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Evaluation of Critical Success Factors for GIS Implementation Using Analytic Hierarchy Process

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Abstract. The identification of factors critical to the successful implementation of GIS is a main concern to GIS managers and practitioners. Although CSFs has been one of the active research topics in GIS implementation and management literature, none of them used any formal method for ranking these CSFs. Many studies claim that each category of the CSFs is the most important than other categories without any technical background. In this study, the CSFs related to GIS were explored and classified into five distinct categories. The analytic hierarchy process (AHP) technique is used to find the relative weights and priorities of these CSFs. The results of this study indicate that management attitude is the most important category of the CSFs, and top management support is the most important CSF related to GIS.

Keywords: GIS implementation, Critical success factors, Analytic hierarchy process technique.

Introduction

During the past decade, despite the increasing level of geographic information systems (GIS) implementation in developing countries, it appears that they are faced with problems in the operation and maintenance phases of the GIS lifecycle [1]. Unfortunately, many organizations complete their GIS projects under pressure without having a strategy or using factors for determining success [2, 3].

Implementing a GIS is more than purchasing hardware, software, and data; but it is a complex interplay of management, technical, human and organizational factors, and it requires education, training, planning, communication, and a great deal of hard work [2]. Many GIS organizations in developing countries invested millions of dollars on this technology and have failed to live up to expectations and as a result some have been outright dissolved [4]. Therefore, it does worth to study the factors that, to a great extent, determine whether the implementation will be successful. CSFs for GIS implementation bring a concept that helps organizations to identify the critical issues that affect the process of GIS implementation. Through a better understanding of the CSFs for the implementation of GIS, an organization can determine the corresponding solution to eliminate or avoid the most common causes of failure in GIS implementation.

Although a number of empirical and non-empirical studies have addressed a variety of CSFs for GIS implementation, none of them used a formal methodology for ranking these CSFs. Therefore, the objective of this study is to rank the CSFs related to GIS using the analytical hierarchy process (AHP) technique.

This paper is organized as follow: Section 2 reviews the research context about GIS and CSF; Section 3 is focused on the research methodology; Section 4 presents and analyzes the results; the paper concludes in section 5.

Theoretical Background

Geographic Information Systems

Geographic information systems (GIS) are one of the most widely used decision aids, especially for solving complex spatial problems. GIS is a computer-based information system that enables capture, modeling, storage, retrieval, sharing, manipulation, analysis, and presentation of geographically referenced data [5]. A working GIS integrates five key components: hardware (the equipment needed to support the many activities of GIS ranging from data collection to data analysis and sharing), software (different GIS software packages for creating, editing and analyzing data), data (the core of any GIS, categorized as spatial and non-spatial data), organizational structure and people (well-trained and skilled people to use and maintain the GIS) and methods (well-designed plan and business rules that are the models and operating practices unique to each organization) [6]. GIS are well established as giving competitive advantage and enhancing organizational decision-making in a wide array of functions including: improved information sharing and flows, better informed decision making, stronger competitive ability, greater analysis and understanding of problems, justification for decision made, improved visualization of data, cost saving, increased effectiveness, and better quality output [7].

Critical Success Factors

Critical success factors (CSFs) occupies a prominent place in information system (IS) research field, a fact easily revealed by thumbing through well known IS journals [8].The concept of CSFs was popularized in the context of IS and project prominent and success management (PM) by [9] as “factors affecting the success of activities and projects”. CSF is defined by [10] as “the limited number of areas in which satisfactory results will ensure successful competitive performance for the individual, department, or organization. CSFs are the few key areas where ‘things must go right’ for the business to flourish and for the managers goal to be attained”. CSFs make it easier for managers to prioritize vital aspects of a project [11]. Although, this does not implicate that just because a project has established their CSFs the whole project will automatically succeed. The only thing that the CSFs state is that it would be erroneously to neglect one of the CSFs [12]. As the concept of CSF has received a wide acceptance among IS scholars and practitioners, numerous scientific publications address the issue of CSF in the field of IS [8, 13, 14, 15, 16, 17], as well as in other fields [18, 19].

In GIS field, CSFs has been one of the active research topics in GIS implementation and management literature. The CSFs related to GIS are summarized in Table 1.

The CSFs of GIS mentioned in the present study were extracted from:

1. GIS success researches cited in the literature which is mostly based on case studies or observations of GIS projects and practices, such as [20, 21].
2. GIS failure researches which is typically based on lessons learned from certain types of GIS projects, but they are mostly similar enough to be generalized, such as [22, 23].
3. Researches about GIS implementation that mentioned CSFs briefly, such as [24, 25].

Table 1. Critical success factors of GIS.

GIS CSFs	Sources
Organization Culture	[2, 26, 27, 28, 29, 30, 31, 32]
Organization Structure	[2, 13, 28, 32, 33, 34, 35, 36]
Clear Goal and Vision	[2, 4, 13, 26, 35, 37, 38, 39]
Top Management Support/Awareness	[2, 4, 13, 20, 21, 28, 32, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45]
External Environment	[28, 34, 35, 37, 46]
Strategic Planning	[2, 4, 21, 22, 28, 31, 36, 37, 39, 40, 47]
Skilled Staff	[4, 13, 23, 28, 31, 32, 33, 35, 36, 37, 42, 43]
Communication Channels	[2, 13, 21, 22, 28, 30, 32, 43, 45, 46]
User Participation	[2, 4, 13, 21, 24, 28, 32, 33, 36, 37, 40, 43, 45]
Education and Training	[4, 13, 20, 22, 24, 28, 33, 34, 35, 37, 38, 40, 43, 48, 49]
Business Process Re-engineering	[4, 13, 40, 48]
Hardware and Software Selection	[4, 23, 28, 32, 38, 40, 43, 45, 50]
Software Customization	[22, 23]
Data Issues	[3, 4, 21, 22, 31, 35, 37, 38, 42, 43, 44, 45, 48, 51]
Perceived Usefulness	[30, 32, 35, 38, 45, 46]
Vendor Support	[2, 21, 23, 30, 35, 45]
User Skills	[30, 35, 38, 46]
User Experience	[13, 20, 23, 24, 32, 34, 35, 38, 40, 43, 45, 46, 52]

Methodology

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 makers, 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 [53].

Since its introduction in the mid 1970s by Dr. Thomas L. Saaty, AHP has been applied in many practical applications in various fields such as vendor selection [54], software evaluation [50, 55] and CSFs ranking [56, 57, 58].

The AHP technique encompasses three basic steps [17, 59]: firstly, decomposing the complex problem into a hierarchy of interrelated decision elements. This structure is the key to interrelate and chain all decision elements of the hierarchy from the top level down to the bottom; secondly, the data has to be collected by pairwise comparisons of former elements and attributes' weights in each level have to be computed using the eigenvalue method; finally, the aggregation of the relative weights of decision elements in order to compute the priority for each alternative.

Construction of the Hierarchy

This study categorizes the critical success factors related to GIS into five categories. These categories are external environment, organization characteristics, technology, management attitude, and human characteristics. The categories are summarized and presented in Figure 1.

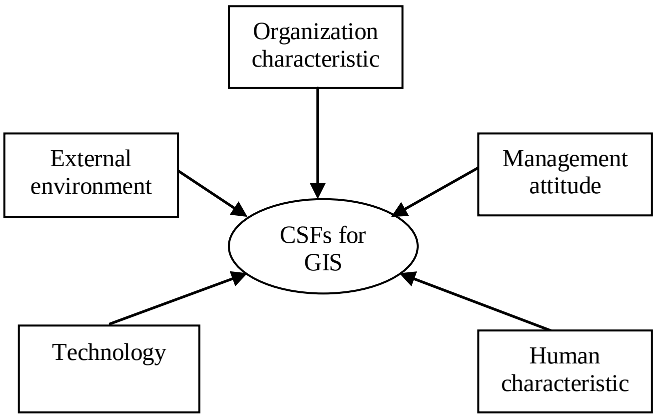

Figure 1. Categories of GIS critical success factors.

The problem of ranking the CSFs related to GIS with respect to their importance can be resolved by decomposing it into subproblems within a hierarchal model. In developing a hierarchy, the top level is the ultimate goal of the decision at hand. The hierarchy then descends from the general to the more specific until a level of attributes is reached. In this study, the hierarchy of all criteria and factors were classified into three levels as shown in Figure 2.

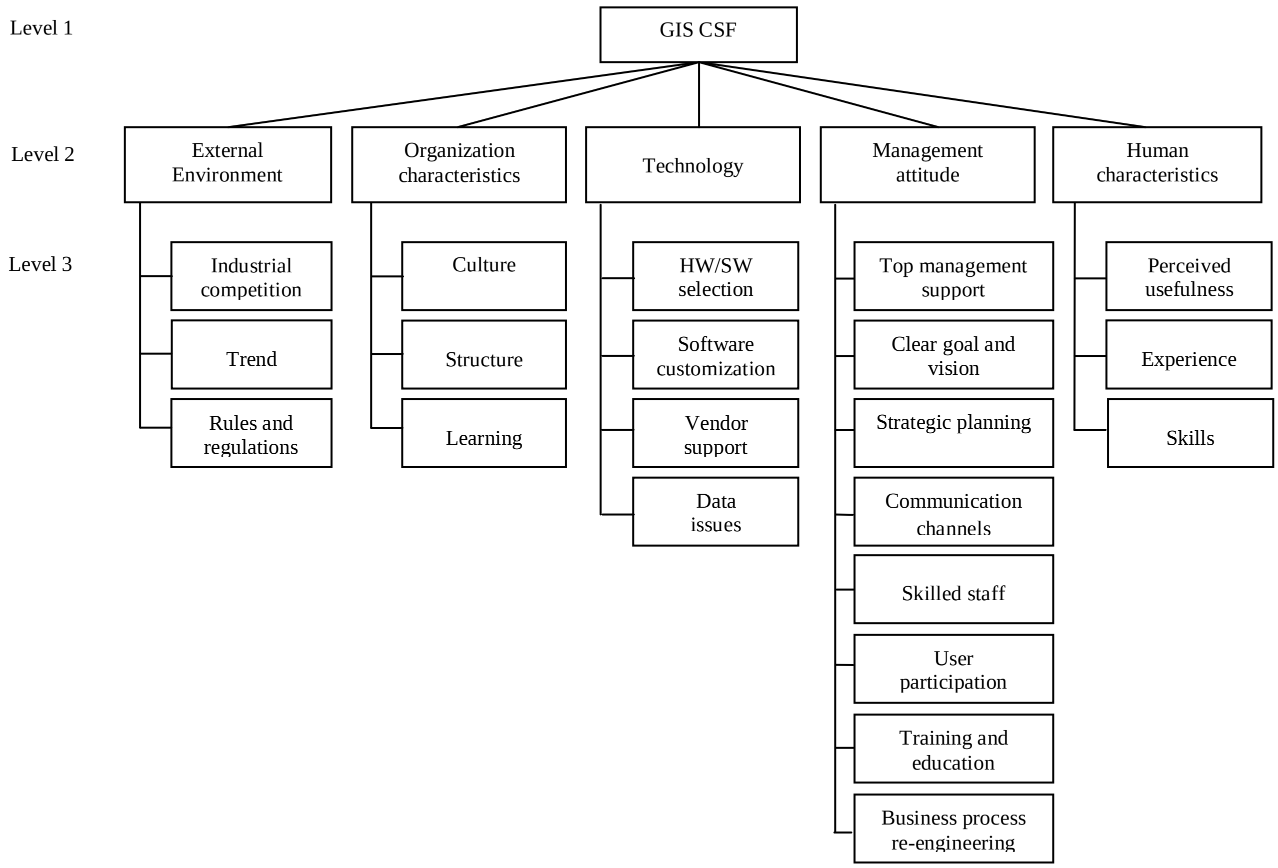

Figure 2. Critical success factors hierarchy model

At level 1 of the hierarchy, are the CSFs. Then, the CSFs are decomposed into five categories as shown in the second level of the hierarchy. The third level shows the factors or attributes within each category. The goal is to obtain the GIS experts' perceptions, through a formal questionnaire, about the importance of CSFs in order to establish rank among them. It is a valuable effort, since many GIS studies claim that each category of the CSFs is the most important than other categories without any technical background [36, 46].

External Environment

External environment category refers to forces outside an organization that may encourage or inhibit GIS adoption in the organization, for example, the incapacity or the political unwillingness to modify economic and social conditions, especially in the developing countries, has often slows down or hamper the GIS implementation [34, 37].

Some external factors that may encourage senior management to adopt GIS for maintaining their organizational market positions are [14, 21, 60]: industrial competition, trend, and governmental rules and regulations that force government organization to adopt GIS.

Organization Characteristics

The organization characteristics category includes the following CSFs: culture, structure, and organization learning.

Any technology is operated by individuals. These individuals generally do not act in isolation but, instead, as groups or at least in relation to one another. Organizations, professional associations, and producer–user relationships are examples of such social relations. Therefore, the analysis of adoption and use of the technology must go beyond the behavior and psychology of the individuals involved [29]. Organizational culture comprises the informal beliefs and values inherent in organizational units and how they shape attitudes and practices. Regardless of the organization's intent, an individual department's culture may not complement the diffusion of GIS innovation [32]. The deep-rooted pervasiveness of culture explains the resistance that can be met in certain conditions when introducing and/or using GIS [31].

On the other hand, organizational structure determines how the roles, power and responsibilities are assigned, controlled, and coordinated, and how information flows between the different levels of management [28]. Some rigid, extremely hierarchical, highly centralized or formalized, multi-layered (with management) structure may result in [26, 32, 61]:

- Limiting the communication channels between users in various departments which in turn will control GIS vision creation activity.
- Limiting the sharing of resources between department units to the GIS project during the implementation stage, at a later stage, department units may be unwilling to agree on standards or sharing of data and information.

The following CSF in this category is being a learning organization. Many factors which have an effect on the success of GIS project implementation will be probably affected by previous experience and the maturity of the organization in developing IS projects. Furthermore, if the organization is a learning organization, it will have in place procedures and people who monitor the success and adapt changes in the GIS implementation process in order to achieve success [62].

Technology

This category includes the following CSFs: hardware/software selection, software customization, vendor support, and data issues.

The selection of appropriate GIS hardware and software is critical to the success of GIS project. An inappropriate selection strategy of GIS hardware and software can lead to adverse effects and the system will not be able to fulfill the required functionalities [50]. The hardware and software selection involves an evaluation of GIS equipment and software alternatives based on the results of the user needs analysis. A major problem in implementing GIS has been the failure to match GIS capabilities with user needs. The high cost of GIS software necessitates that user needs are fully understood prior to hardware and software selection.

The following CSF in this category is software customization. Vendors supplied GIS as generic software and may not always be adequate for particular applications. Therefore, there is a need to develop customized GIS programs to convert the general purpose toolbox of technique based on a high level language or macro capability into something relevant to a particular end user application [23].

Another factor that contributes to the success of GIS projects is the technical support environment [2]. Very common behavior of GIS and IT vendors is to deliver hardware and software only. Aftermath of supply there is nothing seriously achieved in the area of maintenance and proper support [34]. Therefore, the continued support of the vendor is necessary for the long term success of a GIS.

The following CSF in this category is data issues. The data issues are very critical technical issues within the GIS implementation process [21]. Accurate information can only be generated by the system if the data on which it is based on is accurate to begin with. If the data is inaccurate or incomplete, the use of sophisticated GIS technology will only be an expensive graphic and spatial version of “garbage in, garbage out” [43]. There were several data issues faced by senior managers, users and system developers that may hinder GIS implementation such as data quality, data availability, data conversion and integration, and access restrictions [4, 7, 22].

Management Attitude

This category includes the following CSFs: top management support, clear goal and vision, strategic planning, communication channels, skilled staff, user participation, training and education, and business process re-engineering.

The active support of senior management is essential for acquiring the financial and the political support needed to initiate the GIS project, and to insure continued support and effective use of GIS in the future [35, 43, 63]. Lack of full support by senior management often results in insufficient funding and low implementation priority [4, 22].

The following CSF is clear goal and vision. Establishing a clear goal and vision for GIS in organization while initiating GIS project, is critical to its success. In a large, multi-participant GIS effort, it is crucial that all participants fully understand and share that vision, as they will be responsible for making it a reality. Developing a common vision and ensuring that everyone fully understands it may be time consuming, but the benefits are well worth the effort. Many GIS problems and failures can be traced to a single source – conflicting ideas concerning what the GIS should be [2, 26].

Another important CSF is strategic planning. Proper strategic planning is crucial to the success of any GIS project, and many implementation problems can be traced back to inadequacies in the strategic planning process [36]. The lack of an adequate GIS plan can be considered one of the main reasons for difficulties and problems at various stages of GIS development and operations [47]. The purpose of strategic planning is to create a framework within which the complexity and interdependency of GIS implementation can be managed. Also, strategic planning provides a long term view for the organization operations and objectives. Effective GIS strategic planning is built on basic strategic planning methodologies and incorporates techniques that are specific to GIS and to the organizational condition. Several approaches exist for strategic planning, and basic information about strategic planning is available from a variety of sources including textbooks and articles [25, 64, 65].

The following CSF in this category is communication channels. Studies of unsuccessful GIS implementation reveal that communication rarely happened between GIS project members. Each group in GIS project lacks the information needed to act appropriately. Active communication between GIS project managers, GIS developers, and GIS users is essential for successful GIS implementation stage [22, 32, 43]. All involved parties in GIS project must be kept in the communication network from the time they are first contacted through the entire project implementation stage [2].

The following CSF is the skilled staff. GIS staff considers everyone directly concerned with the implementation of GIS, including end users, management group, and systems administration team (network administrators, hardware technicians, and the database administrators). The core GIS staff, however, is where you expect to find the more specialized GIS skills, and it includes the GIS manager, GIS analysts. A good GIS staff is an invaluable tool for a manager. Money can buy more hardware and software, but even money cannot create the motivation and enthusiasm essential to a successful staff and a successful GIS implementation [65].

The following CSF is user participation. Most GIS projects will change the work life of many users, and thus require their participation in the design and the development of the new system [4]. User participation defined as a set of behaviors, activities, and assignments that engage users throughout the system implementation [66].

The following CSF is training and education. Effective training and education is considered very important to equip users with the necessary skills and tools to use GIS efficiently in their day-to- day activities. Before selecting GIS Hardware and software, opportunities should be provided for internal seminars on GIS concepts, presentations by consultants and vendors, and attendance at outside conferences and workshops. After specific hardware and software are selected, training from system vendors directed to different GIS users, support staff, and management personnel should be organized. Organizations should not underestimate the time requirements and resources needed for adequate training [28]. Many GIS projects failed because there were no GIS trained personnel to use the system [22].

Clearly, Adopting new technology forces changes in the organizational paths of information flow, therefore re-engineering of business processes within the organization is required. Business processes re-engineering means the analysis and redesign of workflow within the organization to be adapted with GIS technologies [4]. The business process gap between organizational and GIS processes was found to be the likely cause of many GIS projects failure [48].

Human Characteristics

This category includes the following CSFs: perceived usefulness, experience, and skills.

Perceived Usefulness is defined as the degree to which a person believes that using a particular system would enhance his/her job performance [67]. User's perceived usefulness of GIS technology is an influencing factor that encourages GIS usage [32, 35, 46].

The user skills and computer experience is associated with the successful use of GIS [38]. The system users are those who will use GIS to solve spatial problems. GIS users should have the required GIS skills abilities and confidence to use the GIS successfully. Also, User experience which is the duration or level of an individual's prior use of GISs will play a crucial role in increasing the chance of successful GIS use [34, 52].

Pairwise Comparison Matrix

The principle of comparative judgments requires assessments of pairwise 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 pairwise 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).

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

Table 2. The AHP pair-wise comparison scale (adapted from [44])

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.	2,4,6,8

The analytical solution of equation (2) then provides the relative weights for each decision elements. According to the eigenvalue method [24], the normalized right eigenvector ($W = \{w_1, w_2, \ldots, w_n\}^T$) associated with the largest eigenvalue (λ_{max}) of the square matrix A provides the weighting values for all decision elements.

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

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). 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

Results

This research sent out 15 AHP questionnaires to a group of GIS project managers, and consultants, and all of the respondents have experience in the GIS implementation field for over than 10 years. The composition of the respondents is important. The main selection criterion considered was recognized knowledge in research topic, absence of conflicts of interest and geographic diversity. The respondents of AHP questionnaires are 12 which made the rate of returns (80 %).

According to the collected data from the questionnaire, we figured out the weight of each item by AHP software (Criterion Decision Plus 3.0). After computing, we found that nearly all replies to the questionnaire reached a consistency ratio of less than 0.1, hence the decision maker's pair-wise comparison matrices are acceptable. A summary of category ranking with global weights are shown in Table 3. The ranking of the weights of the constructs are: external environment (0.128), organizational characteristics (0.23), technology (0.166), management attitude (0.358), and human characteristics (0.119).

Table 3. Category ranking with global weights

Category	Global weight
Management attitude	0.358
Organization characteristics	0.230
Technology	0.166
External environment	0.128
Human characteristics	0.119

As shown in Table 4, industrial competition was the most critical factors in the external environment category with a local weight of (0.385). Organization culture was the most critical factor in the organization characteristics category with a local weight of (0.415). Data issue was the most critical factor in the technology category with a local weight of (0.381). Top management support was the most critical factor in the management attitude category with a local weight of (0.295). Experience was the most critical factor in the human characteristics category with a local weight of (0.473).

Table 4. Summary of local weights

Categories	CSFs	Local weights
External Environment	Industrial competition	0.385 (1)
	Trend	0.244 (3)
	Rules and Regulations	0.371 (2)
Organization characteristics	Culture	0.415 (1)
	Structure	0.329 (2)
	Learning	0.256 (3)
Technology	HW/SW Selection	0.228 (3)
	Software Customization	0.146 (4)
	Vendor Support	0.245 (2)
	Data Issues	0.381 (1)
Management attitude	Top Management Support	0.295 (1)
	Clear Goal and Vision	0.095 (6)
	Strategic Planning	0.108 (5)
	Communication Channels	0.139 (2)
	Skilled Staff	0.128 (3)
	User Participation	0.048 (8)
	Training and Education	0.078 (7)
	Business Process Re-engineering	0.111 (4)
Human characteristics	Perceived Usefulness	0.348 (2)
	Experience	0.473 (1)
	Skills	0.179 (3)

Table 5 shows the global weights of CSFs ranking. They have been calculated by multiplying the local weights of each CSF by the global weight of each category. By doing this, each local CSF is balanced by the importance of the category to which it belongs. The top ten factors and their weights of global ranking are: top management support (0.106), organization culture (0.095), organization structure (0.076), data issues (0.063), organization learning (0.059), experience (0.056), communication channels (0.05), industrial competition (0.049), rules and regulations (0.047), and skilled staff (0.046).

Table 5. CSF ranking with global weights

CSFs	Global weights	Category
Top Management Support	0.106	Management attitude
Culture	0.095	Organization characteristics
Structure	0.076	Organization characteristics
Data Issues	0.063	Technology
Learning	0.059	Organization characteristics
Experience	0.056	Human Characteristics
Communication Channels	0.05	Management attitude
Industrial competition	0.049	External environment
Rules and Regulations	0.047	External environment
Skilled Staff	0.046	Management attitude
Perceived Usefulness	0.041	Human Characteristics
Vendor Support	0.041	Technology
Business Process Re-engineering	0.04	Management attitude
Strategic Planning	0.039	Management attitude
HW/SW Selection	0.038	Technology
Clear Goal and Vision	0.034	Management attitude
Trend	0.031	External environment
Training and Education	0.028	Management attitude
Software Customization	0.024	Technology
Skills	0.021	Human Characteristics
User Participation	0.017	Management attitude

Conclusion

A multi criteria decision making technique, AHP, has been applied to prioritize the CSFs related to GIS implementation. AHP technique helps to organize a multi criteria decision making problem in terms of goal, criteria, and sub criteria by structuring the problem into a hierarchal form and evaluating them systematically in order to select the best course of action, as we have done in this study.

From priority weights obtained at levels two and three, it can be concluded that the most important category of the CSFs is the management attitude and the most important CSF is the top management support. This was the most expected finding, since many GIS literatures place much emphasis on the commitment and support from top management for a successful GIS implementation. Without their support, failure of any GIS is likely.

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