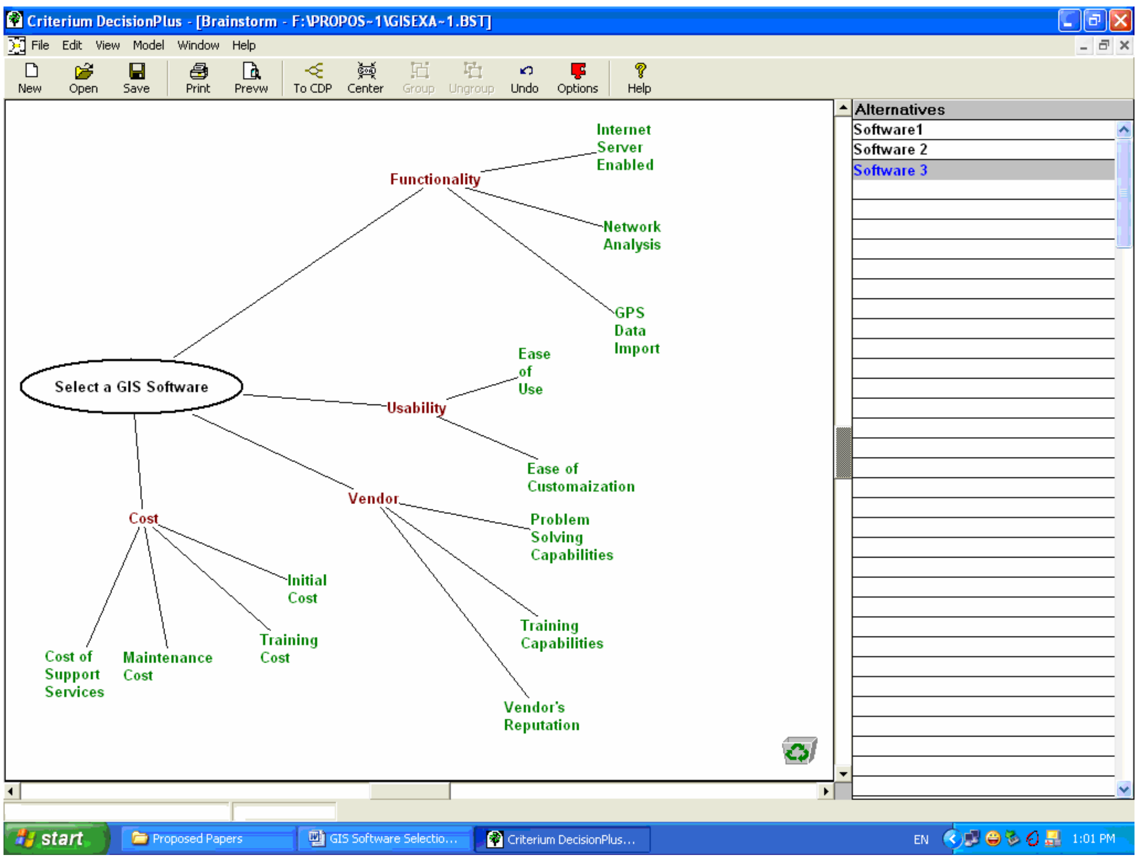


Figure 3 – The brainstorming session

5.2 Build the hierarchy

The next step is to build the structure or hierarchy (AHP decision model) for the GIS software selection problem. The hierarchy can either be generated automatically from the current brainstorming session; or can be built directly in the Hierarchy session of CDP. Figure 4 shows the AHP decision model for selecting GIS software.

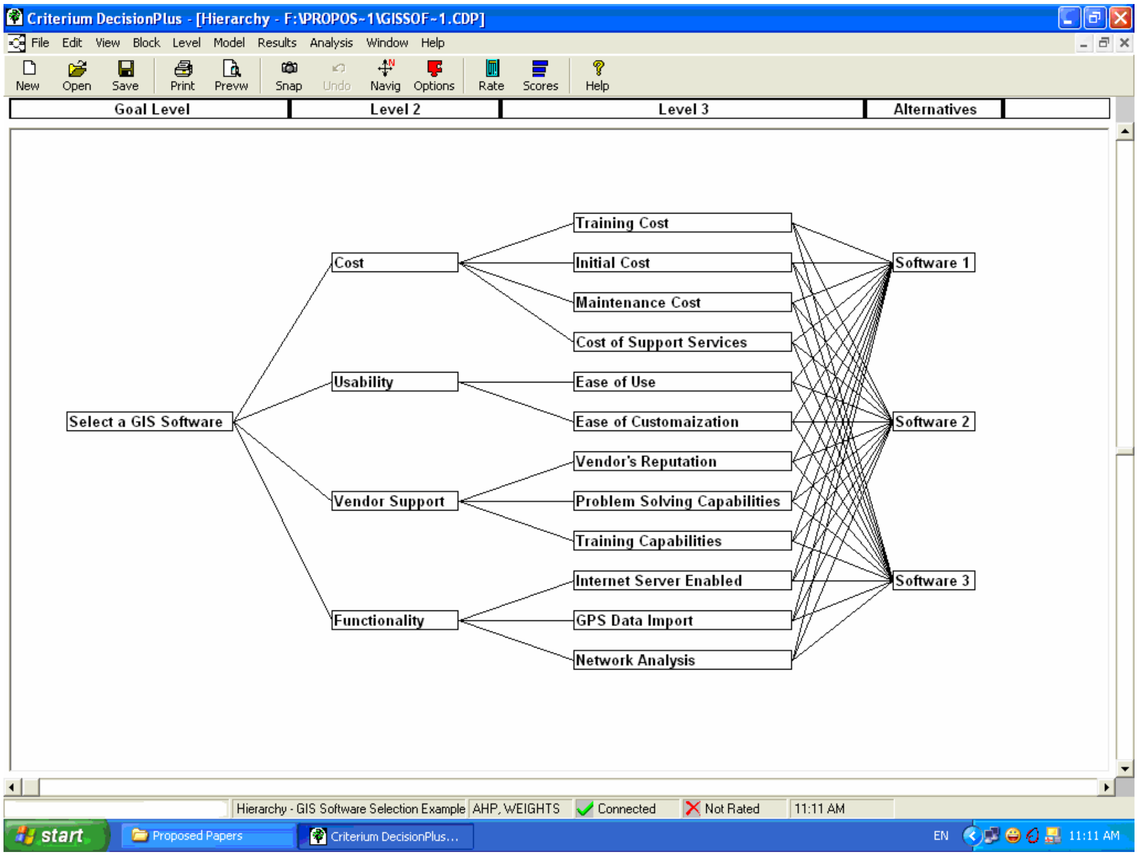


Figure 4 – The AHP decision model

5.3 Rate the hierarchy

Once the AHP model is set up, judging the importance of criteria (weighting the criteria) and scoring alternatives need to be developed. Determining the weights of criteria is performed in the CDP Hierarchy session. The weights technique is used to assign the relative importance of each sub-criterion with respect to the other sub-criteria of a given Goal or parent criterion. You might start at the Goal, relatively weight each of the criteria directly beneath the Goal, then repeat this for every element in the hierarchy until rating the alternatives against the lowest criteria.

Two weighting methods are available: direct comparison or pair-wise comparison. Direct comparison is used to enter quantitative data about each criterion. Usually these values come from a previous analysis or from experience and detailed understanding of the decision problem. Full pair-wise comparison are made by rating criteria, one against another, within their rating set, or by using an abbreviated pair-wise comparison that rates only subsets of all such pairs. Pair-wise comparisons are used when lacking quantitative data about each criterion and become impractical as the number of elements being compared increases.

The choice of weighting method depends on the problem, the information available, and the preferences of the decision maker(s). CDP provides three modes to enter and view each weight: numeric view, verbal view, and graphic view. Each view has a corresponding scale. In this example, direct comparison weighting method is used as shown in Figure 5.

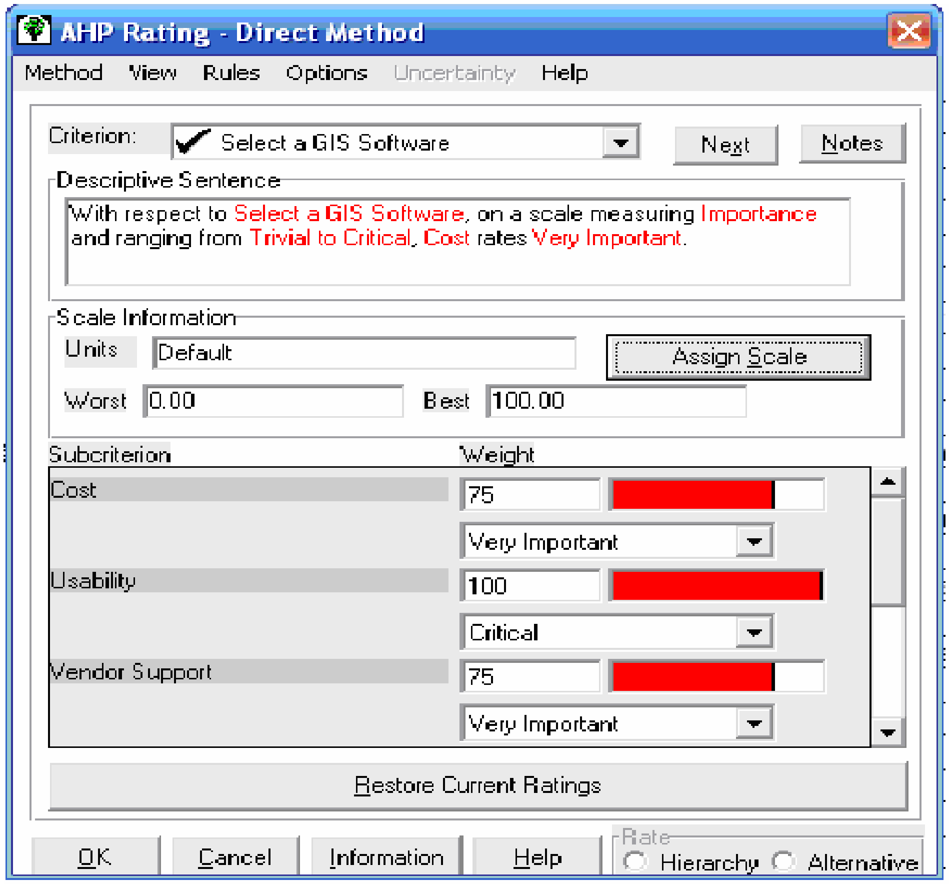


Figure 5 - Rating the AHP decision model using direct comparison weighting

5.4 Select the best alternative

When these comparisons are finished, results can be viewed as decision scores that reflect preference for each alternative, as shown in Figure 6. Software 1 has the highest score.

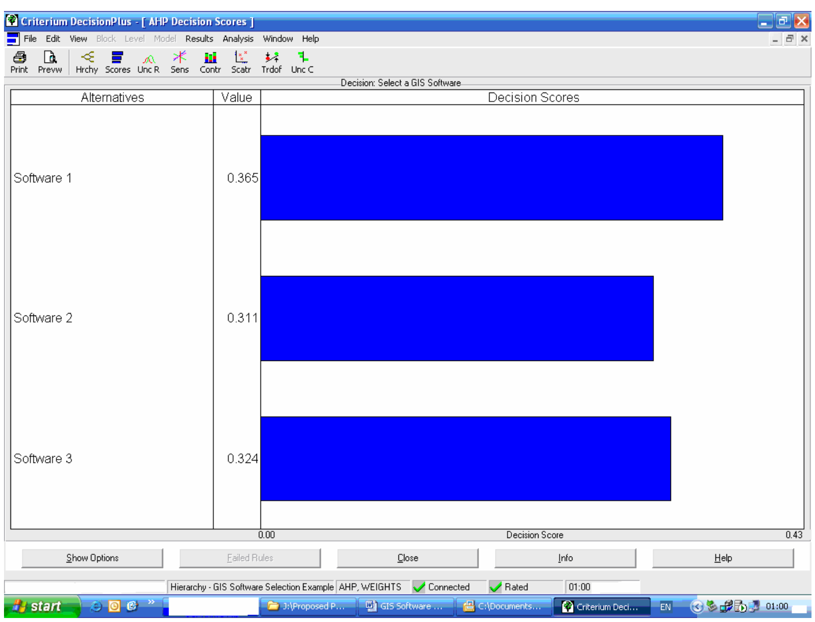


Figure 6 - Decision scores

5.5 Analyze the results

Checking for reasonableness and robustness of the decision is an important part of the decision process. CDP provides many important tools for analyzing the results such as Contribution by Criteria, Sensitivity by Weights, and Tradeoff of Lowest Criteria.

The contribution by Criteria dialog window shows the contributions of criteria, at a selected level in the hierarchy, to the decision score of each alternative, or the contributions of sub-criteria to a selected criterion in the hierarchy. CDP displays the contributions as a stacked-bar histogram, with bars representing the contribution from each criterion. Figure 7 shows the contributions of criteria at level 2 to the decision score of each alternative.

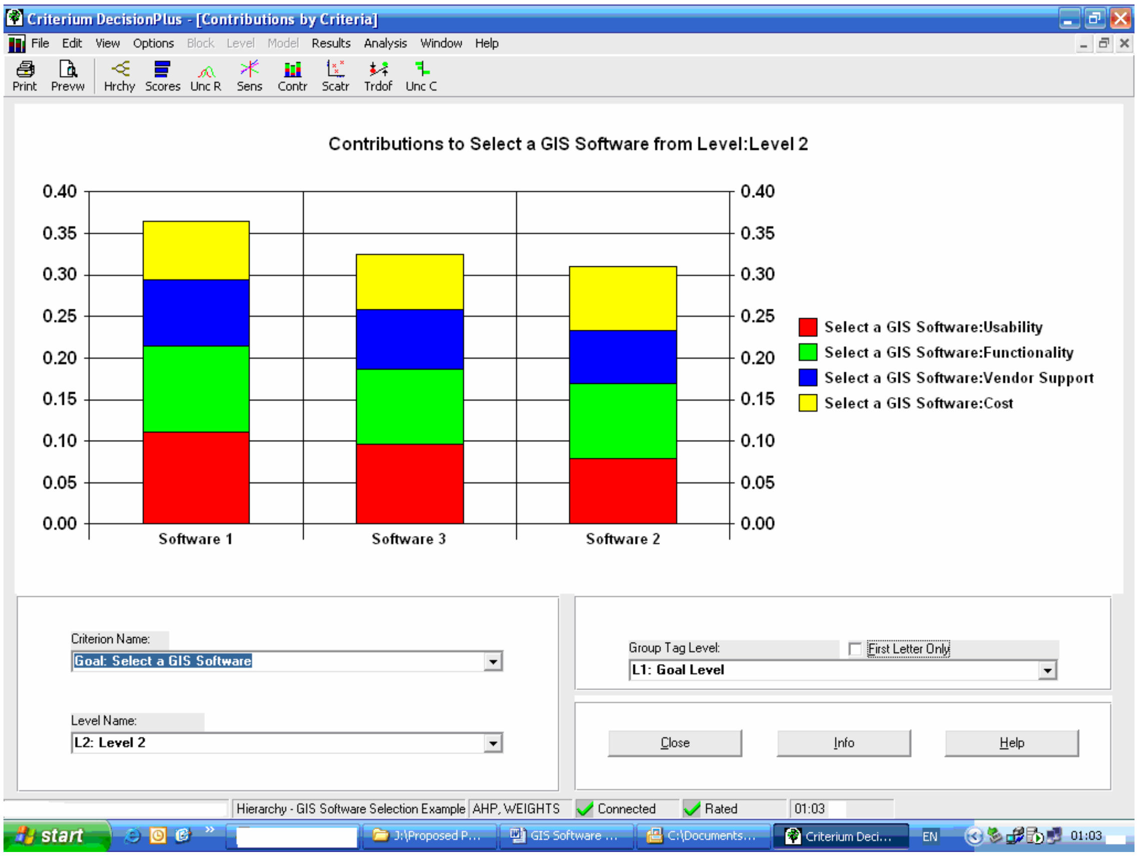


Figure 7 - Contributions of criteria, at Level 2, to the decision score of each alternative

Sensitivity Analysis determines how sensitive the decision is to changes in the relative importance assigned to criteria. Sensitivity Analysis displays a list of weights of sub-criteria with respect to their parent criterion with a metric that measures the sensitivity of the result when the value of that weight is changed. CDP prioritizes the list from most critical to least critical. In this model the most critical criterion is "Cost." It indicates that an increase in the weight of approximately 5.2 % would change the results as shown in Figure 8.

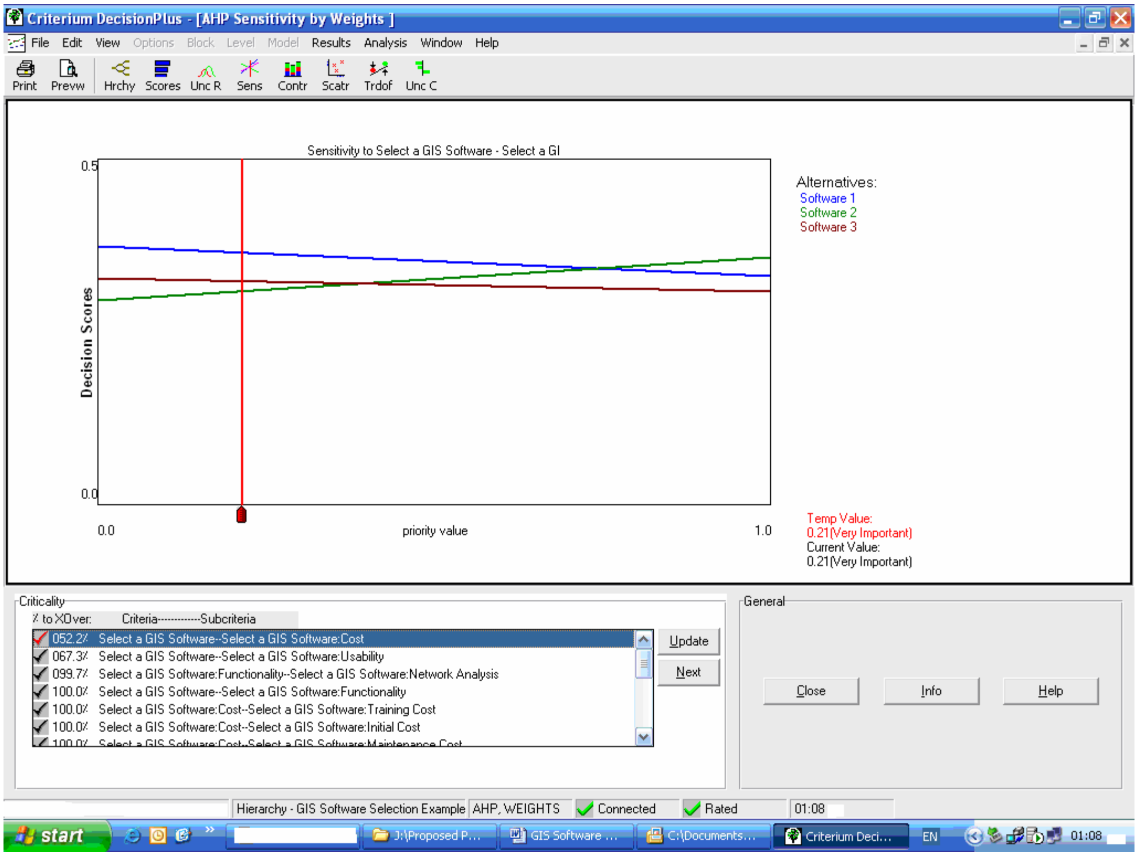
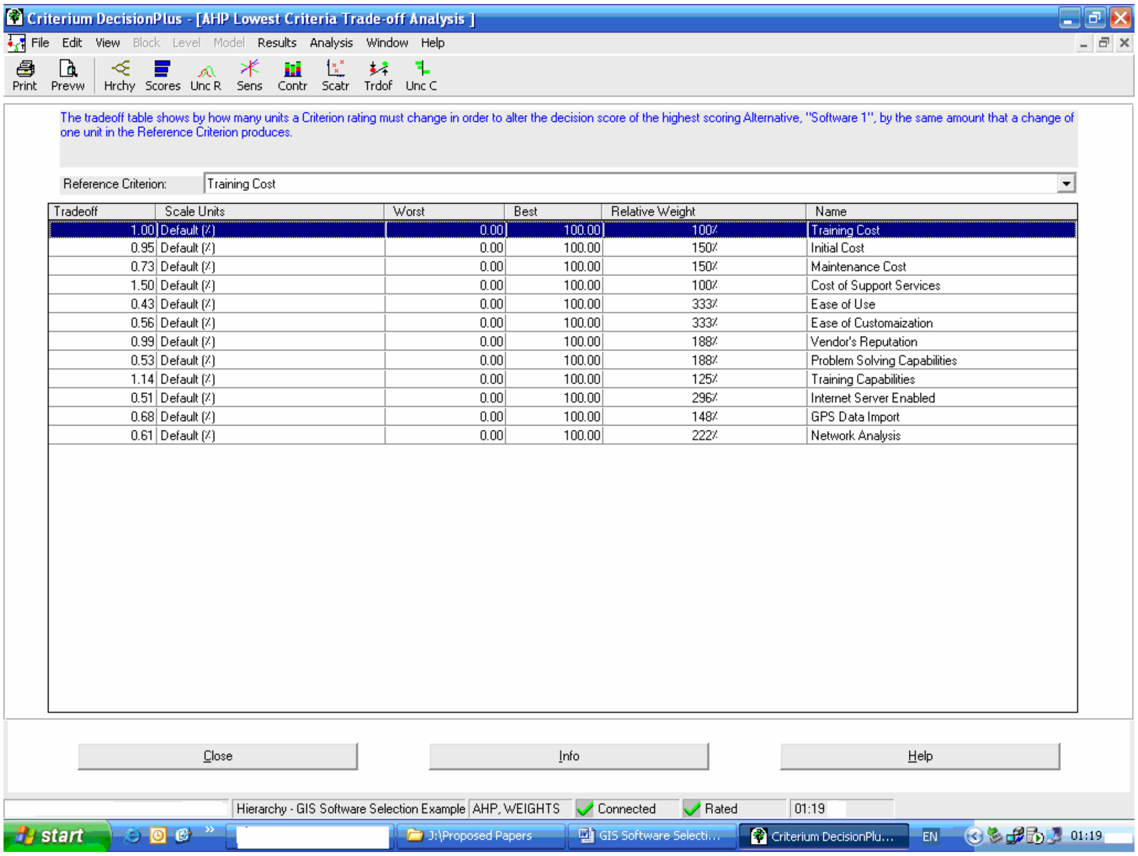


Figure 8 - Sensitivity analysis

The Tradeoff Analysis shows quantitatively how one lowest-level criterion trades off against another as shown in Figure 9.



Tradeoff	Scale Units	Worst	Best	Relative Weight	Name
1.00	Default (%)	0.00	100.00	100%	Training Cost
0.95	Default (%)	0.00	100.00	150%	Initial Cost
0.73	Default (%)	0.00	100.00	150%	Maintenance Cost
1.50	Default (%)	0.00	100.00	100%	Cost of Support Services
0.43	Default (%)	0.00	100.00	333%	Ease of Use
0.56	Default (%)	0.00	100.00	333%	Ease of Customaization
0.99	Default (%)	0.00	100.00	188%	Vendor's Reputation
0.53	Default (%)	0.00	100.00	188%	Problem Solving Capabilities
1.14	Default (%)	0.00	100.00	125%	Training Capabilities
0.51	Default (%)	0.00	100.00	296%	Internet Server Enabled
0.68	Default (%)	0.00	100.00	148%	GPS Data Import
0.61	Default (%)	0.00	100.00	222%	Network Analysis

Figure 9 - Tradeoff analysis

6. Conclusions

The problem of selecting the suitable GIS software package for a particular GIS project is a multi criteria decision making (MCDM) problem. Solving this problem requires consideration of a comprehensive set of factors and balancing of multiple objectives in determining the suitability of particular software for building a defined GIS application.

In this paper Analytic Hierarchy Process (AHP) is used in solving this problem. An AHP decision model is formulated and applied to a hypothetical case study to examine its feasibility in solving GIS software selection problem.

The use of the proposed model indicates that AHP is an efficient MCDM approach for GIS software selection because of its inherent capability to handle qualitative and quantitative criteria used in software selection problems. Furthermore, it can be easily understood and applied by software developers. Also, the AHP can improve the decision making process. Moreover, the use of the proposed AHP model can significantly reduce the time and effort in decision making. The AHP model developed in this paper can be used as a basis for GIS software selection.

This work is intended as a first step toward an intelligent decision support system that integrates the capabilities of expert systems (ES), and MCDM (AHP) and provides an advisory system to assist system developers during the GIS software justification and selection procedure.

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